# HIERARCHAL GENETIC STRATIGRAPHY OF THE RED EAGLE LIMESTONE AND ROCA SHALE FORMATIONS (LOWER PERMIAN) IN NORTHEAST KANSAS

by

Michael H. Clark

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Approved by:

Ronald R. West

Major Professor

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# A C K N O W L E D G E M E T S

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# I N T R O D U C T I O N

## GENERAL STATEMENT

Permo-Carboniferous rocks are typically described and interpreted relative to idealized units composed of rhythmic or cyclic alternations of specific lithofacies or "cyclothems" (North American Commission on Stratigraphic Nomenclature, 1983) following Wanless and Weller (1932). In Kansas, Permo-Carboniferous rocks are currently described relative to "Kansas cyclothems" (Heckel, 1977). According to this gradualistic model (Figure 1), all specific facies are combined into four members composed of: nearshore (outside) shale, transgressive limestone, offshore (core) shale, and regressive limestone, which are arranged into "cycles" or "Kansas cyclothems" (Heckel 1986). While this model is useful at the scale of the basic lithostratigraphic unit, i.e. formations, it is not adequate for recognizing more detailed stratigraphic relationships and associations.

Alternatively, the same rocks can be described and interpreted relative to a hierarchy of their constituent transgressive-regressive (i.e., deepening-shallowing) units, or "T-R units", by considering the total range of facies and facies contacts present in a stratigraphic sequence (Busch and Rollins, 1984; Busch and West, 1987).

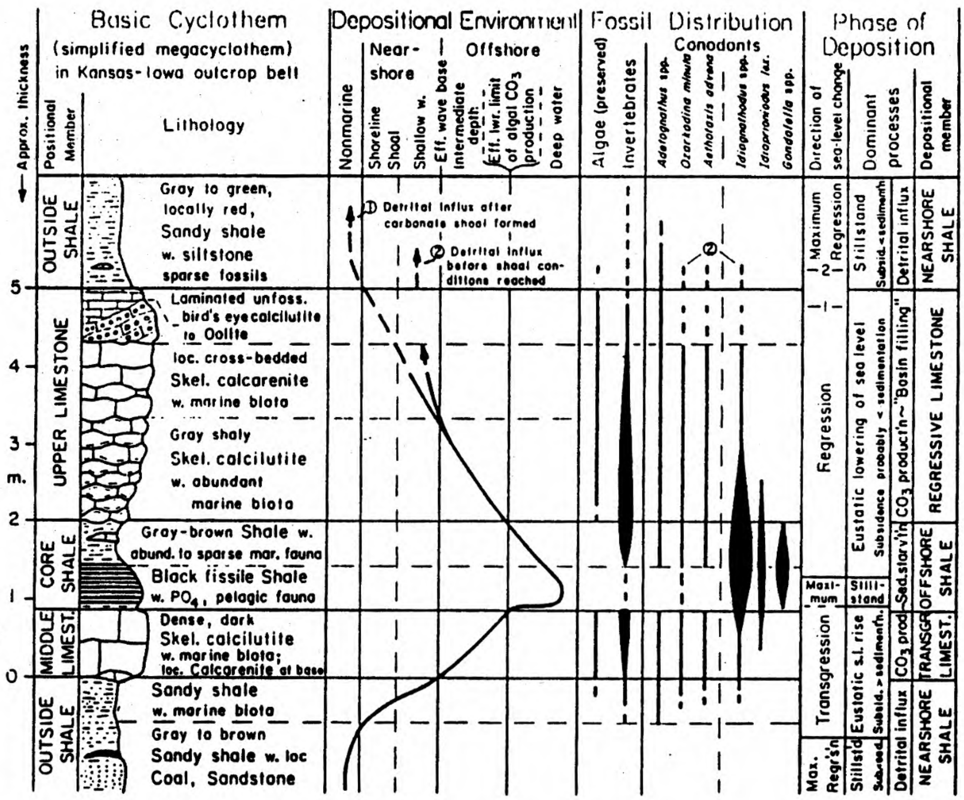



Figure 1. Basic Kansas cyclothem (from Heckel, 1977).

## PURPOSE OF STUDY

The purpose of this study is to delineate the sixth-order "T-R" units (Busch and Rollins, 1984) or Punctuated Aggradational Cycles (Goodwin and Anderson, 1985), within the Red Eagle Limestone and Roca Shale formations (Figure 2). Recognition and correlation of these genetic stratigraphic units (sixth-order T-R units) will make it possible to interpret sea level changes at a scale that is an order of magnitude smaller than has traditionally been recognized in Kansas (i.e., smaller than Kansas cyclothems). Furthermore, stratigraphic data from this study will provide detailed information on one of the few, if not the only, Lower Permian marine black shales/mudstones (i.e., Bennett Shale) known in Kansas.

## AREA AND METHODS OF STUDY

Field work for this study was concentrated in Riley, Pottawatomie, and Wabaunsee counties of northeastern Kansas (Figure 3), where twenty-three stratigraphic sections (twenty-two outcrops and one core) were measured and described in detail (see Appendix II). Each section was carefully measured and described using a tape and hand-held Brunton compass. Thicknesses were measured to the nearest centimeter and later converted to English units. Field observations included color of both fresh

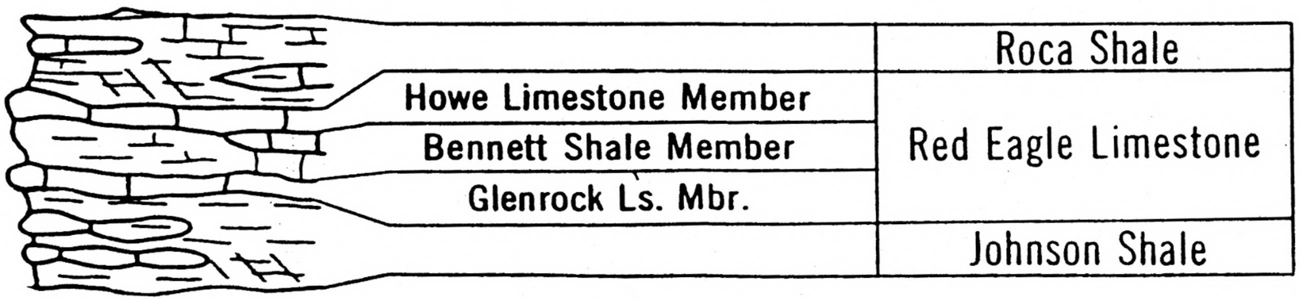





Figure 2. Stratigraphic column of the Johnson Shale, Red Eagle Limestone, and Roca Shale formations (from Zeller, 1968).

# STUDY AREA

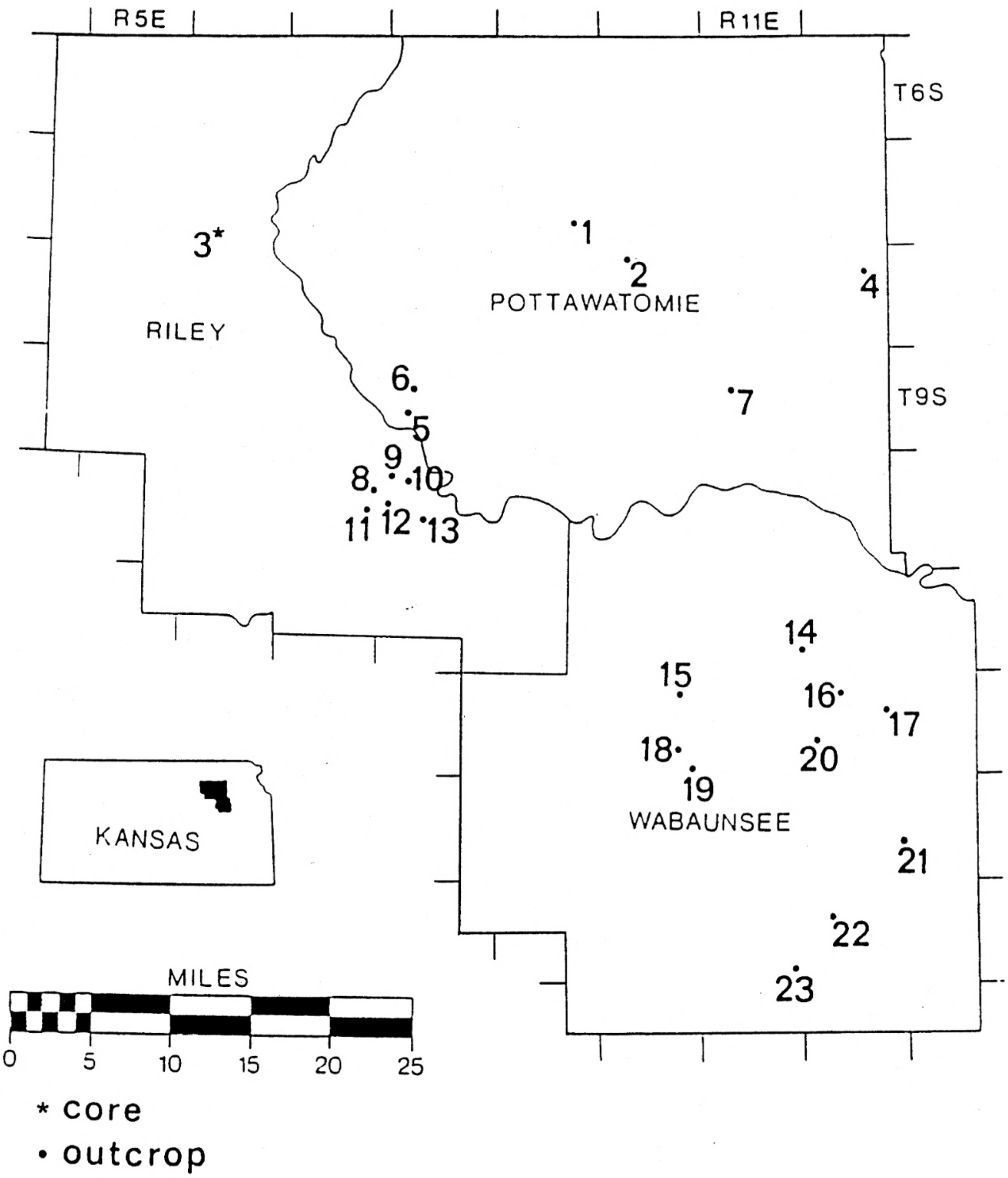



Figure 3. Location map of twenty-three measured sections.

and weathered samples, bedding, texture, composition, fossils, sedimentary structures, and contacts.

Orientated samples of limestone and bulk samples of shale or mudstone were collected at each lithology change, within each measured section. Laboratory study for this project consisted of the examination of over 130 samples, including: polished slabs, thin-sections, acetate peels, and disaggregated shale/mudstone samples, which were used to verify and supplement field data.

## PREVIOUS INVESTIGATIONS

The Red Eagle Limestone was first described by Heald (1916) and was named for exposures found near the Red Eagle School in the Foraker area, Osage County, Oklahoma. In 1927, Condra named the Glenrock Limestone, Bennett Shale, and Howe Limestone from exposures in southeastern Nebraska, which he was able to trace into northern Kansas.

In 1936, Bass recognized, in the Cottonwood River Valley east of Elmdale, Kansas, that the Glenrock Limestone, Bennett Shale, and Howe Limestone of southern Nebraska and northern Kansas were stratigraphically equivalent to the Red Eagle Limestone of southern Kansas and northern Oklahoma. In 1952, O'Connor and Jewett summarized the work of Bass and included detailed stratigraphic sections useful in tracing the Red Eagle Formation across Kansas.

In 1963, McCrone examined the paleoecology and biostratigraphy of the Red Eagle cyclothem from southern Nebraska, through Kansas, and into northern Oklahoma. Al-Khersan (1969) studied the trace elements and carbonate petrography of the Red Eagle Limestone in northern Oklahoma.

The distribution of ostracodes and foraminiferids within the Bennett Shale Member in northeastern Kansas were studied by Sloan (1963). In addition, Little (1965) compared the conodont assemblages in the Hughes Creek Shale and Bennett Shale in northeastern Kansas.

Detailed analysis of cyclicity in the Red Eagle Limestone Formation in Kansas have been provided by Elias (1937), Mudge and Yochelson (1962), McCrone (1963), and Avers (1968). Elias considered the Red Eagle Formation as a "single cycle" with the fusulinid phase of the Glenrock Limestone Member representing a maximum depth of approximately 160-180 feet (Figure 4 and 5). Mudge and Yochelson (1962) also considered the Red Eagle Limestone as representing one cyclothem. Authors of both papers considered the brick-red mudstone in the Johnson and Roca Shales as the beginning and ending point, respectively, for the Red Eagle cyclothem.

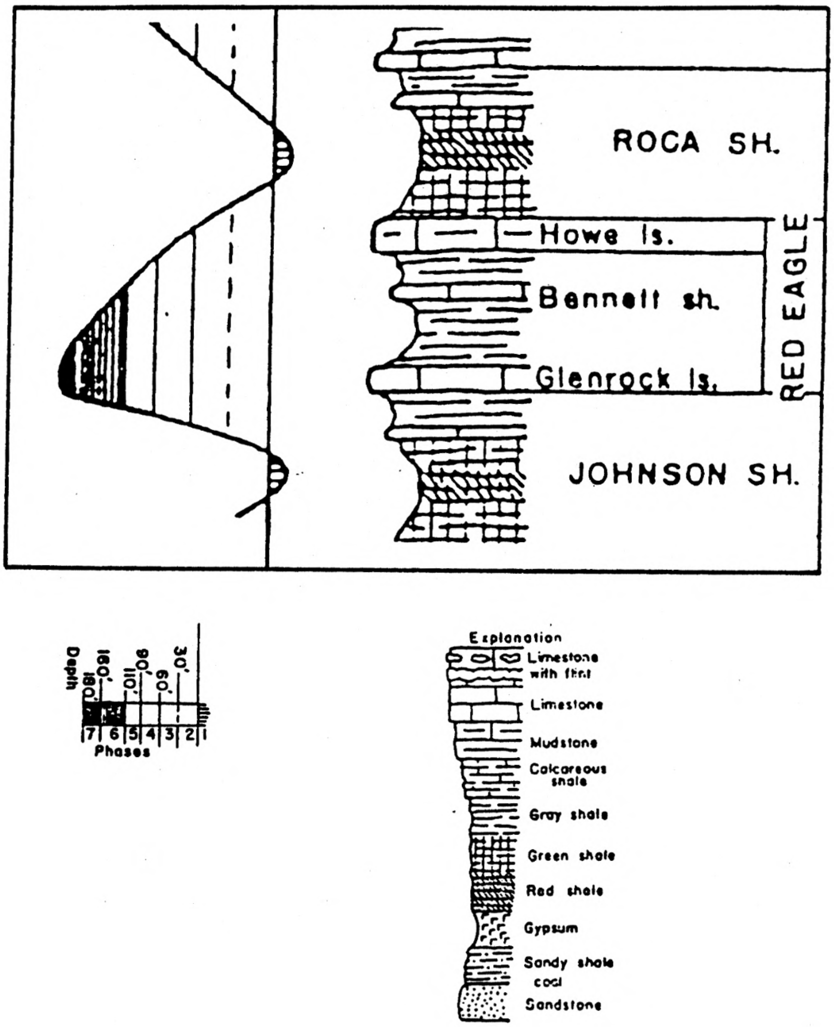



Figure 4. Elias' sea level curve for the Johnson Shale, Red Eagle Limestone, and Roca Shale formations (from Elias, 1937).

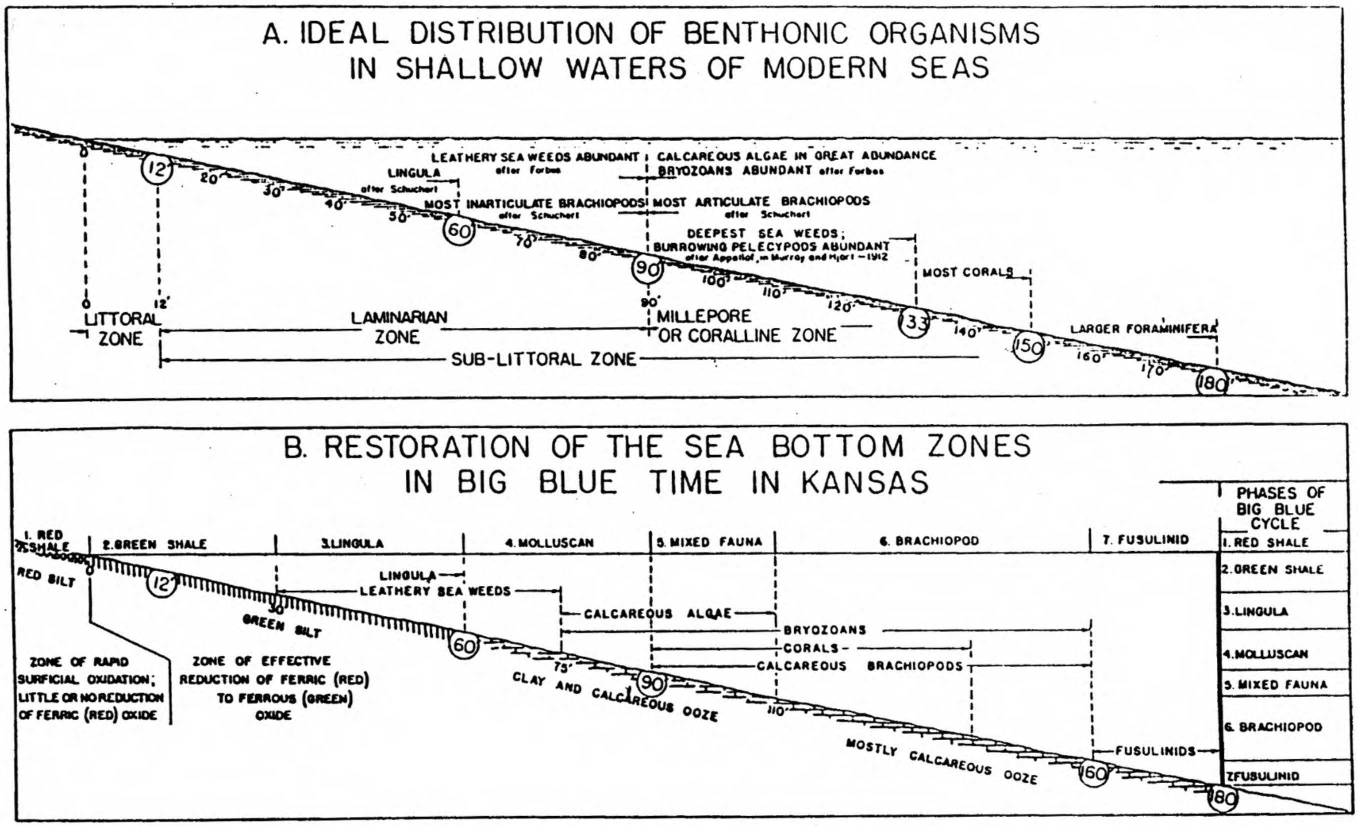



Figure 5. Elias' onshore to offshore phases for the Big Blue Series (Lower Permian) of the Mid-continent (from Elias, 1937).

McCrone (1963) recognized three sea level fluctuations or cycles within the Red Eagle Limestone Formation (Figure 6). McCrone also envisioned a much shallower sea during Red Eagle time, with a maximum depth of 50-60 feet. However, McCrone did agree that the Red Eagle cyclothem started and ended during Johnson and Roca deposition (i.e., time).

Avers (1968) included the Red Eagle Limestone Formation in the top of his lower Council Grove megacyclothem, which extended down to the top of the Houchen Creek Limestone. The Roca Shale Formation was included in the middle Council Grove megacyclothem by Snyder (1968) which extended to the top of the Beattie Formation.

Condra (1927) named the Roca Shale Formation from exposures near Roca in Lancaster County, Nebraska. The Roca Shale is composed of bluish gray, olive green, and reddish mudstones with thin fossiliferous limestone beds in the upper part near the type locality. The base of the Sallyards Limestone Member of the Grenola Limestone Formation marks the upper boundary of the Roca Shale.

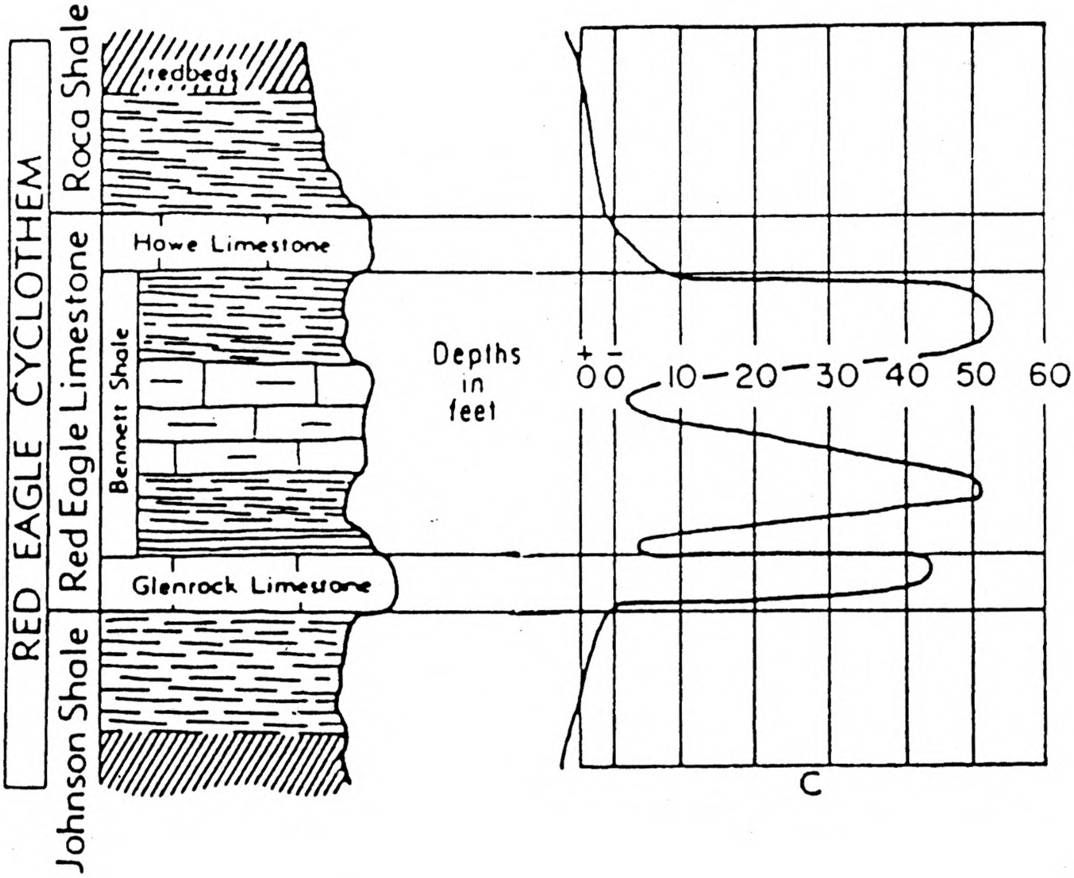



Figure 6. McCrones sea level curve for the Red Eagle Formation (from McCrone, 1963).

# G E O L O G I C   S E T T I N G

## STRUCTURE OF THE STUDY AREA

The study area straddles the northeast-southwest trending Nemaha Anticline, which separates the Forest City Basin on the east from the Salina Basin on the west (Figure 7). This structural feature is a large anticline, which is bounded on the east by both high-angle reverse and normal faults, and dips gently to the west (Jewett, 1951 and Merriam, 1963). Major periods of movement occurred during post-Mississippian and pre-Desmoinesian (Pennsylvanian) time, with Precambrian rocks directly overlain by beds of Pennsylvanian age (Merriam, 1963).

Smaller structural features flanking the Nemaha Anticline include the: Abilene Anticline, Irving Syncline, Zeandale Dome, Humboldt Fault, Brownville Syncline, and Alma-Davis Ranch Anticline (Figure 8).

The Abilene Anticline is a rather pronounced fold west of, and nearly parallel (trends slightly more east) to the Nemaha Anticline (Shenkel, 1959 and Merriam, 1963). The east limb of this structure is bounded by a northeast-trending fault extending from Riley County, Kansas into southeastern Nebraska (Burchett et al., 1983). The Abilene Anticline can also be recognized in the surface rocks of Riley County and southwest Dickinson County (Jewett, 1951).

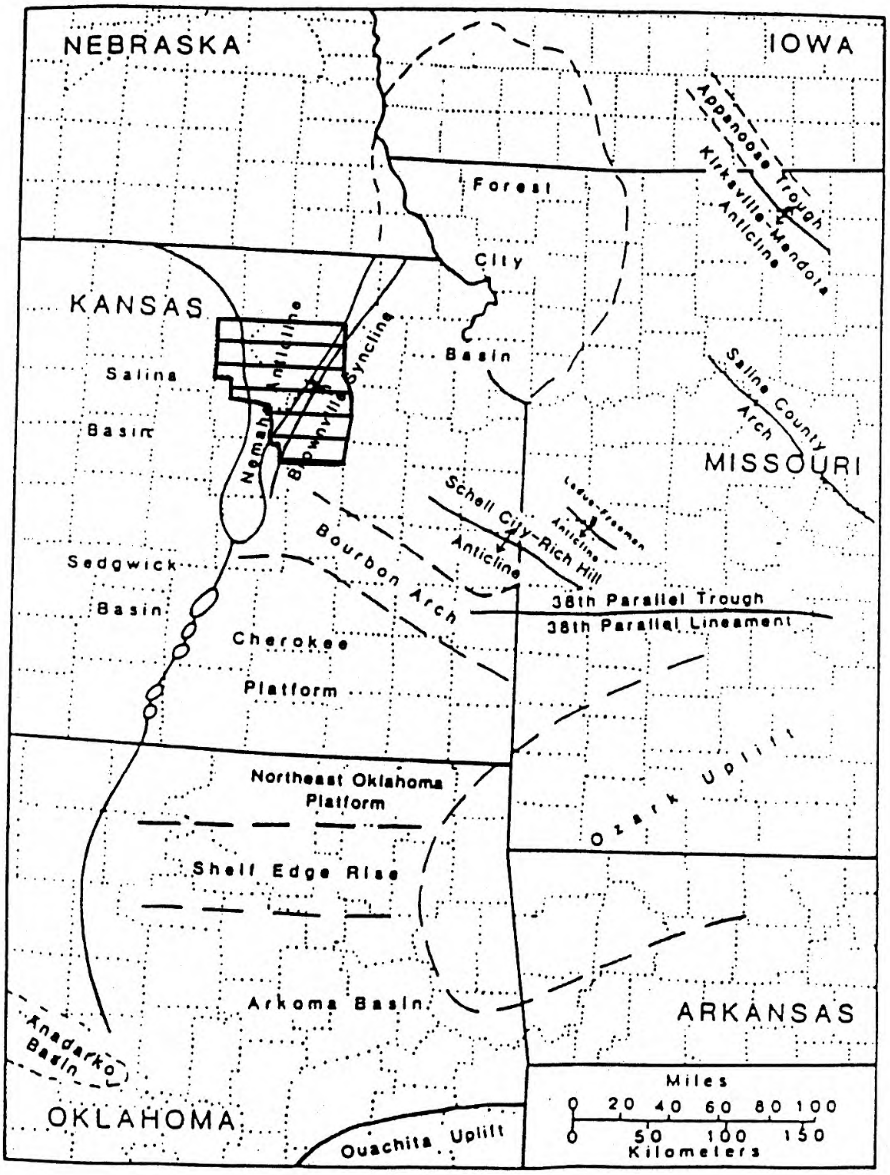
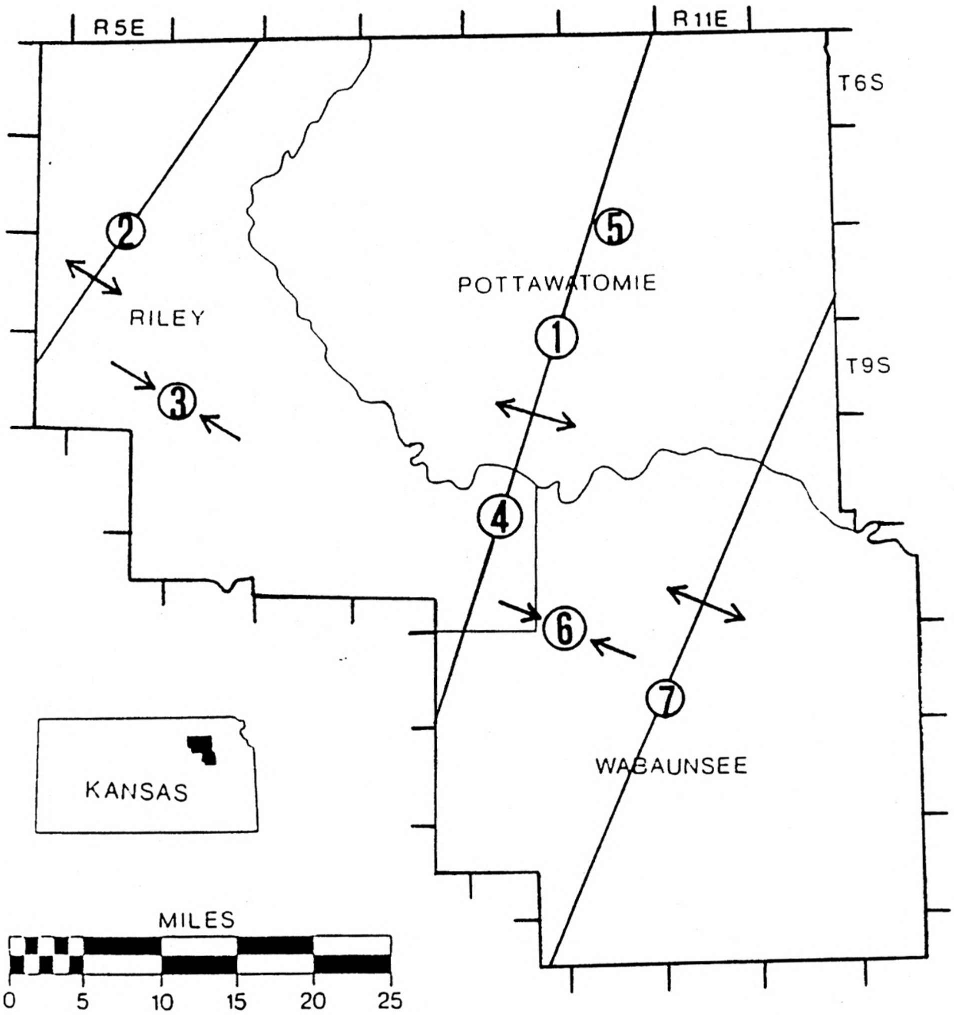



Figure 7. Map of study area in relation to regional structures (from Knight, 1985).




1 Nemaha Anticline

2 Abilene Anticline

3 Irving Syncline

4 Zeandale Dome

5 Humboldt Fault

6 Brownville Syncline

7 Alma-Davis Ranch Anticline

Figure 8. Structural features within the study area.

East of the Abilene Anticline and west of the Nemaha Anticline lies a narrow trough known as the Irving Syncline. The Irving Syncline is an asymmetrical structure, with a relatively steep west flank and a gentler dipping east flank. The axis of this structure extends from Riley County, Kansas northward into southern Nebraska (Jewett, 1951).

Southeast of the town of Zeandale there is a local high along the crest of the Nemaha uplift, which is known as the Zeandale Dome (Koons, 1955; Bruton, 1958; Swett, 1959 and Yarrow, 1974). The Zeandale Dome is a northwest-southeast elongate structure, truncated by faults to the north and east with approximately 600 feet of closure (Koons, 1955). This structure is also recognizable in the surface rocks of southeast Riley and northwest Wabaunsee Counties (Swett, 1959).

The east side of the Nemaha Anticline is bounded by a series of en-echelon faults, which are collectively known as the Humboldt Fault. This fault system extends from Nebraska, into Kansas, and continues into Oklahoma (Berendsen and Blair, 1986).

The Brownville Syncline also lies east of the Nemaha Anticline (Figure 8). This trough extends southwest from southern Nebraska to near Council Grove in northeastern Morris County, Kansas (Berendsen and Blair, 1986). The

Brownville Syncline has an asymmetrical profile, with a relatively steep west flank and a gently dipping east flank (Merriam, 1963). The Brownville Syncline is also recognized as the "deepest part" of the Forest City Basin (Jewett, 1951).

The Alma-Davis Ranch Anticline lies approximately nine miles east of the Nemaha Anticline (Merriam, 1963), and is bounded on the east, by a high-angle reverse fault (Smith and Anders, 1951). The axis of this anticline is also parallel to the larger Nemaha Anticline, and extends the length of Wabaunsee County into northern Lyon County (Jewett, 1951).

## GENERAL STRATIGRAPHY

The Council Grove Group is part of the Gearyan Stage of the Lower Permian Series (Figure 9), and is composed of 310 to 330 feet of interbedded carbonates and shales (Zeller, 1968). The following formations were studied in detail and occur in the lower Council Grove Group in ascending order: Johnson Shale, Red Eagle Limestone, and Roca Shale. The results of the field work are summarized in the measured sections found in Appendix II.

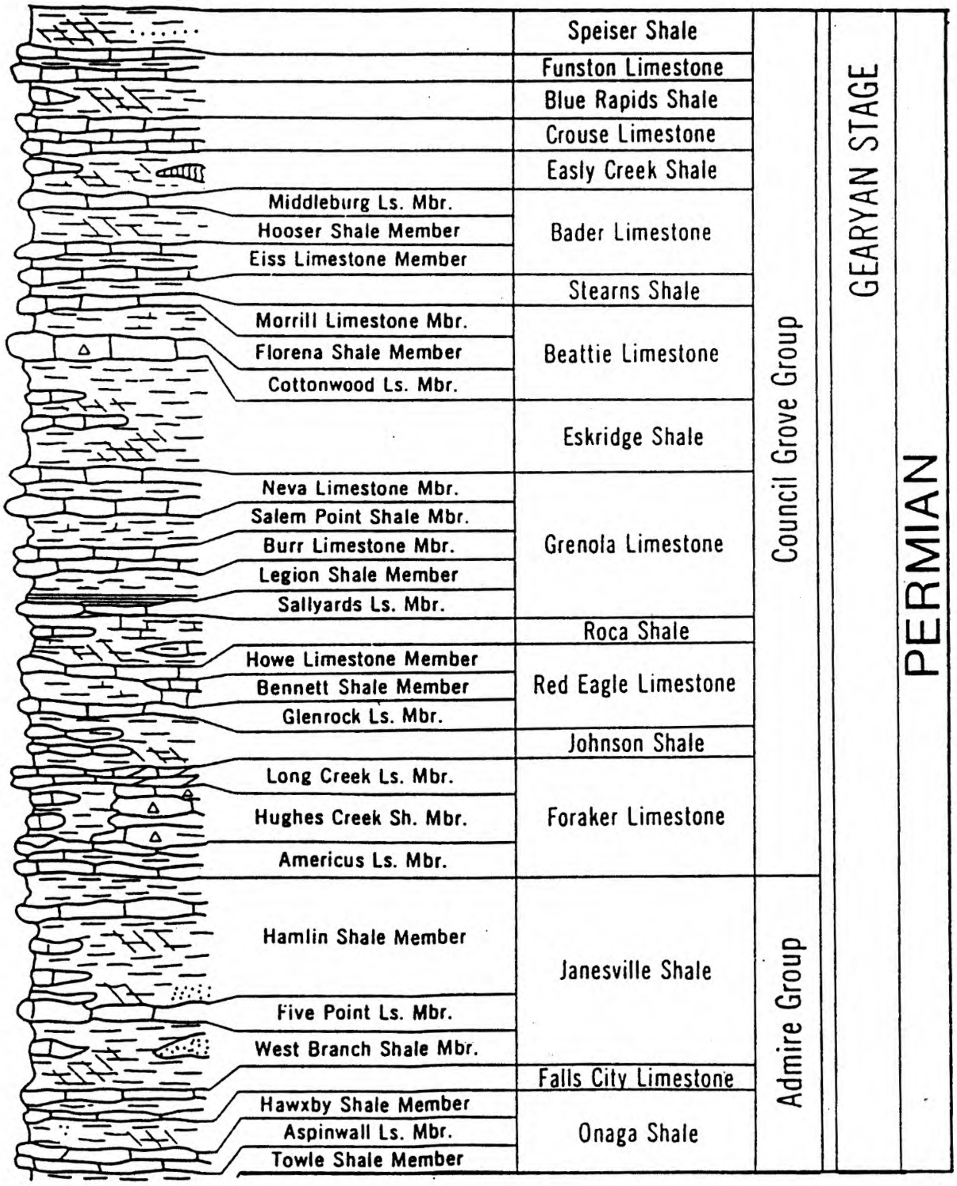



Figure 9. Stratigraphic column of the Council Grove Group (from Zeller, 1968).

## Johnson Shale Formation

The Johnson Shale was first named by Condra (1927, p. 86) from exposures in a creek bank north of Johnson, Nebraska. Generally, the Johnson Shale may be described as a light brown, gray, and green mudstone, which contains thin beds of argillaceous limestone. Root traces, smooth shelled ostracodes, and plant fragments are the common fossils associated with this unit. Charophytes and fish fragments are also common (Lane, 1964).

Thickness of the Johnson Shale ranges from 13-15 feet in Nebraska, and it thickens southward in Kansas to 25-26 feet (McCrone, 1963 and Zeller, 1968). However, complete workable exposures are rare in most places.

## Red Eagle Limestone Formation

The Red Eagle Limestone was first named by Heald (1916, p. 24-25) from exposures near Red Eagle School, southwest of Foraker, Oklahoma. At the type location, the Red Eagle Limestone consists of almost solid limestone with some interbedded shale (O'Connor and Jewett, 1952; McCrone, 1963 and Al-Khersan, 1969). The Red Eagle Limestone becomes clayey northward, through Kansas and into southern Nebraska (O'Connor and Jewett, 1952 and McCrone, 1963). Within the study area, the Red Eagle

Limestone consists of the following members in ascending order: Glenrock Limestone, Bennett Shale, and Howe Limestone.

Glenrock Limestone Member.--The Glenrock Limestone was named by Condra (1927, p. 86) from exposures northwest of Glenrock, Nebraska. Generally, the Glenrock Limestone can be divided into two lithologies: (1) a nonfusulinid lower part, that contains abundant intraclasts (calcilutite - mudstone, 3-7mm. in diameter, subrounded to subangular), rare brachiopods, and is highly burrowed (Thalassinoides, which contain Orbiculoidea fragments and black shale/mudstone from above), and (2) a fusulinid-bearing upper part, containing an abundant and diverse assemblage of articulated brachiopods (i.e., Composita, Neospirifer, Neochonetes, and Wellerella) and bryozoans. The contact between the two lithologies is knife sharp, and probably represents an omission surface. Heim introduced the term "omission surface" in 1924, which Bromley defined (1975, p. 400) "as a discontinuity surface of the most minor nature, which mark temporary halts in deposition but involve little or no erosion".

The Glenrock Limestone Member can be traced in outcrops from southeastern Nebraska to near the Kansas-Oklahoma border, except for a small area in Wabaunsee County, Kansas where it is absent (O'Connor and Jewett, 1952; McCrone, 1963 and Zeller, 1968). Thickness of the Glenrock Limestone ranges from 0 to 3 feet, with an average thickness of about 1.5 feet in the area of study.

Bennett Shale Member.--The Bennett Shale was named by Condra (1927, p. 86) from exposures in a creek bank south of Bennet, Nebraska. (Note: Condra mispelled the town name Bennet and the spelling "Bennett" has been retained in the stratigraphic nomenclature - see Moore, 1952.) Generally, the Bennett Shale can be divided into two lithologies: (1) a dark gray to black, fissile to platy lower part, that contains common *Orbiculoidea*, *Crurithyris*, *Lingula*, and *Permophorus*, and (2) a dark gray to brown, platy to flaggy, slightly calcareous, upper part, containing an abundant and relatively diverse fossil assemblage. *Composita*, *Aviculopecten*, *Hustedia*, *Linoproductus*, *Derybia*, *Antiquationia*, *Aviculopinna*, and *Crurithyris* are the common genera associated with this unit. Bryozoans and crinoids are also common. However, in the southern part of the study area (i.e., Wabaunsee County), the upper part of the Bennett Shale Member is a limestone. This carbonate buildup has also been recognized by O'Connor and Jewett, 1952 and McCrone 1963.

The thickness of the Bennett Shale varies greatly in the study area, averaging 3-4 feet in thickness. However it may be as thin as 0.5 feet over the crest of the Nemaha Anticline (see section 2, Appendix II).

Howe Limestone Member.--The Howe Limestone was named by Condra (1927, p. 86) from exposures south of Howe, Nebraska. The Howe Limestone can be divided into two general lithologies within the study area. The lower part is a blocky, slightly argillaceous, skeletal calcilutite (wackestone), which includes an abundant and relatively diverse assemblage containing *Composita*, *Aviculopecten*, productids, fusulinids, *Hustedia*, crinoids, *Crurithyris*, and bryozoans. The upper lithology is a massive, well-sorted, skeletal calcarenite (packstone-grainstone) containing coated grains (*Osagia*), smooth shelled ostracodes (*Paraparchites*), high-spired gastropods (pyramidellid-like), and hemispheroidal stromatolites.

## Roca Shale Formation

The Roca Shale was named by Condra (1927, p. 86) for exposures near Roca, Nebraska. Generally, the Roca Shale may be described as a light gray, green, and red mudstone, containing thin beds of argillaceous limestone. Root traces, smooth shelled ostracodes, and high-spired gastropods (pyramidellid-like) are the common fossils associated with this unit. The thickness of this unit ranges from 14 to 27 feet within the study area.

# H I E R A R C H A L  G E N E T I C S T R A T I G R A P H Y

## TRANSGRESSIVE-REGRESSIVE UNITS

Recent workers (Vail et al., 1977; Busch and Rollins, 1984; Goodwin and Anderson, 1985; Busch and West, 1987; Vail, 1987) have shown that eustatic sea level changes are the major controls on stratal patterns and the distribution of lithofacies. Vail and others (1977), identified three major depositional sequences (i.e., transgressive-regressive units) which have periodicities of 225-300 million years, 20-90 million years, and 7-13 million years, respectively. For example, Vail et al., (1977), identified two first-order transgressive-regressive units or T-R units within the Phanerozoic, with a first-order transgressive-apex occurring in the Lower Ordovician and another in the Upper Cretaceous (Figure 10). They were also able to further subdivide the Phanerozoic into at least 14 second-order, and 80 third-order T-R units.

In terms of the Permo-Carboniferous, all of the Mississippian strata are encompassed in the upper part of a second-order T-R unit. The Pennsylvanian and early Permian strata comprise another second-order T-R unit, and the middle-late Permian strata are yet another second-order T-R unit (Figure 10).

In addition to Vail's three major scales of T-R units (i.e., first-, second-, and third-order), Busch and Rollins (1984) have identified three minor scales of T-R units (i.e., fourth-, fifth-, and sixth-order; Figure 11 and 12). Fourth-order T-R units tend to have periodicities of 0.8-1.5 million years as shown by Busch and Rollins (1984) for the Late Pennsylvanian of the Appalachian Basin, and are equivalent to Ramsbottom's (1979) mesthothems (i.e., regressive-transgressive units) in the Carboniferous of Europe. Fifth-order T-R units have periodicities of 300,000-500,000 years, and transgressive-regressive units of the same scale have been referred to as: cyclothems by Wanless and Weller (1932); megacyclothems by Moore (1936); and Kansas cyclothems by Heckel (1977). Sixth-order T-R units have periodicities on the order of tens-of-thousands of years and are equivalent to Goodwin and Anderson's (1985) Punctuated Aggradational Cycles (PAC's) and Heckel's *et al*. (1979) minor T-R sequences.

Sixth-order T-R units are best defined in outcrops and cores by looking for, punctuations, often subtle, in the rock record. According to the PAC hypothesis, (Goodwin and Anderson, 1985) most sedimentary sequences

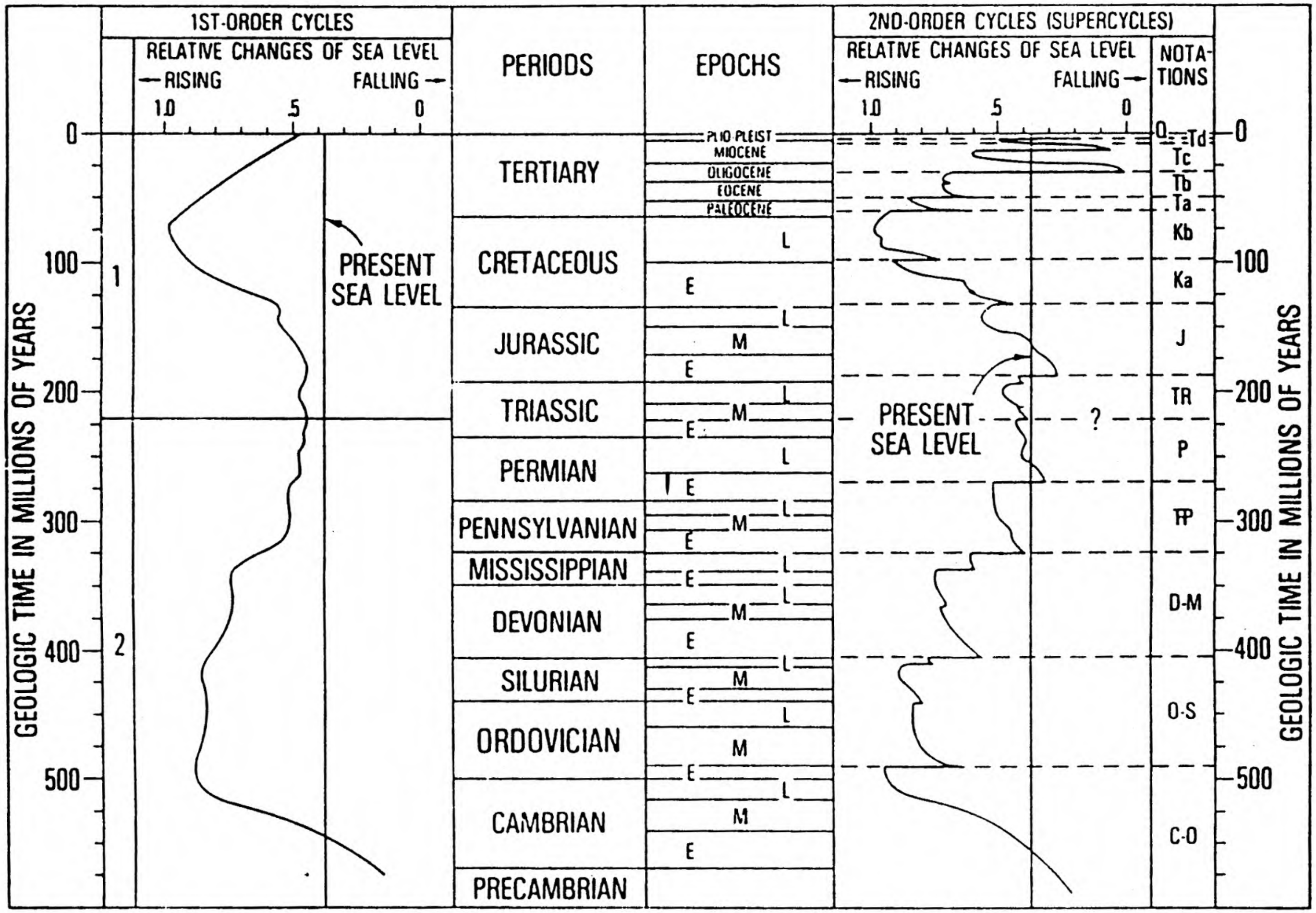
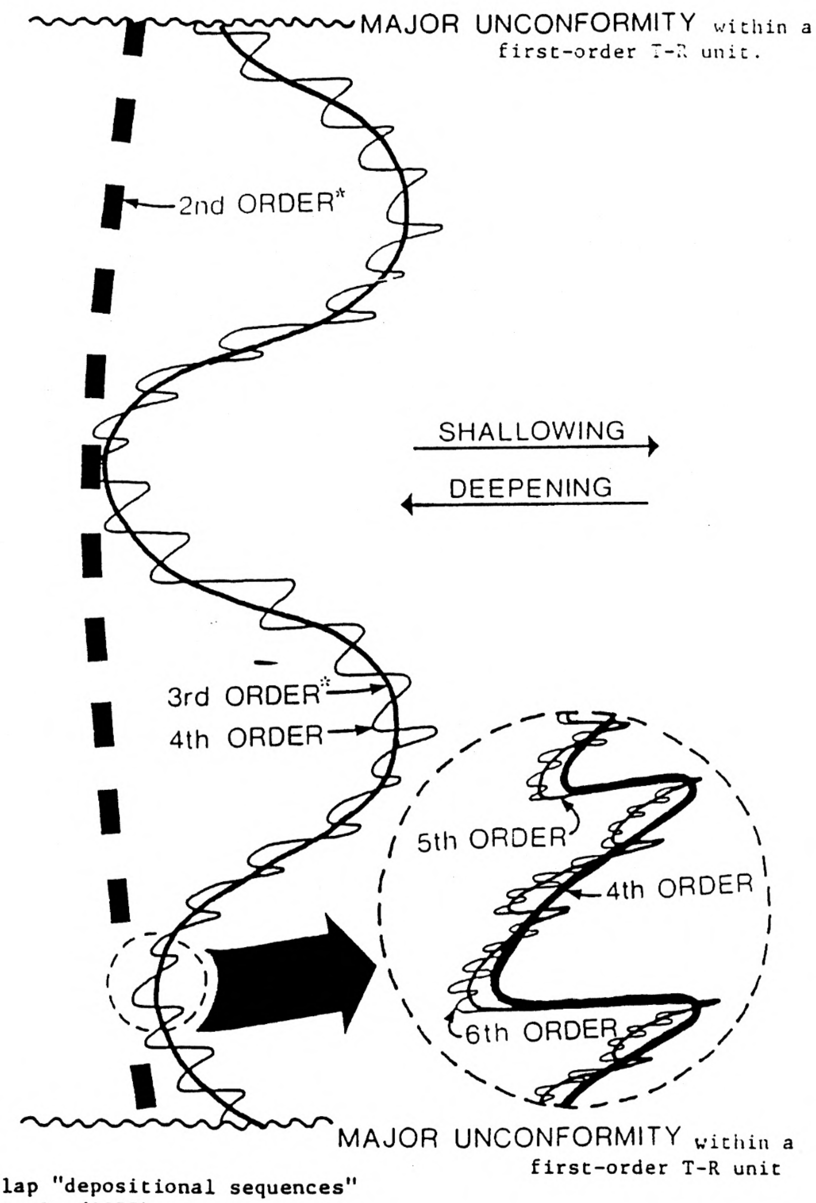



Figure 10. Vail and others (1977) sea level curve showing first- and second-order global cycles during the Phanerozoic.




*onlap-offlap "depositional sequences" of Vail et al. (1977).

Figure 11. Schematic illustration showing a hierarchy of transgressive-regressive units (from Busch and West, 1987).

## HIERARCHY OF PERMO-CARBONIFEROUS T-R UNITS

| BUSCH & ROLLINS, 1984 AND BUSCH, 1984 | VAIL et al., 1977 | CHANG, 1975 AND RAMSBOTTOM, 1979 | MOORE, 1936 | GOODWIN AND ANDERSON, 1985 | HECKEL, 1977 AND HECKEL, 1986 | WANLESS AND WELLER, 1932 |
|---|---|---|---|---|---|---|
| FIRST-ORDER 225-300 Ma | FIRST ORDER DEPOSITIONAL SEQUENCES | | | | | |
| SECOND-ORDER 20-90 Ma | SECOND ORDER DEPOSITIONAL SEQUENCES | SYNTHEMS | | | | |
| THIRD-ORDER 7-13 Ma | THIRD ORDER DEPOSITIONAL SEQUENCES | | | | | |
| FOURTH-ORDER 0.6-3.6 Ma | | MESOTHEMS | | | | |
| FIFTH-ORDER 300-500 ka | | CYCLOTHEMS | MEGACYCLOTHEMS | SHALLOWING PAC SEQUENCES | KANSAS CYCLOTHEMS; MAJOR CYCLES | CYCLOTHEMS |
| SIXTH-ORDER 50-130 ka | | | CYCLOTHEMS | PUNCTUATED AGGRADATIONAL CYCLES (PACs) | MINOR CYCLES | |

Figure 12. Hierarchy of Permo-Carboniferous transgressive-regressive units as utilized in this study (from Busch and Rollins, 1984; Busch and West, 1987).

are composed of thin (1-5 meters) shallowing upward cycles or T-R units, which are presumed to be correlative basinwide. These T-R units are usually asymmetrical, with a very thin transgressive base, due to relatively rapid transgression (i.e., episodic events; Figure 13). Such punctuation events are followed by sea level stasis during which aggradation and progradation occur (Busch, 1983).

## GENETIC SURFACES BOUNDING T-R UNITS

Minor T-R units are regarded as the net result of climate change (i.e., glacio-eustatic; Busch and West, 1987). Boundaries between these small scale T-R units are genetic surfaces of two types: transgressive surfaces, and climate change surfaces (Busch, 1984). Transgressive surfaces are located at the contacts between: (1) a marine facies (i.e., facies containing marine fossils) overlying a nonmarine facies, or (2) a relatively deeper marine facies overlying a relatively shallower marine facies that was transgressed. Climate change surfaces are defined as the contacts between nonmarine facies formed during more humid conditions (i.e., coals or lacustrine limestones) and the subjacent more arid facies (i.e., paleosol or calcrete).

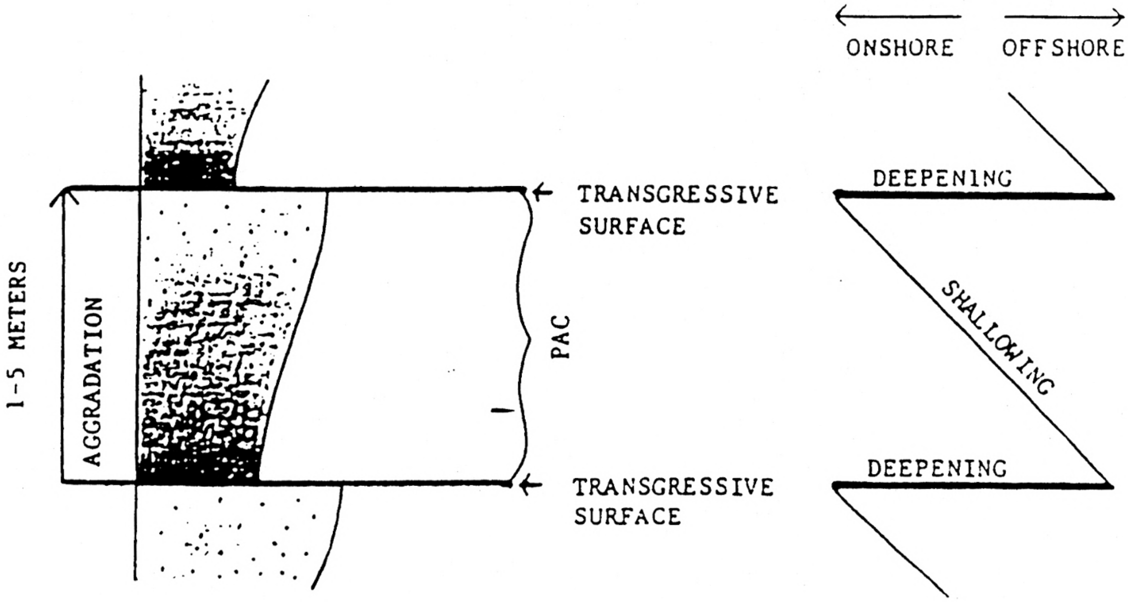



Figure 13. Punctuated Aggradational Cycle concept (from Goodwin and Anderson, 1985).

# WALTHER'S LAW AND DISJUNCT FACIES

According to Middleton (1973, p. 979), Walther stated "only those facies and facies-areas can be superimposed primarily which can be observed beside each other at the present". This concept became known as "Walther's Law of Succession of Facies" (Figure 14), which generally states that adjacent (i.e., contiguous) modern environments become stratigraphically adjacent (i.e., contiguous) in a conformable sequence (Middleton, 1973).

Walther's Law has been traditionally used to describe the gradual accumulation and migration of genetically related facies at the formational scale (e.g., Laporte and Imbrie, 1964). However, the concept of episodic accumulation has been used recently by Byers (1982); Cotter (1983); Anderson _et al._, (1984); Goodwin and Anderson (1985); Goodwin _et al._, (1986) and Hamilton (1989) to challenge this concept. If the stratigraphic record is composed of a hierarchy of small-scale eustatic controlled PAC's or small scale transgressive-regressive units, then basinwide discontinuities are present at PAC boundaries (Goodwin _et al._, 1986). Surfaces separating noncontiguous or disjunct facies represent discontinuities across which Walther's Law does not apply (Goodwin _et al._, 1986). Therefore, Walther's Law is applicable only within the confines of PAC boundaries.

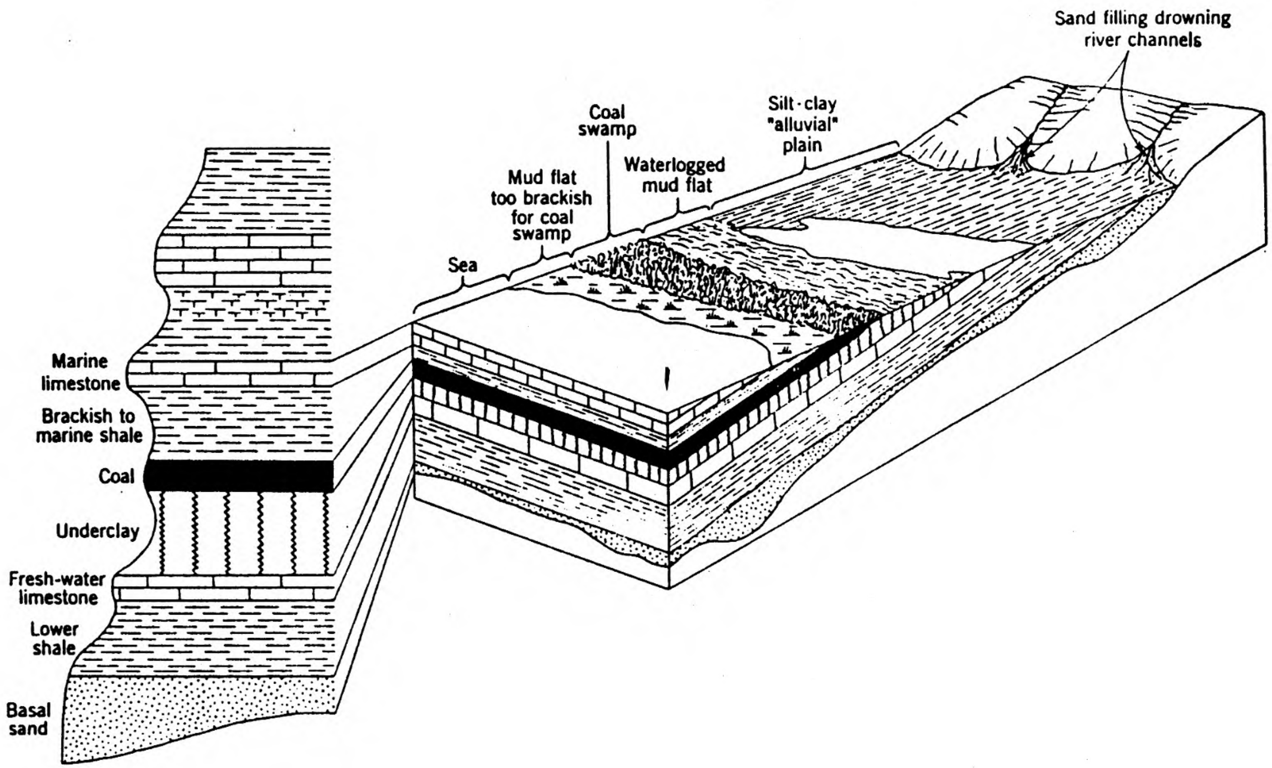



Figure 14. Schematic diagram illustrating the concept known as "Walther's Law of Succession of Facies (from Shaw, 1964).

## ALLOCYCLICITY VERSUS AUTOCYCLICITY

Stratigraphic sequences can be composed of T-R units which are the result of autocyclic processes, allocyclic processes, or a combination of both (Busch *et al.*, 1985) (Figure 15). Autocyclic processes are those which only operate within a particular environment of deposition, and therefore tend to be local (i.e., delta switching or tidal channel migration). On the other hand, allocyclic processes are the result of an overriding mechanism which affects many or all environments of deposition at the same time, within a basin and probably globally (i.e., eustatic sea level change).

All T-R units are assumed to be potentially allocyclic. This assumption can be tested (proved or disproved) by correlating the genetic surfaces relative to "key" marker beds. Correlative T-R units are also time-stratigraphic units, because they represent specific intervals of a transgression and regression (Busch and West, 1987).

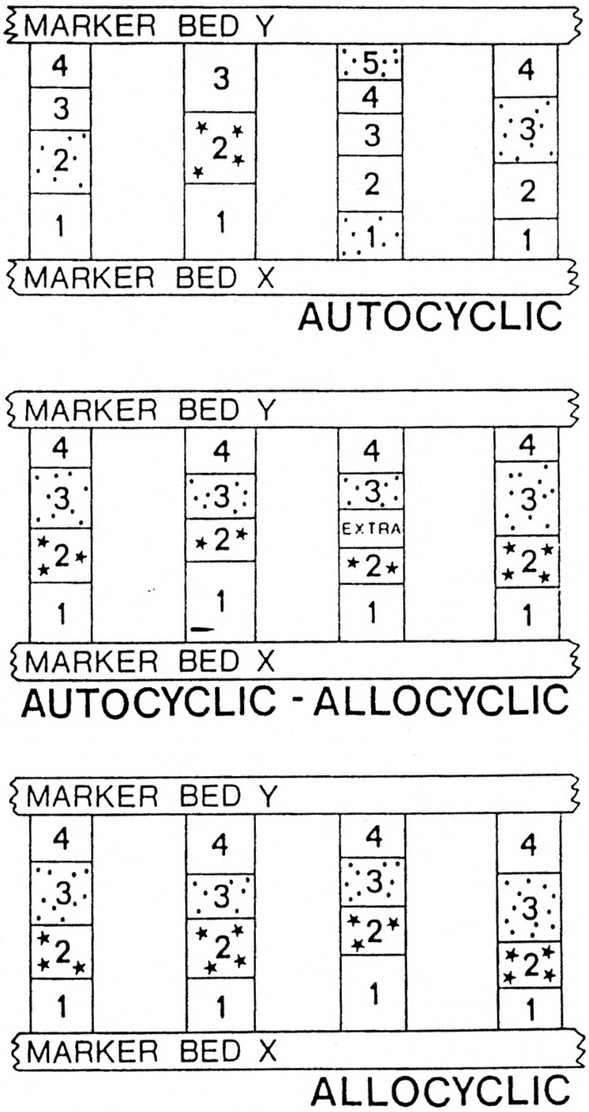



Figure 15. Schematic stratigraphic columns illustrating the relationships of autocyclic, autocyclic-allocyclic, and allocyclic units (from Busch and West, 1987).

# HIERARCHAL GENETIC STRATIGRAPHY OF THE RED EAGLE LIMESTONE AND ROCA SHALE FORMATIONS

## SIXTH-ORDER T-R UNITS

The Red Eagle Limestone and Roca Shale formations comprise one net transgressive-regressive unit (T-R unit) which is equivalent to a fifth-order T-R unit and may represent an interval of about 300-500 Ka. Within this net transgressive-regressive (fifth-order) unit, smaller scale (sixth-order) T-R units, bounded by genetic surfaces, can be recognized. Detailed stratigraphic relationships become apparent when these genetic surfaces are correlated relative to marker beds. Furthermore, development of the transgressive-regressive (fifth-order) unit is better understood in terms of the facies patterns revealed by each small scale (sixth-order) T-R unit within it.

Figure 16 is a schematic diagram of the fossil distribution and lithology changes in the outcrop photo of Figure 17. This illustrated section is from location 12 in Riley County, Kansas and is a typical Red Eagle Limestone-Roca Shale sequence. I will use this section to graphically illustrate the sixth-order T-R units which make up the Red Eagle fifth-order T-R unit.

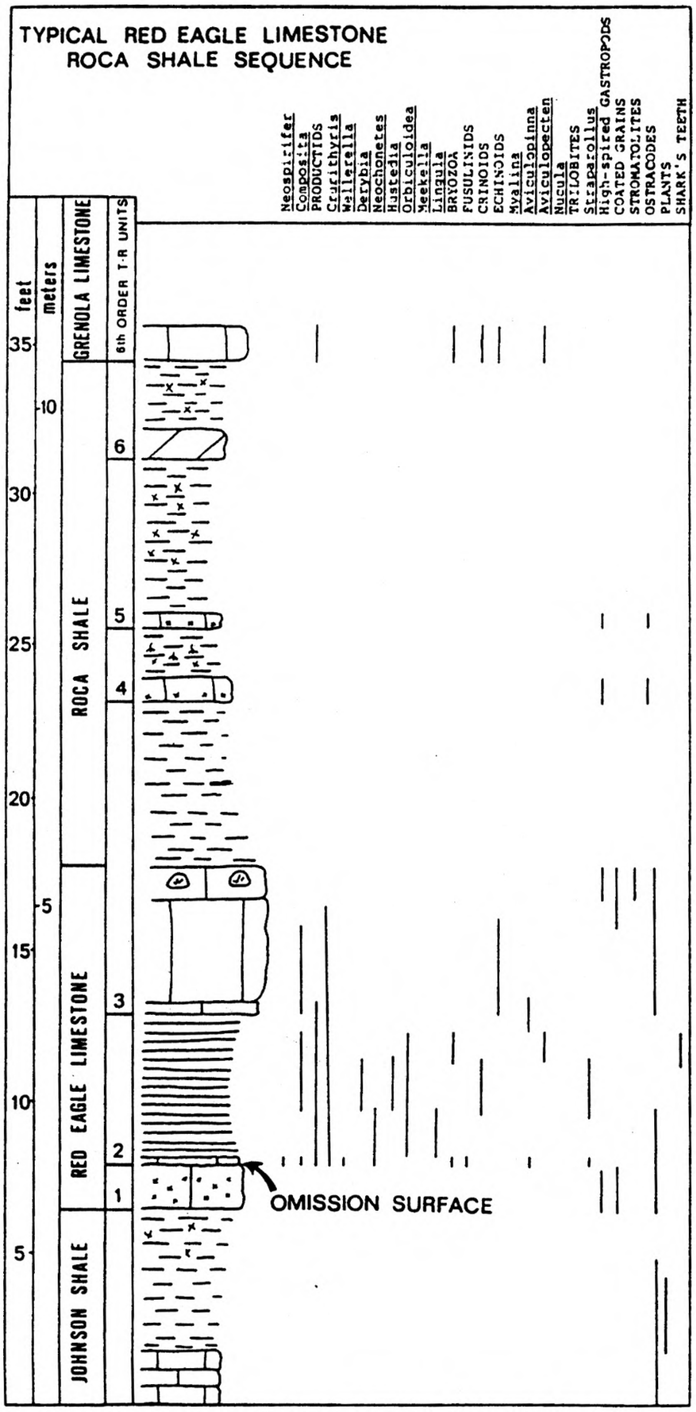



Figure 16. Schematic diagram illustrating the fossil distribution and lithology changes at location 12 (see Appendix II).

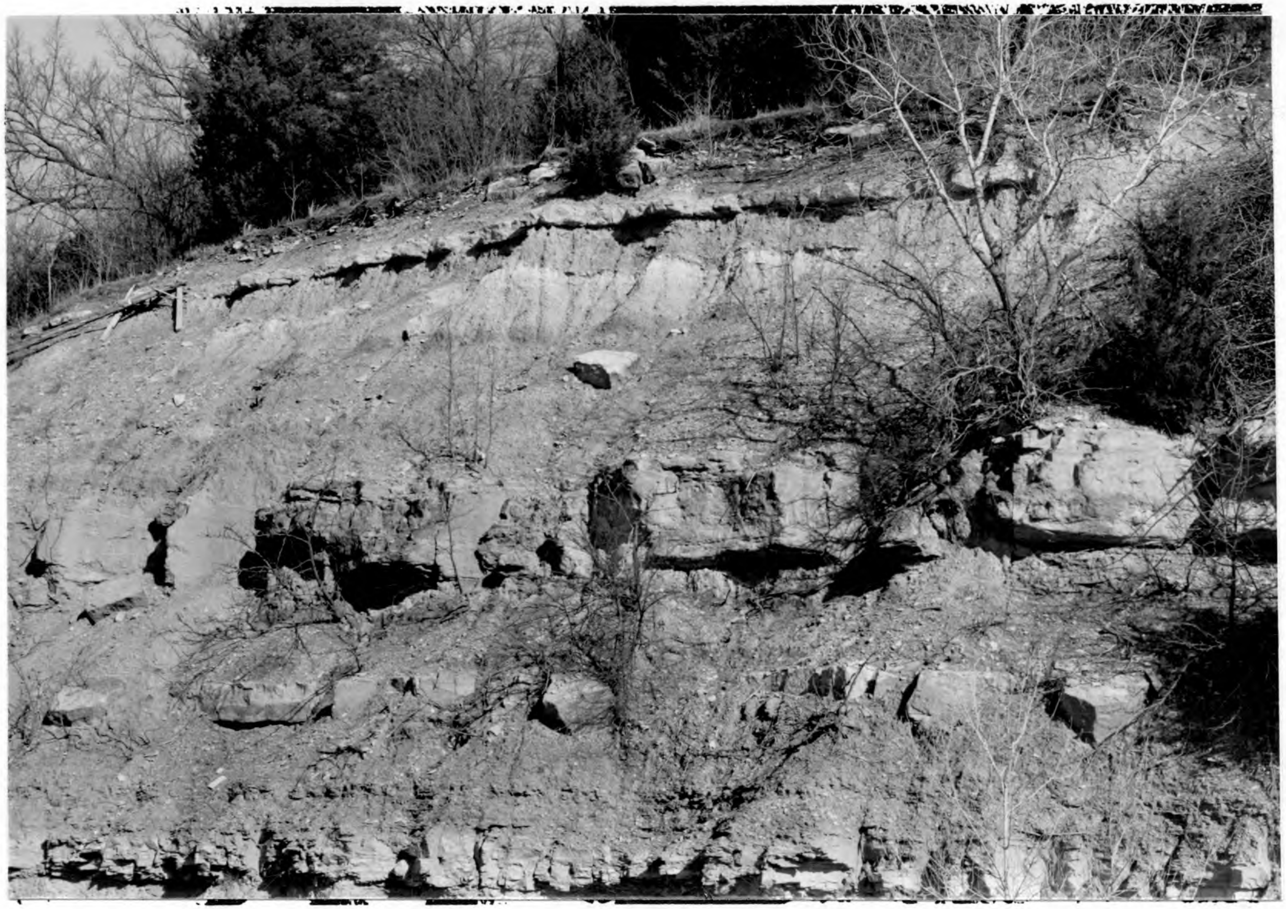


Figure 17. Photo of outcrop at location 12, depicted in figure 16.

Sixth-order T-R unit #1 is composed of the basal 0.41 meters of the Glenrock Limestone Member. This unit was deposited during the initial transgression over pre-existing deposits (i.e., Johnson Shale).

The lithology of this thin basal Glenrock Limestone unit consists of an intraclastic, skeletal wackestone to packstone (conglomerate), which contains high-spired gastropods, small bivalves, coated grains (Osagia) and Thalassinoides burrows. The basal contact is sharp and locally erosional. According to James (1984) units which record the initial transgression over pre-existing deposits, that is basal units, usually reflect a high energy environment. This basal Glenrock Limestone unit was probably deposited in a shoaling environment.

The underlying lithology (i.e., Johnson Shale) is a dark gray, blocky-crumbly, mudstone, which has abundant caliche nodules and root traces. This unit is interpreted as a paleosol based on the following: (1) calcareous nodules (i.e., caliche nodules) probably formed through the dissolution and reprecipitation of calcite from percolating groundwater (Prather, 1985), (2) blocky-crumbly mudstones are indicative of subaerial exposure, especially in areas where there is little or no fluvial influence (Schutter and Heckel, 1985), and (3) root traces in their place of growth are evidence of exposure to the atmosphere and colonization by plants (i.e., a soil; Retallack, 1988). The Johnson Shale also contains a 2-4 meter thick gypsum bed in southeastern Nebraska (Burchett, 1988), and there is also gypsum present in the core (see section #3, Appendix II). Therefore, one can conclude that the climate during Johnson deposition (i.e., time) was probably more arid than at the start of Red Eagle deposition (i.e., time), and the epeiric seas probably shallowed to the north-northeast.

The basal Glenrock Limestone (sixth-order T-R unit #1) has a well preserved Thalassinoides burrow system (Figure 18). Some of these burrows are filled with Orbiculoidea fragments and dark gray shale/mudstone from above. This suggests that the basal Glenrock Limestone was at least partially cemented, or firm enough for the burrows to remain open during deposition of the gray shale/mudstone. In many cases, prelithified burrows, which are associated with an omission surface, often remain open and empty during long periods of nondeposition, and the burrow walls become strongly mineralized (i.e., cemented) as an extension of the sea floor (Bromley, 1967). Hardgrounds in the Lower Tertiary and Upper Cretaceous of North Africa and northwest Europe are usually associated with well preserved prelithification burrow systems of Thalassinoides, which are the work of crustaceans (Cayeux, 1939 and 1941; Voigt,

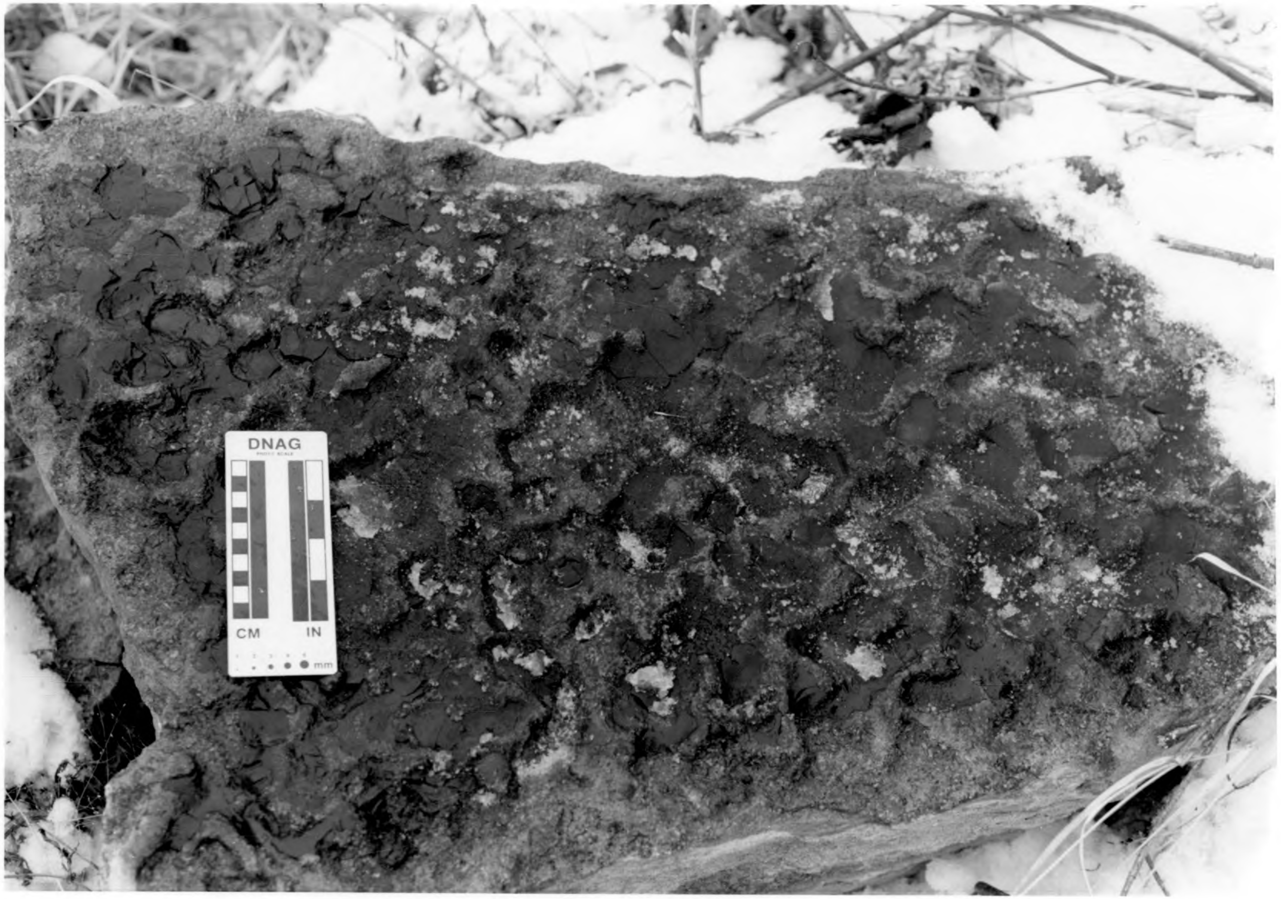



Figure 18. Photo of "omission surface" (<u>Thalassinoides</u> burrows) at the top of the Glenrock Limestone Member near St. Clere, Kansas (see section 4, Appendix II).

1959; Rasmussen, 1971; Bromley, 1967, 1968, and 1975). It has also been suggested that submarine cementation may be initiated along burrows, which act as conduits for the passage of sea water through the sediment (Taylor and Illing, 1969 and Bromley, 1975)

Sixth-order T-R unit #2 represents another deepening event and includes the upper 0.05 meters of the Glenrock Limestone Member and all (1.36 meters) of the Bennett Shale Member. The genetic surface separating sixth-order units #1 and #2 is an omission surface and possibly a firm to hardground. However, no evidence of boring or encrusting has been found within the area of study. Studies of the Holocene sediments in the Persian Gulf indicate that submarine lithification and the subsequent formation of hardgrounds are the result of slow carbonate sedimentation rates and often associated with transgressive-regressive surfaces (Shinn, 1969). Purser (1969) has recognized similar fabrics in Jurassic limestones of the Paris Basin.

The lithology of the basal sixth-order T-R unit #2 (i.e., upper Glenrock Limestone) consists of a very thin (0.05 meters) massive, skeletal wackestone to packstone, which has a very diverse marine biota, including numerous articulated brachiopod genera (i.e., Composita, Neospirifera, Neochonetes, Wellerella, etc.), bryozoans, and fusulinids. None of the fossils are abraded, suggesting that they have not been transported.

Bretsky and Lorenz (1970) demonstrated an increase in diversity, in modern marine faunas, from nearshore unstable environments to more environmentally stable offshore areas. This same trend, of increased diversities in offshore areas, has been documented by Walker and Laporte (1970); Sutton *et al.*, (1970); Stevens (1971); Donahue and Rollins (1974); and Brezinski (1983), and is known as the "stability-time" hypothesis of Sanders (1969) (Figure 19). Donahue and Rollins (1974) documented highest diversities at the time of maximum stability, namely during a transgressive maxima.

The rest of sixth-order T-R unit #2 (i.e., Bennett Shale) consists of a slightly silty, dark gray to black, fissile shale to platy mudstone, which has a relatively diverse marine biota, however, not as diverse as the upper Glenrock Limestone, and contains: *Hustedia*, *Composita*, *Crurithyris*, *Orbiculoidea*, *Derybia*, and productids. This facies reflects stagnant water conditions (i.e., gray to black shale/mudstone). However, there was enough oxygen to support some stenohayline organisms. Maples (1986) showed that anoxic conditions, generally thought to be pervasive during black-shale deposition, could be interrupted by periods of sediment oxygenation, allowing for the establishment of infaunal organisms.

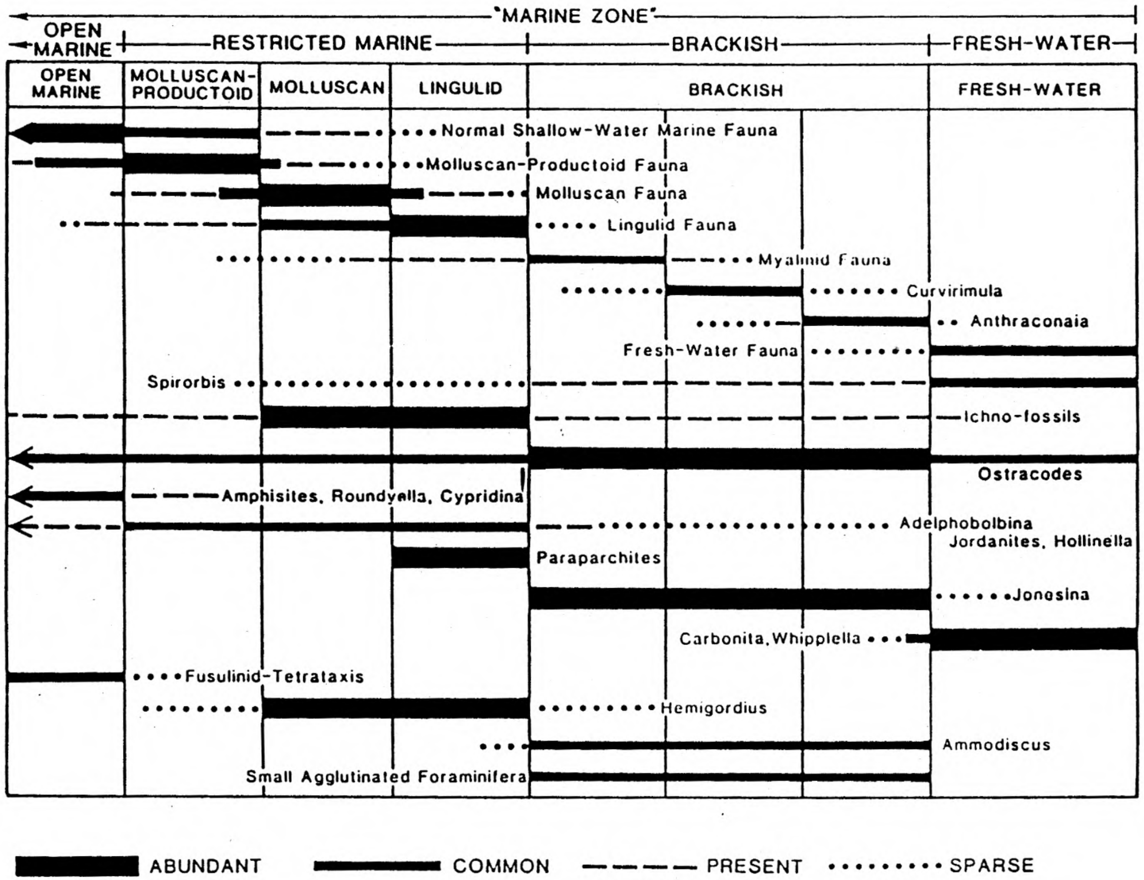



Figure 19. Schematic diagram illustrating the "stability-time" hypothesis (from Chesnut, 1981).

In general, stagnant water conditions can occur when: (1) there is a large freshwater influx into an enclosed epeiric sea; (2) there are broad expanses of shallow water, which dampen wave energy; (3) anoxic basin conditions are transgressed up onto the shelf; (4) upwelling; and (5) reflux of highly saline and anoxic water from an evaporitic basin, which flows across the shelf and produce euxinic conditions (Byers, 1977; Enos, 1983; Demaison and Moore, 1980; Heckel, 1977 and Hite, 1966).

Traditionally, deep water models (i.e., upwelling) have been envoked to explain the occurrence of Midcontinent black shales. However, this need not be the only model. Sea level is highest and river input into a basin is greatest during the full interglacial phase of a glacial-eustatic sea level cycle (Figure 20). This freshwater influx into an enclosed sea combines with the normal temperature gradient to produce a strong density stratification, with the lighter fresh or brackish water floating above the heavier more normal marine water (Byers, 1977 and Demaison and Moore, 1980). This model has been criticized by Heckel (1977); he argued that freshwater influxes sufficient to stagnate the bottom during high sea level stands would freshen the entire sea during low sea level stands. However, as the phase of

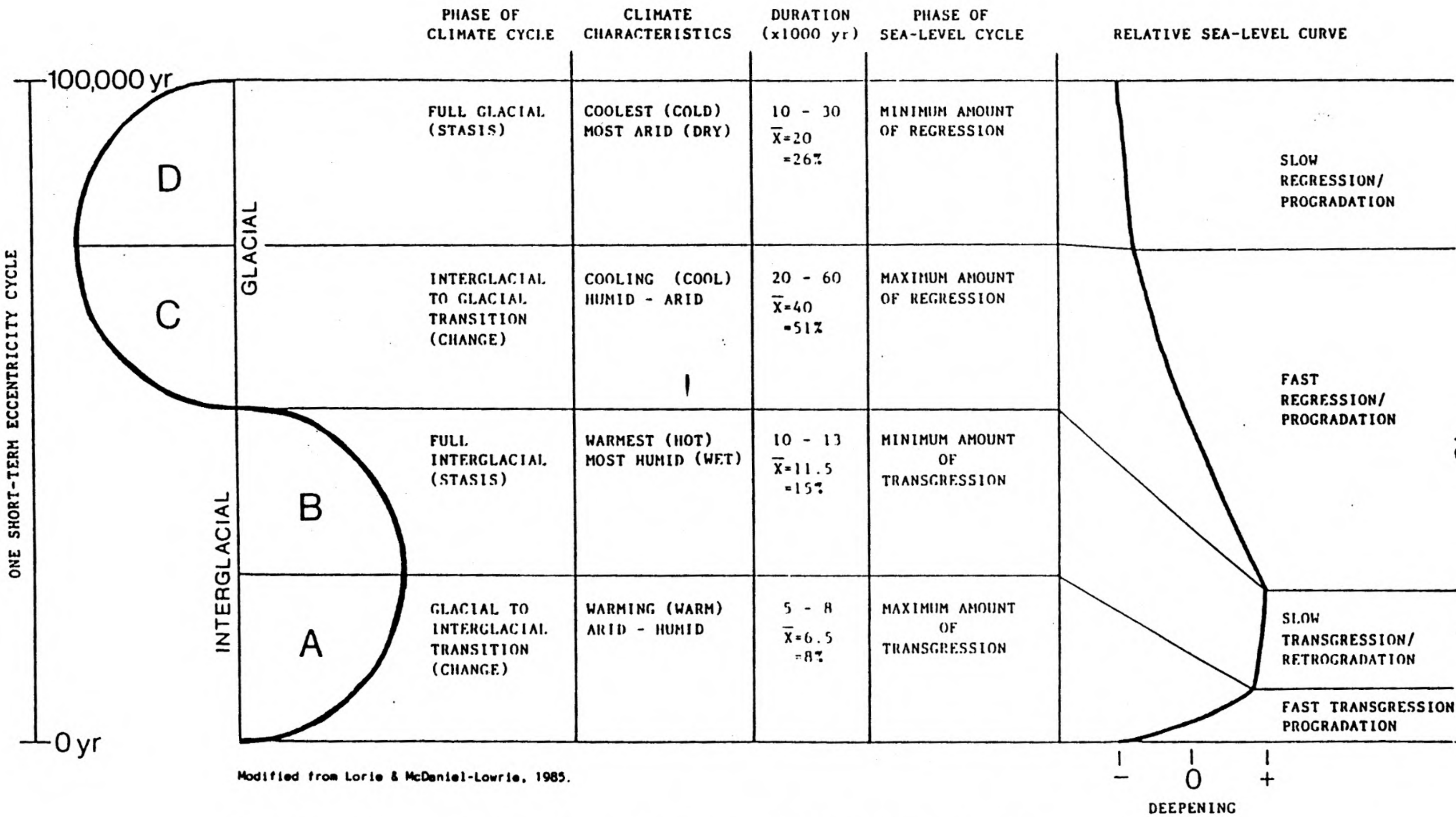



Figure 20. Schematic diagram illustrating the relationship of climate, sea level phase (transgression-regression), sea level stand, and duration.

climate change enters the interglacial to glacial transition (C on Figure 20) river input (i.e., freshwater) decreases.

A deepening event at the base of the Howe Limestone is the beginning of another sixth-order T-R unit #3. The basal unit consists of a skeletal, wackestone, containing a diverse assemblage. Composita, productids, Derybia, Aviculopecten, Aviculopinna, bryozoans, and crinoids, suggest open marine conditions. Hence, with sea level rise and decreasing river input, fine grained terrigenous and organic debris characteristic of Bennett deposition are trapped near shore. The basal Howe Limestone (subtidal facies) grades upward into a well-sorted skeletal packstone-grainstone (shallow marine to intertidal facies), containing coated grains (Osagia), ostracodes, high-spired gastropods, and hemispheriodal stromatolites. As this regression continued unfossiliferous (i.e., nonmarine), platy, silty, mudstone (i.e., Roca Shale) were deposited.

Sixth-order T-R unit #4 punctuates a dominately nonmarine sequence (i.e., sabkha - Roca Shale). This marine incursion is denoted by 0.25 meters of light gray, argillaceous, skeletal calcilutite (mudstone), containing intraclasts, high-spired gastropods, root traces and a fenestral fabric. This small scale deepening event (i.e., supratidal facies) was followed again by sea level stasis and/or regression, during which nonmarine mudstones (i.e., sabkha facies) prograded out onto the shelf.

Sixth-order T-R units #5 and #6 are similar, if not identical to sixth-order T-R unit #4. Again, small scale (0.15-0.30 meters) marine events punctuate the relatively nonmarine sequence, represented by the vari-colored mudstones. Typically, these marine events consist of fine grained dololutites or calcilutites (mudstones), which have lithologies and biota that are indicative of restrictive or supratidal facies (i.e., high-spired gastropods, ostracodes, intraclasts, root traces, *Spirorbis*, and fenestral fabrics.)

The Sallyards Limestone Member of the Grenola Limestone Formation documents a return of full marine conditions (i.e., subtidal conditions). The limestone is a slightly argillaceous, skeletal wackestone, with productids, *Aviculopecten*, crinoids, and algal biscuits (*Osagia*). The genetic surface at the base of the Sallyards Limestone is a sixth- and fifth-order transgressive surface following the methodology of Busch and West (1987), and thus marks the beginning of the next higher (younger) fifth-order transgressive-regressive unit.

## SEA LEVEL CURVE

Recall that figure 4 is Elias' (1937) sea level curve for the Red Eagle cyclothem. Elias (1937) inferred water depths based on different faunal-lithologic "phases" (Figure 5). He reasoned that the depth of deposition was the main factor controlling the sedimentation and biota of the rock sequence. Elias interpreted the "fusulinid phase" as indicative of maximum depth, based on habitat of modern large foraminifers (Elias, 1964). Therefore, he placed the fusulinid facies in the Glenrock Limestone at the transgressive apex and inferred depths of deposition for the rest of the cyclothem based on this centralized position of the fusulinid phase.

McCrone (1963) recognized three sea level changes within the Red Eagle cyclothem, based on paleoecologic and biostratigraphic evidence (Figure 6). McCrone also recognized that water depth was the main factor controlling biotic-lithologic changes. However, he reasoned that the epeiric seas were much shallower and that depositional depths need not exceed 60 feet (McCrone, 1964).

Figure 21 is a detailed relative sea level curve for the Red Eagle Limestone-Roca Shale stratigraphic sequence. It is based on a consideration of the total range of

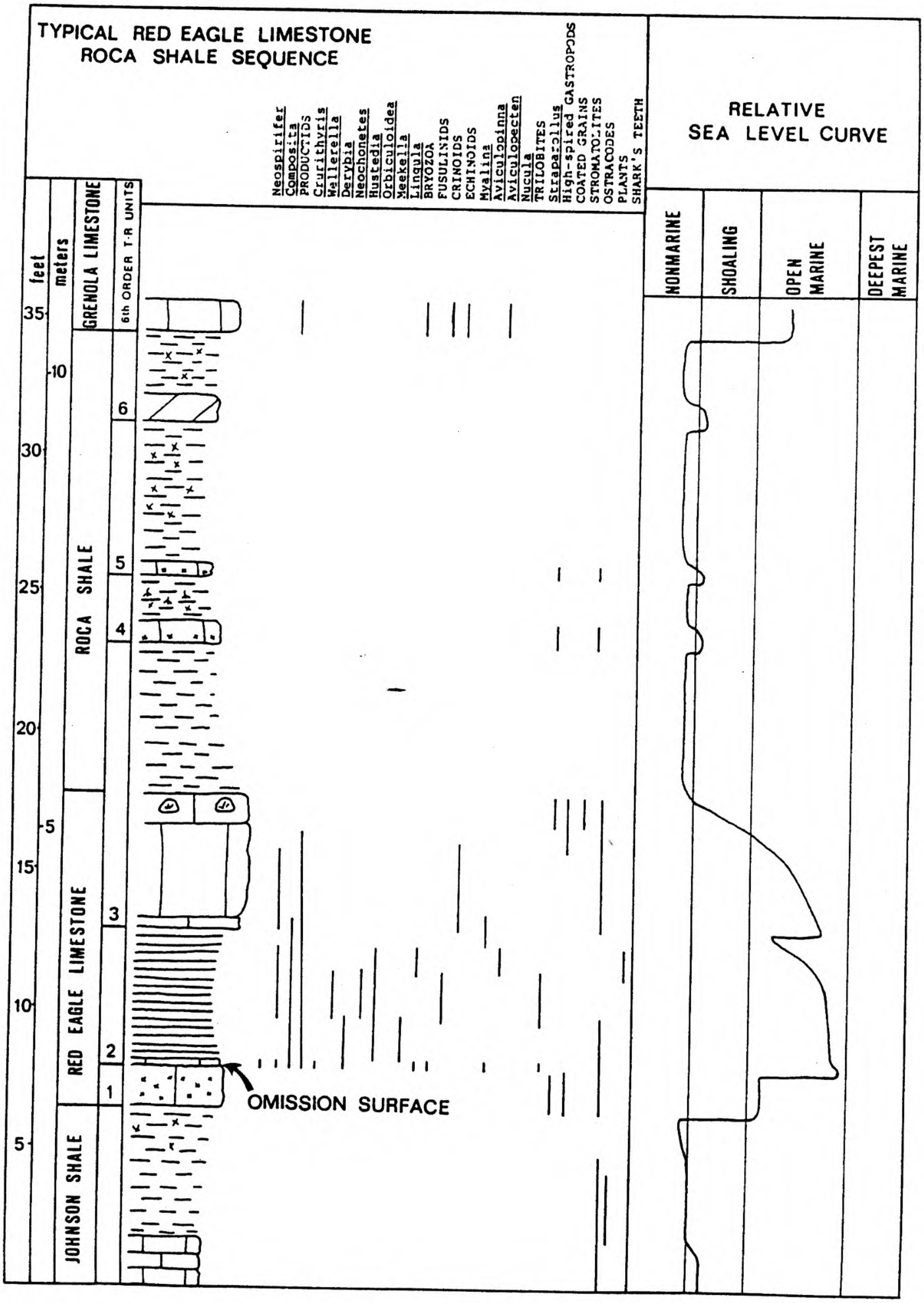



Figure 21. Detailed relative sea level curve for the Red Eagle Limestone-Roca Shale stratigraphic sequence at location 12.

facies (i.e., biofacies and lithofacies) and facies contacts. Sixth-order T-R unit #1 records the inundation of the area by marine water and local reworking of the underlying lithology (i.e., Johnson Shale). This basal unit was punctuated by another deepening event (i.e., sixth-order T-R unit #2).

The base of sixth-order T-R unit #2 (i.e., upper Glenrock Limestone) contains a relatively diverse fauna, indicating open circulation of marine water, in a lithology that was not influenced by terrigenous debris. This unit represents the period of maximum marine inundation and is here interpreted as the transgressive apex of the Red Eagle Limestone-Roca Shale fifth-order T-R unit. The overlying gray to black shale/mudstone represents a period of terrigenous influx that occurred shortly after maximum inundation. This terrigenous influx was a result of high river input into the basin, which resulted from a warm, humid climate (i.e., climate driven; see Figure 20). This high terrigenous influx (i.e., turbidity) also resulted in the "poisoning" of carbonate production (i.e., Glenrock Limestone). Wilson (1967) has recognized clastic influxes of this type, which cause a local regression during a transgressive phase, thus complicating the cycle.

Sixth-order T-R unit #3 represents yet another deepening event, during which terrigenous debris was trapped shoreward, and carbonate deposition began again. This transgression was followed by a period of shallowing during which high energy shoaling facies prograded out onto the shelf. Shallowing continued until the area was emergent and subaerial processes became prominent with the deposition of the Roca Shale (i.e., sabkha).

Sixth-order T-R units #4, #5, and #6 are marginal marine events (i.e., supratidal facies) that punctuate a dominately nonmarine sequence (i.e., Roca Shale), which is interpreted as a sabkha. In fact, the Roca Shale is one of the least fossiliferous shale/mudstones in the Council Grove Group (Lane, 1964).

Tectonic subsidence, sediment volume, climate, and eustatic sea level changes are the four major variables controlling the variation of lithofacies and stratal patterns within a sedimentary basin (Vail, 1987; Figure 22). Tectonic subsidence creates the basin (i.e., space) in which sediments can be deposited. Sediment volume determines how much of the basin will be filled, and climate determines the type of sediment that will be deposited (i.e., arid climates are associated with evaporites). However, eustatic sea level change is the

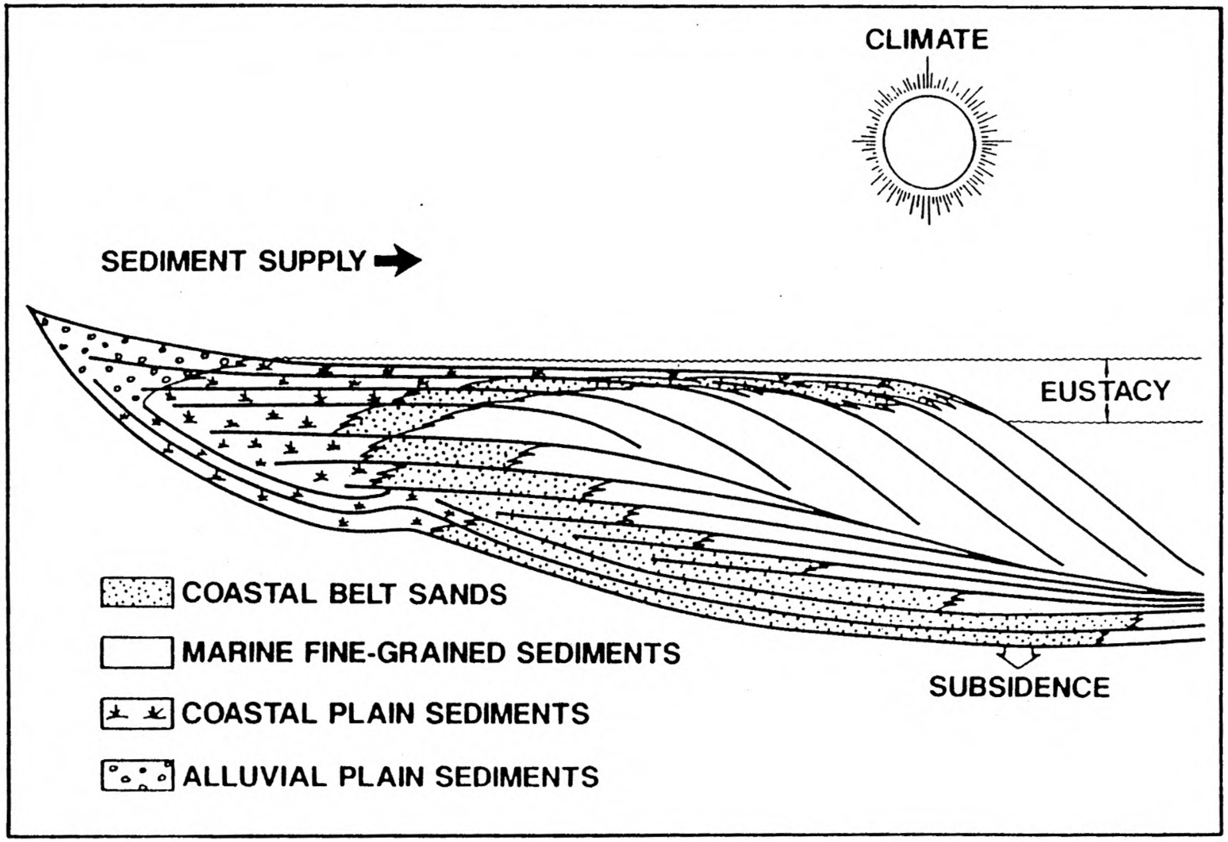



Figure 22. Schematic diagram showing the relationship of subsidence, sediment supply, climate, and eustacy (from Vail, 1987).

overriding mechanism or control on the distribution of lithofacies and stratal patterns (Vail, 1987).

Therefore, these inferred sea level changes do not represent purely eustatic sea level fluctuations but are a combination of eustasy and tectonic subsidence (or in this case more likely inherited topography, that is tectonically controlled). This produces "relative" sea level changes. As Vail (1987) showed, it is the combination of eustacy and tectonic subsidence that produce these relative sea level changes. The "key" to understanding the stratigraphy is to understand the "relative" sea level changes. Therefore, in other parts of the basin we should be able to recognize the eustatic event (if it is allogenically controlled), although the relative sea level "curve" will probably appear different, due to differing conditions (i.e., deeper water, shallower water, etc.).

# PALEOGEOGRAPHIC RECONSTRUCTIONS

A series of detailed paleogeographic maps were constructed for most of the sixth-order T-R unit at the time of maximum transgression and maximum regression to illustrate the development of the Red Eagle fifth-order T-R unit. Maps of the maximum regression of sixth-order T-R units 4, 5, and 6 are not included because they are essentially the same as the one for the maximum regression of sixth-order T-R unit 3. Information from these paleogeographic maps was then used to infer topographic highs and lows, areas which might have influenced the sedimentation patterns within the study area.

The initial Red Eagle marine transgression is shown in Figure 23. The transgressive apex of sixth-order T-R unit #1 is generally characterized by an intraclastic, wackestone to packstone (conglomerate). Except in the northern most part of the area, which is dominated by a massive argillaceous, calcilutite (mudstone), with root traces, ostracodes, and mudcracks (i.e., supratidal facies). This area (location #1) is situated near the crest of the Nemaha Anticline, which probably acted as a topographic high during this time.

Intraclasts generally decrease in abundance away from the Nemaha Anticline. Some of the intraclasts are also

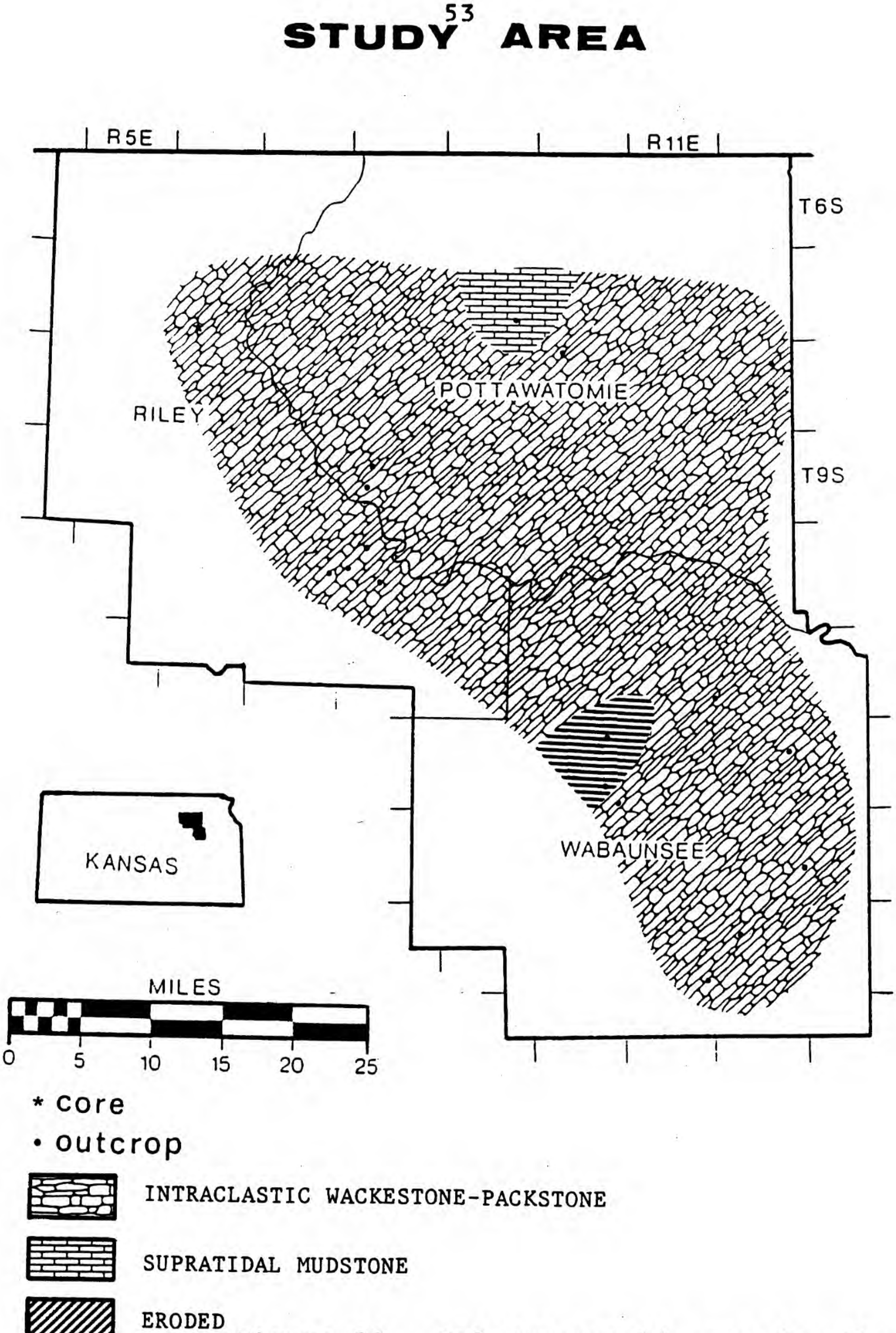



Figure 23. Paleogeographic map for the maximum transgression during sixth-order T-R unit #1, (use acetate overlay in pocket for localities used).

concentrically coated (algae, algal-foraminferids, Osagia). Imbrie et al., (1964) concluded that Osagia coated grains are indicative of shallow, turbulent nearshore environments, in which there was little terrigenous influx.

The Glenrock Limestone Member (sixth-order T-R unit #1) is locally absent at locations #15 and #18 near Alma, Kansas. These sections are situated along the crest of the Alma-Davis Ranch Anticline. This structure also probably acted as a topographic high during Glenrock deposition, and resulted in the nondeposition and/or erosion of sixth-order T-R unit #1.

Maximum regression of sixth-order T-R unit #1 (Figure 24) is characterized by a relatively widespread omission surface. In the northern part of the area there is a supratidal mudstone facies situated on top of the Nemaha Anticline, while in the southeast, northeast, and northwest parts of the map there is a black shale/mudstone facies which contains only Orbiculoidea and/or plant fragments. Orbiculoidea have been interpreted as a common inhabitant of shallow water nearshore environments, although they may be present in other environments (Bretsky, 1969; Donahue and Rollins, 1974; Rollins et al., 1979; Beus, 1984 and Wells, 1985).

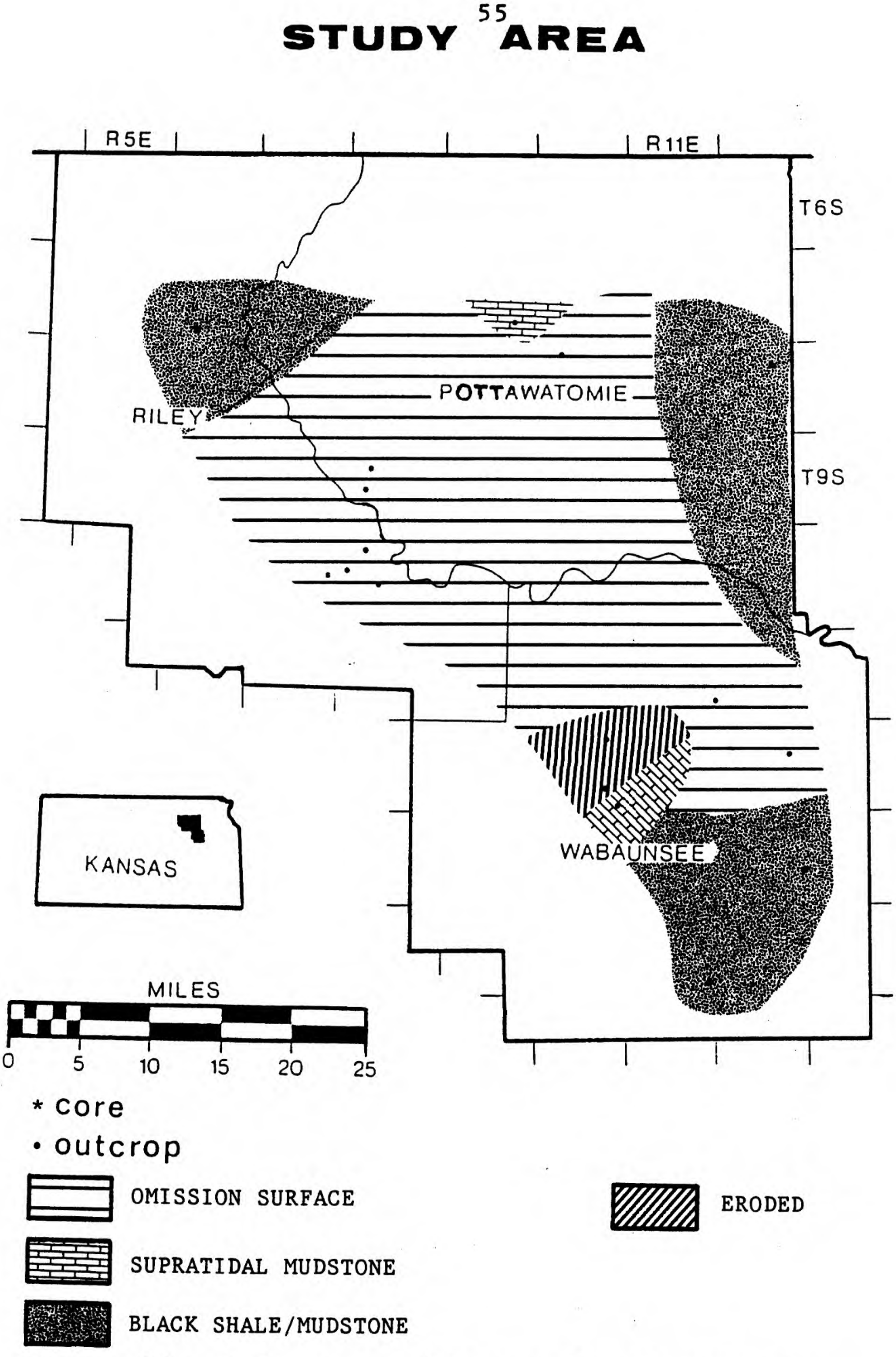



Figure 24. Paleogeographic map for the maximum regression during sixth-order T-R unit #1, (use acetate overlay in pocket for localities used).

Figure 25 illustrates the maximum transgression for sixth-order T-R unit #2. This interval is characterized by a skeletal, wackestone to packstone, with an open marine fossil assemblage (i.e., Composita, Neosprifer, fusulinids, Aviculopecten, Wellerella, Hustedia, Neochonetes, and bryozoans). Facies associated with the Alma-Davis Ranch Anticline in Wabaunsee County are indicative of restrictive conditions, suggesting a possible topographic high. While in the northwest and southern tip of the area, there is a fossiliferous gray shale/mudstone facies. Overall, this interval is characterized by the highest diversity of stenohayline biota and is interpreted as representing the transgressive apex of the Red Eagle Limestone-Roca Shale fifth-order T-R unit.

The maximum regression for sixth-order T-R unit #2 (Figure 26) is dominated by a dark gray, silty, shale/mudstone with few fossils (low diversity), that is indicative of very turbid nearshore conditions. The southwest part of the area, associated with the Alma-Davis Ranch Anticline, again appears to have been emergent during this time.

Figure 27 illustrates a return to more open marine conditions. Most of the area is characterized by a relatively diverse marine assemblage (i.e., Composita, Aviculopecten, productids, bryozoans, fusulinids, and

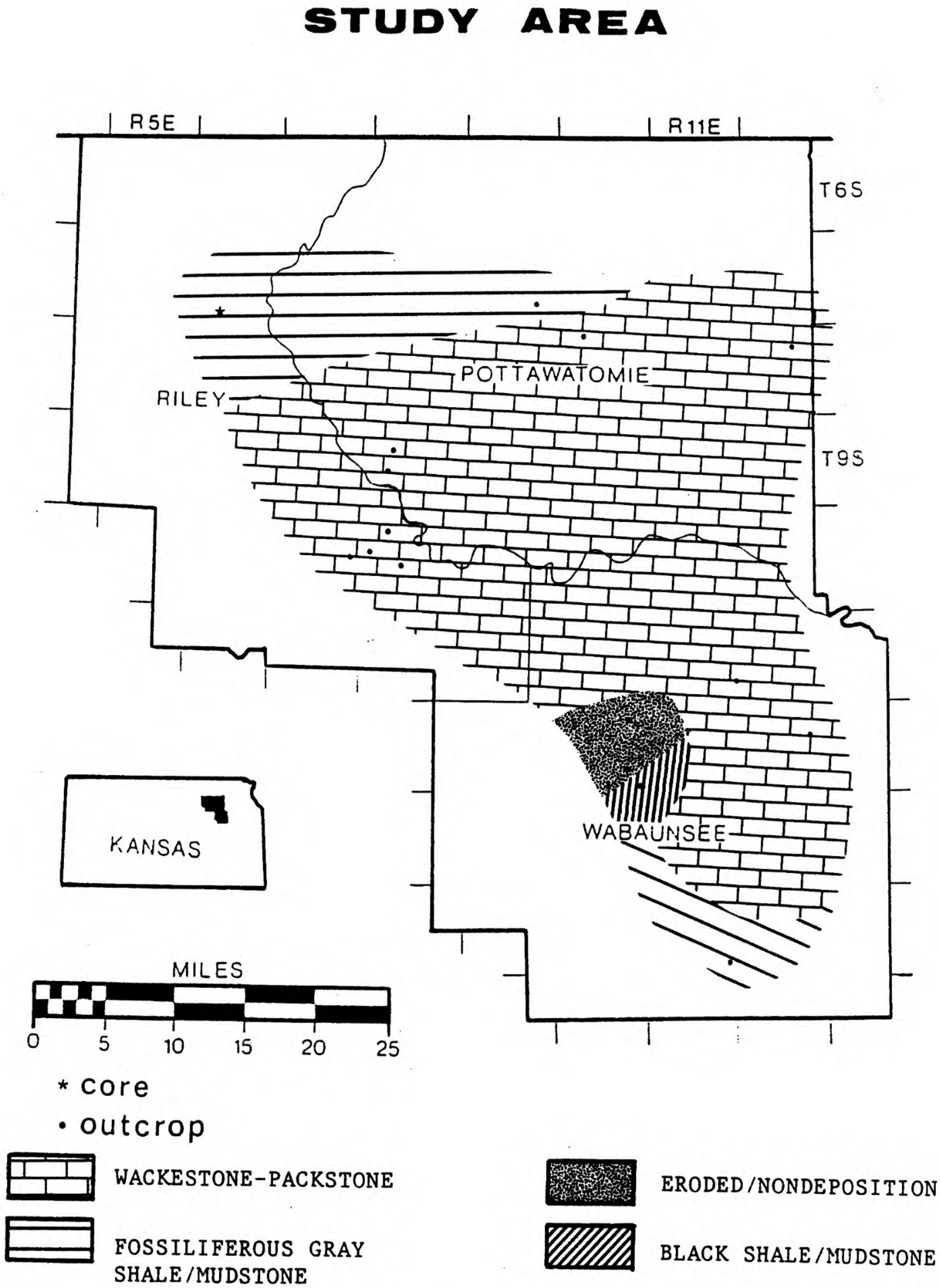



Figure 25. Paleogeographic map for the maximum transgression during sixth-order T-R unit #2, (use acetate overlay in pocket for localities used).

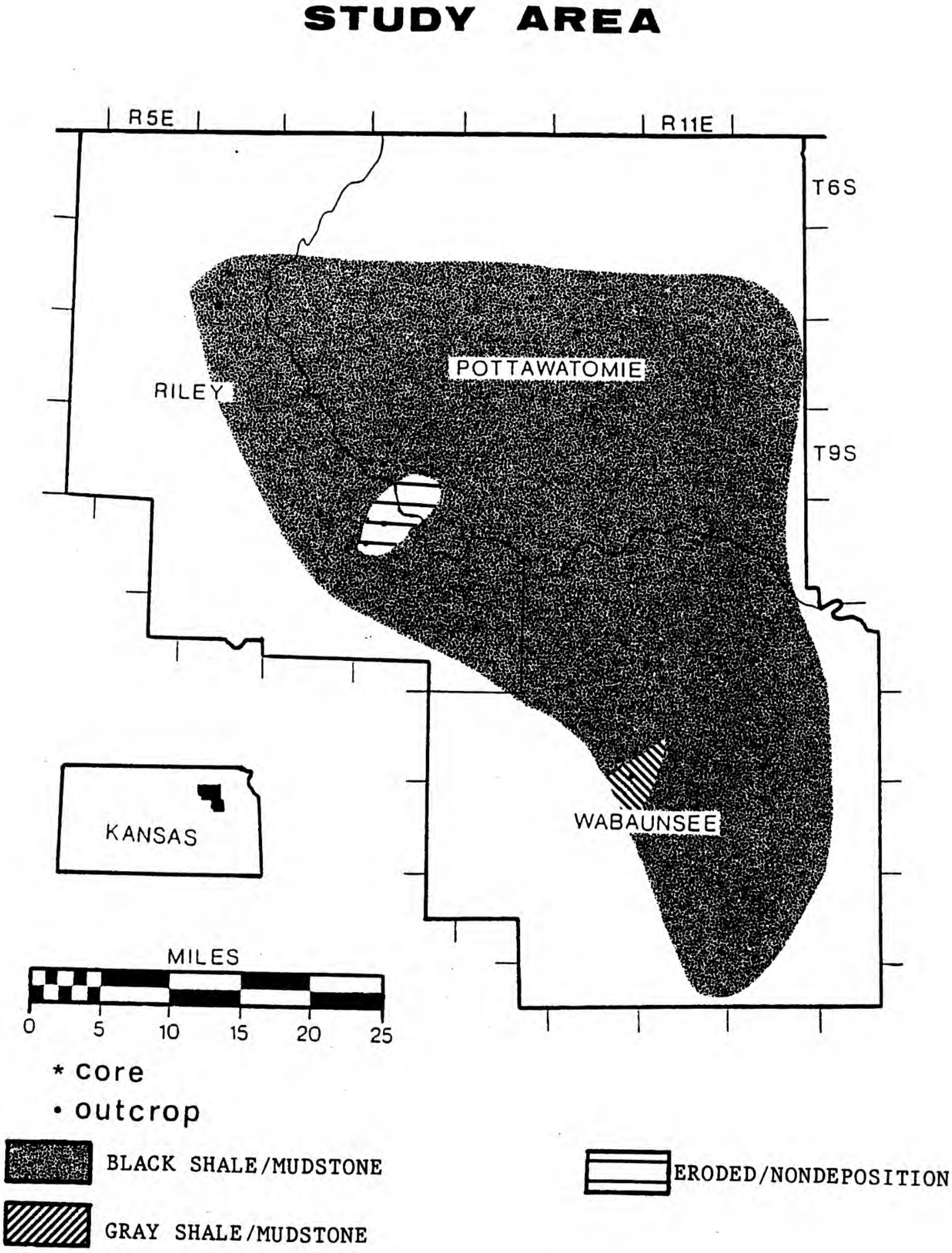



Figure 26. Paleogeographic map for the maximum regression during sixth-order T-R unit #2, (use acetate overlay in pocket for localities used).

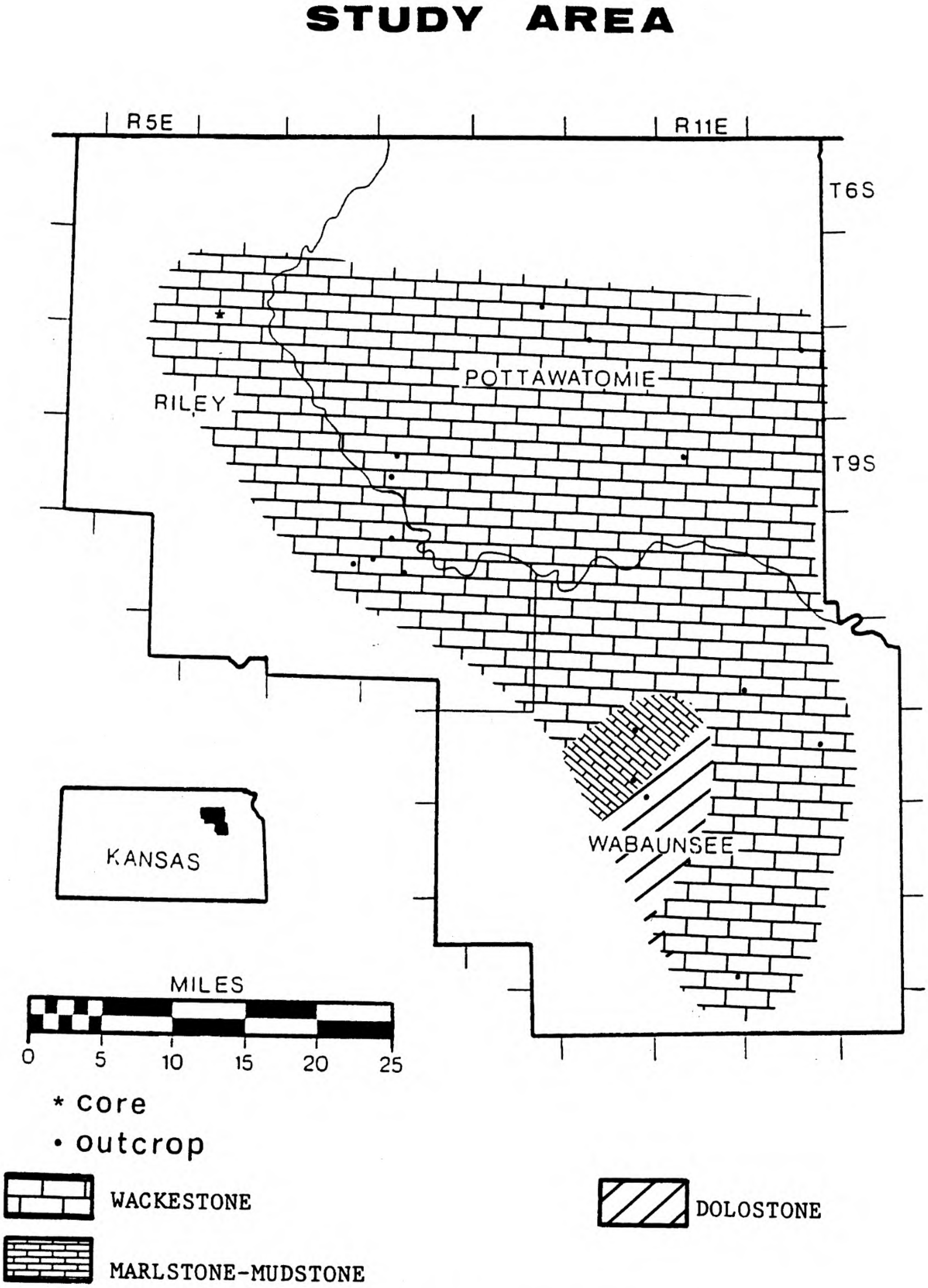



Figure 27. Paleogeographic map for the maximum transgression during sixth-order T-R unit #3, (use acetate overlay in pocket for localities used).

Hustedia), preserved in a skeletal wackestone. However, we again see in the southwest corner, a shallow water higher stressed environment, represented by a dolostone and argillaceous marlstone-mudstone lithologies, indicative of restrictive and slight terrigenous influxes, respectively.

As the sea level fell (sea withdrew) the area became emergent and subaerial processes dominated (i.e., Roca Shale deposition began). These subaerial processes include high evaporation rates, desication, and the formation of soils. Processes such as these are indicative of a sabhka. Facies relationships, at the time of the maximum regression, for sixth-order T-R unit #3 are shown in Figure 28. This unit is characterized by vari-colored mudstones that are typically rooted and indicative of subaerial processes (i.e., caliche nodules, mudcracks, microslickensides, peds, and root traces).

The maximum transgression for sixth-order T-R units 4, 5, and 6, shown in Figures 29, 30, and 31, respectively, illustrate a dominately marginal marine facies. This facies characteristically has a fossil assemblage and lithology indicative of a restrictive and possibly more arid marine environment (i.e., ostracodes, high-spired gastropods, mudcracks, fenestral fabrics, root traces, and boxwork fabrics), in addition gypsum is

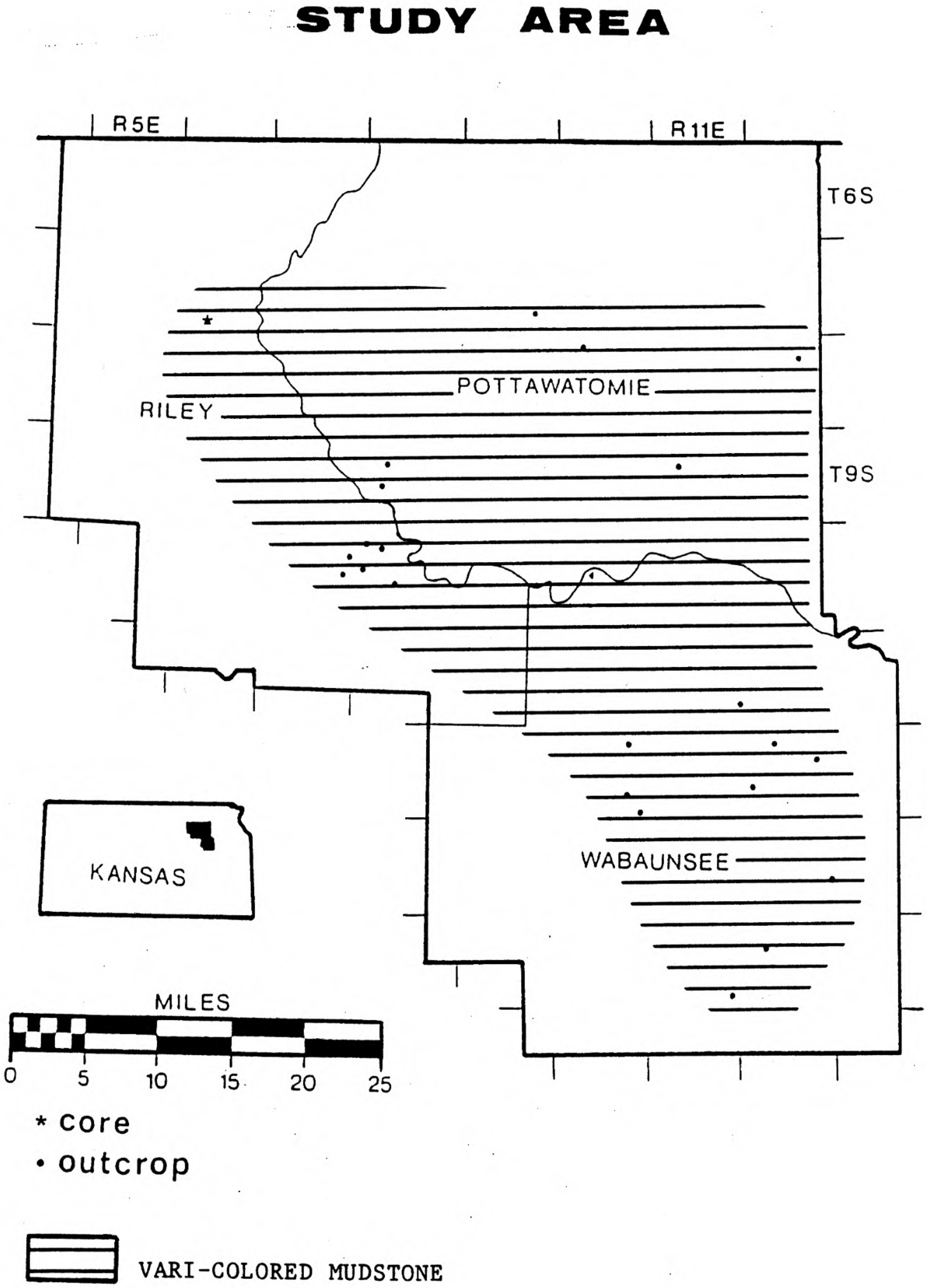



Figure 28. Paleogeographic map for the maximum regression during sixth-order T-R unit #3, (use acetate overlay in pocket for localities used).

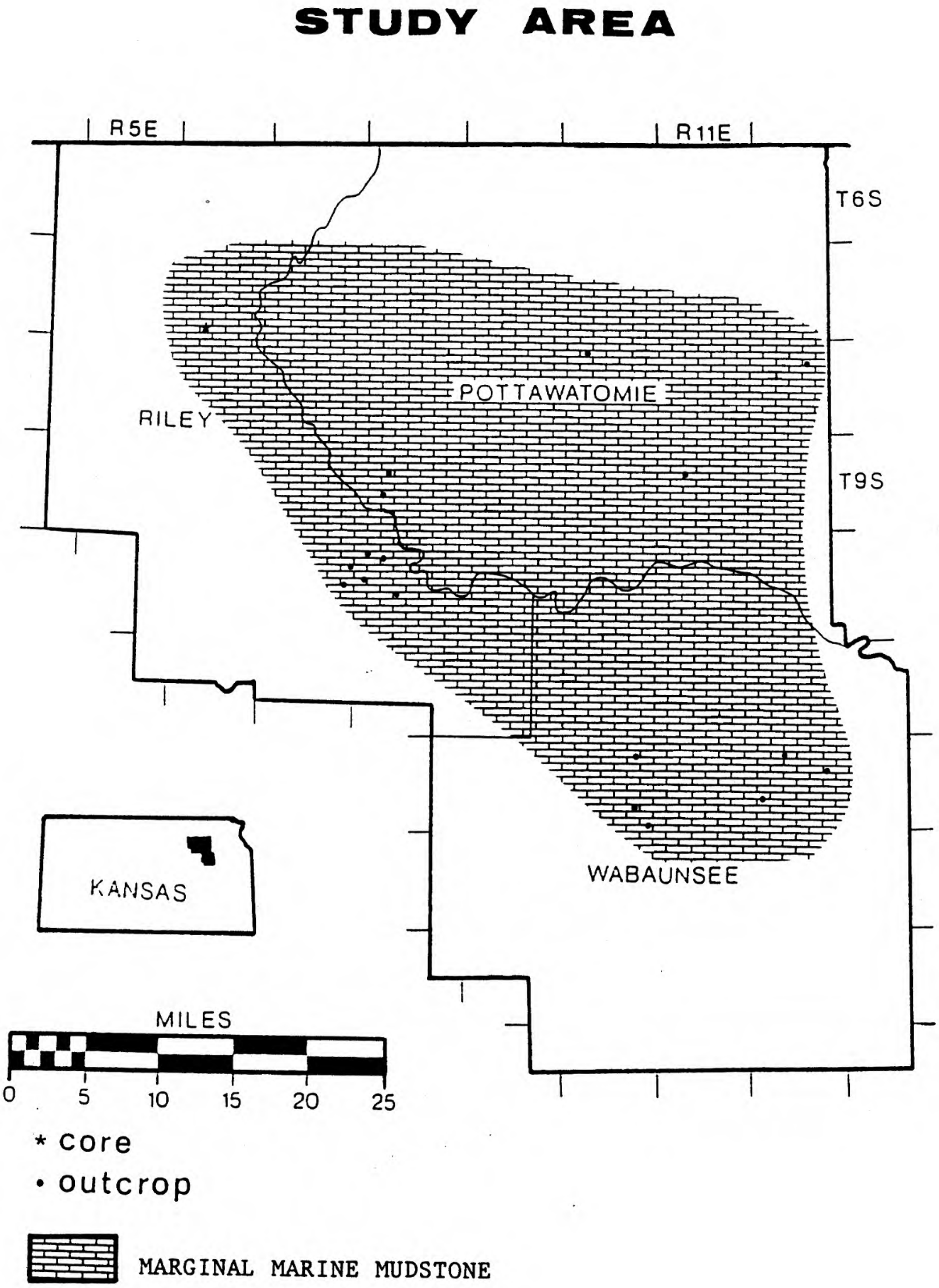



Figure 29. Paleogeographic map for the maximum transgression during sixth-order T-R unit #4, (use acetate overlay in pocket for localities used).

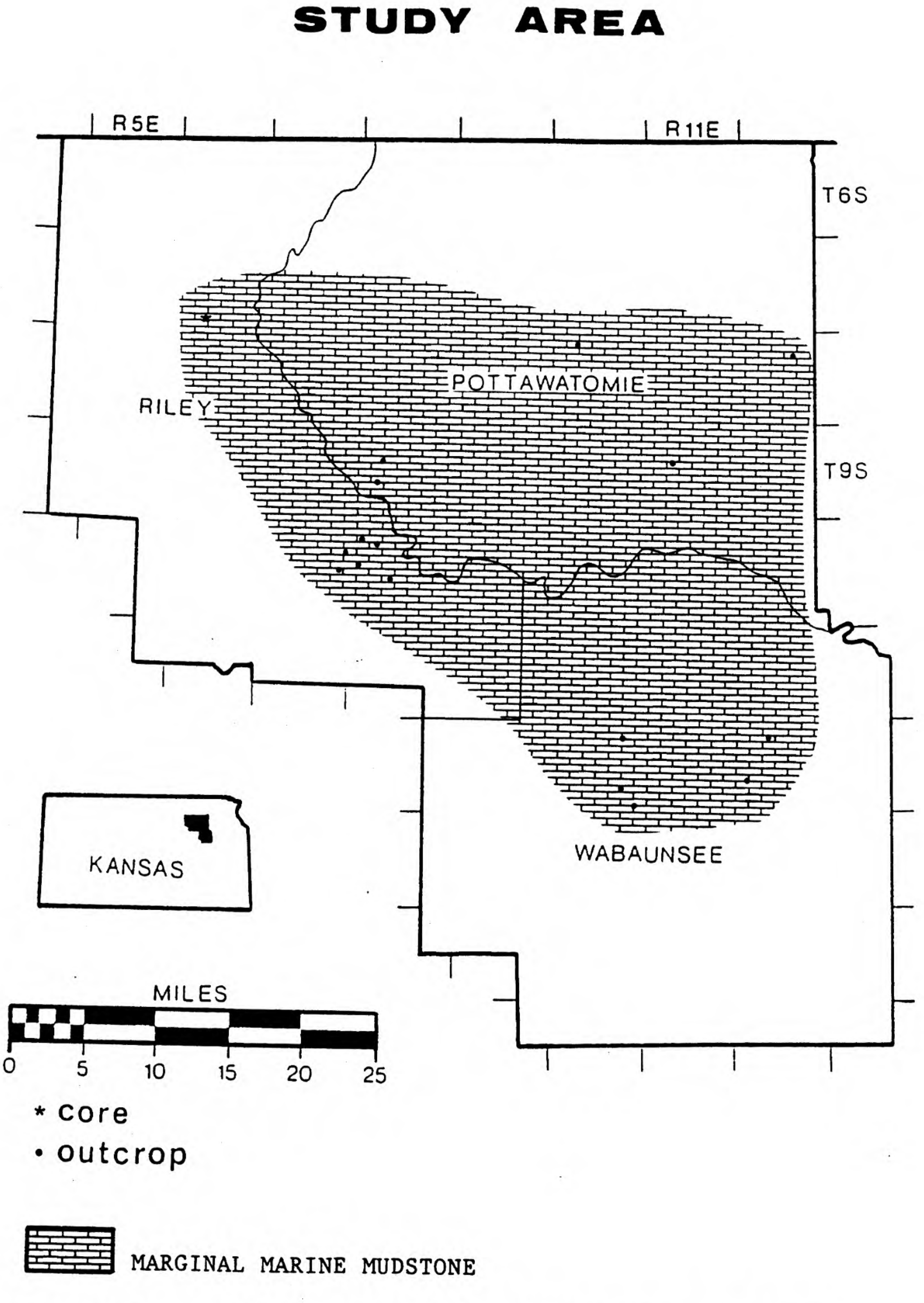



Figure 30. Paleogeographic map for the maximum transgression during sixth-order T-R unit #5, (use acetate overlay in pocket for localities used).

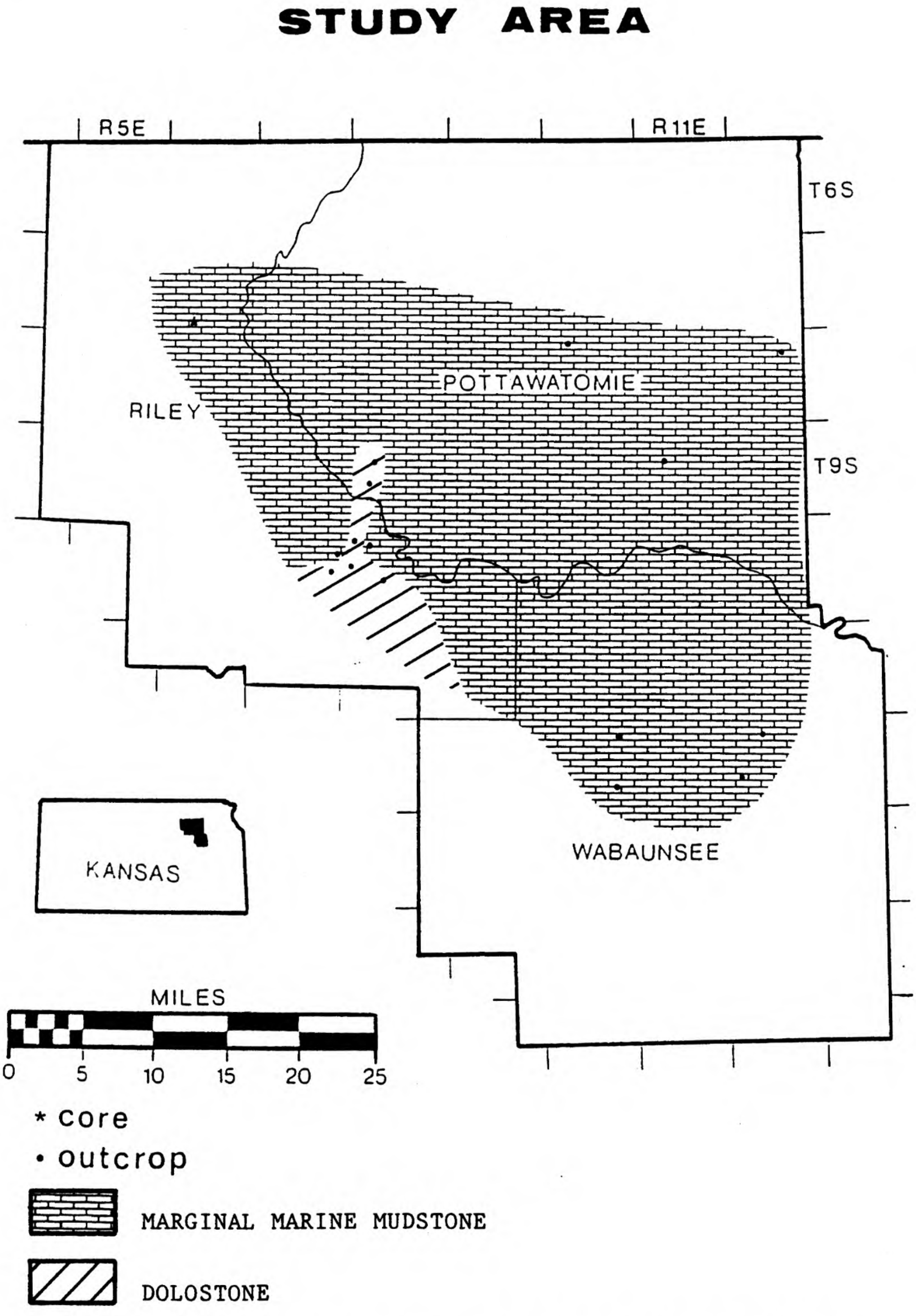



Figure 31. Paleogeographic map for the maximum transgression during sixth-order T-R unit #6, (use acetate overlay in pocket for localities used).

present in the core (see section #3, Appendix II). The maximum regression of sixth-order T-R units 4, 5, 6, is dominately nonmarine (i.e., no marine fossils). This nonmarine facies is typically represented by a lithology indicative of subaerial processes (i.e., sabkha) as noted for the maximum regression of sixth-order T-R unit 3 (i.e., caliche nodules, calcareous peds, root traces, muscovite grains on bedding surfaces, gypsum laminations/crusts, and paleosols).

# CARBONATE BUILDUP

A small carbonate buildup near the Lyon-Wabaunsee County line is noted by O'Connor and Jewett, 1952 and McCrone, 1963. Although this carbonate buildup was not studied in detail, I will speculate on the recognition of genetic surfaces within it based on measured sections of O'Connor and Jewett (1952), McCrone (1963), and my data from the Roca Shale at this locality.

For example, sixth-order T-R unit #1 is recognizable as 0.12 meters of medium brownish gray, massive, fusulinid wackestone to packstone, that has a slightly undulatory base (possibly erosional?). This unit overlies a light yellow gray-brown mudstone (i.e., Johnson Shale), which contains carbonaceous plant remains. The "omission surface" (i.e., Thalassinoides burrows) at the top of the Glenrock Limestone Member is also recognizable from McCrone's work, however he calls them worm tubes, he also notes, that the tubes (i.e., burrows) contain Orbiculoidea fragments and black shale/mudstone from above. Carbonate production was again "poisoned" by an influx of organic rich debris (i.e., Bennett Shale). This 0.61 meters of black shale/mudstone contains Orbiculoidea, Lingula, and carbonaceous debris (plants?). As sea level rose again (sixth-order T-R unit #2), terrigenous debris would be

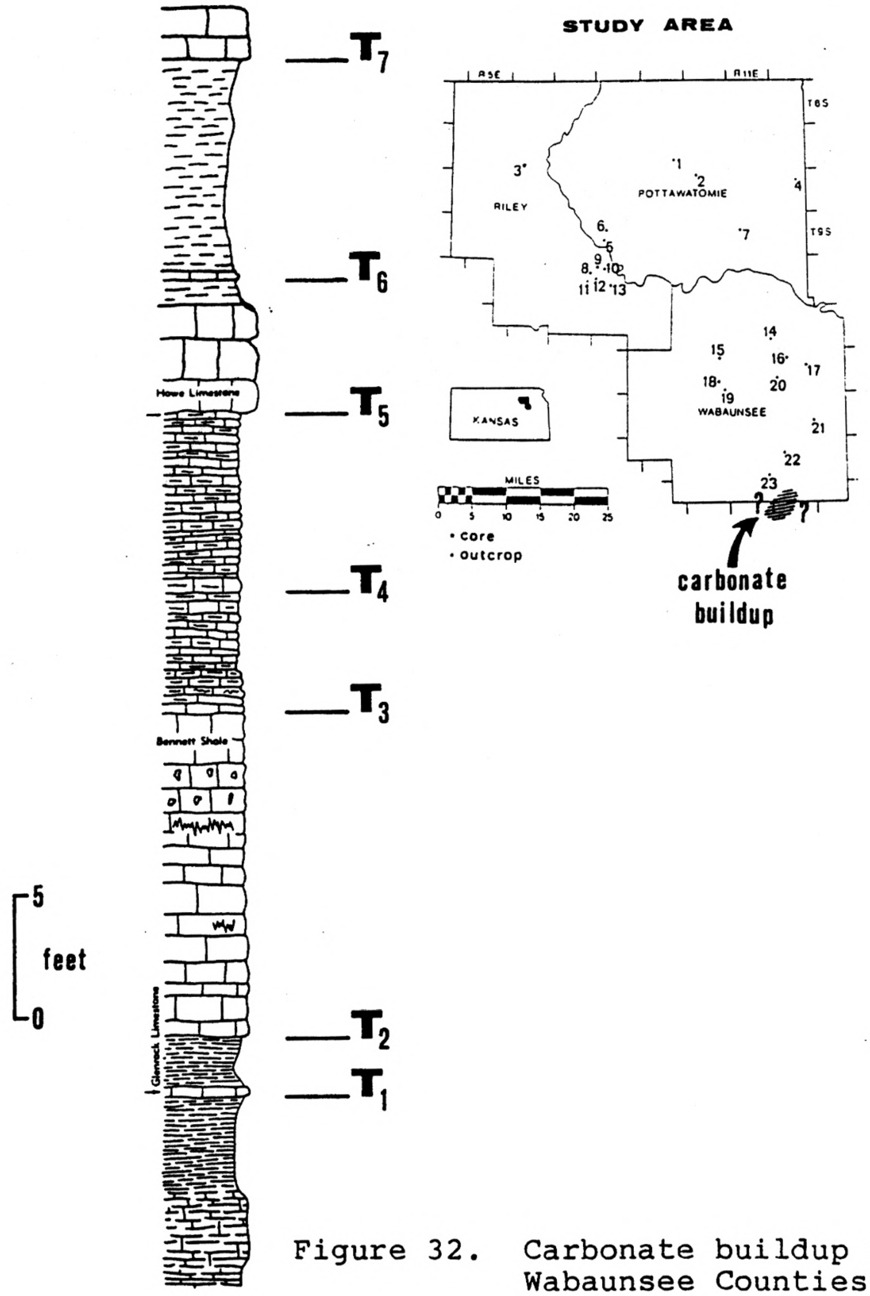



Figure 32. Carbonate buildup in Lyon-Wabaunsee Counties.

trapped shoreward, allowing for the establishment of normal marine carbonate sedimentation farther out on the shelf.

During sixth-order T-R unit #2, 3.8 meters of light brownish gray wackestone (i.e., Bennett Limestone), containing crinoid plates, byrozoans, ostracodes, brachiopod fragments, productid and echinoid spines, Orbiculoidea, and rare horn corals, accumulated. Note, this Bennett Limestone facies is stratigraphically equivalent with the Bennett Shale facies (i.e., dark gray, fossiliferous mudstone) to the north or shoreward; however, terrigenous detritus did not reach this area of the shelf and interrupt carbonate sedimentation.

Sixth-order T-R unit #3 represents another deepening event. This unit is characterized by 0.76 meters of very fossiliferous, skeletal wackestone, that contains abundant articulated fossils, including: crinoid columns, blady algal fragments, fenestrate and ramose bryozoans, brachiopods, and productid and echinoid spines - all suggesting open marine conditions. As sea level fell a regressive phase is recorded by green mudstone stringers.

When sea level again rose (sixth-order T-R unit #4) carbonate deposition resumed during which approximately 2 meters of light brownish gray, skeletal wackestone was deposited. This limestone also has a biota typical of open marine conditions (i.e., crinoid plates, fenestral bryozoans, productids, foraminifers, and brachiopod fragments). However, we again see an influx of green mudstone, as sea level fell and terrigenous mudstones prograded out onto the shelf from the north. This green mudstone, and that of the preceeding regression is inferred is to be stratigraphically equivalent to the Roca Shale to the north.

Sixth-order T-R unit #5 represents another deepening event and includes 1.5 to 1.8 meters of light grayish brown, massive, well sorted, skeletal packstone to grainstone, containing coated grains (Osagia), foraminifers, bellerophontid gastropods, straight nautiloid cephalopods, and ostracodes. As sea level fell again, 0.3 meters of light brown mudstone was deposited. This mudstone is devoid of marine fossils and contains root traces indicating possible subaerial exposure and colonization by plants (i.e., paleosol).

Sixth-order T-R unit #6 punctuates a dominately nonmarine sequence (i.e., Roca Shale). This marine incursion is denoted by 0.1 meters of light gray, slightly argillaceous, skeletal wackestone, that contains Aviculopecten, productid fragments, and ostracodes. Above this unit, is 0.9 meters of dark gray to light brown, silty, mudstone, containing Orbiculoidea, Lingula, and fish scales. This assemblage suggests marginal marine or stressed conditions (possibly lagoonal). This small scale deepening event was followed again by sea level stasis and/or regression, during which approximately 2 meters of vari-colored mudstones (i.e., Roca Shale) prograded out onto the shelf.

The Sallyards Limestone Member, a slightly argillaceous, skeletal wackestone, with productids, Aviculopecten, Nucula, algal biscuits (Osagia), and ostracodes, of the Grenola Limestone Formation again documents a return of full marine conditions. The genetic surface at the base of this unit is a sixth- and fifth-order transgressive surface, marking the beginning of the next (younger) fifth-order transgressive-regressive unit.

I am suggesting (predicting) that genetic surfaces 1-6 can be recognized in the Red Eagle carbonate buildup and Roca Shale along the Lyon-Wabaunsee County line. This carbonate buildup is present because the area was far enough from the source of terrigenous detritus, during Red Eagle and Roca deposition (i.e., time), that carbonate production was not interrupted.

# STRUCTURAL CONTROLS ON DEPOSITION

## GENERAL

Structural elements that may have affected deposition of Red Eagle Limestone-Roca Shale within the study area are: Nemaha Anticline, Abilene Anticline, Irving Syncline, Zeandale Dome, Humboldt Fault, Brownville Syncline, and Alma-Davis Ranch Anticline (Figure 8). Figure 8 shows the location and general northeast-southwest orientation of these structural features. However, a better understanding of the genesis of these structures can be seen in a structure map of the top of the Precambrian basement rocks (Figure 33). This figure clearly illustrates the localized structural highs and lows, which may have been periodically reactivated over time.

## COMPOSITE TRENDS

Boundaries from facies changes at maximum transgression and maximum regression for sixth-order T-R units 1-6 were combined into a composite paleogeographic map. This resultant composite map can be used to detect temporally and spatially recurring "highs" and "lows", which may have influenced sedimentation patterns. For example, one would expect to find higher energy or more

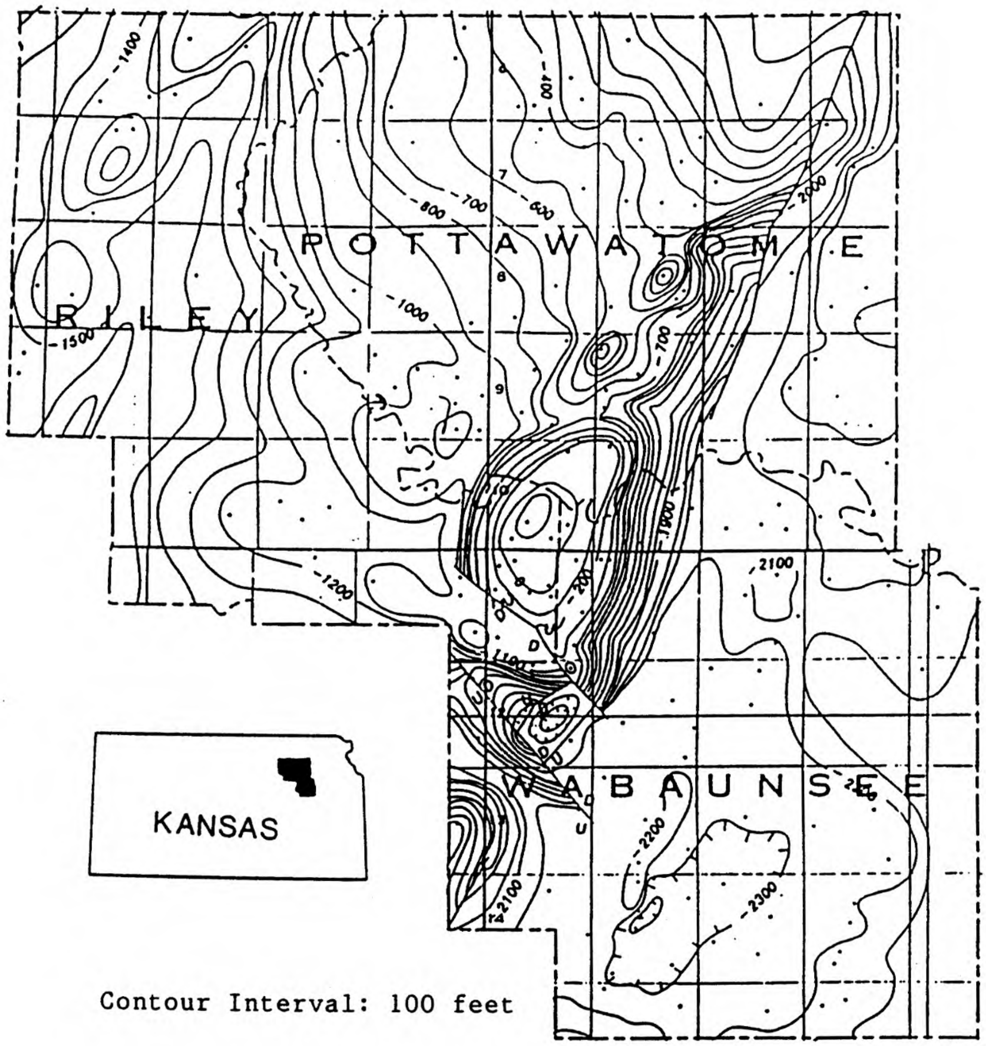



Figure 33. Structure contour map on top of the Precambrian (basement rocks) for the area of the investigation (from Cole, 1976).

restrictive environments on recurring "highs" and lower energy or more open marine conditions on recurring "lows". Therefore, areas which had recurring high energy facies or more restrictive environments, during Red Eagle Limestone-Roca Shale deposition, were labeled as a "high". While areas that had recurring low energy facies or more open marine conditions were labeled as "lows" (Figure 34). Underlying structural controls are suspected.

Figure 35 is a structural map for the top of the Kansas City Group (Pennsylvanian) and Figure 36 is a structural map on the top of the Americus Limestone (Lower Permian). These two maps show that the Zeandale Dome and Nemaha Anticline were still active during Permian time. Most of the positive structures are bounded by faults (i.e., Nemaha Anticline, Alma-Davis Ranch Anticline, and Abiline Anticline). This suggests that the faults bounding these underlying structures were periodically reactivated, thereby affecting the inherent topography, and affecting sedimentation and thickness patterns. For example, the Alma-Davis Ranch Anticline in Wabaunsee County, Kansas repeatedly influenced lithofacies during Red Eagle deposition. Glenrock Limestone Member (i.e., sixth-order T-R unit #1) is absent near Alma Kansas in Wabaunsee County (see sections #15 and #18, Appendix II), because of erosion and/or nondeposition (i.e.,

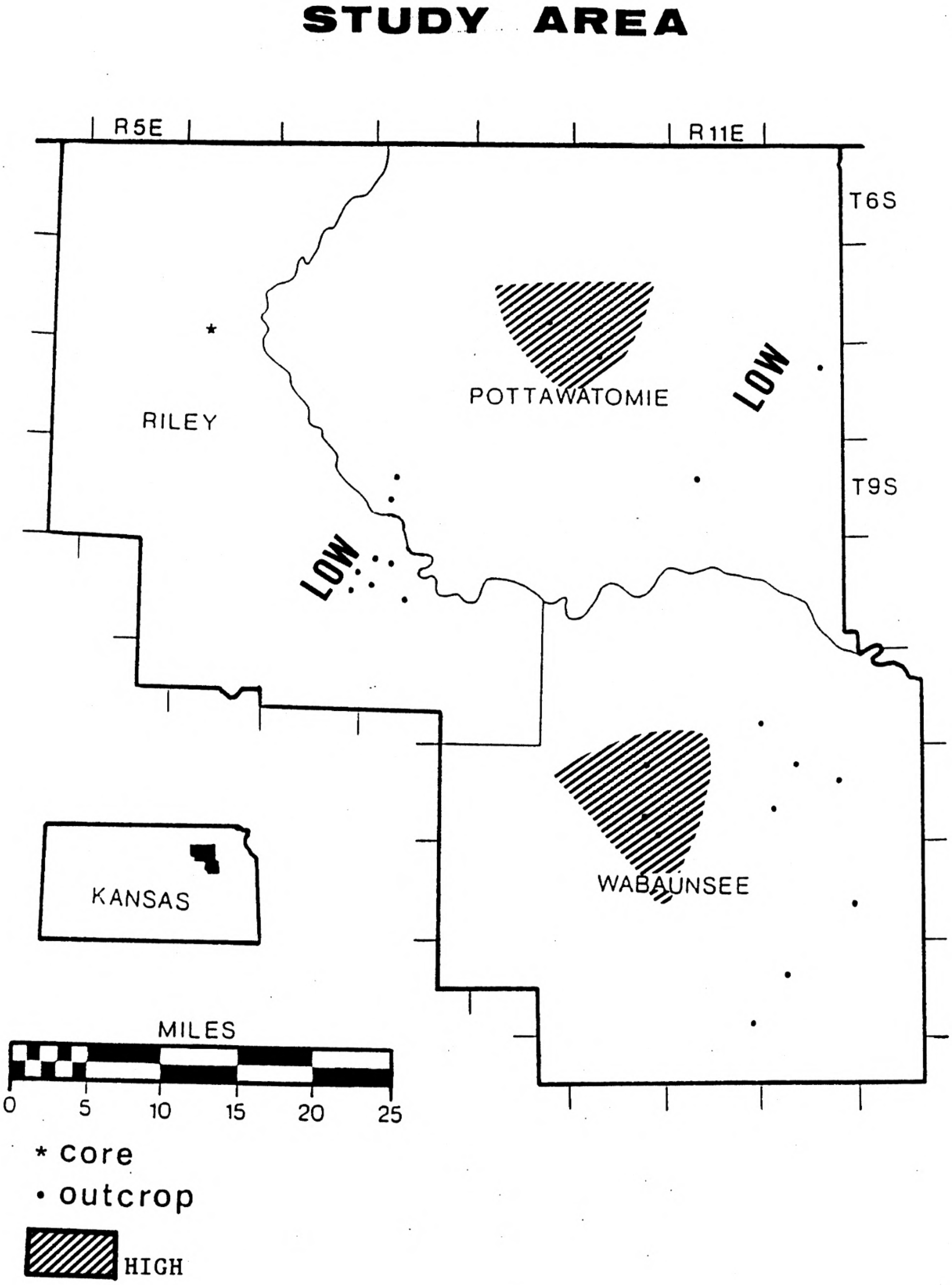



Figure 34. Composite paleogeographic map showing temporally and spatially recurring "highs" and "lows".

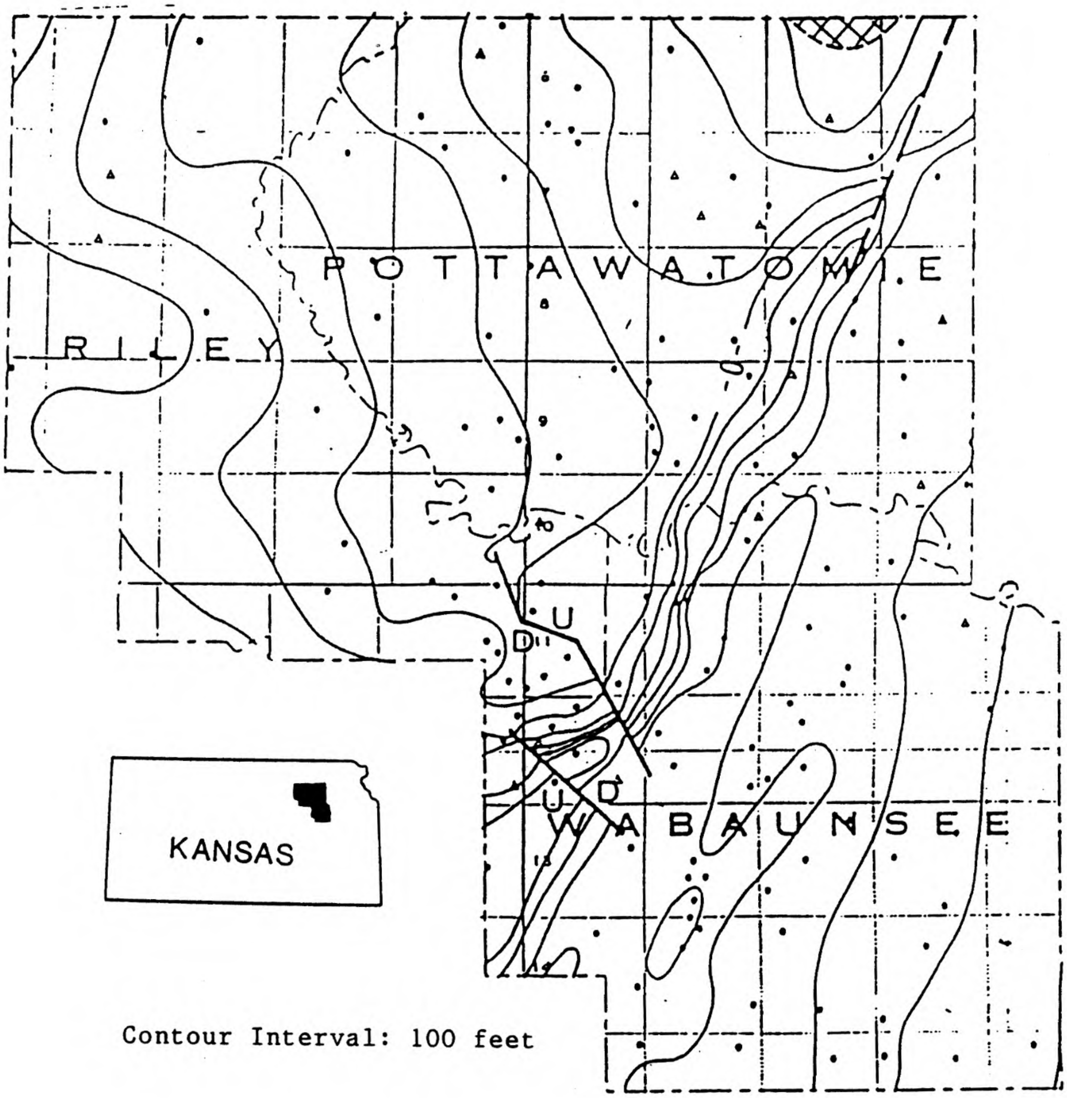



Figure 35. Structure contour map on top of the Kansas City Group for the area of investigation (from Watney, 1978).

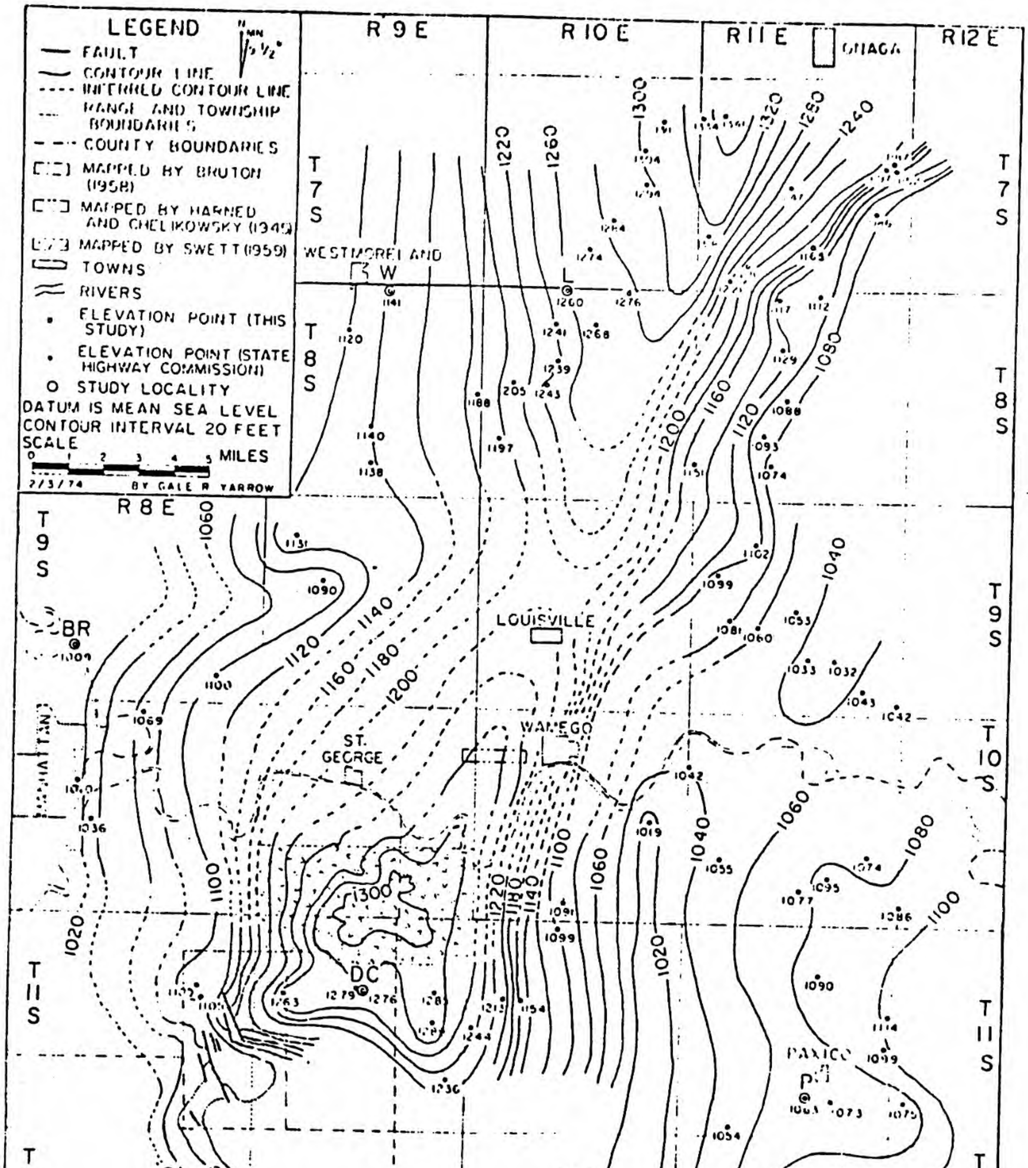


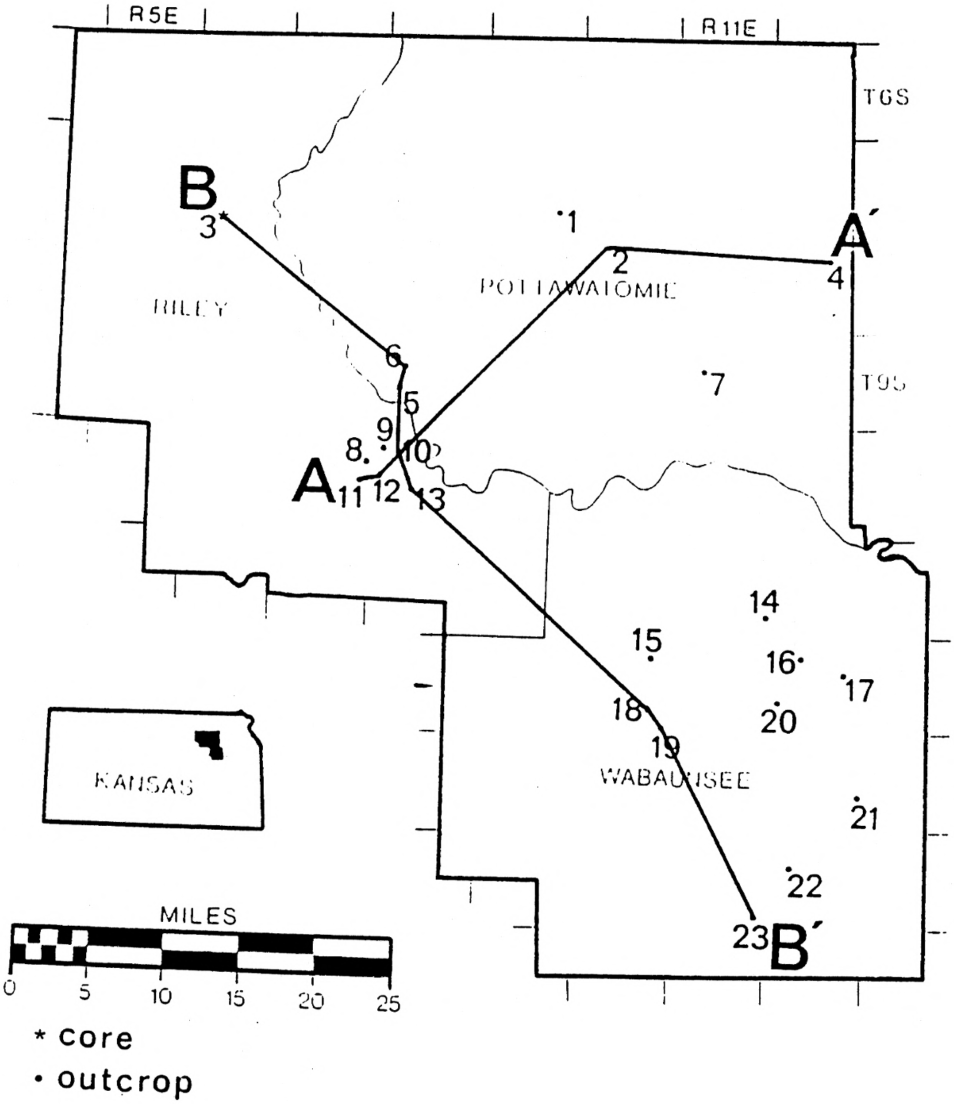

Figure 36. Structure contour map on top of the Americus Limestone for the area of investigation (from Yarrow, 1974).

unconformity) as also noted by O'Connor and Jewett, 1952 and McCrone, 1963. This absence suggests that the area could have been subaerially exposed. The Nemaha Anticline also affected lithofacies patterns, especially thickness changes during deposition (see section #2; and cross section A-A').

## CROSS SECTIONS

Two cross sections were constructed (with transgressive surface 1 as the datum) in a northeast-southwest (A-A') and northwest-southeast (B-B') direction (Figure 37). These cross sections were orientated to further exemplify the effects of structurally controlled topographic "highs" and "lows", which influenced thickness and facies changes across the study area. Furthermore, these cross sections show the correlation of the genetic surfaces that controlled the development of the Red Eagle Limestone-Roca Shale fifth-order T-R unit.

Cross section A-A' shows the effects of the Nemaha Anticline during Red Eagle Limestone-Roca Shale deposition. Marine units (i.e., Red Eagle Limestone Formation) thin over this inferred topographic high. For example, sixth-order T-R unit #2, which contains the Bennett Shale Member, is only 0.6 feet thick on top of the crest of the Nemaha Anticline (see section #2). While,




Figurre 37. Orientation of cross sections A-A' and B-B' within the area of investiogation.

this "package" thickens to the west in the Irving Syncline (see sections 10, 11, and 12) and thickens to the east in the Brownville Syncline (see section 4). However, predominately nonmarine facies (i.e., Roca Shale Formation) thickened over the inferred topographic high (see section 2). For example, sixth-order T-R unit #4 is 12 feet thick on the crest of the Nemaha Anticline (see section #2) and thins to 2.5 feet, to the west, in the Irving Syncline, and 2.6 feet, to the east, in the Brownville Syncline (see section #4). There was also some evidence to suggest that the Nemaha Anticline had been reactivated even after Roca time. For example, bed #25 in section 2 dips 6 degrees to the west.

Cross section B-B' again illustrates thinning of marine packages over topographic highs (i.e., Alma-Davis Ranch Anticline) and even erosion and/or nondeposition, as previously mentioned, during Glenrock deposition (see sections 15 and 18). Sixth-order T-R unit #2, which contains the Bennett Shale Member, again thins dramatically over topographic highs. For example, there is only 0.2 feet of black fissile, Orbiculoidea containing shale in section 15. This fissile, black shale sits on top of a thin (1-2cm.) coal smut, that may be stratigraphically equivalent to the Glenrock Limestone Member elsewhere. Therefore, one could conclude that this area, situated along the Alma-Davis Ranch Anticline, was subaerially exposed during this time (see section 15, Appendix II).

# CONCLUSION

1. The Red Eagle Limestone and Roca Shale formations compose one net transgressive-regressive unit, that is equivalent to a fifth-order T-R unit of Busch and Rollins (1984), and may represents and interval of about 300-500Ka.

2. The Red Eagle-Roca transgressive-regressive (fifth-order) unit is composed of six smaller scale (sixth-order) transgressive-regressive units, that are bounded by genetic surfaces (i.e., transgressive surfaces).

3. Detailed paleogeographic maps, constructed for the times of maximum transgression and regression of most of the sixth-order T-R units, illustrate the development of the Red Eagle Limestone-Roca Shale fifth-order T-R unit as a series of smaller scale (sixth-order) transgressive-regressive units.

4. Deposition of the Red Eagle Limestone (marine) and Roca Shale (predominately nonmarine) sediments was effected by structural elements within the study area. For example, conspicuous changes are related to topographic highs and lows, which potentially are reflecting the underlying structure.

5. The Glenrock Limestone Member (i.e., sixth-order T-R unit #1) is absent near Alma Kansas in Wabaunsee County (see sections #15 and #18, Appendix II), due to erosion and/or nondeposition (i.e., unconformity). This absence suggests that this area, which is situated on the crest of the Alma-Davis Ranch Anticline, could have been subaerially exposed.

6. Sixth-order T-R unit #2 represents a time when the sea level stand and freshwater input into the basin were at their highest. These conditions were induced by a warm and humid (wet) climate (i.e., climate driven). High terrigenous influxes increased turbidity and "poisoned" carbonate production. The freshwater influx also combined with normal temperature gradient to produce a strong density stratification, envoking anoxic conditions (i.e., black shale/mudstone - Bennett Shale). However, anoxic conditions were interrupted by periods of sediment oxygenation and the establishment of infaunal organisms.

7. Genetic surfaces 1-6 can be recognized in the carbonate buildup along the Lyon-Wabaunsee County line. This carbonate buildup is present because this area was, during Red Eagle and Roca time, far enough from the source of terrigenous detritus that carbonate production was not interrupted.

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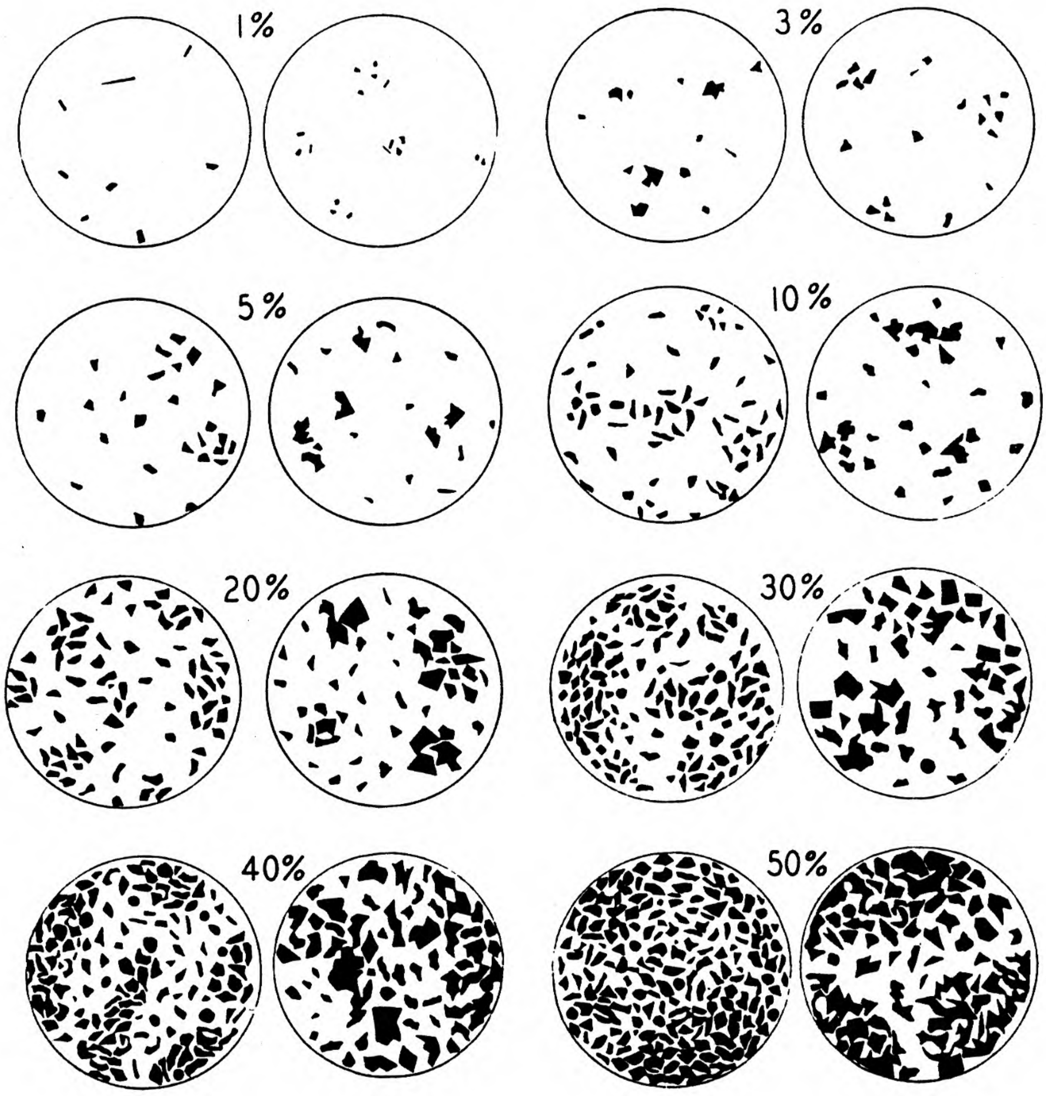
# A P P E N D I X  I

Comparison charts and classification schemes used in this study

Comparison Chart For Visual Percentage Estimation (After Terry and Chilingar, 1955).



**Grain-Size Scale for Carbonate Rocks**

| | Transported Constituents | Authigenic Constituents | |
|---|---|---|---|
| | Very coarse calcirudite | Extremely coarsely crystalline | |
| 64 mm | Coarse calcirudite | | |
| 16 mm | Medium calcirudite | | |
| 4 mm | Fine calcirudite | Very coarsely crystalline | 4 mm |
| 1 mm | Coarse calcarenite | Coarsely crystalline | 1 mm |
| 0.5 mm | Medium calcarenite | | |
| 0.25 mm | Fine calcarenite | Medium crystalline | 0.25 mm |
| 0.125 mm. | Very fine calcarenite | | |
| 0.062 mm | Coarse calcilutite | Finely crystalline | 0.062 mm |
| 0.031 mm | Medium calcilutite | | |
| 0.016 mm | Fine calcilutite | Very finely crystalline | 0.016 mm |
| 0.008 mm | Very fine calcilutite | | |
| 0.004 mm | | Aphanocrystalline | 0.004 mm |

Carbonate rocks contain both physically transported particles (oolites, intraclasts, fossils, and pellets) and chemically precipitated minerals (either as pore-filling cement, primary ooze, or as products of recrystallization and replacement). Therefore the size scale must be a double one, so that one can distinguish which constituent is being considered (e.g. calcirudites may be cemented with very finely crystalline dolomite, and finer calcarenites may be cemented with coarsely crystalline calcite).

The size scale for transported constituents uses the terms of Grabau but retains the finer divisions of Wentworth except in the calcirudite range; for dolomites of obviously allochemical origin, the terms *dolorudite, doloarenite,* and *dololutite* are substituted for those shown. The most common crystal size for dolomite appears to be between .062 and .25 mm, and for this reason that interval was chosen as the *medium crystalline* class (from Folk, 1962).

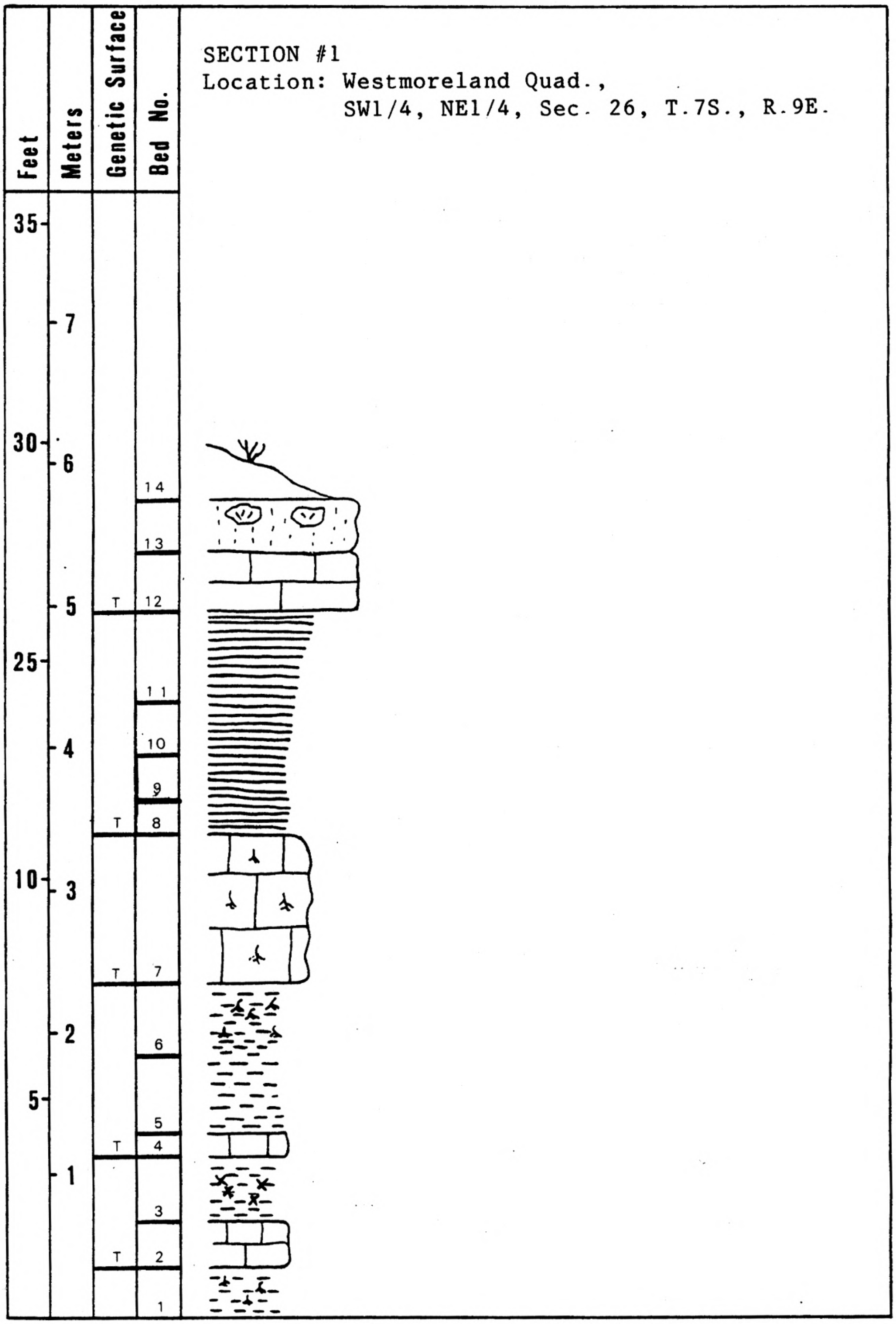
Dunham's (1962) classification of carbonate rocks

<table>
<tr><th colspan="5">DEPOSITIONAL TEXTURE RECOGNIZABLE</th><th rowspan="2">DEPOSITIONAL TEXTURE NOT RECOGNIZABLE</th></tr>
<tr><td colspan="4">Original Components Not Bound Together During Deposition</td><td rowspan="4">Original components were bound together during deposition... as shown by intergrown skeletal matter, lamination contrary to gravity, or sediment-floored cavities that are roofed over by organic or questionably organic matter and are too large to be interstices.</td></tr>
<tr><td colspan="3">Contains mud<br>( particles of clay and fine silt size )</td><td rowspan="3">Lacks mud and is grain-supported</td><td rowspan="4"><u>Crystalline Carbonate</u><br><br>( Subdivide according to classifications designed to bear on physical texture or diagenesis.)</td></tr>
<tr><td colspan="2">Mud-supported</td><td rowspan="2">Grain-supported</td></tr>
<tr><td>Less than 10 percent grains</td><td>More than 10 percent grains</td></tr>
<tr><td><u>Mudstone</u></td><td><u>Wackestone</u></td><td><u>Packstone</u></td><td><u>Grainstone</u></td><td><u>Boundstone</u></td></tr>
</table>

# A P P E N D I X  I I

Detailed description of measured sections used in this study

(For locality map, see Figure 5)


Feet
Meters
Genetic Surface
Bed No.
SECTION #1
Location: Westmoreland Quad.,
SW1/4, NE1/4, Sec. 26, T.7S., R.9E.
35
30
25
10
5
7
6
5
4
3
2
1
T
T
T
T
T
14
13
12
11
10
9
8
7
6
5
4
3
2
1

SECTION #1 northeast of Westmoreland Pottawatomie County, KS; Westmoreland Quadrangle; SW1/4, NE1/4, SEC. 26, T.7S., R.9E.; measured by Michael H. Clark (June 1987)

14. Roca Shale: weathered and covered by soil.

13. Howe Limestone: (1.2ft.; 0.36m.) light gray (weathers pale orange-brown), blocky to massive, skeletal calcarenite (grainstone to packstone); well sorted; 70-90% coated grains (Osagia), high-spired gastropods, smooth shelled ostracodes (Paraparchites), fossil fragments, and large hemispheroidal stromatolites (12-16cm. in diameter); upper contact sharp.

12. Howe Limestone: (1.3ft.; 0.41m.) light gray-brown (weathers pale orange-brown), massive, slightly argillaceous, skeletal calcilutite (wackestone); with productids fragments, articulated Nucula, articulated Aviculopecten, fossil fragments, and Fenestrellina; basal contact sharp.

11. Bennett Shale: (2.1ft.; 0.64m.) olive-gray (weathers light brown), flaggy, mudstone; with productids, Crurithyris, and Orbicloidea; basal contact gradational.

10. Bennett Shale: (1.3ft.; 0.38m.) light gray-brown (weathers light brown), flaggy, mudstone; with Crurithyris, Aviculopecten, and productids; basal contact gradational.

9. Bennett Shale: (1.0ft.;0.30m.) light gray to brown (weathers light brown), flaggy, mudstone; with Crurithyris, articulated Wellerella, Aviculopecten, productids, Fenestrellina, and Composita; basal contact sharp.

8. Bennett Shale: (0.7ft.; 0.20m.) light gray-brown (weathers light brown), flaggy, mudstone; with Orbiculoidea and Crurithyris; basal contact sharp.

7. Glenrock Limestone: (3.4ft.; 1.04m.) medium gray (weathers light brown), massive, argillaceous, skeletal calcilutite (mudstone); root mottled; with intraclasts of the underlying lithology (subrounded to angular, 3-7mm. in diameter), root traces, ostracodes, and mudcracks in the upper foot; basal contact sharp and erosional(?).

6. Johnson Shale: (1.6ft.; 0.48m.) light gray to gray-green (weathers light green-brown), blocky, slightly indurated, mudstone; with root traces and mudcracks; basal contact sharp.

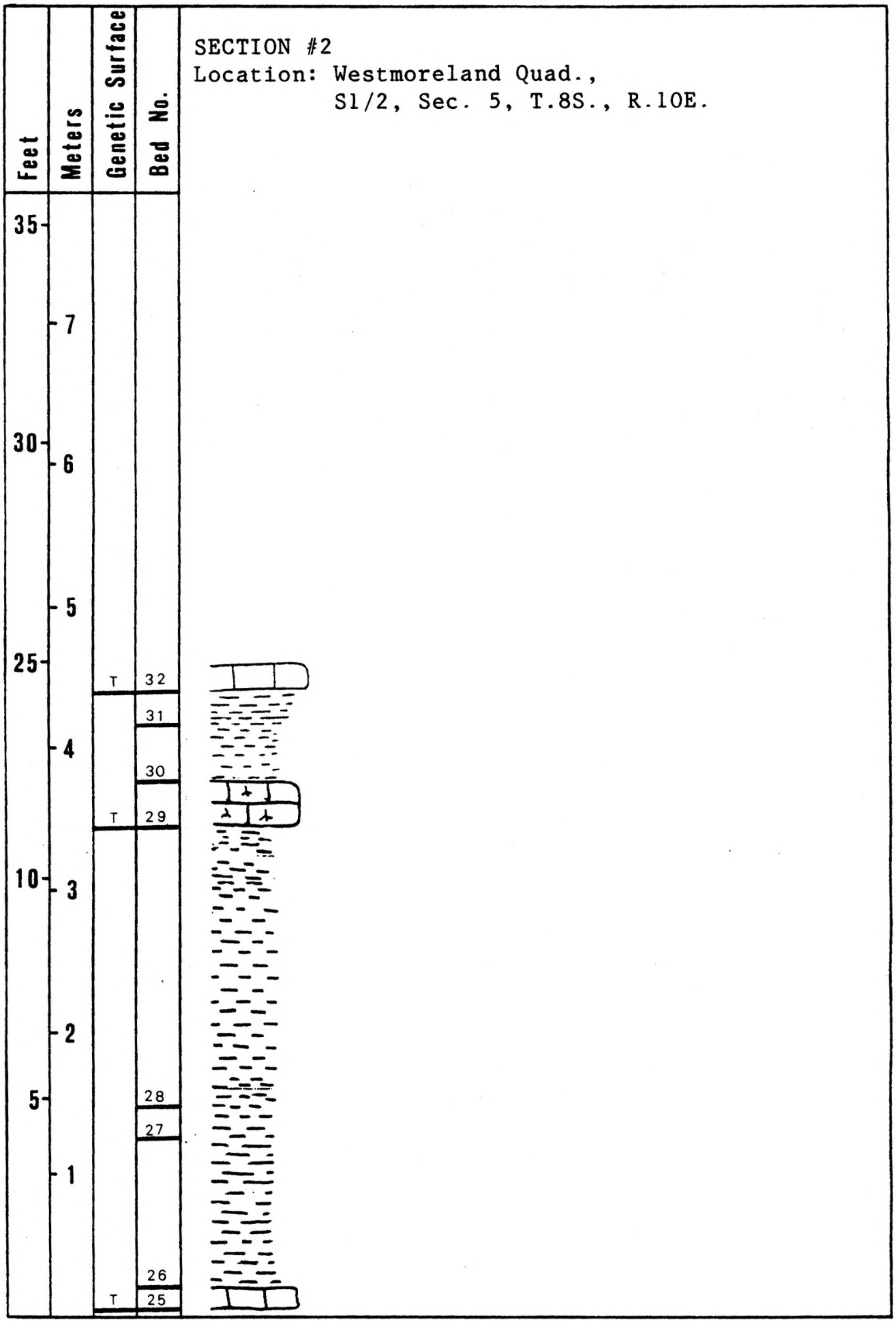
5. Johnson Shale: (1.8ft.; 0.56m.) dark gray to black (weathers light brown), platy, mudstone; with (15-30%) ostracodes at base becoming less common at top; gradational upper contact; basal contact sharp.

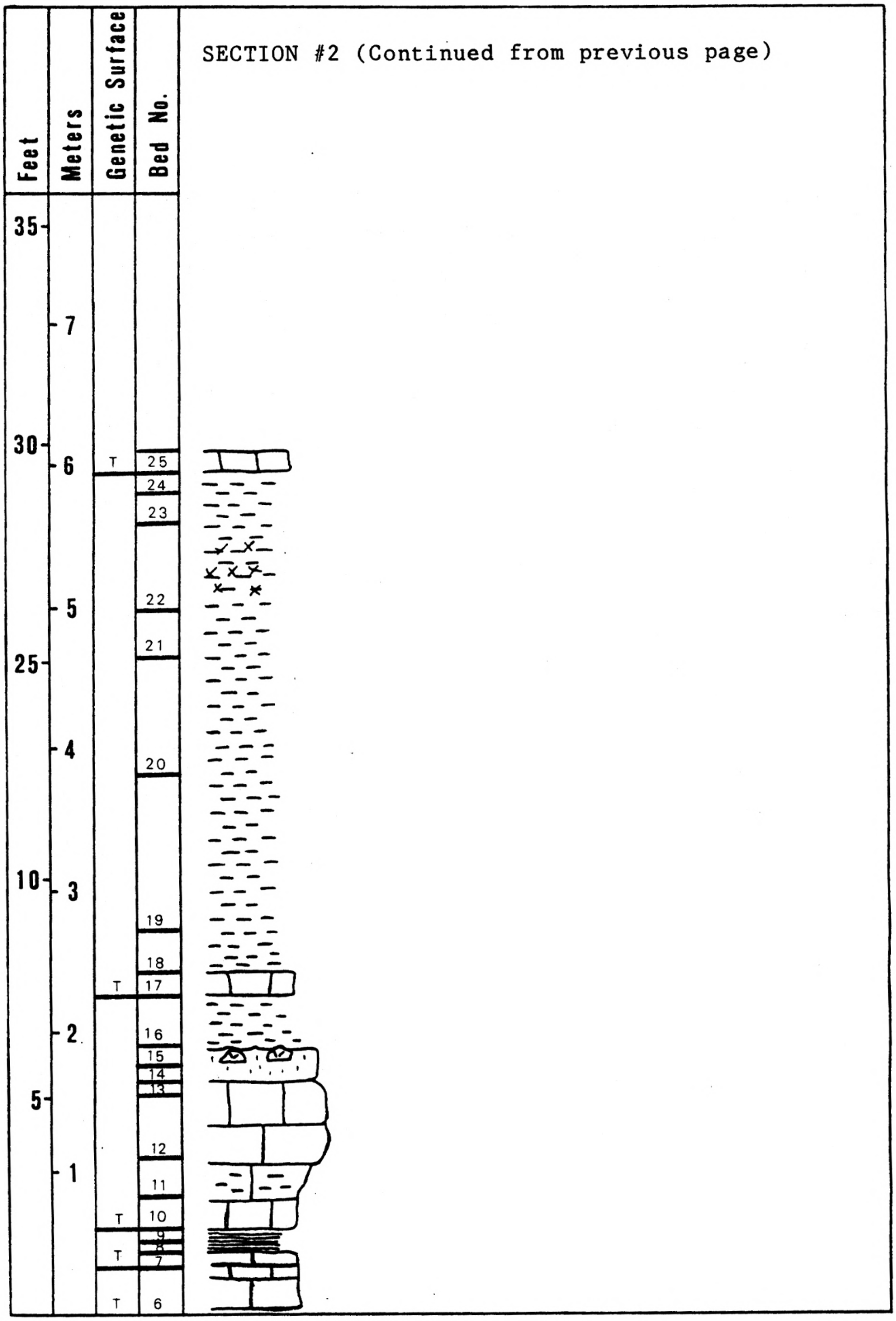
4. Johnson Shale: (0.6ft.; 0.18m.) light gray (weathers light brown), flaggy, slightly argillaceous, skeletal calcilutite (mudstone); mudcracked; with (10-20%) smooth shelled ostracodes; basal contact sharp.

3. Johnson Shale: (1.6ft.; 0.48m.) reddish-brown (weathers darker reddish-brown), blocky-crumbly, indurated, mudstone; with root traces, caliche nodules, and microslickensides; basal contact sharp.

2. Johnson Shale: (1.1ft.; 0.33m.) light gray-brown (weathers light brown) calcareous calcilutite (mudstone); with root traces; basal contact sharp.

1. Johnson Shale: (1.0ft.; 0.30m.) light green (weathers light green-brown),blocky-crumbly, indurated, slightly calcareous, silty, mudstone; with microslickensides and root traces; basal contact covered.


SECTION #2
Location: Westmoreland Quad.,
S1/2, Sec. 5, T.8S., R.10E.
Feet
Meters
Genetic Surface
Bed No.
35
30
25
10
5
7
6
5
4
3
2
1
T
T
T
32
31
30
29
28
27
26
25


SECTION #2 (Continued from previous page)
Feet
Meters
Genetic Surface
Bed No.
35
30
25
10
5
7
6
5
4
3
2
1
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T
T
T
T
25
24
23
22
21
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8
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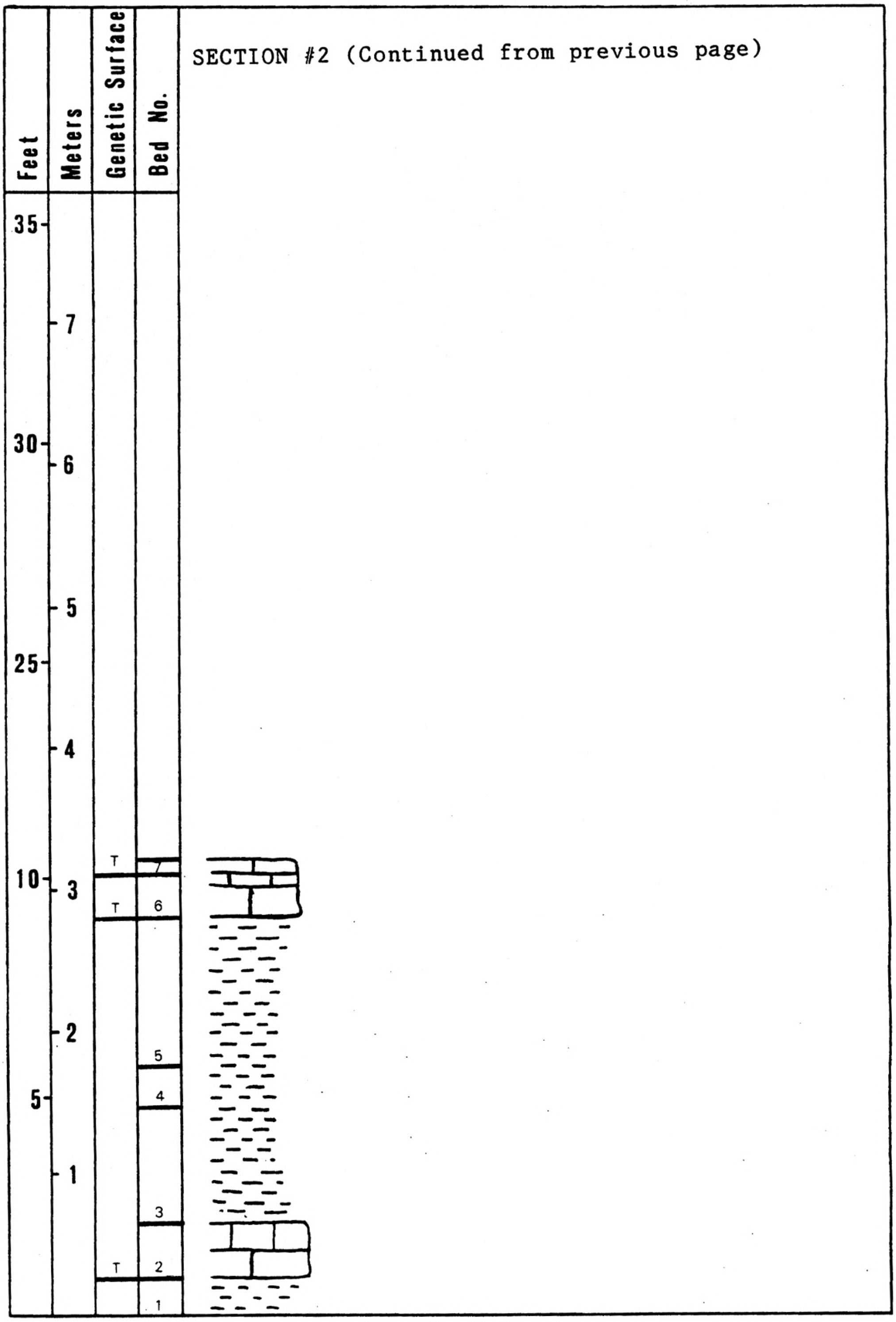
6

SECTION #2 (Continued from previous page)



SECTION #2 roadcut Pottawatomie County, KS; Westmoreland Quadrangle; S1/2, SEC.5, T.8S., R.10E.; measured by Michael H. Clark (July, 1987)

32. Sallyards Limestone:(0.6ft.; 0.18m.) light gray-brown (weathers medium brown), slabby, slightly argillaceous, fossiliferous, skeletal calcilutite (wackestone); with Aviculopectens, productids, Nucula, fossil fragments, and algal biscuits; basal contact sharp.

31. Roca Shale: (0.7ft.; 0.20m.) light brown (weathers medium brown) platy to flaggy, unfossiliferous, mudstone; calcareous; basal contact sharp.

30. Roca Shale: (1.3ft.; 0.41m.) light green (weathers green-brown), blocky-crumbly, indurated, slightly silty, root mottled, mudstone; with root traces; basal contact sharp.

29. Roca Shale: (1.0ft.; 0.30m.) light greenish-brown (weathers medium greenish-brown), flaggy, root mottled, argillaceous, skeletal calcilutite (mudstone); with root traces, smooth shelled ostracodes, and fenestral fabric (1-2mm. in diameter sparite filled vugs); basal contact sharp.

28. Roca Shale: (6.3ft.; 1.93m.) light olive-brown (weathers light brown), flaggy, unfossiliferous, mudstone; slightly calcareous; with iron stains; basal contact gradational.

27. Roca Shale: (0.7ft.; 0.20m.) dark maroon to gray (weathers medium maroon to gray), massive, unfossiliferous, mudstone; mottled; with microslickensides and iron stains; basal contact gradational.

26. Roca Shale: (3.6ft.; 1.09m.) light olive-green (weathers light brown), platy, unfossiliferous, mudstone; slightly indurated at the top of the unit; basal contact sharp.

25. Roca Shale: (0.5ft.; 0.15m.) light gray-brown (weathers light brown), slabby, slightly argillaceous, skeletal calcilutite (mudstone); with Permphorus, ostracodes (Carbonita & Geisina), broken sharks teeth, fish teeth, fish bones, Spirorbis, high-spired gastropods, amphibian tracks (3 toe impressions, 1.5cm. in diameter), & mudcracks; basal contact sharp. Note: this bed dips 6 degrees to the west.

24. Roca Shale: (0.2ft.; 0.05m.) light brown (weathers same), flaggy, slightly calcareous, unfossiliferous, mudstone; basal contact sharp.

23. Roca Shale: (1.0ft.; 0.30m.) light green (weathers greenish brown), blocky, slightly silty, unfossiliferous, mudstone; indurated; with iron stains; basal contact gradational.

22. Roca Shale: (2.1ft.; 0.64m.) brick-red (weathers reddish-brown), blocky-crumbly, indurated, unfossiliferous, slightly silty, mudstone; with caliche nodules, microslickensides, and iron stains; basal contact gradational.

21. Roca Shale: (1.0ft.; 0.30m.) brick-red to light brown (weathers reddish-brown), blocky-crumbly, indurated, unfossiliferous, slightly silty, mudstone; with microslickensides; basal contact gradational.

20. Roca Shale: (2.5ft.; 0.76m.) brick-red (weathers reddish-brown), blocky-crumbly, silty mudstone; indurated; slightly calcareous; with microslickensides and root traces; basal contact gradational.

19. Roca Shale: (3.7ft.; 1.12m.) varigated (gray-maroon, weathers light brown) blocky-crumbly, mudstone; mottled; with root traces and calcareous mudstone intraclasts (light brown, subrounded to angular, up to 7mm. in diameter); basal contact gradational.

18. Roca Shale: (1.0ft.; 0.30m.) varigated (maroon-gray-brown, weathers reddish-brown), blocky, slightly silty, unfossiliferous, calcareous mudstone; with a calcrete bed 14cm. from base; basal contact sharp.

17. Roca Shale: (0.5ft.; 0.15m.) light gray-brown (weathers light brown), flaggy, slightly argillaceous, skeletal, calcareous calcilutite (mudstone); vuggy; with ostracodes; basal contact sharp.

16. Roca Shale: (1.3ft.; 0.38m.) light green (weathers greenish-brown), massive, slightly calcareous, unfossiliferous, mudstone; basal contact sharp.

15. Howe Limestone: (0.2ft.; 0.05m.) light orange-brown (weathers light brown), massive, well sorted, coarse skeletal calcarenite (grainstone); with (80-90%) coated grains (Osagia), ostracodes (Paraparchites), high-spired gastropods, and algal stromatolites (hemispheroidal-form with mamelons) on the top bedding surface (boundstone); the top surface also has interference ripple marks; basal contact sharp.

14. Howe Limestone: (0.2ft.; 0.05m.) light orange-brown (weathers light brown), slabby, well sorted, skeletal calcarenite (wackestone to packstone); friable; slightly argillaceous; with (60-80%) coated grains (Osagia), Aviculopecten, productids, and ostracodes (Paraparchites); basal contact sharp.

13. Howe Limestone: (0.4ft.; 0.13m.) light gray-brown (weathers medium brown), slabby, skeletal calcilutite (wackestone); thinly laminated; lower 4cm. is slightly argillaceous; with (20-30%) ostracodes, coated grains (Osagia), ramose bryozoan fragments, and fossil fragments; basal contact gradational.

12. Howe Limestone: (1.8ft.; 0.56m.) light gray to light brown (weathers light brown), slabby to blocky, slightly argillaceous, skeletal calcilutite (wackestone); with brachiopod fossil fragments; basal contact sharp.

11. Howe Limestone: (0.8ft.; 0.25m.) light brown (weathers same), very argillaceous calcilutite (mudstone-wackestone?); highly weathered; basal contact sharp.

10. Howe Limestone: (0.7ft.; 0.20m.) light brown to pale orange (weathers orange-brown), slabby to blocky, skeletal calcilutite (wackestone); with Aviculopecten, Nucula, Myalina, high-spired gastropods, and crinoids; basal contact sharp.

9. Bennett Shale: (0.3ft.; 0.10m.) very dark gray to black (weathers light brown), unfossiliferous, fissile shale to platy mudstone; basal contact gradational.

8. Bennett Shale: (0.2ft.; 0.05m.) dark gray-brown (weathers light brown), flaggy, mudstone; with Aviculopecten, fish teeth, and Orbiculoidea; basal contact sharp.

7. Glenrock Limestone: (0.2ft.; 0.05m.) light gray (weathers gray-brown), massive, skeletal calcarenite (wackestone); with productids, Nucula, Aviculopecten, ostracodes, productids, and fossil fragments; basal contact irregular.

6. Glenrock Limestone: (1.1ft.; 0.33m.) light gray (weathers gray-brown), massive, skeletal calcarenite to calcirudite (wackestone to packstone); poorly sorted; with intraclasts (pale yellow-weather same, 1-4mm. in diameter, subrounded to subangular, appear to be from the underlying lithology), articulated Aviculopecten, Nucula, productids, smooth shelled ostracodes, and fossil fragments; top surface is irregular and has horizontal burrows (Thalassinoides?); basal contact sharp and probably erosional.

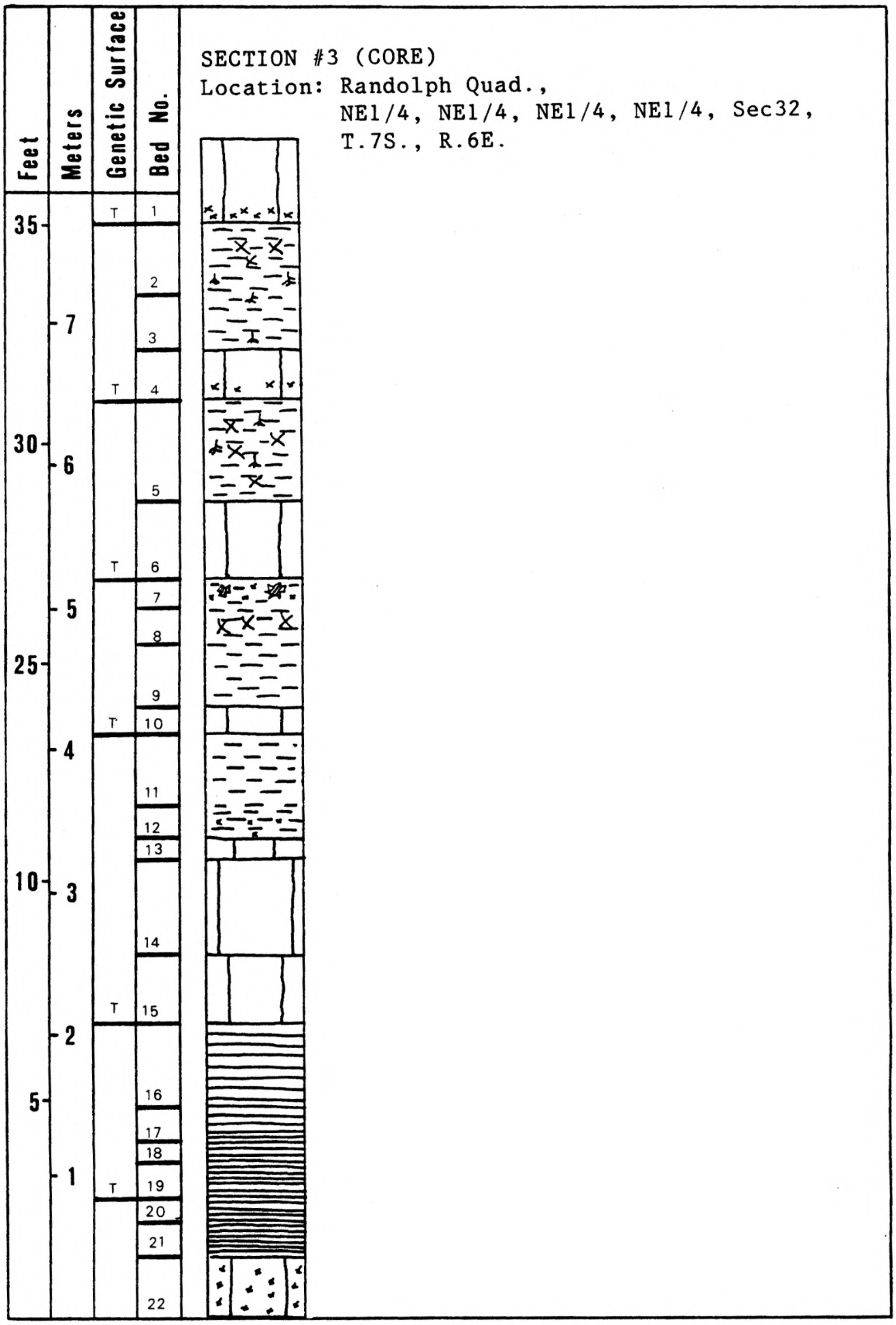
5. Johnson Shale: (3.3ft.; 1.02m.) light olive-brown (weathers light brown), flaggy, unfossiliferous, calcareous mudstone; thinly laminated, with Fe and Mg stains; basal contact gradational.

4. Johnson Shale: (1.0ft.; 0.30m.) dark gray (weathers light brown), flaggy, mudstone; with smooth shelled ostracodes and root traces; basal contact sharp.

3. Johnson Shale: (2.7ft.; 0.81m.) light olive-brown (weathers brown), flaggy, unfossiliferous, calcareous mudstone; thinly laminated; with Fe and Mg stains; basal contact sharp.

2. Johnson Shale: (1.3ft.; 0.38m.) light gray (weathers gray-brown), slabby to blocky, skeletal calcilutite to calcarenite (wackestone); with brachiopod fossil fragments; basal contact sharp.

1. Johnson Shale: light green (weathers greenish-brown), blocky, unfossiliferous, slightly silty, mudstone; basal contact covered.


Feet
Meters
Genetic Surface
Bed No.
SECTION #3 (CORE)
Location: Randolph Quad.,
NE1/4, NE1/4, NE1/4, NE1/4, Sec32,
T.7S., R.6E.
35
30
25
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5
7
6
5
4
3
2
1
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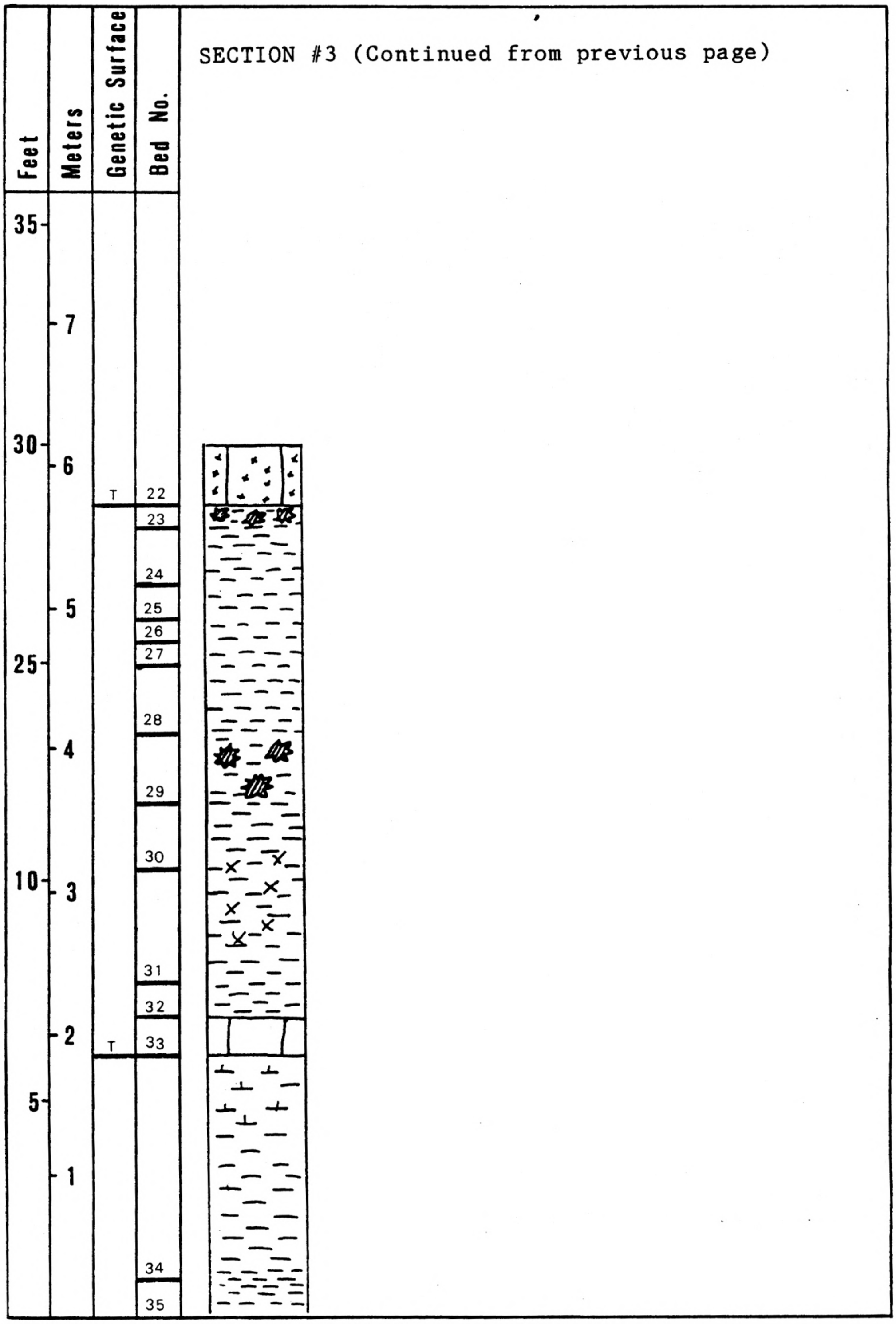
SECTION #3 (Continued from previous page)



SECTION #3; CORE: #1 Hargrave; Riley County, KS; Randolph Quadrangle; NE1/4, NE1/4, NE1/4, NE1/4, SEC. 32, T.7S., R.6E.; measured by Michael H. Clark (October 1987) Elevation: ground level @ 1351ft. above sea level; Drlg. measured from top casing @ 1352.5ft. above sea level.

1. Sallyards Limestone: (1.9ft.; 0.58m.) light gray, argillaceous, skeletal calcilutite (wackestone); bioturbated; with (20-30%) fossils: Aviculopecten, productids, ostracodes, coated grains (Osagia), algal biscuits (Osagia), gastropods, fossil fragments, and mudstone intraclasts (light green, subrounded to angular, up to 7mm. in diameter) of underlying lithology in basal 8cm.; basal contact sharp and erosional. Top of Sallyards Limestone tentatively picked at 527.0ft. by wellsite geologist.

2. Roca Shale: (2.0ft.; 0.61m.) light green, silty, unfossiliferous mudstone; caliche nodules abundant throughout; basal contact sharp. Top of Roca Shale tentatively picked at 529.0ft. by wellsite geologist.

3. Roca Shale: (1.9ft.; 0.58m.) light green, mudstone; with small root traces; basal contact sharp.

4. Roca Shale: (1.1ft.; 0.33m.) light green to light brown, slightly argillaceous, skeletal calcilutite (mudstone); with ripped up algal-laminated, mudstone intraclasts, fenestral fabric, and ostracodes; basal contact sharp.

5. Roca Shale: (2.3ft.; 0.69m.) light green, slightly calcareous, mudstone; with root traces and small caliche nodules; basal contact sharp.

6. Roca Shale: (1.8ft.; 0.53m.) light green to light brown, slightly argillaceous, algal laminated to slightly nodular, calcilutite (mudstone); upper 8cm. highly weathered; basal contact sharp.

7. Roca Shale: (0.7ft.; 0.20m.) light olive-green, calcareous, laminated mudstone; with intraclasts and gypsum crust (2cm. thick 10cm. from the base); basal contact sharp.

8. Roca Shale: (0.8ft.; 0.23m.) light green, unfossiliferous, calcareous mudstone; caliche nodules throughout; basal contact gradational.

9. Roca Shale: (1.3ft.; 0.41m.) varigated (light green to maroon), slightly calcareous mudstone; with root traces; basal contact gradational.

10. Roca Shale: (0.6ft.; 0.18m.) light gray-brown, slightly argillaceous, algal laminated, skeletal calcilutite (mudstone); with high-spired gastropods, and ostracodes; basal contact sharp.

11. Roca Shale: (1.7ft.; 0.51m.) light green, unfossiliferous, slightly calcareous, silty, mudstone; thinly laminated (slightly wavy); with small muscovite flakes (<0.5mm. in diameter) on the bedding surfaces; basal contact sharp.

12. Roca Shale: (0.8ft.; 0.23m.) light green, slightly calcareous mudstone; with mudstone clasts (light brown, angular to subrounded, <5mm. in diameter) and root traces, basal contact sharp.

13. Howe Limestone: (0.5ft.; 0.15m.) light brown, massive, algal laminated, skeletal calcilutite (wackestone to boundstone?); with smooth shelled ostracodes, coated grains (Osagia), and hemispheroidal stromatolites(?); basal contact sharp. Top of Howe Limestone tentatively picked at 545.0ft. by wellsite geologist.

14. Howe Limestone: (2.2ft.; 0.66m.) medium gray, massive, bioturbated, coarse skeletal calcilutite (wackestone); with fossil fragments (brachiopod?) and one gypsum lens; basal contact gradational.

15. Howe Limestone: (1.6ft.; 0.48m.) dark gray to light brown, massive, coarse skeletal calcilutite (wackestone); fossiliferous: fusulinids, echinoid spines, Composita?, crinoids, bryozoans, productids, Crurithyris, fossil fragments, and one gypsum lens; basal contact sharp.

16. Bennett Shale: (2.0ft.; 0.61m.) light brown, noncalcareous, slightly silty, mudstone; with (10-15%) fossil fragments: small bivalves, productid spines, and two quartz nodules (up to 2.5cm. in diameter in the top 5cm.); basal contact gradational. Top of Bennett Shale tentatively picked at 551.0ft. by wellsite geologist.

17. Bennett Shale: (0.9ft.; 0.28m.) gray to brown, very fossiliferous mudstone; with (15-30%) fossils: Composita, Crurithyris, crinoids, ostracodes, productids, echinoid spines, bryozoans, fossil fragments, and Hustedia; basal contact sharp.

18. Bennett Shale: (0.5ft.; 0.15m.) dark gray, calcareous, fossiliferous mudstone; with (10-20%) fossils: Composita, productids, Aviculopecten, Hustedia, Crurithyris, echinoid spines, small crinoids, and fossil fragments (brachiopod?); basal contact gradational.

19. Bennett Shale: (0.9ft.; 0.28m.) gray to light brown, calcareous, slightly silty mudstone; with (10-20%) fossils: ostracodes, productids, echinoid spines, Crurithyris, Aviculopecten, and fossil fragments; basal contact sharp.

20. Bennett Shale: (0.4ft.; 0.13m.) dark gray, calcareous, silty, unfossiliferous claystone; with a 5cm. thick gypsum bed/lens(?); basal contact gradational.

21. Bennett Shale: (0.5ft.; 0.15m.) gray, slightly silty, calcareous mudstone; with (10-20%) fossils: Crurithyris, ostracodes, fossil fragments (brachiopod?), and abundant small bivalves (Nucula?); basal contact sharp.

22. Glenrock Limestone: (1.4ft.; 0.43m.) gray to light brown, massive, skeletal calcirudite (packstone to grainstone); with fossil fragments (brachiopod?) and (30-40%) intraclasts (subrounded to subangular, up to 7mm. in diameter), the intraclasts fine upward, and some are algal coated (Osagia); basal contact sharp.

23. Johnson Shale: (0.3ft.; 0.08m.) light gray-green, unfossiliferous, calcareous siltstone; with gypsum nodules throughout; basal contact gradational. Top of Johnson Shale tentatively picked at 555.0ft. by wellsite geologist.

24. Johnson Shale: (1.4ft.; 0.43m.) light green to gray, calcareous, silty, unfossiliferous, mudstone; with gypsum laminations (3-4mm.) throughout; basal contact gradational.

25. Johnson Shale: (0.8ft.; 0.25m.) dark gray, slightly calcareous, slightly silty, unfossiliferous mudstone; with gypsum laminations (3-5mm.) throughout; basal contact gradational.

26. Johnson Shale: (0.5ft.; 0.15m.) gray to dark gray, thin-bedded, unfossiliferous siltstone; with gypsum laminations (3-5mm.) throughout; basal contact sharp.

27. Johnson Shale: (0.5ft.; 0.15m.) gray, calcareous, thinly laminated, siltstone; with muscovite grains (<1mm. in diameter) on bedding surfaces and root traces; basal contact gradational.

28. Johnson Shale: (1.7ft.; 0.51m.) gray to light gray, unfossiliferous, calcareous siltstone; with gypsum laminations throughout; basal contact gradational.

29. Johnson Shale: (1.6ft.; 0.48m.) light gray, slightly calcareous, unfossiliferous siltstone; with gypsum nodules throughout; basal contact sharp.

Note: a negative 1.7ft. depth correction was accounted for at this point, between the driller's log and the core.

30. Johnson Shale: (1.2ft.; 0.35m.) light green, calcareous, siltstone; with root traces; basal contact gradational.

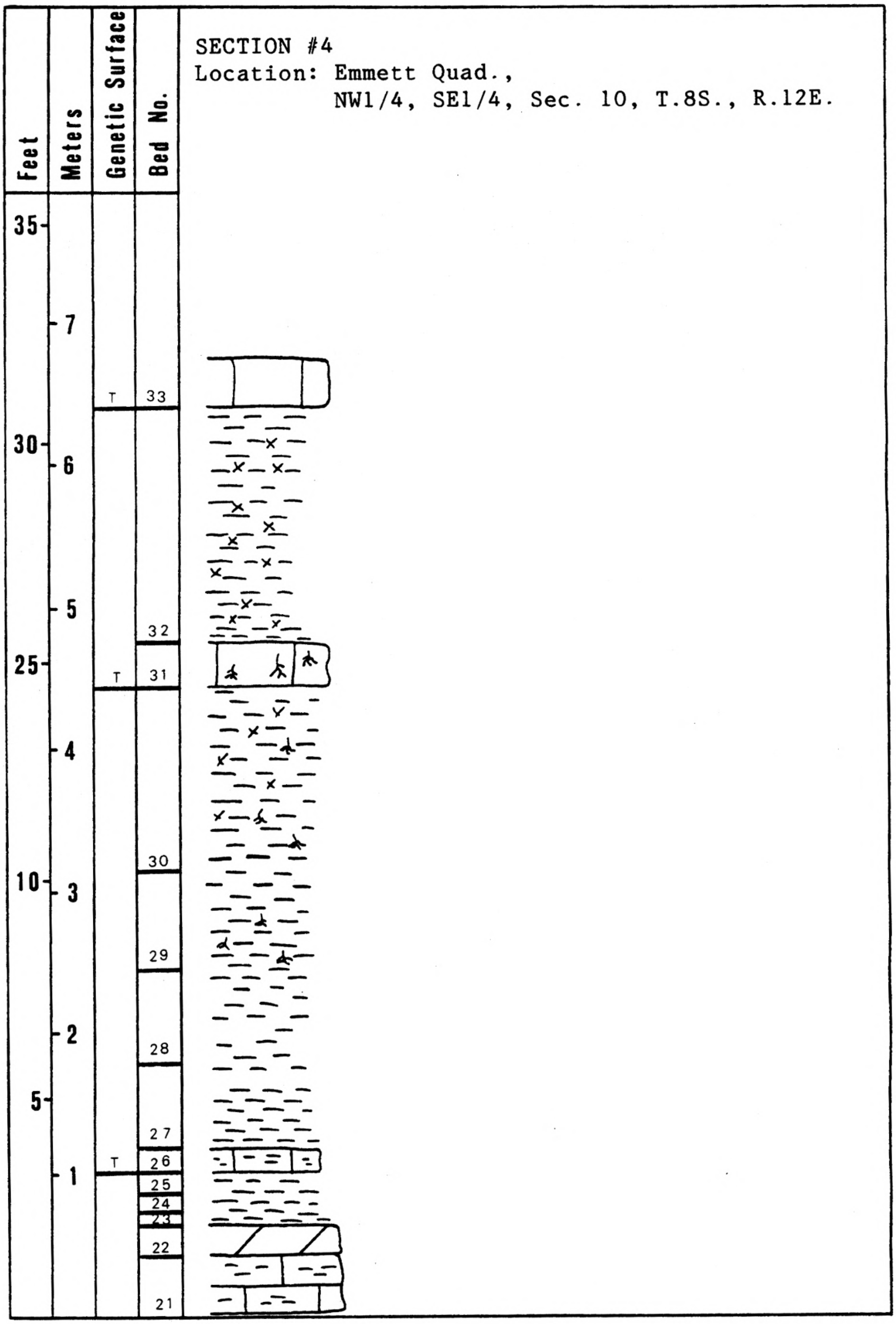
31. Johnson Shale: (2.8ft.; 0.86m.) medium gray-green, slightly calcareous, silty, root mottled, mudstone; with root traces and caliche nodules which increase in abundance upwards; basal contact gradational.

32. Johnson Shale: (0.8ft.; 0.25m.) medium gray-green, slightly calcareous, silty, mudstone; mottled to slightly laminar bedding; with root traces; basal contact sharp.

33. Johnson Shale: (0.8ft.; 0.25m.) light brown, argillaceous, skeletal calcilutite (mudstone to wackestone); bioturbated; with mudstone intraclasts (3-4mm. in diameter, subrounded to subangular), small bivalves, and smooth shelled ostracodes; basal contact sharp.

34. Johnson Shale: (5.1ft.; 1.56m.) medium olive-gray, slightly silty, calcareous mudstone; slightly laminar and becoming more calcareous upwards, with mudstone intraclasts (3-4mm. in diameter, subrounded to subangular) and smooth shelled ostracodes; basal contact sharp.

35. Johnson Shale: (0.8ft.; 0.23m.) medium olive-gray, slightly calcareous, silty, unfossiliferous mudstone; slightly laminar; basal contact sharp.


SECTION #4
Location: Emmett Quad.,
NW1/4, SE1/4, Sec. 10, T.8S., R.12E.
Feet
Meters
Genetic Surface
Bed No.
35
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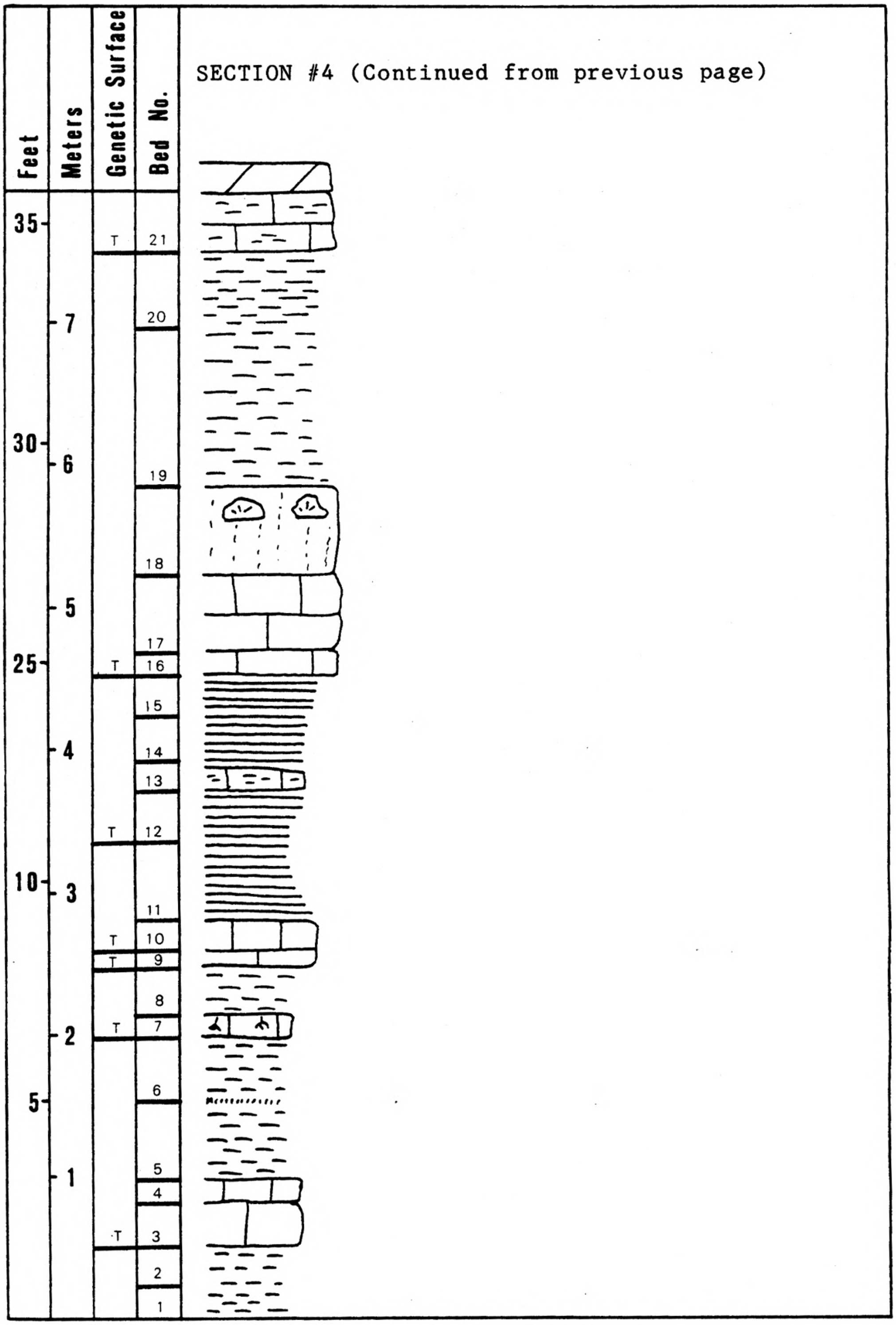
22
21



Feet
Meters
Genetic Surface
Bed No.
SECTION #4 (Continued from previous page)
35
30
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SECTION #4, St. Clere Pottawatomie County, KS; Emmett Quadrangle; NW1/4, SW1/4, SE1/4, SEC.10, T.8S., R.12E.; measured by Michael H. Clark (June 1987)

33. Sallyards Limestone: (1.1ft.; 0.33m.) light gray (weathers light brown), slabby, skeletal calcarenite (wackestone); with ostracodes, crinoids, high-spired gastropods, fossil fragments, and algal biscuits; basal contact sharp.

32. Roca Shale: (5.3ft.; 1.6m.) light olive-green (weathers greenish brown), blocky-crumbly, indurated, mudstone; blocky-crumbly; with caliche nodules and root traces; basal contact gradational.

31. Roca Shale: (1.0ft.; 0.30m.) light brown to light olive-green (weathers light brown), boxwork calcilutite (mudstone); massive (with very vuggy structure due to dissolution of evaporites); root mottled; basal contact sharp.

30. Roca Shale: (4.3ft.; 1.30m.) light olive-green (weathers light brown), indurated, mudstone; with root traces and caliche nodules; basal contact gradational.

29. Roca Shale: (2.5ft.; 0.76m.) varigated (maroon-green-gray), indurated, mudstone; with root traces; basal contact gradational.

28. Roca Shale: (2.1ft.; 0.64m.) maroon to olive-gray (weathers reddish brown), indurated, unfossiliferous mudstone; basal contact gradational.

27. Roca Shale: (1.5ft.; 0.46m.) olive-gray (weathers light green-brown), indurated, unfossiliferous mudstone; basal contact sharp.

26. Roca Shale: (0.5ft.; 0.15m.) light gray to light brown (weathers medium brown), slabby, slightly argillaceous, skeletal calcilutite (mudstone); with smooth shelled ostracodes; basal contact sharp.

25. Roca Shale: (0.4ft.; 0.13m.) varigated (maroon-gray-light green; weathers reddish brown), indurated, slightly silty, mudstone; with root traces; basal contact gradational.

24. Roca Shale: (0.5ft.; 0.13m.) brick-red (weathers reddish brown), indurated, slightly silty, mudstone; with root traces; basal contact gradational.

23. Roca Shale: (0.2ft.; 0.05m.)light olive-green (weathers light greenish brown), indurated, slightly silty, mudstone; with root traces; basal contact sharp.

22. Roca Shale: (0.7ft.; 0.20m.) light gray (weathers light brown), massive, dololutite (mudstone); with plant fragments; basal contact sharp.

21. Roca Shale: (1.3ft.; 0.38m.) light green (weathers light brown), slabby, argillaceous, skeletal calcilutite (mudstone); slabby; with ostracodes and plant fragments; basal contact sharp.

20. Roca Shale: (1.7ft.; 0.51m.) light olive-green (weathers brown-green), flaggy, slightly silty, mudstone; with plant fragments; basal contact sharp.

19. Roca Shale: (3.8ft.; 1.14m.) varigated (maroon-light green-gray; weathers brown), blocky-crumbly, indurated, mudstone; blocky-crumbly; indurated; with caliche nodules, microslickensides, and root traces; basal contact sharp.

18. Howe Limestone: (2.0ft.; 0.61m.) light brown (weathers light orange-brown), massive, skeletal calcilutite (wackestone); weathered; with smooth shelled ostracodes (Paraparchites) and hemispheroidal stromatolites (15-20cm. in diameter in upper 0.30m.); basal contact sharp.

17. Howe Limestone: (1.7ft.; 0.51m.) light brown (weathers pale orange-brown), slabby to blocky, argillaceous, skeletal calcilutite (wackestone); with Linoproductus, Nucula, Aviculopecten, Straparollus, crinoid fragments, ostracodes (Paraparchites), fecal pellets, trilobite fragments, and ramose bryozoans; basal contact gradational.

16. Howe Limestone: (0.5ft.; 0.15m.) light gray (weathers light brown), slabby, argillaceous, skeletal calcilutite (wackestone); with Crurithyris, Derybia, productids, Aviculopinna, Nucula, and Composita; basal contact sharp.

15. Bennett Shale: (0.9ft.; 0.28m.) dark gray (weathers light brown), flaggy to slabby, calcareous, slightly silty, mudstone; with very small Crurithyris, Orbiculoidea, and productids; basal contact gradational.

14. Bennett Shale: (1.1ft.; 0.33m.) dark gray (weathers light brown), flaggy to slabby, calcareous, slightly silty, fossiliferous, mudstone; with Crurithyris, Orbiculoidea, Wellerella, Hustedia, productids, Aviculopecten, Fenestrellina, and Composita; basal contact gradational.

13. Bennett Shale: (0.5ft.; 0.15m.) dark gray (weathers gray-brown), slabby, argillaceous, skeletal calcilutite (wackestone); fossiliferous; with Crurithyris, Orbiculoidea, Wellerella, Hustedia, Composita, Antiquatonia, Aviculopecten, Linoproductus, Fenestrellina, and ramose bryozoans; basal contact gradational.

12. Bennett Shale: (1.3ft.; 0.38m.) Dark gray (weathers light brown), flaggy to slabby, hard, calcareous, slightly silty, mudstone; fossiliferous: Hustedia, Wellerella, Antiquatonia, Linoproductus, Crurithyris, and Orbiculoidea; basal contact sharp.

11. Bennett Shale: (1.7ft.; 0.51m.) dark gray (weathers light brown), fissile, silty, shale/mudstone; with rare (<10%) small (3-5mm. in diameter) Orbiculoidea; basal contact sharp.

10. Glenrock Limestone: (0.7ft.; 0.21m.) medium gray (weathers light brown), massive, skeletal calcilutite (wackestone); with fusulinids, smooth shelled ostracodes, gastropods, intraclasts, crinoids, broken Neospirifer, Orbiculoidea fragments, and other fossil fragments; top surface highly burrowed with horizontal burrows (Thalassinoides; some of the burrows are filled with dark gray shale/mudstone and Orbiculoidea fragments from above); basal contact irregular and sharp.

9. Glenrock Limestone: (0.2ft.; 0.06m.) medium gray (weathers gray-brown), slabby, algal laminated, skeletal calcilutite (boundstone); with hemispheroidal stromatolites; basal contact sharp.

8. Glenrock Limestone: (0.2ft.; 0.06m.) medium gray (weathers gray-brown), thinly laminated, skeletal calcilutite (mudstone); with smooth shelled ostracodes, Nucula, and carbonaceous plant fragments; basal contact sharp.

7. Johnson Shale: (0.5ft.; 0.15m.) light green (weathers gray-green), blocky-crumbly, silty, mudstone; with iron stains, root traces, and microslickensides; basal contact gradational.

6. Johnson Shale: (1.2ft.; 0.36m.) dark gray (weathers light brown), slabby, mudstone; with root traces, and ostracodes; basal contact gradational.

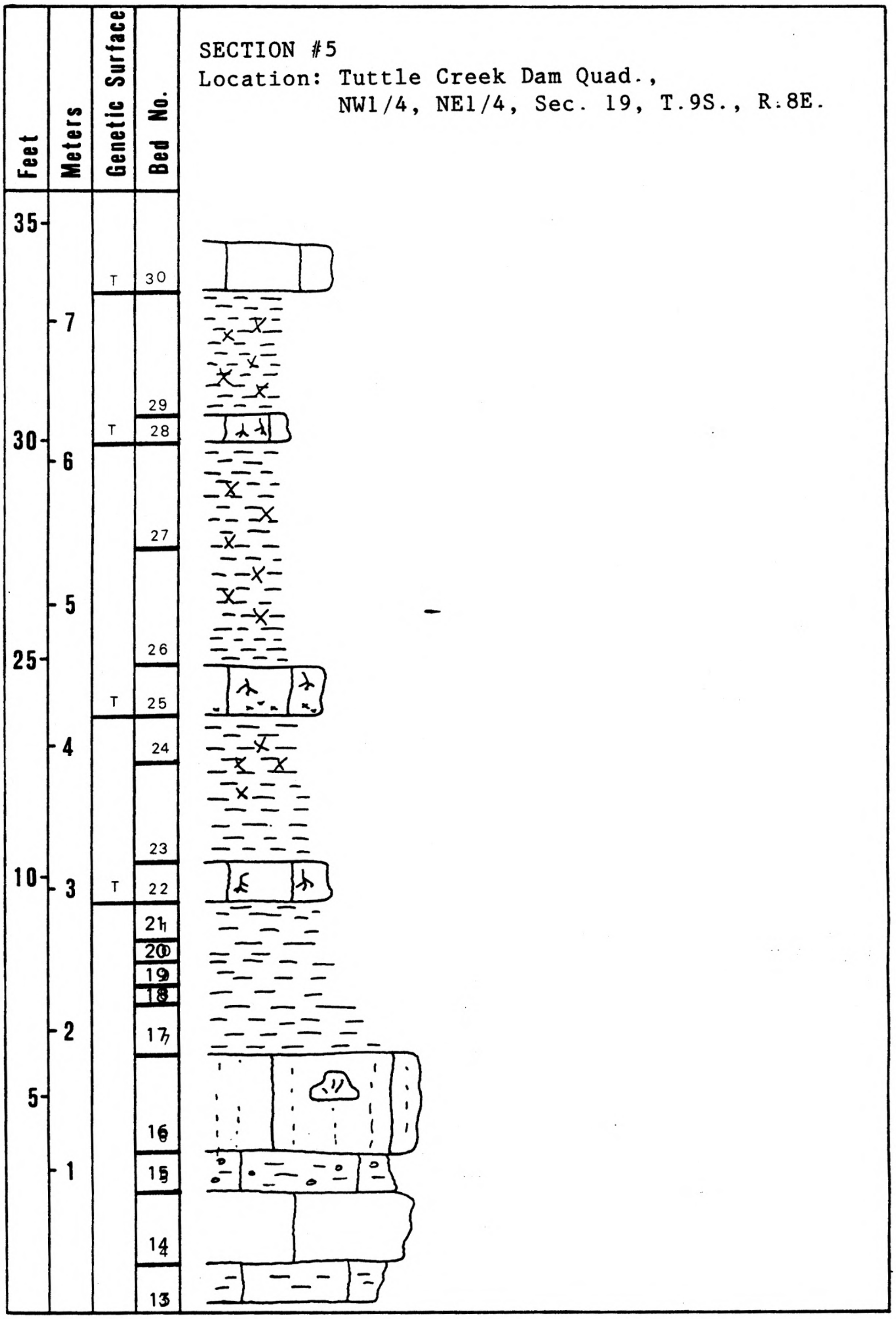
5. Johnson Shale: (1.4ft.; 0.43m.) dark gray (weathers brown), flaggy to slabby, slightly silty, mudstone; with plant fragments, ostracodes, and mudcracks; basal contact gradational.

4. Johnson Shale: (1.8ft.;0.56m.) dark gray to black (weathers dark gray), platy to flaggy, slightly silty, mudstone; with plant fragments, smooth shelled ostracodes, and mudcracks; basal contact sharp.

3. Johnson Shale: (0.5ft.; 0.15m.) gray (weathers gray-brown), platy to flaggy, skeletal calcilutite (mudstone); with ostracodes, silty partings, and mudcracks; basal contact gradational.

2. Johnson Shale: (1.0ft.; 0.30m.) light gray-brown (weathers light brown), slabby, cross-laminated, skeletal calcilutite (mudstone); with ostracodes, silty partings, and mudcracks; basal contact sharp.

1. Johnson Shale: (1.5ft.; 0.46m.) light green (weathers gray-green), blocky-crumbly, slightly silty, mudstone; with plant fragments; base covered.


Feet
Meters
Genetic Surface
Bed No.
SECTION #5
Location: Tuttle Creek Dam Quad.,
NW1/4, NE1/4, Sec. 19, T.9S., R.8E.
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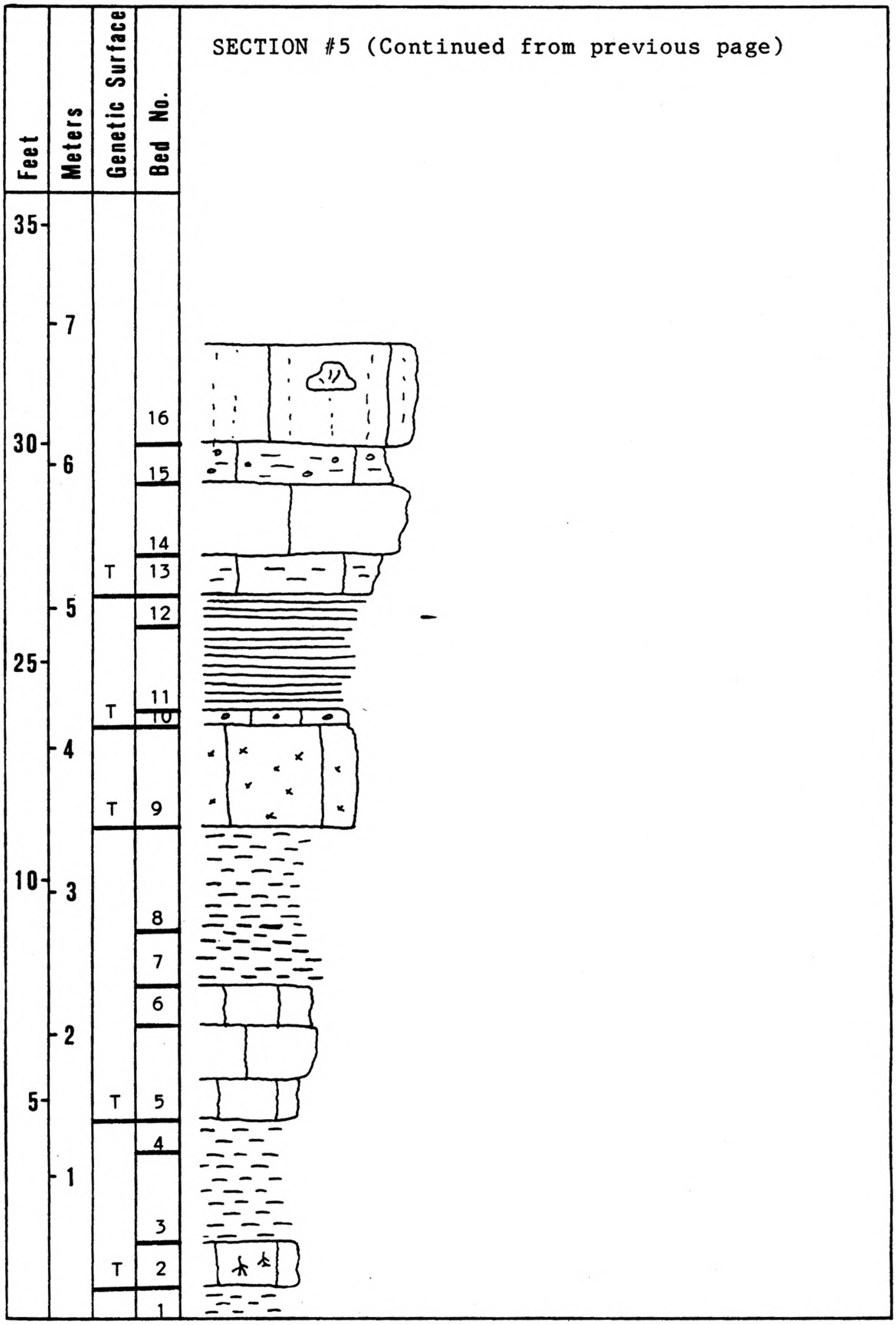
SECTION #5 (Continued from previous page)



SECTION #5 Tuttle Creek Spillway, Pottawatomie County, KS; Tuttle Creek Dam Quadrangle; NW1/4, NE1/4, SEC. 19, T.9S., R.8E.; measured by Michael H. Clark (June 1987).

30. Sallyards Limestone: (1.1ft.; 0.33m.) light gray (weathers medium brown), slabby, argillaceous, skeletal calcilutite (wackestone); with algal biscuits (Osagia), Aviculopecten, productids, and Nucula; basal contact sharp.

29. Roca Shale: (3.0ft.; 0.91m.) olive-green (weathers green-brown), blocky-crumbly, indurated, mudstone; with microslickensides, root traces, and caliche nodules; basal contact sharp.

28. Roca Shale: (0.6ft.; 0.18m.) light gray (weathers gray brown), massive, root mottled, boxwork calcilutite (mudstone); vuggy due to dissolution of evaporites; with root traces; basal contact sharp.

27. Roca Shale: (2.2ft.; 0.66m.) green (weathers light green-brown), blocky-crumbly, indurated, mudstone; with root traces, microslickensides, and caliche nodules; lower contact gradational.

26. Roca Shale: (2.8ft.; 0.86m.) varigated (maroon-green-gray, weathers reddish-brown), blocky-crumbly, indurated, mudstone; with very abundant caliche nodules and calcified peds; basal contact sharp.

25. Roca Shale: (1.2ft., 0.36m.) pale green to gray (weathers light gray), massive, root mottled, intraclastic calcilutite (mudstone); vuggy due to dissolution of evaporites; with root traces and intraclasts (subangular to subrounded, <7mm. in diameter); basal contact sharp.

24. Roca Shale: (1.0ft.; 0.86m.) green to dark gray (weathers light green-brown), blocky-crumbly, indurated, mudstone; with microslickensides and root traces; basal contact gradational.

23. Roca Shale: (2.3ft.; 0.25m.) varigated (maroon-gray-green, weathers red-brown), blocky-crumbly, indurated, mudstone; with root traces, microslickensides, and caliche nodules; basal contact sharp.

22. Roca Shale: (0.8ft.; 0.25m.) gray (weathers gray-brown), slabby, algal laminated, calcilutite (mudstone); with root traces, and fenestral fabric; basal contact sharp.

21. Roca Shale: (0.9ft.; 0.28m.) varigated (maroon-gray-green, weathers reddish-brown), blocky-crumbly, indurated, mudstone; with root traces; basal contact gradational.

20. Roca Shale: (0.3ft.; 0.20m.) light green (weathers green-brown), blocky-crumbly, indurated, mudstone; with root traces; basal contact gradatoinal.

19. Roca Shale: (0.6ft.; 0.18m.) gray (weathers gray-brown), blocky-crumbly, indurated, mudstone; with root traces; basal contact gradational.

18. Roca Shale: (0.3ft.; 0.08m.) brick-red, blocky-crumbly, indurated, mudstone; with root traces; basal contact gradational.

17. Roca Shale: (1.3ft.; 0.41m.) varigated (maroon-green-gray, weathers red-brown), blocky-crumbly, indurated, mudstone; with root traces; basal contact sharp.

16. Howe Limestone: (2.3ft.; 0.68m.) gray, slabby to blocky, skeletal calcarenite (packstone grading upwards into grainstone); well sorted; with small high-spired gastropods, coated grains (Osagia), ostracodes (Paraparchites), echinoid plates and spines, and hemispheroidal stromatolites (in the upper foot); basal contact sharp.

15. Howe Limestone: (0.8ft.; 0.25m.) light gray (weathers pale orange-brown, (highly weathered), vuggy, argillaceous, skeletal calcilutite to calcarenite (wackestone to packstone); fossiliferous; with 40-50% fusulinids, Composita, Neospirifer, small high-spired gastropods, echinoid plates and spines, Crurithyris, productids, and crinoids; basal contact gradational.

14. Howe Limestone: (1.7ft.; 0.51m.) gray (weathers pale orange-brown), blocky to massive, skeletal calcilutite (wackestone); with Composita, fusulinids, crinoids, echinoid spines and plates, and Crurithyris, ostracodes (Paraparchites), Aviculopinna, and skeletal fragments; basal contact gradational.

13. Howe Limestone: (0.9ft.; 0.28m.) light gray (weathers light brown to pale orange), slabby, argillaceous, skeletal calcilutite (wackestone); highly weathered (tripoli); with Orbiculoidea, and Crurithyris; basal contact sharp.

12. Bennett Shale: (0.4ft.; 0.13m.) brown (weathers light brown), flaggy, mudstone; with Orbiculoidea and Crurithyris; basal contact gradational.

11. Bennett Shale: (2.1ft.; 0.61m.) gray to very dark gray (weathers light brown), flaggy, slightly silty, mudstone; with <u>Crurithyris</u>, <u>Orbiculoidea</u>, <u>Permphorus</u>, and productids; basal contact sharp.

10. Glenrock Limestone: (0.3ft.; 0.08m.) gray (weathers medium gray-brown), massive, skeletal calcarenite (wackestone to packstone); fossiliferous; with fusulinids, <u>Derybia</u>, <u>Composita</u>, <u>Hustedia</u>, <u>Wellerella</u>, <u>Crurithyris</u>, <u>Rhipidomella</u>, and rare intraclasts; basal contact sharp.

9. Glenrock Limestone: (2.3ft.; 0.71m.) gray (weathers gray-brown), blocky to massive, skeletal calcarenite to calcirudite (packstone); poorly sorted; with intraclasts (subangular to subrounded, <5mm. in diameter), ostracodes, high-spired gastropods, small bivalves (<u>Nucula</u>?), fossil fragments, and <u>Thalassinoides</u> burrows; basal contact sharp.

8. Johnson Shale: (2.6ft.; 0.79m.) olive-brown to dark gray (weathers medium brown), root mottled, mudstone; with root traces and mudcracks; basal contact gradational.

7. Johnson Shale: (1.2ft.; 0.36m.) olive-brown to dark gray (weathers light brown), platy to flaggy, mudcracked mudstone; upper contact gradational, becoming more indurated upwards; with plant fragments and mudcracks; lower contact gradational.

6. Johnson Shale: (0.9ft.; 0.28m.) gray (weathers gray-brown), platy to flaggy, mudcracked calcilutite (mudstone); lower contact gradational.

5. Johnson Shale: (1.3ft.; 0.38m.) gray (weathers gray-brown), slabby, skeletal calcilutite (mudstone); with mudcracks, ostracodes, and silty partings; basal contact sharp..

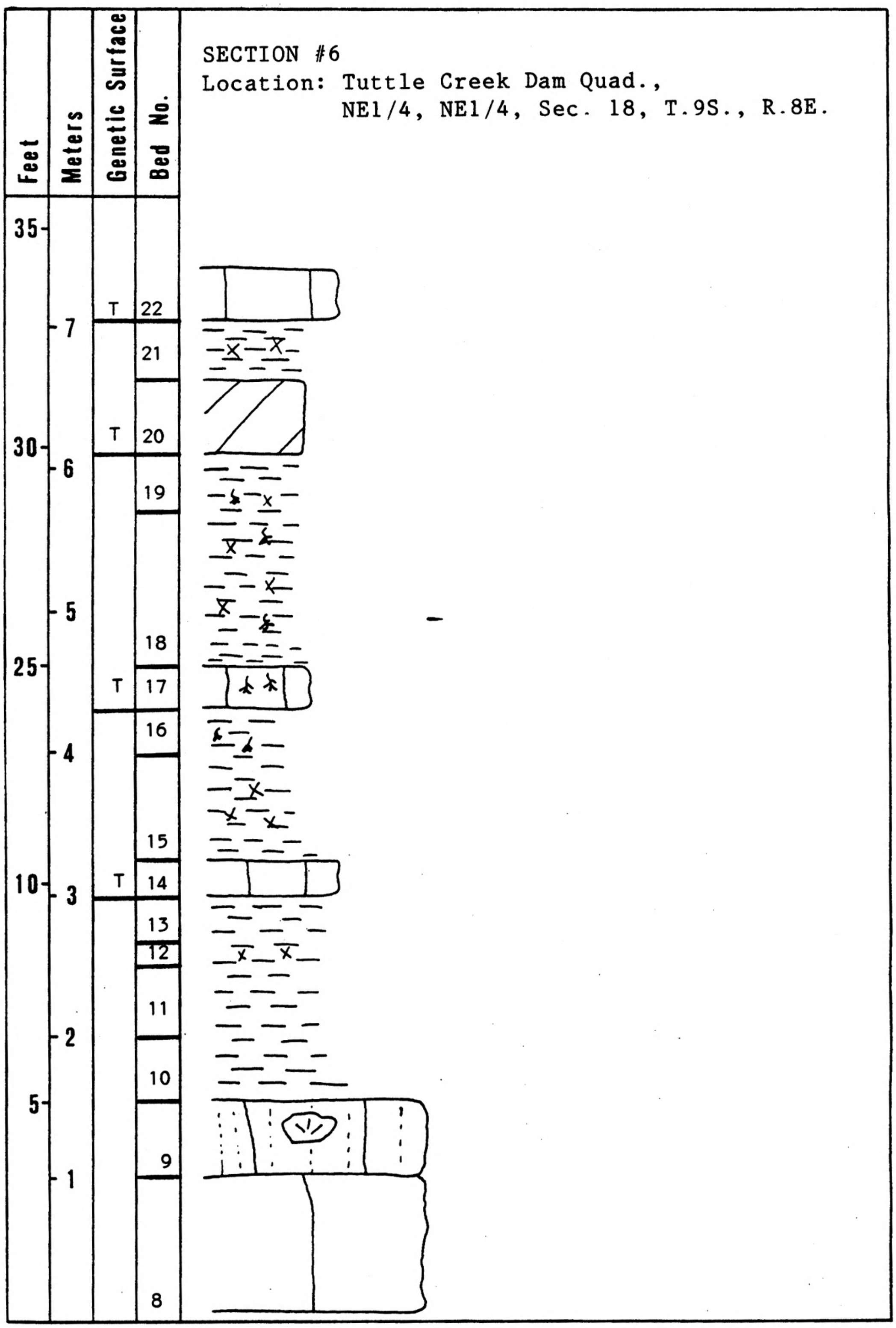
4. Johnson Shale: (0.8ft.; 0.25m.) light brown to pale yellow-orange (weathers same), tripoli; basal contact sharp.

3. Johnson Shale: (2.8ft.; 0.86m.) light olive-brown (weathers medium olive-brown), blocky, slightly indurated, mudstone; with root traces; basal contact sharp.

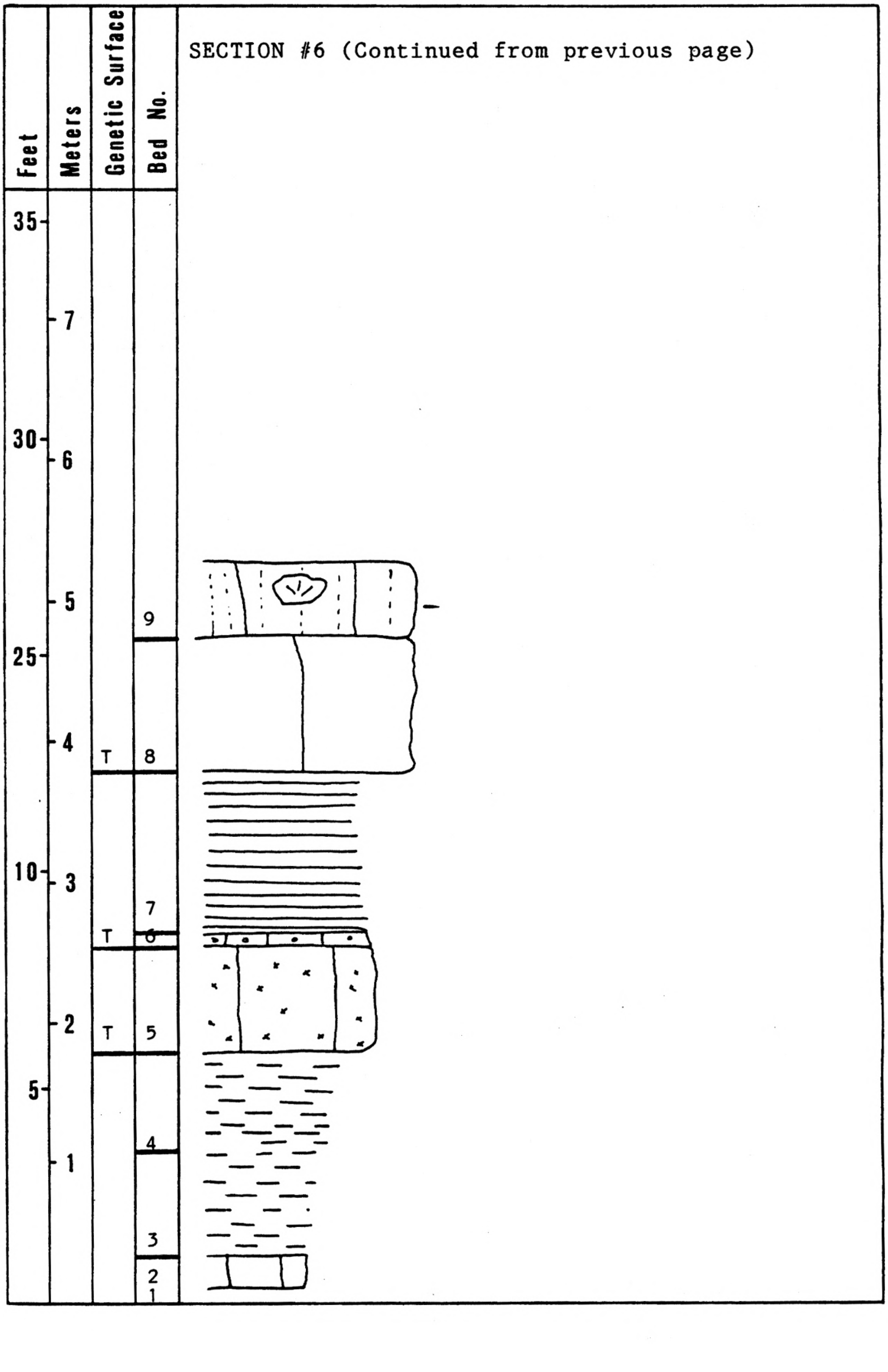
2. Johnson Shale: (1.0ft.; 0.30m.) light gray (weathers gray-brown), indurated calcilutite (mudstone); with root traces; basal contact sharp.

1. Johnson Shale: (0.3ft.; 0.10m.) light green (weathers green-brown), blocky-crumbly, mudstone; with microslickensides and root traces; basal contact covered.

SECTION #6
Location: Tuttle Creek Dam Quad.,
NE1/4, NE1/4, Sec. 18, T.9S., R.8E.



SECTION #6 (Continued from previous page)



SECTION #6, Cedar Creek, Pottawatomie County, KS; Tuttle Creek Dam Quadrangle; NE1/4, NE1/4, SEC.18, T.9S., R.8E.; measured by Michael H. Clark (June 1987).

22. Sallyards Limestone: (1.2ft.; 0.36m.) light gray (weathers gray-brown), slabby to blocky, slightly argillaceous, skeletal calcilutite (wackestone); with algal biscuits (Osagia), Aviculopecten, productids, fossil fragments, and Rhipidomella; basal contact sharp.

21. Roca Shale: (1.3ft.; 0.41m.) green to light brown (weathers greenish brown), blocky-crumbly, indurated, slightly silty, mudstone; with caliche nodules and microslickensides; basal contact sharp.

20. Roca Shale: (1.7ft.; 0.51m.) light gray-brown (weathers brown), massive, root mottled, argillaceous dololutite (mudstone); with root traces; basal contact sharp.

19. Roca Shale: (1.3ft.; 0.41m.) light green (weathers light green-brown), blocky-crumbly, indurated, slightly silty, mudstone; with root traces and microslickensides; basal contact gradational.

18. Roca Shale: (3.5ft.; 1.07m.) varigated (gray-maroon-green, weathers reddish brown), blocky-crumbly, indurated, slightly silty, mudstone; with microslickensides, root traces, caliche nodules, and calcified peds; basal contact sharp.

17. Roca Shale: (1.0ft.; 0.30m.) light gray-brown (weathers light brown), blocky, root mottled, argillaceous calcilutite (mudstone); with root traces; basal contact sharp.

16. Roca Shale: (1.0ft.; 0.30m.) light gray to green (weathers greenish brown), blocky-crumbly, indurated, slightly silty, mudstone; with root traces; basal contact sharp.

15. Roca Shale: (2.3ft.; 0.71m.) maroon (weathers reddish brown), blocky-crumbly, indurated, slightly silty mudstone; with microslickensides, rootlets, and caliche nodules; basal contact sharp.

14. Roca Shale: (0.8ft.; 0.25m.) light gray-brown (weathers light brown), slabby, algal laminated, fenestral calcilutite (mudstone); with smooth shelled ostracodes and fenestral fabric (1-3mm. in diameter sparite filled vugs); basal contact sharp.

13. Roca Shale: (1.0ft.; 0.30m.) varigated (maroon-gray-green, weathers reddish brown), blocky-crumbly, indurated, slightly silty, mudstone; with microslickensides and root traces; basal contact gradational.

12. Roca Shale: (0.5ft.; 0.15m.) light green (weathers greenish brown), blocky-crumbly, indurated, mudstone; with root traces, microslickensides, and caliche nodules; basal contact sharp.

11. Roca Shale: (1.8ft.; 0.56m.) brick-red (weathers reddish brown), blocky-crumbly, indurated, slightly silty, mudstone; with root traces and microslickensides; basal contact gradational.

10. Roca Shale: (1.3ft.; 0.41m.) varigated (gray-maroon-green, weathers reddish brown), blocky-crumbly, indurated, unfossiliferous, mudstone; with microslickensides; basal contact sharp.

9. Howe Limestone: (1.8ft.; 0.53m.) light brown (weathers pale orange-brown), blocky to massive, skeletal calcarenite (packstone to grainstone); well sorted; with coated grains (Osagia), ostracodes (Paraparchites), and hemispheroidal stromatolites (in the upper foot); basal contact sharp.

8. Howe Limestone: (3.1ft.; 0.94m.) light brown (weathers pale orange-brown), slabby to blocky, skeletal calcilutite (wackestone); with echinoid spines, Crurithyris, Orbiculoidea, Derybia, Nucula, Composita, productids, ostracodes, Aviculopecten, and fossil fragments; upper 12-14cm. slightly argillaceous; basal contact sharp.

7. Bennett Shale: (3.7ft.; 1.09m.) dark gray to black (weathers light brown), platy to flaggy, slightly silty, mudstone; with Orbiculoidea and Crurithyris; basal contact sharp.

6. Glenrock Limestone: (0.2ft.; 0.05m.) light brown to pale orange-brown, tripoli.

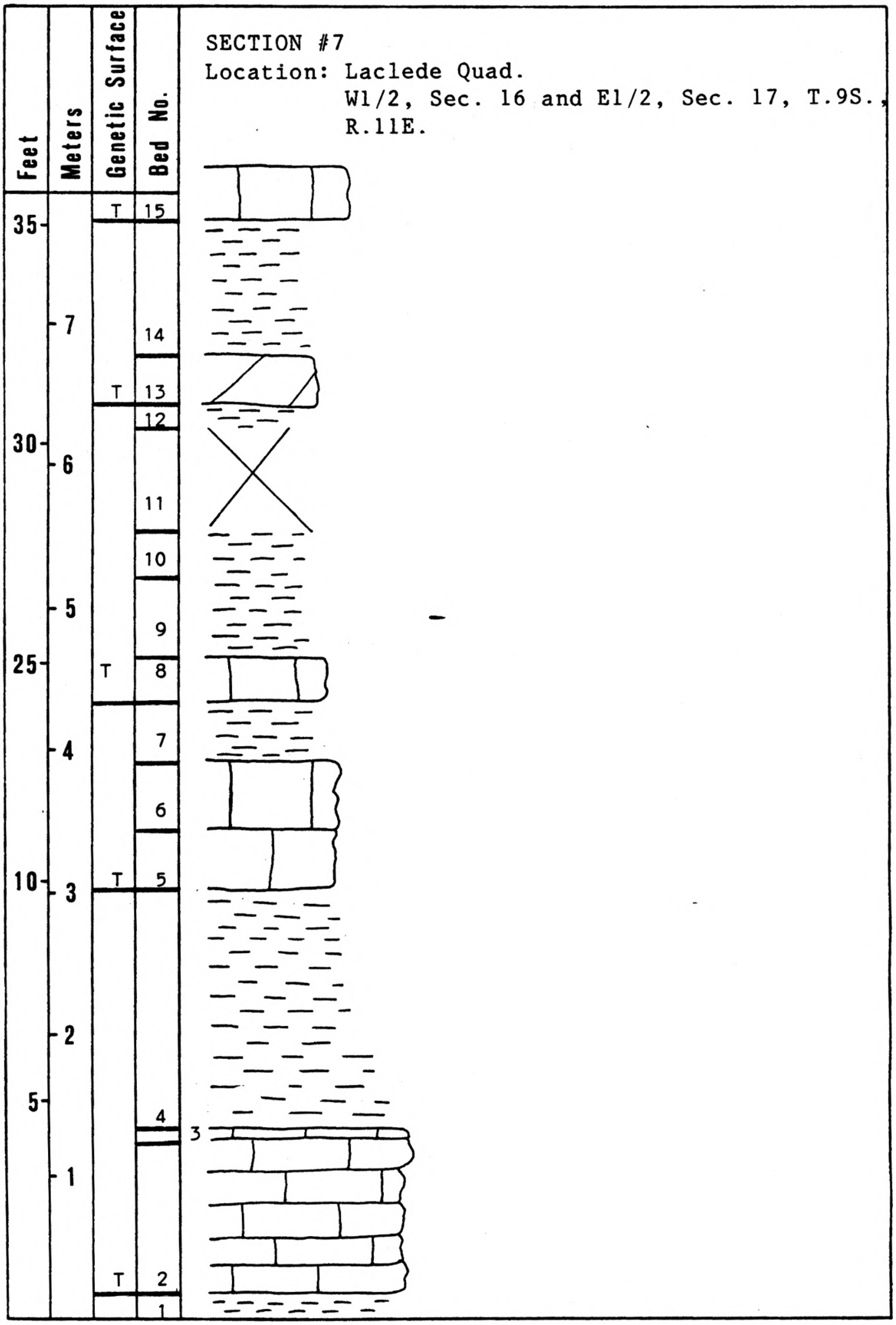
5. Glenrock Limestone: (0.3ft.; 0.08m.) light gray (weathers light brown), massive, fossiliferous, skeletal calcarenite (wackestone to packstone); with articulated fossils: (up to 30%) fusulinids, Composita, Derybia, productids, Wellerella, Rhipidomella, Hustedia, crinoids, Crurithyris, coated grains (Osagia), and <5% intraclasts (subrounded to subangular, <5mm. in diameter); basal contact sharp.

4. Glenrock Limestone: (2.4ft.; 0.74m.) light gray to light brown (weathers pale orange-brown), blocky to massive, skeletal, coarse calcarenite to calcirudite (packstone); poorly sorted; with up to 50% intraclasts (subangular to subrounded, up to 6mm. in diameter), coated grains (Osagia), echinoid spines, fossil fragments, and Thalassinoides burrows; basal contact sharp.

3. Johnson Shale: (2.3ft.; 0.74m.) medium gray to light brown (weathers light brown), platy to flaggy, slightly silty, unfossiliferous, mudstone; mudcracked; basal contact gradational.

2. Johnson Shale: (2.5ft.; 0.76m.) medium gray to light brown (weathers light brown), flaggy, mudcracked, slightly silty, unfossiliferous, mudstone; basal contact sharp.

1. Johnson Shale: (0.5ft.; 0.15m.) light gray-brown (weathers light brown), flaggy, slightly argillaceous, calcilutite (mudstone); with mudcracks; basal contact covered.


Feet
Meters
Genetic Surface
Bed No.
SECTION #7
Location: Laclede Quad.
W1/2, Sec. 16 and E1/2, Sec. 17, T.9S.,
R.11E.
35
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12
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2
1

SECTION #7, Belvue Section, Pottawatomie County, KS; Laclede Quadrangle; W1/2, SEC.16 and E1/2, SEC.17, T.9S., R.11E.; measured by Michael H. Clark (July 1987).

15. Sallyards Limestone: (1.2ft.; 0.36m.) light gray (weathers gray-brown), slabby to blocky, slightly argillaceous, skeletal calcilutite (wackestone); with algal biscuits, productids, Aviculopecten, Aviculopinna, and large bivalves (?); basal contact sharp.

14. Roca Shale: (3.0ft.; 0.91m.) light green (weathers greenish brown), blocky-crumbly, indurated, mudstone; with iron stains and root traces; basal contact sharp.

13. Roca Shale: (1.2ft.; 0.36m.) light gray to light brown (weathers light brown), massive, punky, slightly argillaceous, dololutite (mudstone); with iron stains; basal contact

12. Roca Shale: (0.5ft.; 0.15m.) light green (weathers greenish brown), blocky-crumbly, indurated, slightly silty, mudstone; with root traces; basal contact covered.

11. Roca Shale: (2.3ft.; 0.71m.) COVERED

10. Roca Shale: (1.0ft.; 0.30m.) light green (weathers greenish brown), blocky-crumbly, indurated, slightly silty, mudstone; with root traces; basal contact sharp.

9. Roca Shale: (2.2ft.; 0.66m.) brick-red to medium gray (weathers reddish brown), blocky-crumbly, indurated, slightly silty, mudstone; with iron stains and root traces; basal contact sharp.

8. Roca Shale: (1.0ft.; 0.30m.) light gray-brown (weathers light brown), vuggy, slightly argillaceous, calcilutite (mudstone); with a boxwork structure, suggesting dissolution of evaporites; basal contact sharp.

7. Roca Shale: (1.7ft.; 0.51m.) varigated (brick-red to green, weathers reddish brown), blocky-crumbly, mudstone; with root traces; basal contact sharp.

6. Roca Shale: (1.5ft.; 0.46m.) light gray (weathers gray-brown), slabby, slightly argillaceous, calcilutite (mudstone); with root traces and fenestral fabric (1-3mm. in diameter sparite filled vugs); basal contact gradational.

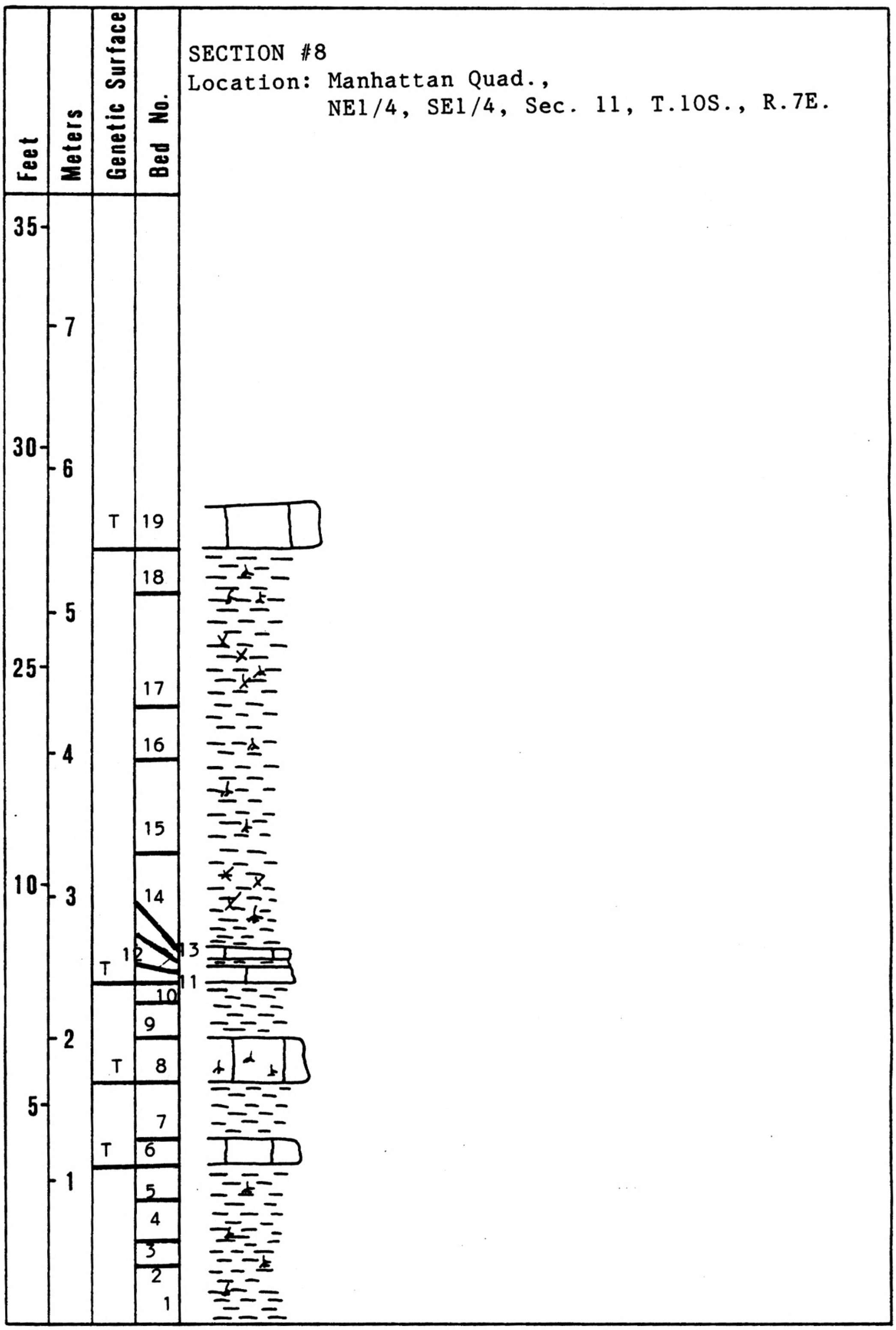
5. Roca Shale: (1.3ft.; 0.41m.) light gray (weathers gray-brown), slabby, mudcracked, calcilutite (mudstone); thinly bedded, with iron stains; basal contact sharp.

4. Roca Shale: (5.5ft.; 1.68m.) light gray (weathers light gray-brown), platy to flaggy, slightly calcareous, unfossiliferous, mudstone; thinly laminated; with iron stains; basal contact sharp.

3. Howe Limestone: (0.3ft.; 0.08m.) light brown-gray (weathers pale orange-brown), slabby, skeletal calcilutite (wackestone); with hemispheroidal stromatolites, coated grains (Osagia), and ostracodes; basal contact gradational.

2. Howe Limestone: (3.4ft.; 1.04m.) light brown-gray (weathers pale orange-brown), flaggy, argillaceous, skeletal calcilutite (wackestone); with fossil fragments (brachiopod?); basal contact sharp.

1. Bennett Shale: (0.5ft.; 0.15m.) dark gray (weathers light brown), flaggy, calcareous mudstone; weathered; basal contact covered.


SECTION #8
Location: Manhattan Quad.,
NE1/4, SE1/4, Sec. 11, T.10S., R.7E.
Feet
Meters
Genetic Surface
Bed No.
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SECTION #8 behind Dillons Manhattan, Riley County, KS; Manhattan Quadrangle; NE1/4, SE1/4, SEC. 11, T.10S., R.7E.; measured by Michael H. Clark (July 1987)

19. Sallyards Limestone: (1.0ft.; 0.30m.) medium gray (weathers gray-brown), blocky to slabby, argillaceous, skeletal calcilutite (wackestone); with algal biscuits (Osagia), productids, Aviculopecten, and Derybia; basal contact sharp.

18. Roca Shale: (1.0ft.; 0.30m.) light brown (weathers medium brown), blocky-crumbly, indurated, mudstone; with microslickensides and root traces; basal contact sharp.

17. Roca Shale: (2.7ft.; 0.81m.) olive-green (weathers olive-brown), blocky-crumbly, indurated, mudstone; with microslickensides, caliche nodules, and root traces; basal contact gradational.

16. Roca Shale: (1.3ft.; 0.38m.) light green-brown (weathers light brown), massive, indurated, mudstone; with mudstone clasts (3-4mm. in diameter, subrounded to subangular) and root traces; basal contact gradational.

15. Roca Shale: (2.2ft.; 0.66m.) light green (weathers green-brown), blocky-crumbly, indurated, slightly silty, mudstone; with microslickensides and root traces; basal contact gradational.

14. Roca Shale: (2.0ft.; 0.61m.) varigated (green-maroon-gray, weathers reddish brown), blocky-crumbly, indurated, silty, unfossiliferous mudstone; with microslickensides and caliche nodules; basal contact sharp.

13. Roca Shale: (0.3ft.; 0.08m.) light gray (weathers gray-brown), slabby, argillaceous calcilutite (mudstone); basal contact sharp.

12. Roca Shale: (0.2ft.; 0.05m.) light green (weathers brownish green), platy, calcareous mudstone; with mudcracks; basal contact sharp.

11. Roca Shale: (0.3ft.; 0.08m.) light gray (weathers gray-brown), slabby, argillaceous, skeletal calcilutite (mudstone); with ostracodes; basal contact sharp.

10. Roca Shale: (0.3ft.; 0.08m.) light gray (weathers gray-brown), blocky-crumbly, indurated, mudstone; with microslickensides and root traces; basal contact sharp.

9. Roca Shale: (0.8ft.; 0.25m.), brick-red (weathers reddish brown), blocky-crumbly, indurated, silty, claystone; with microslickensides and root traces; basal contact gradational.

8. Roca Shale: (0.9ft.; 0.28m.) medium gray to very pale red (weathers brown), slabby, root mottled, calcilutite (mudstone); with fenestral fabric (1-2mm. in diameter sparite filled vugs) and root traces; basal contact sharp.

7. Roca Shale: (0.6ft.; 0.18m.) brick-red (weathers reddish brown), blocky-crumbly, indurated, silty, mudstone; with microslickensides and root traces; basal contact sharp.

6. Roca Shale: (0.7ft.; 0.20m.) light green (weathers brown-green), blocky-crumbly, indurated, silty, unfossiliferous mudstone; basal contact sharp.

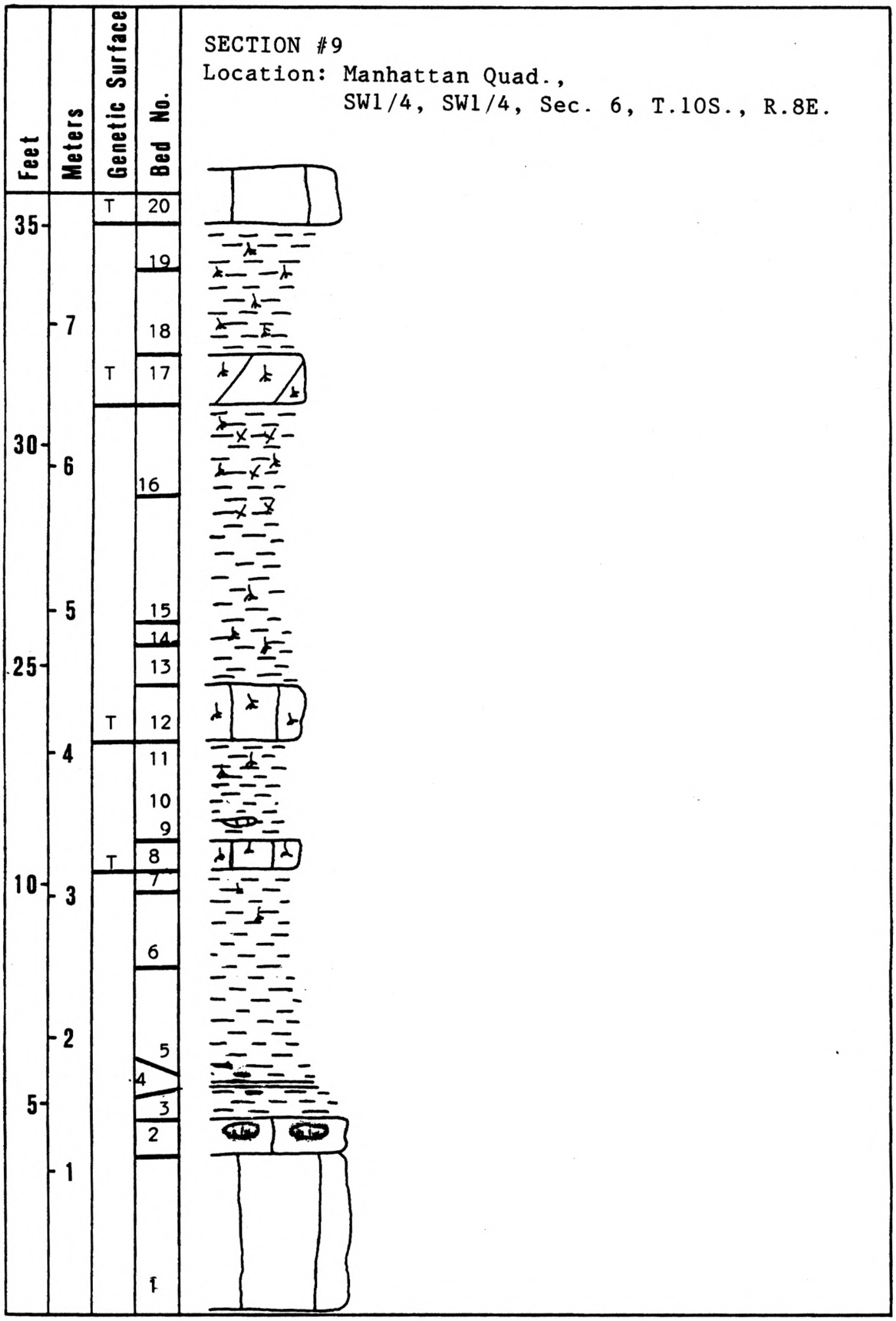
5. Roca Shale: (0.6ft.; 0.18m.) light gray (weathers brown), slabby, skeletal calcilutite (mudstone); with high-spired gastropods and ostracodes; basal contact sharp.

4. Roca Shale: (0.6ft.; 0.18m.) light green (weathers green-brown), blocky-crumbly, indurated, silty, mudstone: with root traces; basal contact sharp.

3. Roca Shale: (1.2ft.; 0.36m.) brick-red (weathers reddish brown), flaggy, indurated, mudstone; with root traces; basal contact sharp.

2. Roca Shale: (0.3ft.; 0.08m.) light green (weathers brownish green), blocky-crumbly, indurated, mudstone; with root traces; basal contact sharp.

1. Roca Shale: (1.5ft.; 0.46m.) brick-red (weathers reddish brown), blocky-crumbly, indurated, mudstone; with root traces; basal contact covered.


SECTION #9
Location: Manhattan Quad.,
SW1/4, SW1/4, Sec. 6, T.10S., R.8E.
Feet
Meters
Genetic Surface
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SECTION #9, Bluemont Hill, Manhattan, Riley County, KS; Manhattan Quadrangle; SW1/4, SW1/4, SEC.6, T.10S., R.8E.; measured by Michael H. Clark (June, 1987).

20. Sallyards Limestone: (1.2ft.; 0.36m.) light gray (weathers light brown), blocky to massive, skeletal calcilutite (wackestone); with crinoids, high-spired gastropods, Bellerophon, algal biscuits (Osagia), brachiopod fragments and intraclasts in basal portion (subrounded to angular, <6mm. in diameter); basal contact sharp and erosional(?).

19. Roca Shale: (1.0ft.; 0.30m.) light brown (weathers same), blocky-crumbly, mudstone; with root traces; basal contact gradational.

18. Roca Shale: (2.0ft.; 0.61m.) olive-green (weathers greenish brown), blocky-crumbly, slightly silty, mudstone; with root traces; basal contact sharp.

17. Roca Shale: (1.1ft.; 0.33m.) light gray-brown (weathers light brown), blocky-crumbly, punky, dololutite (mudstone); with root traces; basal contact sharp.

16. Roca Shale: (2.3ft.; 0.71m.), olive-green (weathers light brown), blocky-crumbly, unfossiliferous, slightly silty, mudstone; with microslickensides and caliche nodules which increase in abundance upwards; basal contact sharp.

15. Roca Shale: (3.0ft.; 0.91m.) brick-red (weathers reddish brown), blocky-crumbly, unfossiliferous, slightly silty, mudstone; with microslickensides and caliche nodules increasing in abundance upwards; basal contact sharp.

14. Roca Shale: (0.3ft.; 0.10m.) light olive-green (weathers greenish brown), blocky-crumbly, slightly silty, mudstone; with root traces; basal contact sharp.

13. Roca Shale: (0.6ft.; 0.18m.) dark brick-red (weathers reddish brown), blocky-crumbly, slightly silty, mudstone; with root traces and microslickensides; basal contact sharp.

12. Roca Shale: (1.3ft.; 0.38m.) light gray (weathers gray-brown), flaggy, highly root mottled, argillaceous, skeletal calcilutite (mudstone); with root traces, 10-15% ostracodes, algal laminations, and fossil fragments; basal contact sharp.

11. Roca Shale: (1.0ft.; 0.30m.) brick-red to olive-green (weathers reddish brown), blocky-crumbly, slightly silty, mudstone; with root traces and microslickensides; basal contact gradational.

10. Roca Shale: (0.3ft.; 0.10m.) dark olive-green (weathers olive-brown), blocky-crumbly, unfossiliferous, slightly silty, mudstone; with microslickensides; basal contact gradational.

9. Roca Shale: (0.5ft.; 0.15m.) light olive-green (weathers olive-brown), flaggy to slabby, mudstone; with thin (1-3cm.) calcilutite (mudstone) lenses; basal contact gradational.

8. Roca Shale: (0.6ft.; 0.18m.) light gray (weathers gray-brown), slabby, argillaceous, algal-laminated calcilutite (mudstone); with root traces and root mottling at the top; basal contact sharp.

7. Roca Shale: (0.3ft.; 0.10m.) pale olive-green (weathers green-brown), platy to slabby, slightly silty, mudstone; with root traces; basal contact gradational.

6. Roca Shale: (1.9ft.; 0.58m.) light brick-red (weathers reddish brown), platy to flaggy, slightly silty, unfossiliferous, mudstone; basal contact gradational.

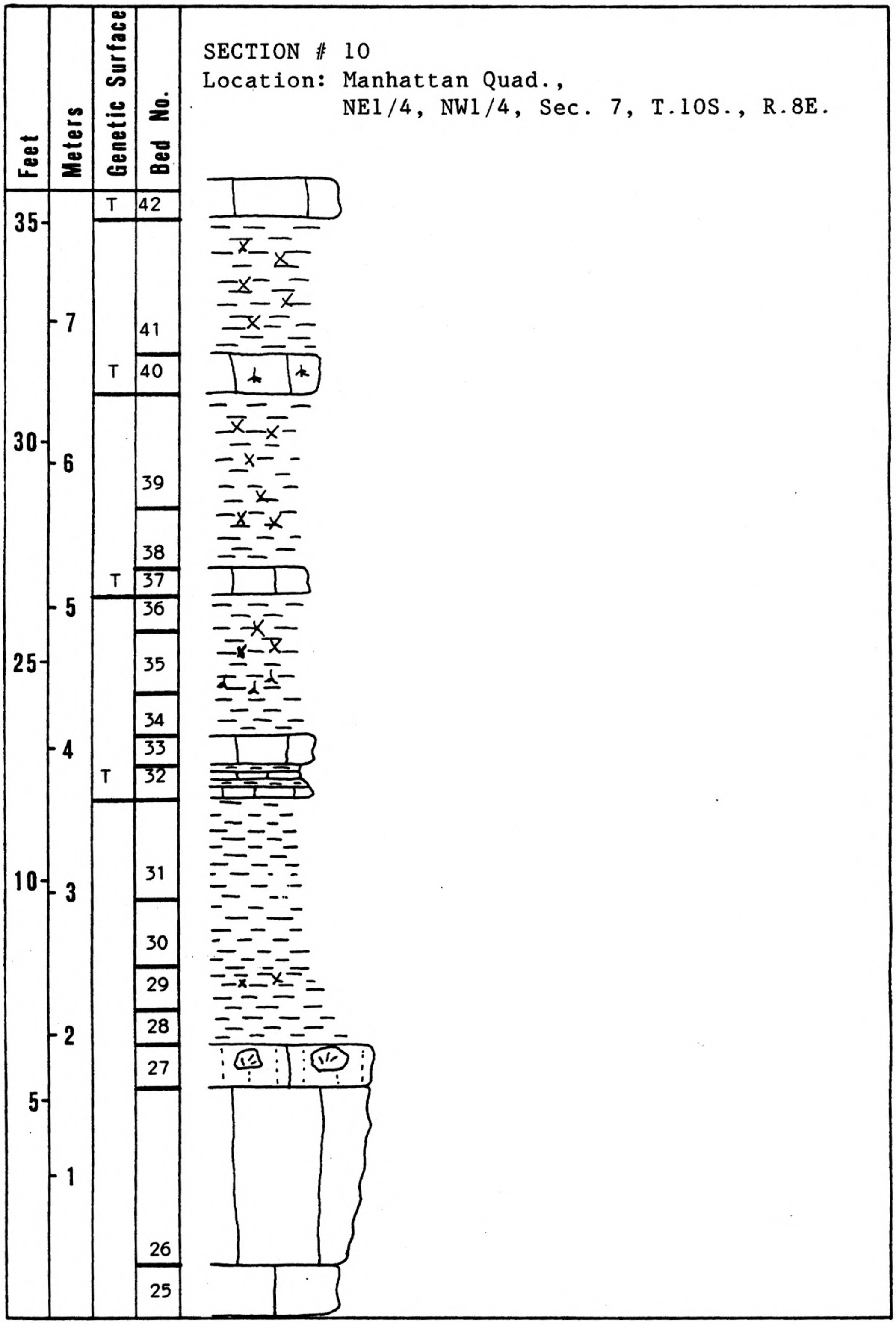
5. Roca Shale: (2.5ft.; 0.76m.) olive-green (weathers olive-brown), platy, slightly silty, unfossiliferous, mudstone; basal contact sharp.

4. Roca Shale: (0.1ft.; 0.03m.) varigated (gray-maroon-green, weathers same), calcareous calcrete(?); rooted; basal contact sharp.

3. Roca Shale: (0.8ft.; 0.25m.) light green (weatherrs green-brown), blocky-crumbly, indurated, unfossiliferous, slightly silty, mudstone; with microslickensides; basal contact sharp.

2. Howe Limestone: (1.0ft.; 0.30m.) light gray-brown (weathers pale orange-brown), slabby to blocky, skeletal calcarenite (packstone to grainstone); well sorted; with coated grains (Osagia), high-spired gastropods, ostracodes (Paraparchites), fossil fragments, and large hemispheroidal stromatolites (15-20cm. in diameter); basal contact sharp.

1. Howe Limestone: (3.5ft.; 1.07m.) light brown (weathers pale orange-brown), blocky to massive, skeletal calcilutite (wackestone); with echinoid spines and plates, crinoids, Composita, ramose bryozoan, and fossil fragments (brachiopod?); basal contact covered.


Feet
Meters
Genetic Surface
Bed No.
SECTION # 10
Location: Manhattan Quad.,
NE1/4, NW1/4, Sec. 7, T.10S., R.8E.
35
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42
41
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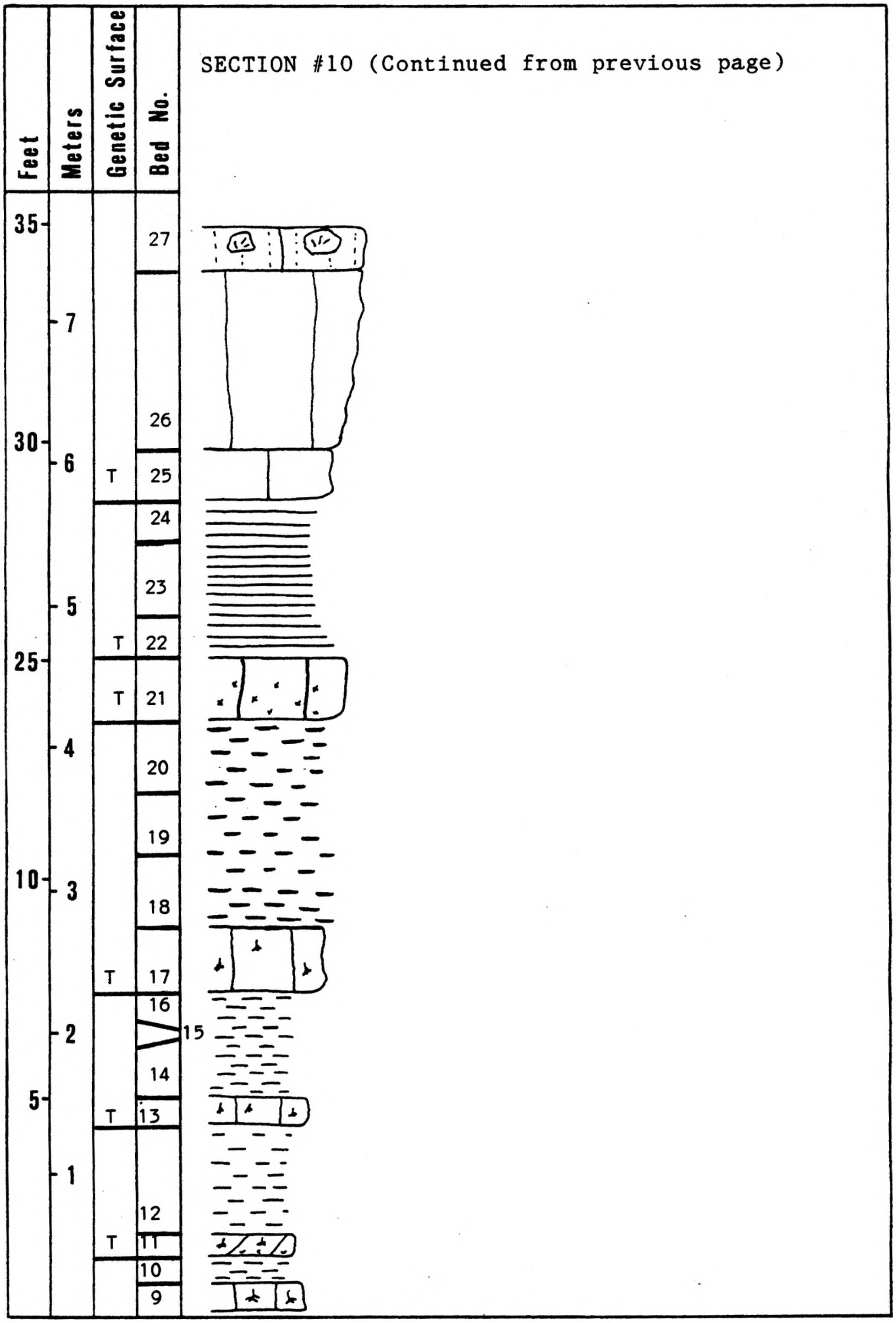
SECTION #10 (Continued from previous page)
Feet
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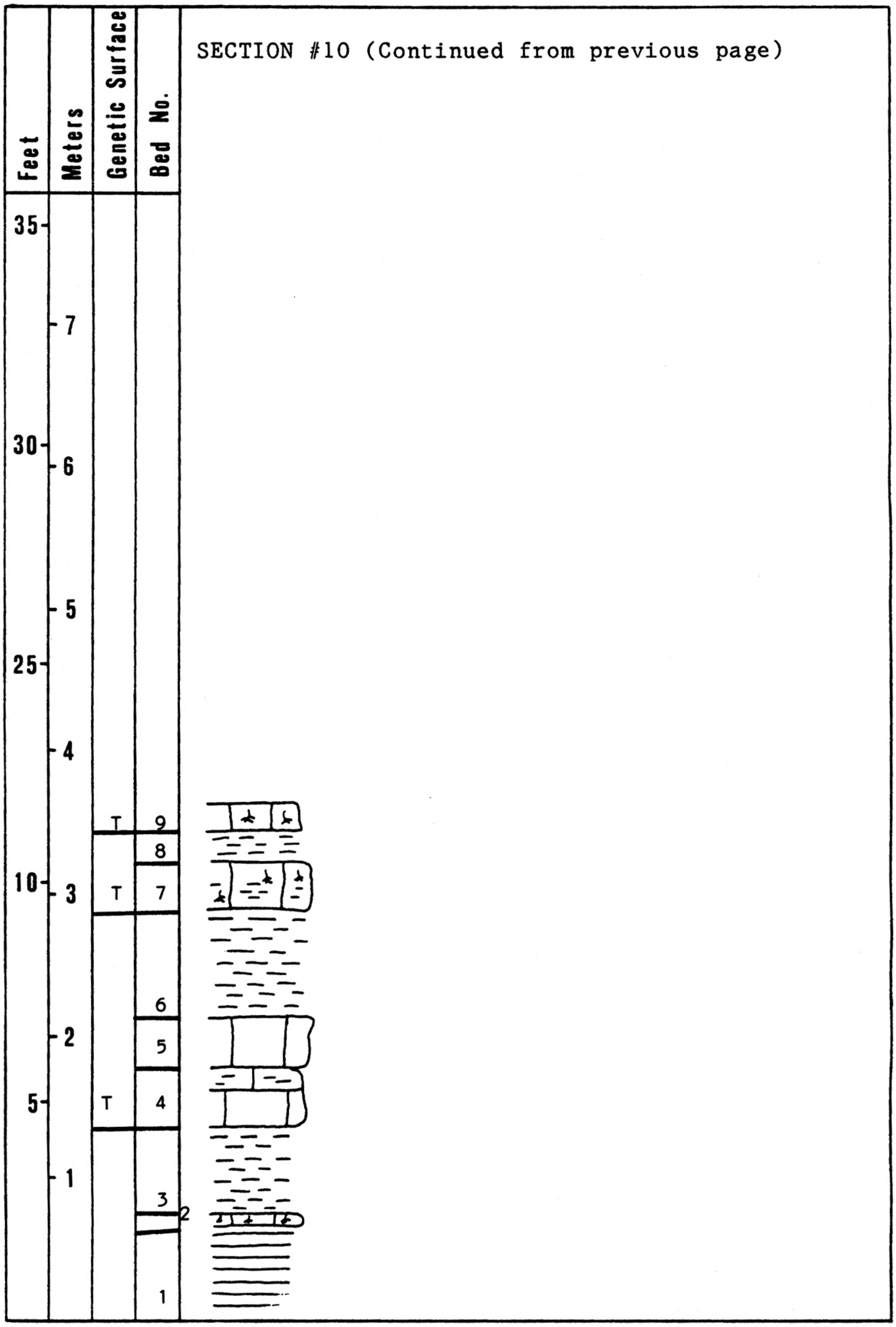
SECTION #10 (Continued from previous page)



SECTION #10, west side of Highway-177, south of Four-Seasons Motel, Manhattan, Riley County, KS; NE1/4, NW1/4, SEC.7, T.10S., R.8E.; measured by Michael H. Clark (July 1987).

42. Sallyards Limestone: (0.9ft.; 0.28m.) light gray (weathers gray-brown), slabby to blocky, skeletal calcilutite (wackestone); with crinoids, algal biscuits (Osagia), Aviculopecten, productids, intraclasts (3-4mm. in diameter, subrounded to subangular) and large gastropods; basal contact sharp and erosional.

41. Roca Shale: (3.0ft.; 0.91m.) light green (weathers greenish brown), blocky-crumbly, slightly silty mudstone; highly indurated; with root traces, microslickensides, and caliche nodules; basal contact sharp.

40. Roca Shale: (0.9ft.; 0.28m.) light gray-green (weathers gray-brown), rooted calcilutite (mudstone); indurated; with root traces; basal contact sharp.

39. Roca Shale: (2.8ft.; 0.86m.) light olive-green (weathers olive-brown), blocky-crumbly, slightly silty, mudstone; with microslickensides, caliche nodules, and root traces; basal contact sharp.

38. Roca Shale: (1.3ft.; 0.38m.) varigated (brick-red to gray, weathers reddish brown), blocky-crumbly, unfossiliferous, slightly silty, mudstone; with caliche nodules; basal contact sharp.

37. Roca Shale: (0.7ft.; 0.20m.) varigated (gray-green-maroon, weathers reddish brown), indurated, root mottled calcilutite (mudstone); with root traces; basal contact sharp.

36. Roca Shale: (0.8ft.; 0.25m.) dark gray-brown (weathers brown), platy to flaggy, unfossiliferous, mudstone; basal contact sharp.

35. Roca Shale: (1.5ft.; 0.46m.) brick-red (weathers reddish brown), blocky-crumbly, indurated, slightly silty, claystone; with root traces, microslickensides, and caliche nodules; basal contact sharp.

34. Roca Shale: (0.8ft.; 0.25m.) olive-green (weathers olive-brown), blocky-crumbly, indurated, slightly silty, mudstone; with root traces; basal contact sharp.

33. Roca Shale: (0.7ft.; 0.20m.) light gray (weathers gray-brown), slabby, argillaceous, skeletal calcilutite (wackestone); with smooth shelled ostracodes and high-spired gastropods; basal contact sharp.

32. Roca Shale: (0.9ft.; 0.28m.) light green (weathers green-brown), platy, calcareous mudstone, interbedded with thin (1-3cm.) skeletal calcilutite (mudstone) beds; with small high-spired gastropods and bivalves (Nucula?); basal contact sharp.

31. Roca Shale: (2.3ft.; 0.71m.) brick-red (weathers reddish brown), flaggy, slightly silty, unfossiliferous, mudstone; with mudcracks; basal contact gradational.

30. Roca Shale: (1.5ft.; 0.46m.) varigated (maroon-green-gray, weathers reddish brown), flaggy, slightly silty, unfossiliferous, mudstone; with mudcracks; basal contact sharp.

29. Roca Shale: (0.9ft.; 0.28m.) light green (weathers olive-brown), blocky-crumbly, indurated, unfossiliferous, mudstone; with microslickensides; basal contact gradational.

28. Roca Shale: (0.7ft.; 0.20m.) varigated (pale orange to light green, weathers light brown), indurated, unfossiliferous, mudstone; with a (3-4cm.) calcrete bed in the upper 7-8cm.; basal contact sharp.

27. Howe Limestone: (1.0ft.; 0.30m.) light brown (weathers pale orange-brown), massive, skeletal calcarenite (packstone to grainstone); well sorted; with coated grains (Osagia), ostracodes, fossil fragments, and hemispheroidal stromatolites; basal contact gradational.

26. Howe Limestone: (4.0ft.; 1.22m.) light gray-brown (weathers pale orange-brown), blocky to massive, skeletal calcilutite (wackestone); with crinoids, fusulinids, Fenestrellina, and brachiopod fragments; basal contact sharp.

25. Howe Limestone: (1.2ft.; 0.36m.) dark brown (weathers pale orange-brown), slabby to blocky, argillaceous, skeletal calcilutite (wackestone); with productids, Hustedia, Crurithyris, bryozoans, fusulinids, crinoids, and Composita; basal contact sharp.

24. Bennett Shale: (0.8ft.; 0.25m.) dark gray (weathers light brown), platy to flaggy, slightly silty, mudstone; with Crurithyris, Aviculopecten, and productids; basal contact gradational.

23. Bennett Shale: (1.7ft.; 0.48m.) dark gray to gray-brown (weathers light brown), flaggy, slightly silty, mudstone; with Composita, Aviculopecten, Crurithyris, Permophorus, Orbiculoidea, gastropods, and productids; basal contact gradational.

22. Bennett Shale: (1.3ft.; 0.38m.) dark olive-green, mottled light brown (weathers light brown), flaggy, very fossiliferous, calcareous, mudstone; with articulated fossils: Composita, Wellerella, Orbiculoidea, Linoproductus, Derybia fragments, Hustedia, Crurithyris, Fenestrellina, and brachiopod fragments; basal contact sharp.

21. Glenrock Limestone: (1.3ft.; 0.41m.) light gray (weathers pale orange-brown), massive, skeletal calcarenite to calcirudite (wackestone to packstone); poorly sorted; with (30-60%) intraclasts (rounded to subangular, <7mm. in diameter), coated grains (Osagia), high-spired gastropods, Orbiculoidea, ostracodes, brachiopod fossil fragments, and Wellerella; top surface highly burrowed (Thalassinoides); basal contact sharp.

20. Johnson Shale: (1.8ft.; 0.56m.) dark gray to dark olive-gray (weathers light brown), platy to crumbly, slightly indurated, mudstone; with root traces; basal contact gradational.

19. Johnson Shale: (1.5ft.; 0.46m.) light brown (weathers brown), platy to flaggy, mudstone; with mudcracks, ostracodes, and plant fragments; basal contact gradational.

18. Johnson Shale: (1.6ft.; 0.46m.) varigated (dark gray to light brown, weathers medium brown), platy to flaggy, mudstone; with mudcracks, root traces, and ostracodes; basal contact gradational.

17. Johnson Shale: (1.5ft.; 0.46m.) light gray-browm (weathers medium brown), flaggy to slabby, thin-bedded, skeletal calcilutite (mudstone); with ostracodes; basal contact sharp.

16. Johnson Shale: (0.8ft.; 0.23m.) light brown (weathers same), massive, unfossiliferous, mudstone; basal contact sharp.

15. Johnson Shale: (0.1ft.; 0.30m.) light gray-brown (weathers light brown), massive, calcareous, calcrete(?); basal contact sharp.

14. Johnson Shale: (1.5ft.; 0.46m.) light brown (weathers same), indurated, hard, slightly silty mudstone; with root traces and mudstone clasts (subrounded to angular, <5mm. in diameter); basal contact sharp.

13. Johnson Shale: (0.7ft.; 0.20m.) light gray to pale maroon (weathers light gray-brown), slabby, calcilutite (mudstone); with root traces; basal contact sharp.

12. Johnson Shale: (2.4ft.; 0.74m.) olive-green to light brown (weathers olive-brown), flaggy, silty, mudstone; with root traces; basal contact gradational.

11. Johnson Shale: (0.5ft.; 0.15m.) olive-green to light brown (weathers olive-brown), slabby, argillaceous, dolomitic calcilutite (mudstone); with root traces and rounded mudstone clasts of the underlying lithology (3-5mm. in diameter); basal contact sharp and erosional(?).

10. Johnson Shale: (0.7ft.; 0.20m.) dark olive-green (weathers olive-brown), blocky-crumbly, silty, mudstone; with root traces; basal contact sharp.

9. Johnson Shale: (0.7ft.; 0.20m.) light gray to light brown (weathers gray-brown), slabby to blocky, rooted, calcilutite (mudstone); with root traces; basal contact sharp.

8. Johnson Shale: (0.7ft.; 0.20m.) dark olive-gray (weathers olive-brown), blocky-crumbly, silty, mudstone; with root traces; basal contact sharp.

7. Johnson Shale: (1.1ft.; 0.33m.) dark olive-gray (weathers olive-brown), flaggy to slabby, very calcareous, mudstone; with (10-25%) root trace (rooted) and smooth shelled ostracodes; basal contact sharp.

6. Johnson Shale: (2.5ft.; 0.76m.) dark gray to olive-green (weathers olive brown), blocky-crumbly, silty, mudstone; with root traces and microslickensides; basal contact sharp.

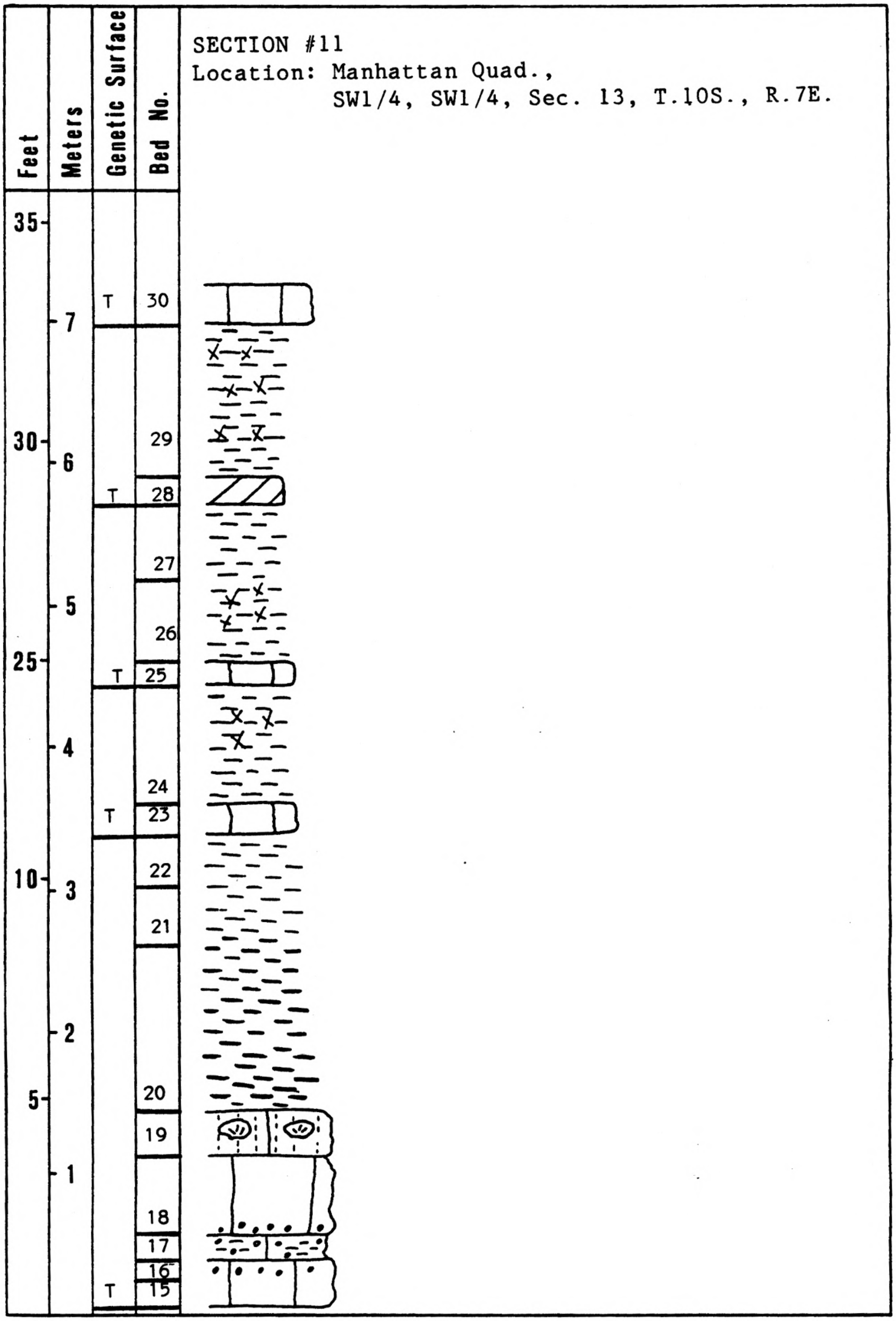
5. Johnson Shale: (1.1ft.; 0.33m.) gray-brown (weathers medium brown), slabby, skeletal calcilutite (mudstone); with fossil fragments; basal contact gradational.

4. Johnson Shale: (1.3ft.; 0.41m.) medium gray to olive-green (weathers gray-brown), slabby, argillaceous, skeletal calcilutite (mudstone); with ostracodes; basal contact sharp.

3. Johnson Shale: (2.0ft.; 0.61m.) olive-brown (weathers brown), blocky-crumbly, silty, mudstone; with root traces; basal contact sharp.

2. Johnson Shale: (0.3ft.; 0.08m.) olive-brown (weathers medium brown), argillaceous, indurated, calcilutite (mudstone); with root traces; basal contact sharp.

1. Johnson Shale: (2.0ft.; 0.61m.) olive-green (weathers olive-brown), platy to flaggy, slightly silty, mudstone; with root traces; basal contact covered.


Feet
Meters
Genetic Surface
Bed No.
SECTION #11
Location: Manhattan Quad.,
SW1/4, SW1/4, Sec. 13, T.10S., R.7E.
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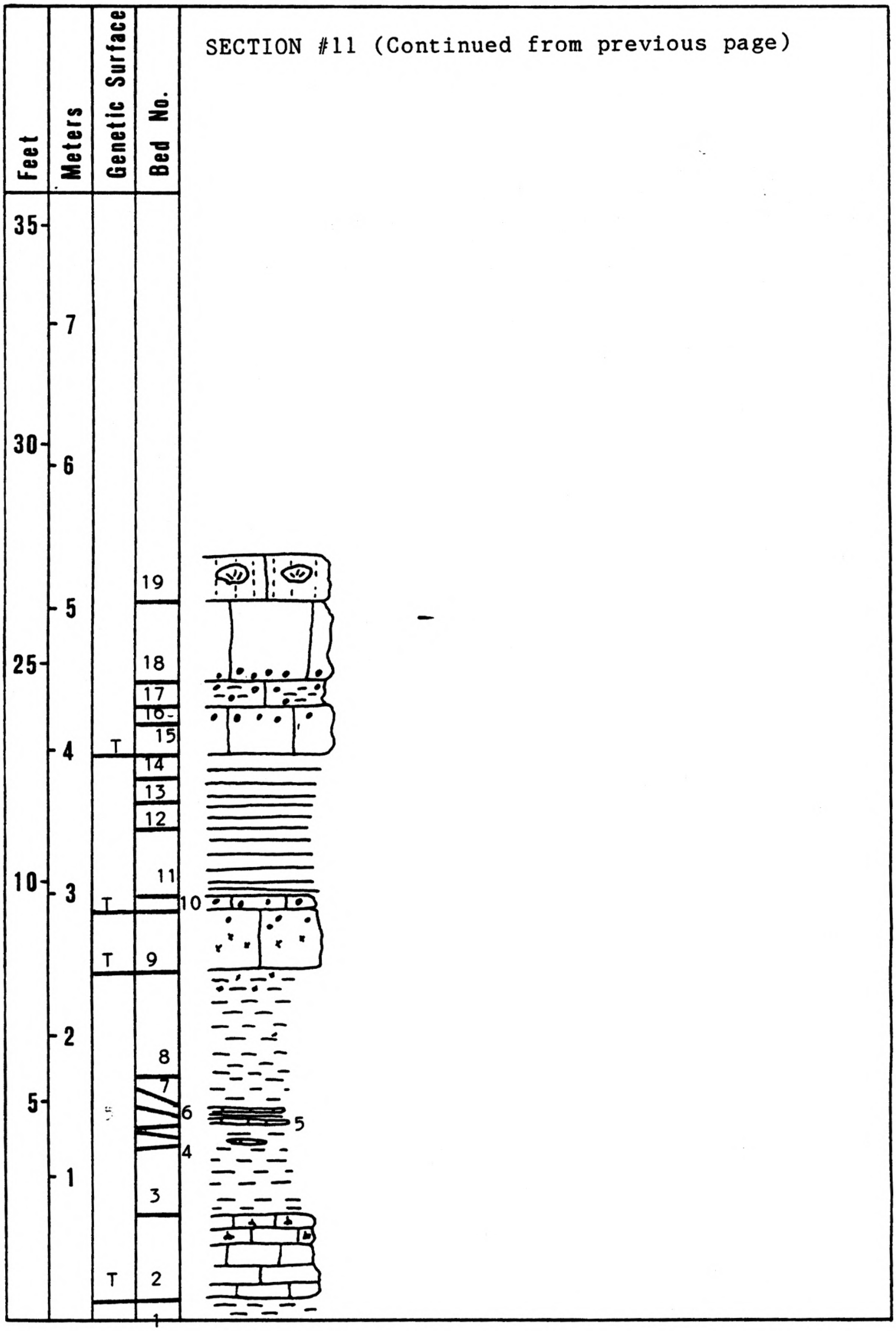
SECTION #11 (Continued from previous page)



SECTION #11 Sethchilds, Manhattan, Riley County, KS; Manhattan Quadrangle; SW1/4, SW1/4, SEC.13, T.10S., R.7E.; measured by Michael H. Clark and Dr. Richard M. Busch (May 1987)

30. Sallyards Limestone: (0.8ft.; 0.25m.) medium gray (weathers gray-brown), slabby to blocky, argillaceous, skeletal calcilutite (wackestone); with common Linoproductus, algal biscuits (Osagia), ostracodes, Dunbarella, and Aviculopecten; basal contact sharp.

29. Roca Shale: (3.5ft.; 1.07m.) pale green (weathers light brown), blocky-crumbly, slightly silty, unfossiliferous mudstone; with caliche nodules throughout; basal contact sharp.

28. Roca Shale: (0.6ft.; 0.18m.) light gray-brown (weathers light brown), massive, dololutite (mudstone); highly indurated; basal contact sharp.

27. Roca Shale: (1.8ft.; 0.56m.) pale green to olive-green (weathers olive-brown), blocky-crumbly, slightly silty, unfossiliferous mudstone; with microslickensides; basal contact sharp.

26. Roca Shale: (1.7ft.; 0.51m.) brick-red (weathers reddish brown), blocky-crumbly, slightly silty, unfossiliferous mudstone; with caliche nodules; basal contact sharp.

25. Roca Shale: (0.5ft.; 0.15m.) light gray to pale green (weathers brown), argillaceous, skeletal calcilutite (mudstone); with root traces, ostracodes, intraclasts (3-4mm. in diameter, subrounded to angular), and fossil fragments; basal contact sharp.

24. Roca Shale: (2.6ft.; 0.79m.) brick-red (weathers reddish brown), blocky-crumbly, slightly silty, unfossiliferous mudstone; with caliche nodules increasing in abundance upwards; basal contact sharp.

23. Roca Shale: (0.7ft.; 0.20m.) pale green-gray (weathers brown), argillaceous, skeletal calcilutite (mudstone); with small bivalves, high-spired gastropods, and ostracodes; basal contact sharp.

22. Roca Shale: (0.7ft.; 0.20m.) light green (weathers green-brown), platy, unfossiliferous, mudstone; basal contact sharp.

21. Roca Shale: (0.7ft.; 0.20m.) brick-red (weathers reddish brown), platy, slightly silty, unfossiliferous mudstone; basal contact sharp.

20. Roca Shale: (3.5ft.; 1.07m.) light green (weathers green-brown), platy, unfossiliferous mudstone; basal contact sharp.

19. Howe Limestone: (1.0ft.; 0.30m.) light brown (weathers orange-brown), massive, skeletal calcarenite (packstone to grainstone); well sorted; with (70-80%) coated grains (Osagia), small bivalves (Nucula?), ostracodes (Paraparchites), high-spired gastropods, and hemispheroidal stromatolites (20-25cm. in diameter); basal contact gradational.

18. Howe Limestone: (1.8ft.; 0.53m.) light gray-brown (weathers pale orange-brown), blocky to massive, skeletal calcilutite (wackestone); with coated grains (Osagia), fusulinids, ostracodes, and fossil fragments; basal contact sharp.

17. Howe Limestone: (0.6ft.; 0.18m.) light brown (weathers pale orange-brown), argillaceous, nodular, coarse skeletal calcarenite (packstone); friable; with (40-60%) fusulinids; basal contact gradational.

16. Howe Limestone: (0.3ft.; 0.10m.) light brown (weathers pale orange-brown), massive, argillaceous, skeletal calcilutite (wackestone); with fusulinids, and Aviculopinna; basal contact gradational.

15. Howe Limestone: (0.7ft.; 0.20m.) light brown (weathers pale orange-brown), massive, argillaceous, skeletal calcilutite (wackestone); with Crurithyris, Orbiculoidea, and Aviculopinna; basal contact sharp.

14. Bennett Shale: (0.3ft.; 0.08m.) light olive-green (weathers brown), platy, mudstone; with Orbiculoidea; basal contact sharp.

13. Bennett Shale: (0.5ft. 0.15m.) dark brown (weathers light brown), platy, mudstone; with productids, Wellerella, and plant fragments; basal contact gradational.

12. Bennett Shale: (0.6ft.; 0.18m.) dark gray to black (weathers brown), platy, fossiliferous mudstone; with Composita, Crurithyris, Wellerella, Hustedia, Linoproductus, and Antiquatonia; basal contact gradational.

11. Bennett Shale: (1.9ft.; 0.55m.) dark gray to gray-brown (weathers brown), platy, mudstone; with Crurithyris, Wellerella, Lingula, Nucula, Orbiculoidea and sharks teeth; basal contact sharp.

10. Glenrock Limestone: (0.3ft.; 0.08m.) light gray (weathers light brown), massive, fossiliferous, skeletal calcarenite (packstone to grainstone); with abundant articulated fossils: fusulinids, Composita, Crurithyris, Neochonetes, Linoproductus, Wellerella, crinoids, Antiquatonia, Orbiculoidea, small bivalves, fenestral and ramose bryozoan, and rare intraclasts (3-4mm. in diameter, subrounded); basal contact sharp.

9. Glenrock Limestone: (1.4ft.; 0.43m.) light gray-brown (weathers pale orange-brown), massive, skeletal calcarenite (wackestone to packstone); with small bivalves (Nucula?), high-spired gastropods, intraclasts (up to 4.5mm. in diameter, subangular to subrounded), fossil fragments (brachiopod), fusulinids and burrow (Thalassinoides); basal contact sharp.

8. Johnson Shale: (2.5ft.; 0.76m.) gray to light brown (weathers brown), blocky-crumbly, mudstone; with plant fragments and intraclasts (3-4mm.in diameter, subrounded to subangular) in the upper 20-25cm.; basal contact gradational.

7. Johnson Shale: (0.8ft.; 0.23m.) light gray-brown (weathers brown), platy, slightly silty, mudstone; with ostracodes, mudcracks, and thin (2-3cm. thick) skeletal calcilutite (mudstone) lenses; basal contact sharp.

6. Johnson Shale: (0.1ft.; 0.03m.) light brown (weathers brown), thin-bedded, flaggy, argillaceous calcilutite (mudstone); with (30-40%) ostracodes and mudcracks; basal contact sharp.

5. Johnson Shale: (0.3ft.; 0.10m.) light gray-brown (weathers brown), platy, slightly silty, mudstone; with ostracodes and mudcracks; basal contact sharp.

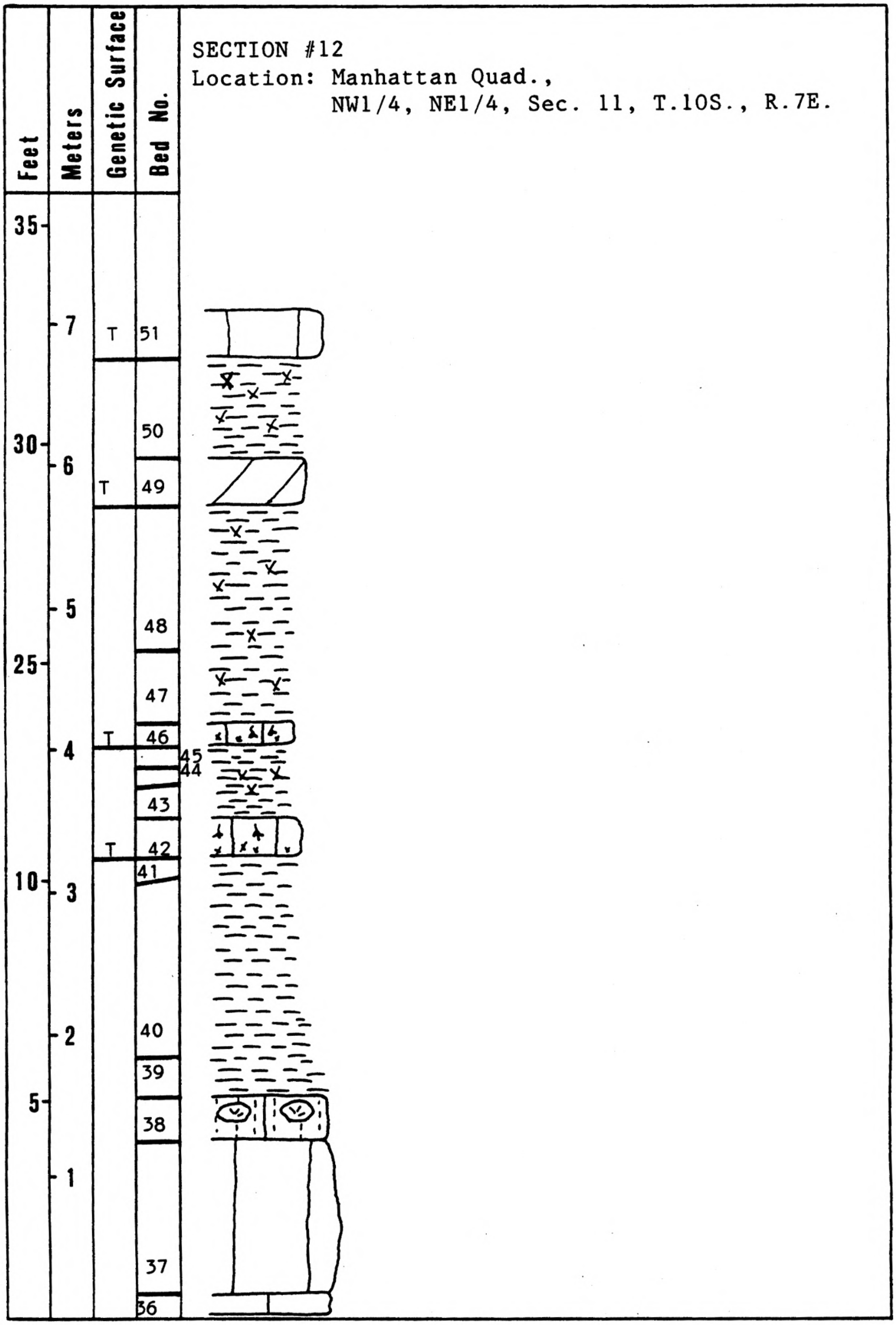
4. Johnson Shale: (0.1ft.; 0.03m.) light brown (weathers brown), thin-bedded, flaggy, argillaceous, calcilutite (mudstone); with (30-40%) ostracodes; basal contact sharp.

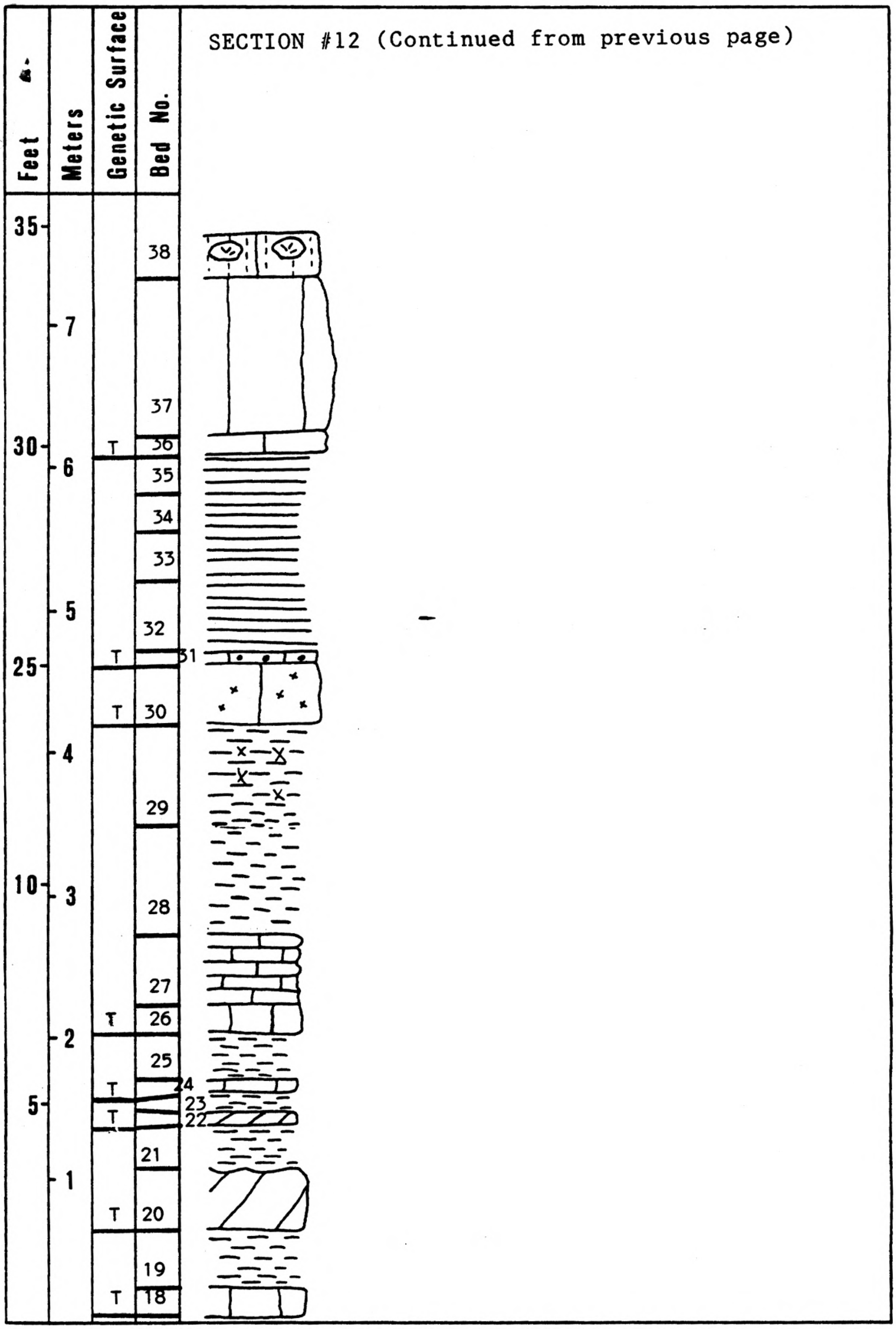
3. Johnson Shale: (2.0ft.; 0.61m.) dark gray (weathers medium brown), platy, mudstone; with (20-30%) ostracodes; mudcracks, and thin (1-2cm.) skeletal calcilutite (mudstone) lenses; basal contact gradational.

2. Johnson Shale: (1.8ft.; 0.56m.) light brown (weathers brown), slabby to flaggy, argillaceous, skeletal calcilutite (mudstone); with mudcracks and ostracodes; basal contact sharp.

1. Johnson Shale: (0.5ft.; 0.15m.) light brown (weathers brown), blocky-crumbly, unfossiliferous mudstone; basal contact covered.

SECTION #12
Location: Manhattan Quad.,
NW1/4, NE1/4, Sec. 11, T.10S., R.7E.




SECTION #12 (Continued from previous page)
Feet
Meters
Genetic Surface
Bed No.
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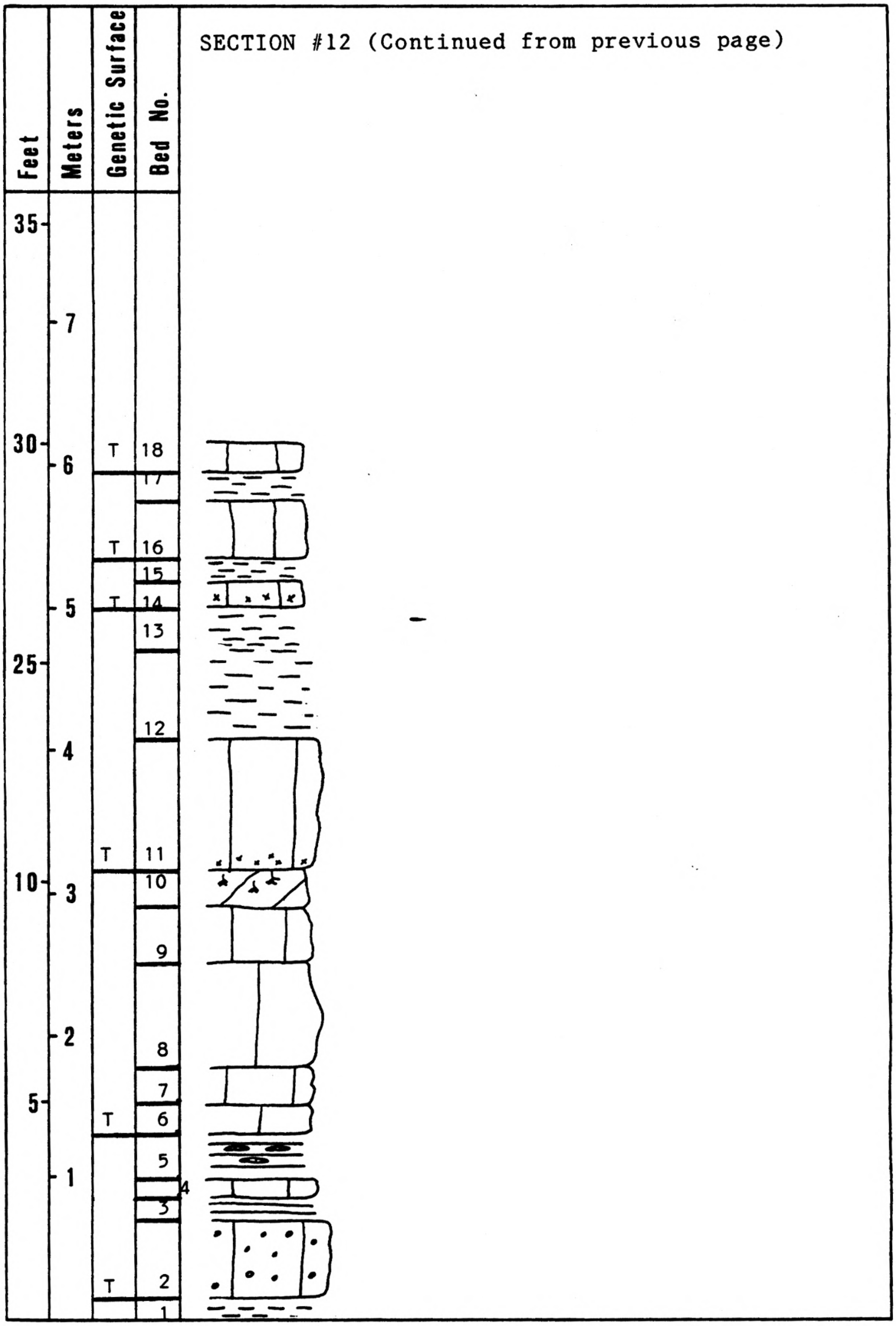
SECTION #12 (Continued from previous page)



SECTION #12 Railroad Cut, Manhattan, Riley County, KS; Manhattan Quadrangle; NW1/4, NE1/4, SEC.11, T.10S., R.7E.; measured by Michael H. Clark and Dr. Richard M. Busch (June 1987)

51. Sallyards Limestone: (1.0ft.; 0.30m.) medium gray (weathers gray-brown), massive, slightly argillaceous, skeletal calcilutite to calcarenite (wackestone); with Linoproductus, Aviculopecten, ramose and fenestral bryozoans, echinoid spines, algal biscuits (Osagia), and crinoids; basal contact sharp.

50. Roca Shale: (2.3ft.; 0.71m.) pale olive-green (weathers olive-brown), blocky-crumbly, silty, unfossiliferous mudstone; with common caliche nodules and microslickensides; basal contact sharp.

49. Roca Shale: (1.0ft.; 0.30m.) light gray-brown (weathers light brown), massive, laminated, dololutite (mudstone); basal contact sharp.

48. Roca Shale: (3.3ft.; 1.02m.) pale olive-green (weathers green-brown), blocky-crumbly, silty, unfossiliferous mudstone; with common caliche nodules and granules; basal contact sharp.

47. Roca Shale: (1.8ft.; 0.56m.) brick-red (weathers reddish brown), blocky-crumbly, silty, unfossiliferous mudstone; with caliche nodules in the upper part; basal contact sharp.

46. Roca Shale: (0.5ft.; 0.15m.) light gray (weathers brown), slabby to blocky, argillaceous, skeletal calcilutite (mudstone); with high-spired gastropods (pyramidellid-like), ostracodes, root traces, intraclasts (3-4mm. in diameter, subrounded to subangular), and a fenestral fabric; basal contact sharp.

45. Roca Shale: (0.2ft.; 0.05m.) olive-green (weathers olive-brown), flaggy, silty, unfossiliferous, mudstone; basal contact sharp.

44. Roca Shale: (0.2ft.; 0.05m.) dark gray (weathers brown), blocky-crumbly, unfossiliferous, mudstone; basal contact sharp.

43. Roca Shale: (1.3ft.; 0.41m.) brick-red (weathers reddish brown), blocky-crumbly, silty, mudstone; with root traces, microslickensides, and abundant caliche nodules increasing in abundance upwards; basal contact sharp.

42. Roca Shale: (0.8ft.; 0.25m.) light gray (weathers gray brown), slabby to blocky, argillaceous, skeletal calcilutite (mudstone); with intraclasts (3-4mm. in diameter, subrounded to subangular), high-spired gastropods (pyramidellid-like), ostracodes, root traces, and a fenestral fabric; basal contact sharp.

41. Roca Shale: (0.3ft.; 0.08m.) olive-green (weathers olive brown), platy, silty, unfossiliferous mudstone; basal contact sharp.

40. Roca Shale: (4.3ft.; 1.30m.) brick-red (weathers reddish brown), platy, silty, unfossiliferous mudstone; basal contact sharp.

39. Roca Shale: (1.0ft.; 0.30m.) olive-green (weathers olive-brown), platy, silty, unfossiliferouis mudstone; basal contact sharp.

38. Howe Limestone: (1.0ft.; 0.30m.) light brown (weathers pale orange-brown), massive, skeletal calcarenite (packstone to grainstone); well sorted; with (70-80%) coated grains (Osagia), high-spired gastropods (pyramidellid-like), ostracodes (Paraparchites), and large hemispheroidal stromatolites (20-25cm. in diameter); basal contact gradational.

37. Howe Limestone: (3.5ft.; 1.07m.) light gray-brown (weathers pale orange-brown), massive, skeletal calcilutite (wackestone); with small crinoids, echinoid plates and spines, Composita, productids, coated grains (Osagia), ostracodes (Paraparchites), and fossil fragments (brachiopod); basal contact gradational.

36. Howe Limestone: (0.4ft.; 0.13m.) light brown (weathers brown), massive, argillaceous, skeletal calcarenite (wackestone); with Composita, Crurithyris, Aviculopinna, productids, and fossil fragments (brachiopod); basal contact sharp.

35. Bennett Shale: (0.8ft.; 0.23m.) dark gray (weathers gray-brown), fissile to platy, shale/mudstone; with Crurithyris, Aviculopinna, and Antiquatonia; basal contact gradational.

34. Bennett Shale: (0.7ft.; 0.21m.) dark gray-brown (weathers dark brown), flaggy, slightly silty, mudstone; with Linoproductus, Antiquatonia, Aviculopectin, Crurithyris, Orbiculoidea, Composita, fish scales, fish teeth, and bryozoan; basal contact gradational.

33. Bennett Shale: (1.5ft.; 0.46m.) dark gray to black (weathers dark brown), fissile, slightly silty, fossiliferous, shale/mudstone; with Composita, Linoproductus, Hustedia, Orbiculoidea Straparollus, Derybia, Antiquatonia, and small crinoids; basal contact gradational.

32. Bennett Shale: (1.6ft.; 0.46m.) dark gray to black (weathers brown), fissile, slightly silty, shale/mudstone; with Hustedia, Neochonetes, Lingula, Permophorus, ostracodes, Crurithyris, Orbiculoidea, and productids; basal contact sharp.

31. Glenrock Limestone: (0.2ft.; 0.05m.) medium gray (weathers brown), slightly argillaceous, very fossiliferous, skeletal calcarenite (wackestone to packstone); with abundant articulated fossils: (40%) fusulinids, Neospirifer, Composita, productids, Crurithyris, Neochonetes, small bivalves, Straparollus, Aviculopinna, Wellerella, bryozoan, and burrows (Thalassinoides); basal contact sharp.

30. Glenrock Limestone: (1.3ft.; 0.41m.) light gray (weathers pale orange-brown), massive, skeletal calcarenite to calcirudite (wackestone to packstone); with high-spired gastropods, intraclasts (3-5mm. in diameter, subrounded to subangular), bivalves, coated grains (Osagia), ostracodes, fossil fragments (brachiopod) and burrows (Thalassinoides; some of the burrows are filled with Orbiculoidea fragments and black shale/mudstone from above); basal contact sharp.

29. Johnson Shale: (2.4ft.; 0.74m.) dark gray (weathers brown), blocky-crumbly, mudstone; with caliche nodules and root traces; basal contact gradational.

28. Johnson Shale: (2.3ft.; 0.71m.) dark gray to black (weathers medium brown), fissile to platy, slightly silty, shale/mudstone; with plant fragments and ostracodes; basal contact gradational.

27. Johnson Shale: (1.7ft.; 0.51m.) light brown (weathers brown), massive, laminated calcilutite (mudstone); with ostracodes and mudcracks; basal contact sharp.

26. Johnson Shale: (0.6ft.; 0.18m.) light gray-brown (weathers pale orange-brown), brecciated, interbedded calcilutite (mudstone) and mudstone; highly weathered and fetid; basal contact sharp.

25. Johnson Shale: (1.1ft.; 0.33m.) medium olive-green (weathers olive-brown), blocky-crumbly, unfossiliferous mudstone; basal contact gradational.

24. Johnson Shale: (0.3ft.; 0.08m.) dark brown to gray (weathers medium brown), massive, argillaceous, skeletal calcilutite (mudstone); mottled; with ostracodes; basal contact sharp.

23. Johnson Shale: (0.5ft.; 0.15m.) dark olive-green (weathers olive-brown), blocky-crumbly, unfossiliferous mudstone; basal contact sharp.

22. Johnson Shale: (0.3ft.; 0.08m.) light gray-green (weathers light gray-brown), massive, very argillaceous, dololutite (mudstone); mottled; with pink celestite crystals; basal contact sharp.

21. Johnson Shale: (1.2ft.; 0.36m.) light brown to olive-green (weathers olive-brown), blocky-crumbly, unfossiliferous mudstone; basal contact sharp.

20. Johnson Shale: (1.1ft.; 0.33m.) light brown-gray (weathers brown), massive, very argillaceous, dololutite (mudstone); basal contact sharp.

19. Johnson Shale: (1.3ft.; 0.41m.) dark olive-green (weathers olive-brown), blocky-crumbly, unfossiliferous mudstone; with iron-oxide mottling and microslickensides; basal contact sharp.

18. Johnson Shale: (0.7ft.; 0.20m.) light gray-brown (weathers brown), flaggy, very argillaceous, laminated, skeletal calcilutite (mudstone); with ostracodes; basal contact sharp.

17. Johnson Shale: (0.7m.; 0.20m.) dark olive-green (weathers olive-brown), blocky-crumbly, unfossiliferous mudstone; basal contact sharp.

16. Johnson Shale: (1.3ft.; 0.38m.) light gray-brown (weathers brown), flaggy to blocky, calcilutite (mudstone); with mudcracks in the upper 10-12cm.; upper surface is erosional with relief of several centimeters; basal contact sharp.

15. Johnson Shale: (0.5ft.; 0.15m.) light green (weathers green-brown), platy, unfossiliferous mudstone; basal contact sharp.

14. Johnson Shale: (0.6ft.; 0.18m.) light gray-brown (weathers brown), flaggy, slightly argillaceous, laminated calcilutite (mudstone); with intraclasts (3-4mm. in diameter, subrounded to subangular) and mudcracks; basal contact sharp.

13. Johnson Shale: (1.0ft.; 0.30m.) light brown (weathers pale orange-brown), blocky, root-mottled, mudstone; with abundant iron-oxide granules and root traces; basal contact sharp.

12. Johnson Shale: (2.0ft.; 0.61m.) light green to yellow-brown (weathers brown), platy, slightly silty, mudstone; basal contact sharp.

11. Long Creek Limestone: (3.0ft.; 0.91m.) light gray-brown (weathers brown), massive, laminated, calcilutite (wackestone); with fossil fragments (?); upper 8-10cm. has argillaceous mudstone partings; basal 8cm. intraclastic (3-4mm. in diameter, subrounded to subangular); basal contact irregular and erosional.

10. Long Creek Limestone:_(0.8ft.; 0.23m.) light gray-brown (weathers pale orange-brown), massive, vuggy, dololutite (mudstone); with root traces; basal contact sharp.

9. Long Creek Limestone: (1.3ft.; 0.38m.) light brown (weathers brown), laminated to cross-laminated, argillaceous, calcilutite (wackestone); with thin (2-3cm.) clay shale partings and mudcracks throughout; basal contact sharp.

8. Long Creek Limestone: (2.4ft.; 0.74m.) light gray-brown (weathers brown), massive, cross-laminated, thinly interbedded, skeletal calcilutite (wackestone) to crinoidal calcarenite (packstone); basal contact sharp.

7. Long Creek Limestone: (0.8ft.; 0.25m.) light gray-brown (weathers brown), massive, skeletal calcilutite (wackestone); with (10-15%) crinoid fragments and other fossil fragments; basal contact sharp.

6. Long Creek Limestone: (0.7ft.; 0.20m.) light gray-brown (weathers brown), laminated, skeletal calcilutite (wackestone); with plant fragments and bivalves; basal contact sharp.

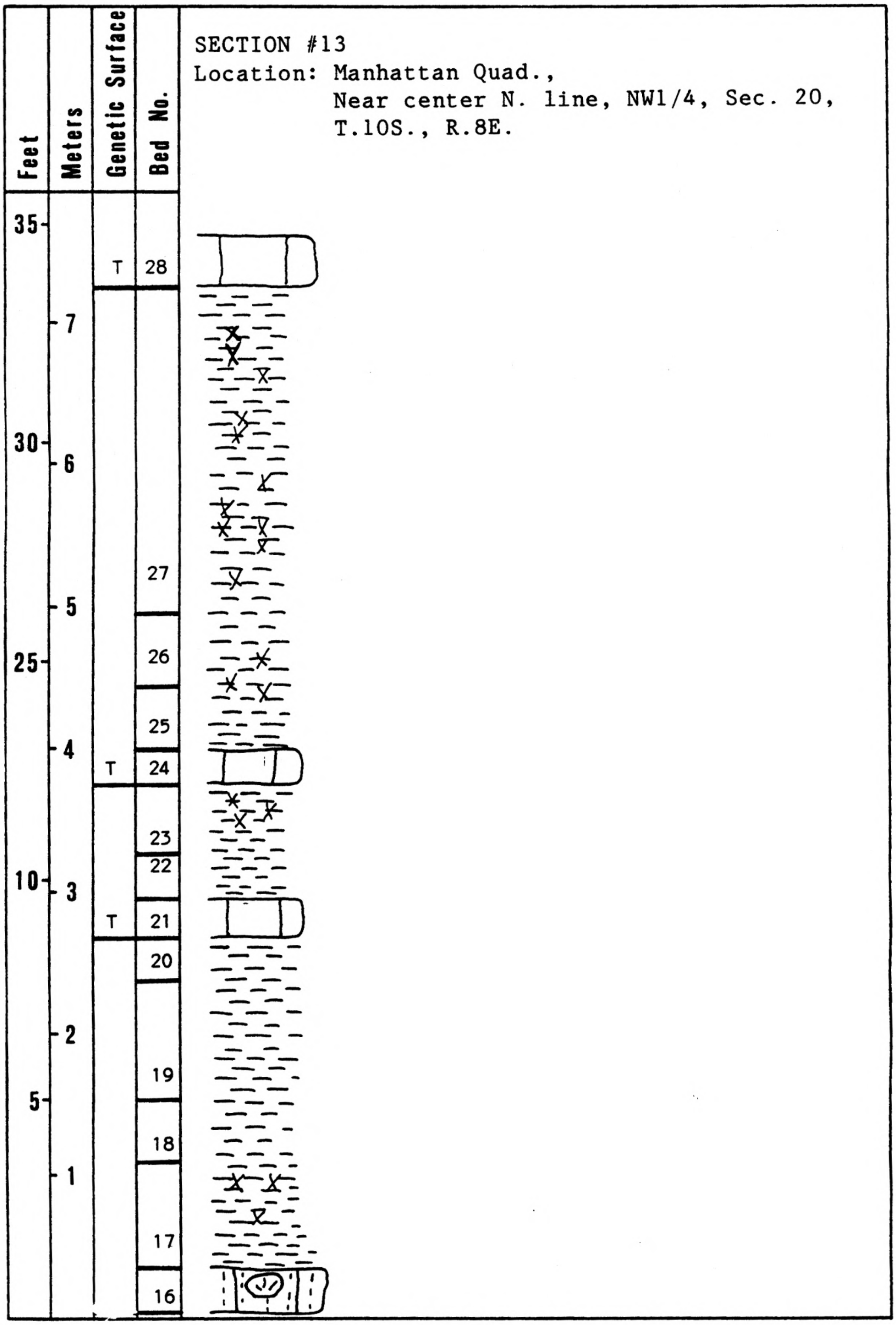
5. Hughes Creek Shale: (1.0ft.; 0.30m.) dark gray (weathers gray-brown), calcareous, siltstone; with thin (3-4cm.) quartz sandstone lenses; basal contact sharp.

4. Hughes Creek Shale: (0.4ft.; 0.13m.) light brown (weathers brown), slightly argillaceous, laminated, skeletal calcilutite (wackestone); with crinoids, bivalves, and fossil fragments; basal contact sharp.

3. Hughes Creek Shale: (0.5ft.; 0.15m.) light gray to olive-green (weathers olive-brown), calcareous, fissile to platy, fossiliferous, shale/mudstone; with Neospirifera, Composita, Neochonetes, Crurithyris, Straparollus, echnoid spines and plates, and Fenestrellina; basal contact sharp.

2. Hughes Creek Shale: (1.8ft.; 0.53m.) light brown (weathers pale orange-brown), massive, argillaceous, skeletal calcarenite (packstone); with (50-60%) fusulinids; basal contact sharp.

1. Hughes Creek Shale: (0.5ft.; 0.15m.) light green-gray to olive-green (weathers olive-brown), platy to flaggy, silty, unfossiliferous mudstone; basal contact covered.


Feet
Meters
Genetic Surface
Bed No.
SECTION #13
Location: Manhattan Quad.,
Near center N. line, NW1/4, Sec. 20,
T.10S., R.8E.
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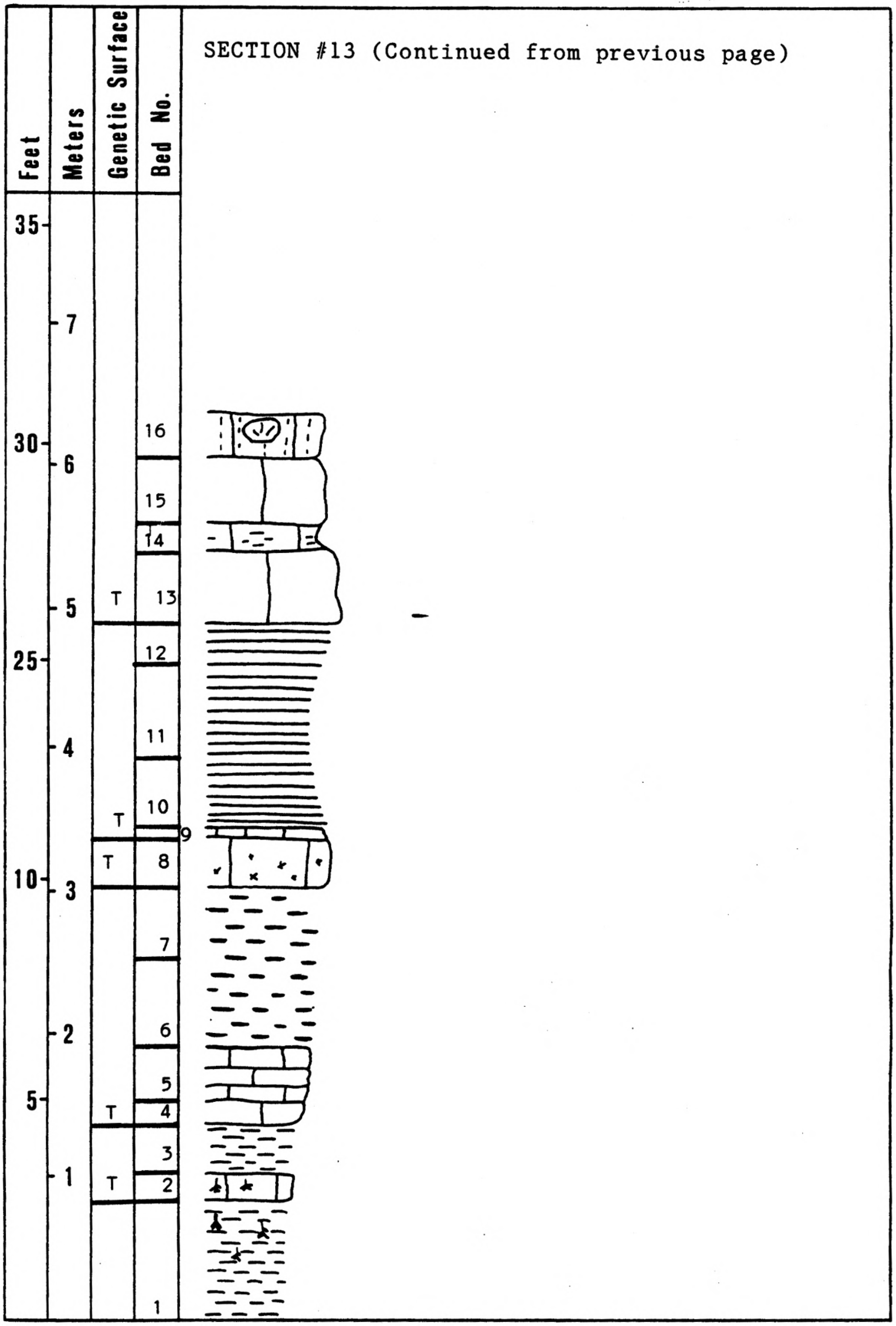
SECTION #13 (Continued from previous page)



SECTION #13 on K-Hill southeast of Manhattan, Riley County, KS; Manhattan Quadrangle; Near center N. line, NW1/4, SEC.20, T.10S., R.8E.; measured by Michael H. Clark (July 1987)

28. Sallyards Limstone: (1.2ft.; 0.36m.) medium gray (weathers gray-brown), blocky, argillaceous, skeletal calcilutite (wackestone); with Derybia, algal biscuits (Osagia), high-spired gastropods, productids, Aviculopecten, ostracodes, fossil fragments, burrows (Thalassinoides?), and small crinoids; basal contact sharp.

27. Roca Shale: (7.8ft.; 2.36m.) light green (weathers green-brown), blocky-crumbly, indurated, slightly silty, unfossiliferous mudstone; with microslickensides and calache nodules throughout; basal contact gradational.

26. Roca Shale: (1.8ft.; 0.56m.) brick-red (weathers reddish brown), blocky-crumbly, indurated, slightly silty, unfossiliferous mudstone; with caliche nodules and microslickensides; basal contact gradational.

25. Roca Shale: (1.0ft.; 0.30m.) light green (weathers green-brown), blocky-crumbly, indurated, slightly silty, unfossiliferous mudstone; with caliche noduels and microslickensides; basal contact sharp.

24. Roca Shale: (0.8ft.; 0.23m.) light gray (weathers gray-brown), slabby, root mottled, argillaceous, skeletal calcilutite (mudstone); with fenestral fabric (1-2mm. in diameter sparite filled vugs), ostracodes, and root traces; basal contact sharp.

23. Roca Shale: (1.8ft.; 0.53m.) brick-red (weathers reddish brown), blocky-crumbly, indurated, slightly silty mudstone; with caliche nodules, microslickensides, and root traces; basal contact sharp.

22. Roca Shale: (0.8ft.; 0.23m.) light green (weathers green-brown), blocky-crumbly, indurated, slightly silty, unfossiliferous mudstone; with microslickensides; basal contact sharp.

21. Roca Shale: (0.8ft.; 0.25m.) light gray (weathers gray-brown), slabby, argillaceous, skeletal calcilutite (mudstone); with small high-spired gastropods (pyramidellid-like), fenestral fabric (1-2mm. in diameter sparite filled vugs) and ostracodes (including bairdia-like); basal contact sharp.

20. Roca Shale: (1.0ft.; 0.30m.) light gray to green (weathers greenish brown), blocky-crumbly, indurated, slightly silty, mudstone; with microslickensides and root traces; basal contact sharp.

19. Roca Shale: (2.9ft.; 0.80m.) brick-red (weathers reddish brown), blocky-crumbly, indurated, slightly silty, claystone; with root traces and microslickensides; basal contact sharp.

18. Roca Shale: (1.3ft.; 0.38m.) light green (weathers greenish brown), blocky-crumbly, indurated, slightly silty, mudstone; with microslickensides and root traces; basal contact gradational.

17. Roca Shale: (2.3ft.; 0.69m.) light brown to pale green (weathers greenish brown), blocky-crumbly, slightly silty, claystone; with root traces, microslickensides, and caliche nodules; basal contact sharp.

16. Howe Limestone: (1.0ft.; 0.30m.) light gray-brown (weathers pale orange-brown), massive, skeletal calcarenite (packstone to grainstone); well sorted; with (70-80%) coated grains (Osagia), high-spired gastropods (pyramidellid-like), Nucula, ostracodes (Paraparchites and Bairdia-like), fossil fragments, and large (20-25cm. in diameter) hemispheroidal stromatolites; basal contact gradational.

15. Howe Limestone: (1.5ft.; 0.46m.) light gray-brown (weathers pale orange-brown), blocky to massive, slightly argillaceous, skeletal calcilutite (wackestone); with crinoids, productids, ostracodes (Paraparchites and Bairdia-like), and fossil fragments; basal contact sharp.

14. Howe Limestone: (0.7ft.; 0.20m.) light gray-brown (weathers pale orange-brown), slabby, argillaceous, skeletal calcilutite (wackestone); with Composita, crinoids, productids, echinoid spines, and fossil fragments; basal contact gradational.

13. Howe Limestone: (1.7ft.; 0.51m.) light brown (weathers pale orange-brown), blocky to masssive, slightly argillaceous, skeletal calcilutite to calcarenite (wackestone); with Wellerella, Composita, coated grains (Osagia), productids, crinoids, Derybia, Crurithyris, and fossil fragments; basal contact sharp.

12. Bennett Shale: (0.9ft.; 0.28m.) dark olive-gray (weathers light brown), flaggy, slightly silty, unfossiliferous, slightly calcareous, mudstone; basal contact gradational.

11. Bennett Shale: (2.2ft.; 0.69m.) dark olive-gray (weathers light brown), flaggy, slightly silty, slightly calcareous, mudstone; with Composita, Aviculopinna, Derybia, Hustedia, productid spines, Orbiculoidea, ostracodes, and Crurithyris; basal contact gradational.

10. Bennett Shale: (1.5ft.; 0.46m.) dark gray (weathers light brown), flaggy, slightly silty, slightly calcareous, mudstone; with Composita, Wellerella, Hustedia, Crurithyris, Orbiculoidea, fenestral bryozoans, ostracodes, Aviculopecten, and productids; basal contact sharp.

9. Glenrock Limestone: (0.2ft.; 0.05m.) light gray (weathers light brown), massive, skeletal calcilutite to calcarenite (packstone); fossiliferous; with Composita, Wellerella, Hustedia, Crurithyuis, Aviculopecten, Derybia, productids, Orbiculoidea, echinoid spines and plates, rare (<5%) intraclasts (3-4mm._in diameter, subrounded to subangular), ostracodes, crinoids and burrows (Thalassinoides; some of the burrows are filled with dark gray mudstone and Orbiculoidea fragments from above); basal contact gradational.

8. Glenrock Limestone: (1.1ft.; 0.33m.) medium gray-brown (weathers pale orange-brown), blocky to massive, skeletal calcarenite to calcirudite (packstone); with (40-50%) intraclasts (up to 5mm. in diameter, subangular to subrounded), echinoid spines, ostracodes, coated grains (Osagia), small crinoids, and burrows (Thalassinoides; some of the burrows are filled with dark gray mudstone and Orbiculoidea fragments from above); basal contact sharp.

7. Johnson Shale: (1.7ft.; 0.51m.) light brown to dark gray (weathers light brown), platy, slightly indurated, slightly silty, mudstone; with root traces, mudcracks, and ostracodes; basal contact gradational.

6. Johnson Shale: (1.9ft.; 0.58m.) olive-brown to dark gray (weathers light brown), platy, slightly silty, mudstone; with ostracode lenses, root traces, mudcracks, silty partings; basal contact gradational.

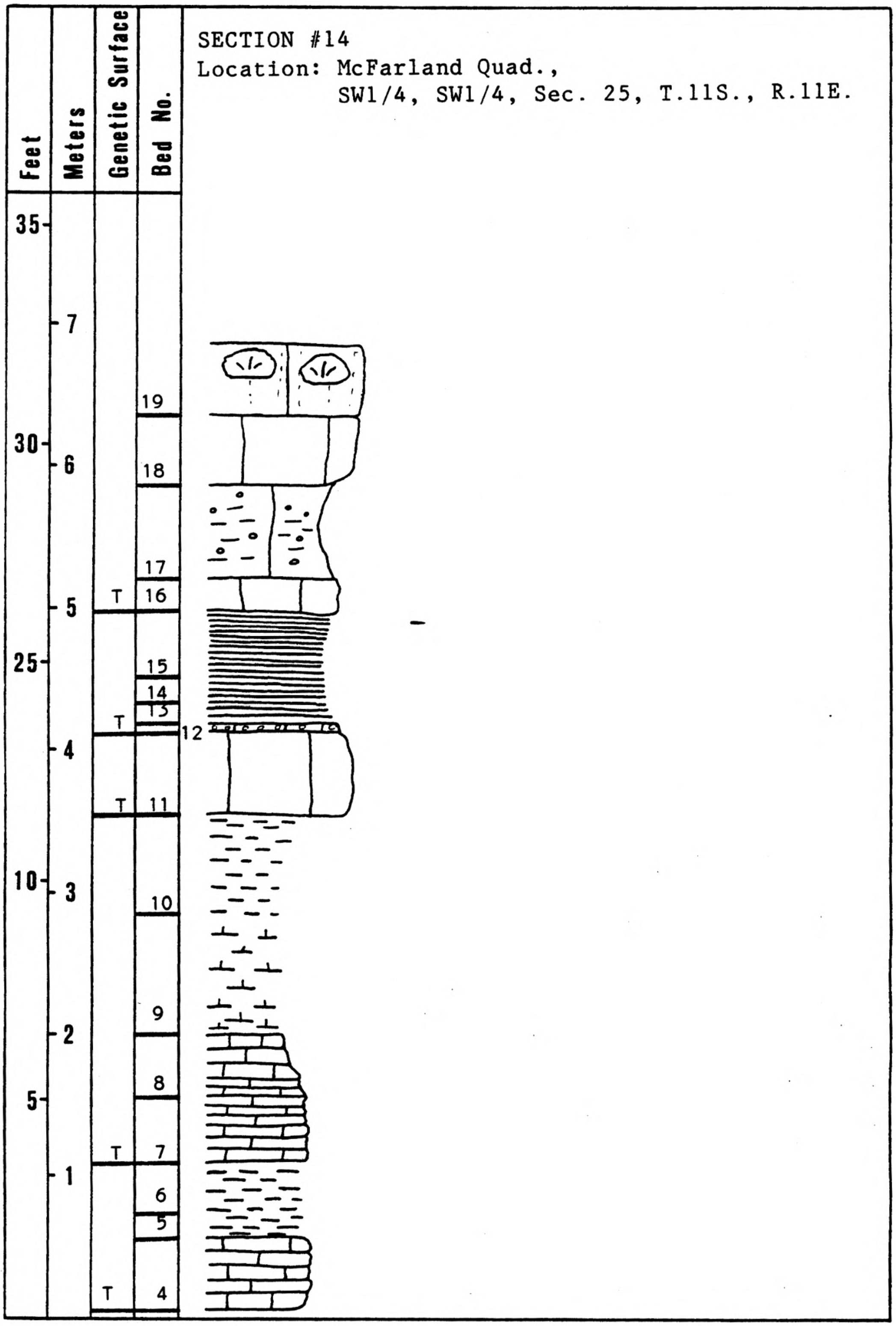
5. Johnson Shale: (1.8ft.; 0.53m.) light gray (weathers pale orange-brown), flaggy to slabby, slightly argillaceous, skeletal calcilutite (mudstone); with mudcracks, high-spired gastropods (pyramidellid-like), and fossil fragments; basal contact sharp.

4. Johnson Shale: (0.3ft.; 0.08m.) light brown to pale orange (weathers same), massive, tripoli; basal contact sharp.

3. Johnson Shale: (1.0ft.; 0.30m.) olive-green to maroon, blocky-crumbly (weathers olive-brown), slightly silty, mudstone; with root traces and microslickensides; basal contact sharp.

2. Johnson Shale: (0.6ft.; 0.18m.) light gray (weathers gray-brown), slabby, slightly argillaceous, calcilutite (mudstone); with root traces; basal contact sharp.

1. Johnson Shale: (3.0ft.; 0.91m.) light olive-green (weathers olive-brown), blocky-crumbly, slightly silty, mudstone; with root traces and microslickensides; basal contact covered.


SECTION #14
Location: McFarland Quad.,
SW1/4, SW1/4, Sec. 25, T.11S., R.11E.
Feet
Meters
Genetic Surface
Bed No.
35
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25
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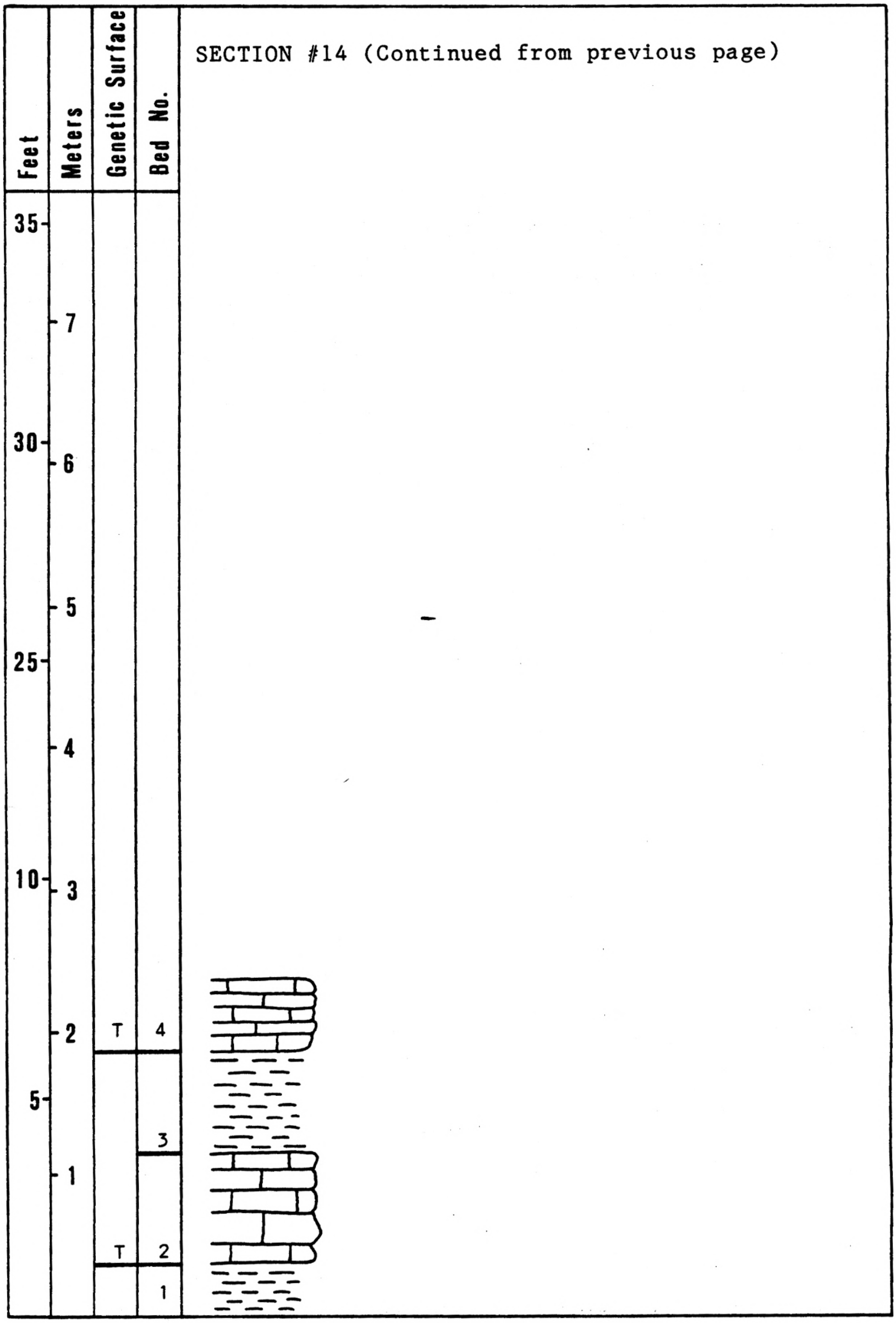
SECTION #14 (Continued from previous page)



SECTION #14 Paxico, on I-70, Wabaunsee County, KS; McFarland Quadrangle; SW1/4, SW1/4, SEC.25, T.11S., R.11E.; measured by Michael H. Clark (July 1987)

20. Roca Shale: COVERED

19. Howe Limestone: (1.7ft.; 0.51m.) light brown (weathers pale orange-brown), massive, skeletal calcarenite (wackestone to packstone); well sorted; with (70-80%) coated grains (Osagia), ostracodes (including Bairdia-like), Nucula, high-spired gastropods (pyramidellid-like), and large (20-25cm. in diameter) hemispheroidal stromatolites (in the upper 25cm.); basal contact gradational.

18. Howe Limestone: (1.7ft.; 0.51m.) light brown (weathers pale orange-brown), massive, slightly argillaceous, skeletal calcilutite (wackestone); with echinoid spines, ostracodes, coated grains (Osagia), productids, and fossil fragments; basal contact sharp.

17. Howe Limestone: (2.2ft.; 0.66m.) light gray-brown (weathers brown), very argillaceous, skeletal calcilutite (wackestone); fossiliferous: Composita, Neospirifer, Neochonetes, fusulinids, Wellerella, crinoid columns, echinoid plates and spines, ramose and fenestral bryozoans, productids, and fossil fragments; basal contact sharp.

16. Howe Limestone: (0.8ft.; 0.23m.) light gray-brown (weathers brown), slabby, slightly argillaceous, skeletal calcilutite (wackestone); with Orbiculoidea, crinoids, ramose and fenestral bryozoans, productids, and brachiopod fragments; basal contact sharp.

15. Bennett Shale: (1.8ft.; 0.56m.) dark gray (weathers light brown), flaggy, slightly calcareous, mudstone; with rare (<10%) Orbiculoidea and Orbiculoidea fragments; basal contact gradational.

14. Bennett Shale: (0.5ft.; 0.15m.) dark gray (weathers light brown), flaggy, slightly calcareous, mudstone; with common (10-20%) Orbiculoidea and common (10-20%) Permophorus; basal contact gradatioanl.

13. Bennett Shale: (0.2ft.; 0.05m.) pale orange-brown (weathers light brown), platy, very fossiliferous mudstone; with (30-40%) articulated fossils: Composita, fusulinids, Wellerella, productids, Orbiculoidea, and bryozoans; basal contact sharp.

12. Glenrock Limestone: (0.2ft.; 0.05m.) light gray-brown (weathers brown), massive, very fossiliferous, skeletal calcilutite (wackestone to packstone); with (40-50%) fusulinids, <u>Composita</u>, <u>Wellerella</u>, <u>Neospirifer</u>, ramose and fenestral bryozoans, productids, and echinoid fragments; basal contact sharp.

11. Glenrock Limestone: (1.9ft.; 0.58m.) light gray-brown (weathers brown), massive, skeletal calcilutite (wackestone); with (15-20%) fusulinids, intraclasts (3-6mm. in diameter, subangular to subrounded), echinoid spines, and fossil fragments (brachiopod); basal contact sharp.

10. Johnson Shale: (2.3ft.; 0.71m.) dark gray to brown (weathers brown), platy to flaggy, slightly silty, mudstone; with mudcracks, ostracode lenses, and root traces; upper 20-25cm. is slightly indurated; basal contact gradational.

9. Johnson Shale: (2.7ft.; 0.81m.) light brown (weathers brown), flaggy to slabby, very argillaceous calcilutite (mudstone) to very calcareous mudstone (marl); with ostracodes; basal contact gradational.

8. Johnson Shale: (1.4ft.; 0.43m.) light gray to light brown (weathers brown), platy to flaggy, very argillaceous, thin-bedded calcilutite (mudstone); with mudcracks and ostracodes; basal contact gradational.

7. Johnson Shale: (1.6ft.; 0.48m.) light gray (weathers light brown), slabby to flaggy, argillaceous, thin-bedded calcilutite (mudstone); with mudcracks and ostracodes; basal contact sharp.

6. Johnson Shale: (1.3ft.; 0.38m.) light brown (weathers brown), massive, slightly indurated, unfossiliferous, calcareous mudstone; basal contact gradational.

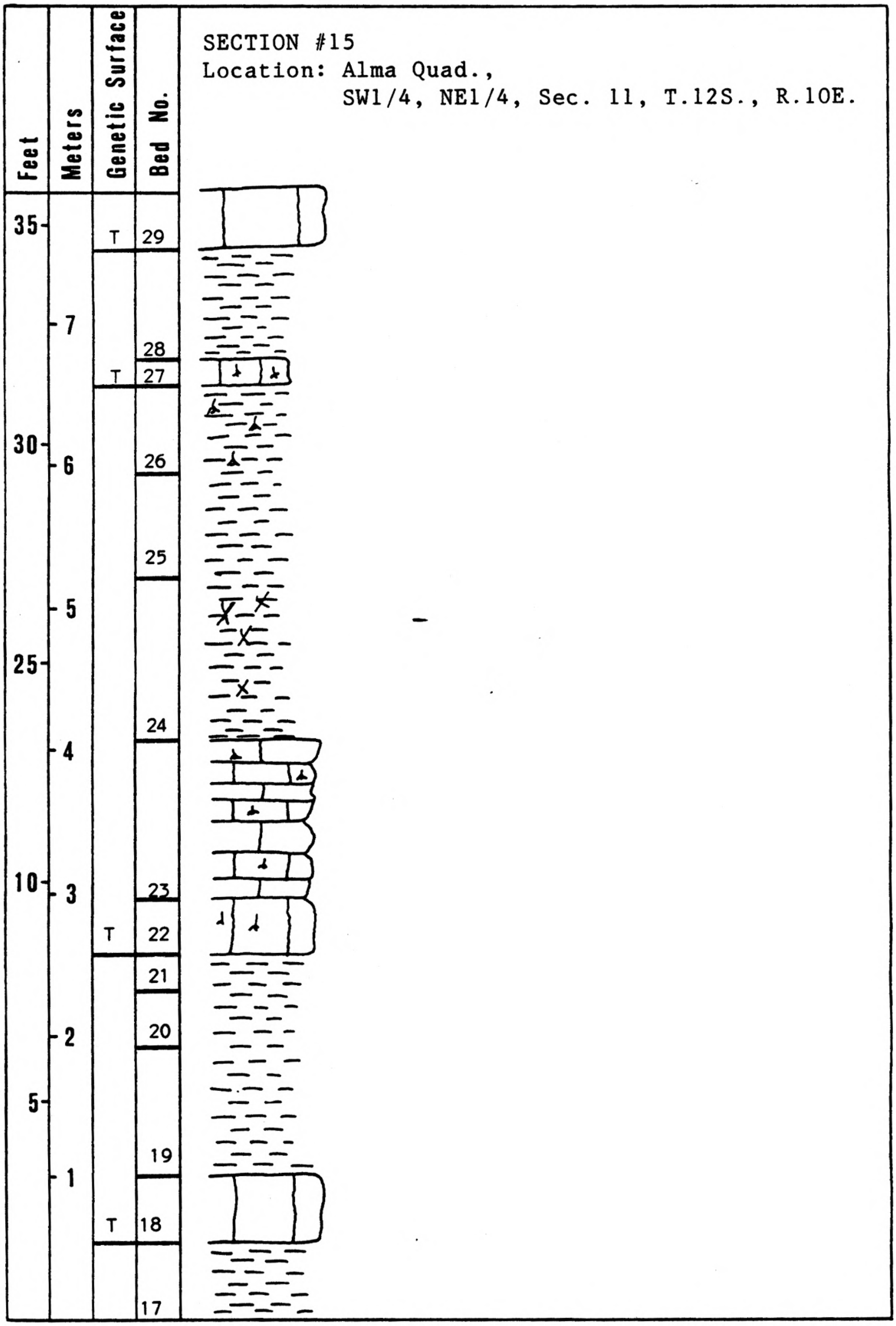
5. Johnson Shale: (0.5ft.; 0.15m.) varigated (gray-green-brown, weathers greenish brown), platy to flaggy, slightly silty, calcareous mudstone; slightly root mottled; basal contact sharp.

4. Johnson Shale: (1.7ft.; 0.51m.) light gray-brown (weathers brown), flaggy to slabby, very argillaceous, skeletal calcilutite (mudstone); with ostracodes and iron stains; basal contact sharp.

3. Johnson Shale: (2.3ft.; 0.71m.) light olive-green (weathers light brown), massive, slightly indurated, unfossiliferous, slightly silty, calcareous mudstone; with iron stains and local iron nodules; basal contact sharp.

2. Johnson Shale: (2.5ft.; 0.76m.) light gray-brown (weathers light brown), slabby to blocky, argillaceous calcilutite (mudstone); with fenestral fabric (1-3mm. in diameter sparite filled vugs) and Mg-stains on some of the joints; basal contact sharp.

1. Johnson Shale: (1.0ft.; 0.30m.) light olive-green (weathers greenish brown), massive to blocky, slightly silty, unfossiliferous mudstone; slightly indurated; with intraclasts (3-4mm. in diameter, subrounded to subangular); basal contact covered.


SECTION #15
Location: Alma Quad.,
SW1/4, NE1/4, Sec. 11, T.12S., R.10E.
Feet
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Genetic Surface
Bed No.
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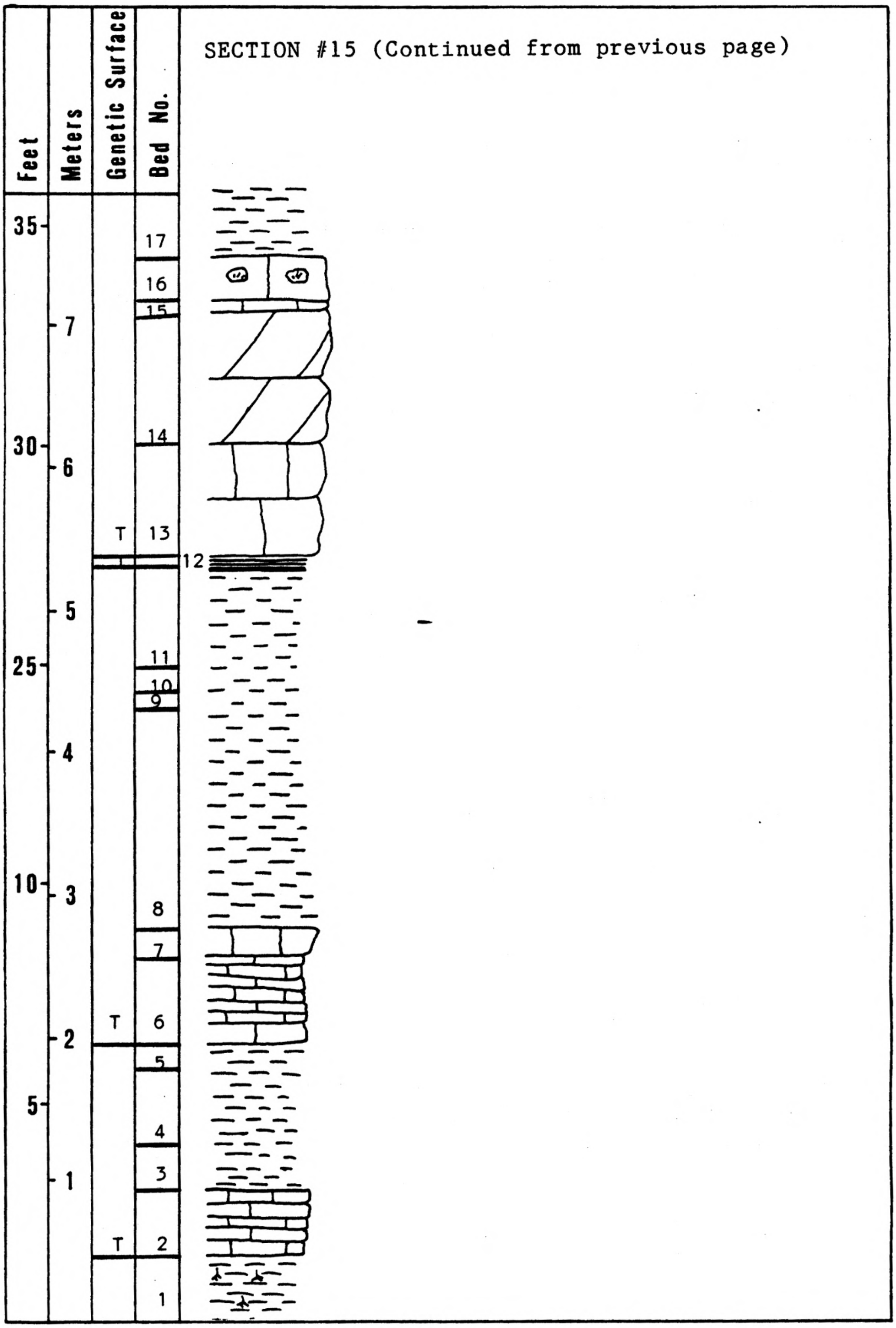
SECTION #15 (Continued from previous page)



SECTION #15 northeast of Alma in a stream cut (east bank) in Mill Creek, Wabaunsee County, KS; Alma Quadrangle; SW1/4, NE1/4, SEC.11, T.12S., R.10E.; measured by Michael H. Clark and Dr. Richard M. Busch (June 1987)

29. Sallyards Limestone: (1.4ft.; 0.43m.) light gray (weathers gray-brown), blocky to slabby, slightly argillaceous, skeletal calcilutite (wackestone); with Aviculopecten, algal biscuits (Osagia), ostracodes, productids, and small bivalves; basal contact sharp.

28. Roca Shale: (2.5ft.; 0.76m.) light brown (weathers same), blocky, calcareous, slightly silty, unfossiliferous mudstone; basal contact sharp.

27. Roca Shale: (0.7ft.; 0.20m.) light gray (weathers gray-brown), slabby, slightly argillaceous, skeletal calcilutite (mudstone); with root traces, iron stains, ostracodes (including Bairdia-like), and small high-spired gastropods (pyramidellid-like); basal contact sharp.

26. Roca Shale: (2.1ft.; 0.64m.) light brown (weathers same), blocky, calcareous, slightly silty, mudstone; with iron stains and root traces; basal contact gradational.

25. Roca Shale: (2.3ft.; 0.71m.) olive-gray (weathers olive-brown), blocky, calcareous, slightly silty, unfossiliferous mudstone; with iron stains; basal contact gradational.

24. Roca Shale: (3.6ft.; 1.09m.) dark gray to light green (weathers greenish brown), blocky-crumbly, well indurated, slightly silty, mudstone; calcareous peds developed throughout; with root traces; basal contact gradational.

23. Roca Shale: (3.7ft.; 1.12m.) light gray-brown (weathers brown), flaggy, argillaceous calcilutite (mudstone); with root traces and iron stains; basal contact gradational.

22. Roca Shale: (1.3ft.; 0.38m.) light gray (weathers gray-brown), slabby to blocky, skeletal calcilutite (mudstone); with fenestral fabric (1-2mm. in diameter, sparite filled vugs) and ostracodes (including Bairdia-like); basal contact sharp.

21. Roca Shale: (0.8ft.; 0.25m.) light green (weathers greenish brown), blocky, unfossiliferous mudstone; basal contact sharp.

20. Roca Shale: (1.3ft.; 0.38m.) brick-red (weathers reddish brown), blocky, silty, unfossiliferous mudstone; with iron stains; basal contact gradational.

19. Roca Shale: (3.0ft.; 0.91m.) gray (weathers medium brown), blocky, calcareous, unfossiliferous mudstone; with iron stains; basal contact sharp.

18. Roca Shale: (1.5ft.; 0.46m.) light gray (weathers gray-brown), blocky to slabby, thinly-laminated calcilutite (mudstone); basal contact sharp.

17. Roca Shale: (1.8ft.; 0.53m.) light green (weathers greenish brown), blocky-crumbly, indurated, unfossiliferous mudstone; basal contact sharp.

16. Howe Limestone: (1.0ft.; 0.30m.) light gray-brown (weathers brown), slabby, skeletal calcilutite to calcarenite (wackestone); with large (10-15cm. in diameter) hemispheroidal stromatolites, high-spired gastropods (pyramidellid-like), coated grains (Osagia), and ostracodes (including Bairdia-like and Paraparchites); basal contact sharp.

15. Howe Limestone: (0.3ft.; 0.08m.) light brown to pale yellow-orange (weathers same), friable, coarse skeletal calcarenite (grainstone), tripoli; composed of bivalves (Nucula?), ostracodes and high-spired gastropods (pyramidellid-like); basal contact sharp.

14. Bennett Shale: (3.0ft.; 0.91m.) light gray-brown (weathers medium gray-brown), slabby to massive, skeletal dololutite (mudstone-wackestone); with small bivalves; basal contact gradational.

13. Bennett Shale: (2.5ft.; 0.76m.) light gray (weathers gray-brown), slabby to massive, argillaceous, skeletal dolomitic calcilutite (mudstone-wackestone); with sharks teeth, crinoid plates, and brachiopod fragments; basal contact sharp.

12. Bennett Shale: (0.2ft.; 0.05m.) black (weathers dark brown), fissile, shale/mudstone; with Orbiculoidea fragments and brachiopod spines; basal contact sharp.

NOTE: Glenrock Limestone Member missing at this location.

11. Johnson Shale: (2.3ft.; 0.71m.) dark gray to dark olive-gray (weathers light brown), platy, mudstone; with ostracodes (including Bairdia-like, which are more abundant basally), celestite geodes (2-4cm. in diameter, in the upper 10-14cm.), and a thin (1-2cm. thick) smut coal at the top of the unit; basal contact gradational.

10. Johnson Shale: (0.6ft.; 0.18m.) black (weathers dark brown), platy, mudstone; with light brown skeletal calcilutite (mudstone) laminations up to 5mm. thick, which contain abundant (20-30%) ostracodes (including Bairdia-like); also mudcracked; basal contact sharp.

9. Johnson Shale: (0.3ft.; 0.10m.) light brown (weathers brown), flaggy, argillaceous, calcareous mudstone; with very abundant (20-40%) ostracodes (including Bairdia-like) and common (10-30%) reworked plant fragments (lepidopphylloid-like); basal contact is sharp and erosional(?).

8. Johnson Shale: (5.2ft.; 1.57m.) medium brown (weathers light brown), flaggy, argillaceous, very calcareous, mudstone; with mudcracks, iron stains, and rare (<5%) ostracodes; basal contact sharp.

7. Johnson Shale: (0.6ft.; 0.18m.) light gray-brown (weathers brown), slabby, skeletal calcilutite (mudstone); thinly-laminated; with ostracodes and mudcracks; basal contact sharp.

6. Johnson Shale: (2.0ft.; 0.61m.) light gray-brown (weathers brown), flaggy, argillaceous, skeletal calcilutite (mudstone); with ostracodes, mudcracks, and iron stains; basal contact sharp.

5. Johnson Shale: (0.4ft.; 0.13m.) light brown (weathers same), massive, calcareous, unfossiliferous mudstone; basal contact gradational.

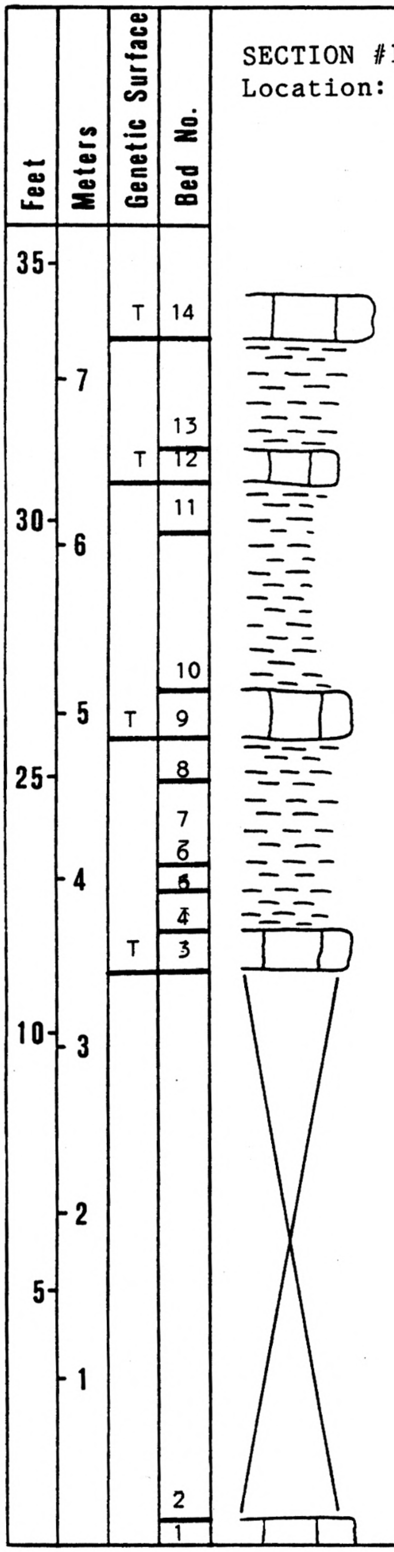
4. Johnson Shale: (2.0ft.; 0.61m.) light green (weathers greenish brown), slabby, slightly indurated, calcareous, unfossiliferous mudstone; with iron stains; basal contact gradational.

3. Johnson Shale: (1.0ft.; 0.30m.) light brown (weathers same), slabby, slightly indurated, unfossiliferous mudstone; with iron stains; basal contact sharp.

2. Johnson Shale: (1.5ft.; 0.46m.) light gray-brown (weathers brown), slabby, calcilutite (mudstone); fetid; with iron stains; basal contact sharp.

1. Johnson Shale: (1.5ft.; 0.46m.) medium brown (weathers light brown), slabby, slightly argillaceous, mudstone; with iron stains and root traces; basal contact covered.

SECTION #16
Location: Maple Hill Quad.,
SW1/4, NW1/4, NW1/4, Sec.9, T.12S., R.12E.



SECTION #16 Wabaunsee County, KS; Maple Hill Quadrangle; SW1/4, NW1/4, NW1/4, SEC.9, T.12S., R.12E.; measured by Michael H. Clark (August 1987)

14. Sallyards Limestone: (0.8ft.; 0.25m.) light gray (weathers brown), slabby, slightly argillaceous, skeletal calcilutite (wackestone); with Aviculopecten, productids, Derybia, and algal biscuits (Osagia); basal contact sharp.

13. Roca Shale: (2.0ft.; 0.61m.) light brown (weathers brown), massive, slightly indurated, slightly silty, unfossiliferous, calcareous mudstone; with Fe and Mg stains; basal contact sharp.

12. Roca Shale: (0.6ft.; 0.18m.) light gray-brown (weathers brown), slabby, argillaceous calcilutite (mudstone); with Fe and Mg stains; basal contact sharp.

11. Roca Shale: (1.0ft.; 0.30m.) light green (weathers greenish brown), blocky, indurated, unfossiliferous mudstone; basal contact gradational.

10. Roca Shale: (3.0ft.; 0.91m.) varigated (gray-maroon-green, weathers reddish brown), blocky, slightly indurated, slightly silty, unfossiliferous mudstone; basal contact sharp.

9. Roca Shale: (0.9ft.; 0.28m.) light gray (weathers gray-brown), slabby, slightly argillaceous, calcilutite (mudstone); with a fenestral fabric (1-2mm. in diameter, sparite filled vugs) and Mg stains; basal contact sharp.

8. Roca Shale: (0.7ft.; 0.20m.) light green-brown (weathers greenish brown), slightly calcareous, unfossiliferous mudstone; basal contact sharp.

7. Roca Shale: (0.3ft.; 0.10m.) maroon (weathers reddish brown), blocky, unfossiliferous mudstone; slightly indurated; basal contact gradational.

6. Roca Shale: (1.8ft.; 0.83m.) light olive-green (weathers olive-brown), blocky, slightly silty, unfossiliferous mudstone; basal contact gradational.

5. Roca Shale: (0.3ft.; 0.10m.) maroon (weathers reddish brown), blocky, slightly silty, unfossiliferous mudstone; basal contact gradational.

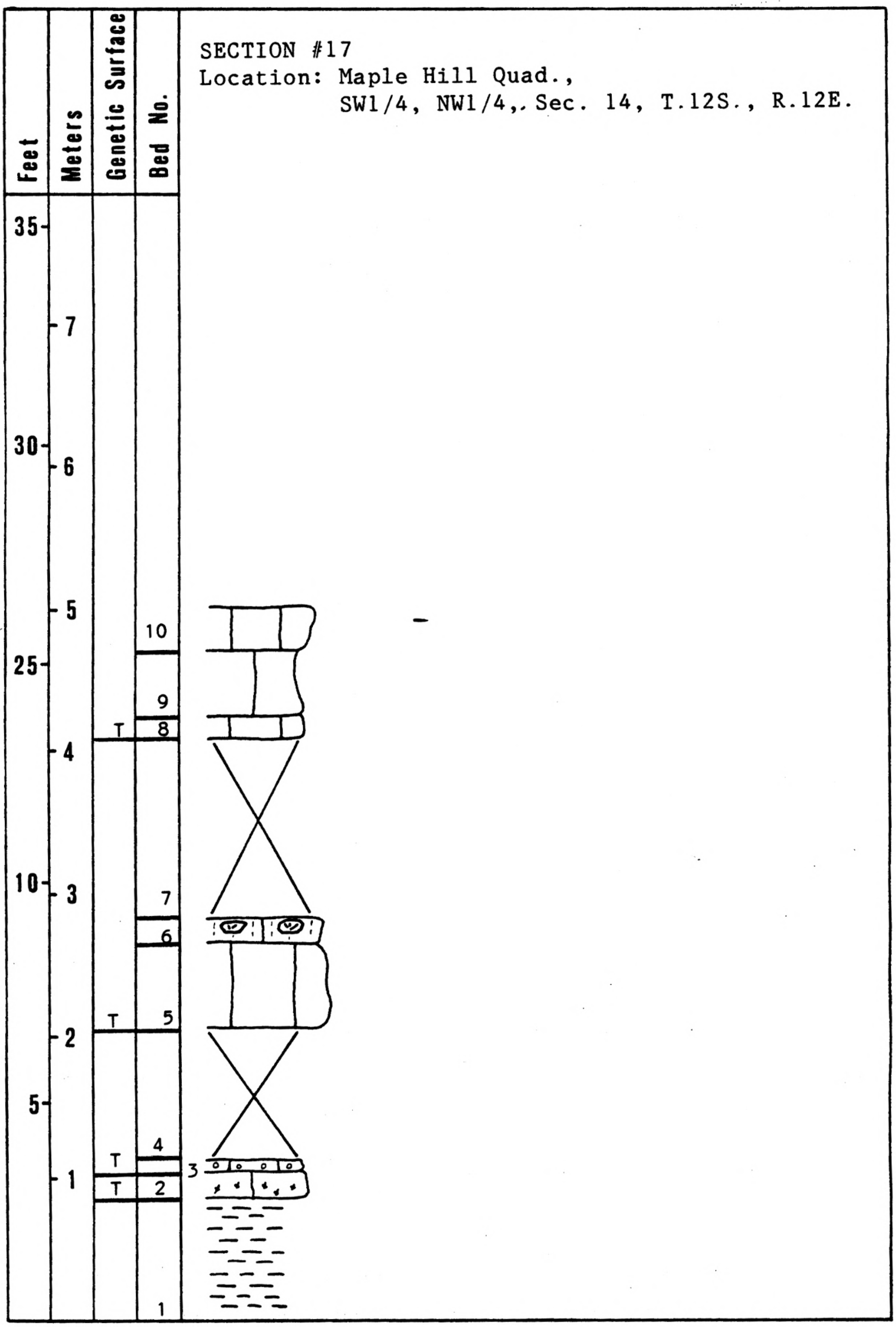
4. Roca Shale: (0.7ft.; 0.20m.) light olive-green (weathers olive-brown), blocky-crumbly, slightly silty, unfossiliferous mudstone; basal contact gradational.

3. Roca Shale: (0.8ft.; 0.23m.) light gray-brown (weathers brown), slabby, slightly argillaceous, calcilutite (mudstone); slightly mottled; basal contact sharp.

2. Roca Shale: (10.8ft.; 3.30m.) COVERED.

1. Howe Limestone: COVERED.

SECTION #17
Location: Maple Hill Quad.,
SW1/4, NW1/4, Sec. 14, T.12S., R.12E.



SECTION #17 Wabaunsee County, KS; Maple Hill Quadrangle; SW1/4, NW1/4, SEC.14, T.12S., R.12E.; measured by Michael H. Clark (August 1987)

10. Roca Shale: (0.8ft.; 0.28m.) light gray (weathers gray-brown), slabby to blocky, skeletal calcilutite (mudstone); with ostracodes (including Bairdia-like) and high-spired gastropods (pyramidellid-like); basal contact sharp.

9. Roca Shale: (1.5ft.; 0.46m.) light gray (weathers gray-brown), platy, very argillaceous, skeletal calcilutite (mudstone); with ostracodes (including Bairdia-like); basal contact gradational.

8. Roca Shale: (0.5ft.; 0.15m.) light gray (weathers gray-brown), flaggy to slabby, slightly argillaceous calcilutite (mudstone); with mudcracks; basal contact sharp.

7. Roca Shale: (4.0ft.; 1.22m.) COVERED.

6. Howe Limestone: (0.7ft.; 0.20m.) light brown (weathers pale orange-brown), massive, skeletal calcarenite (packstone-grainstone); well sorted; with (60-80%) coated grains (Osagia), ostracodes (including Bairdia-like and Paraparchites), and small (8-12cm. in diameter) hemispheroidal stromatolites; basal contact gradational.

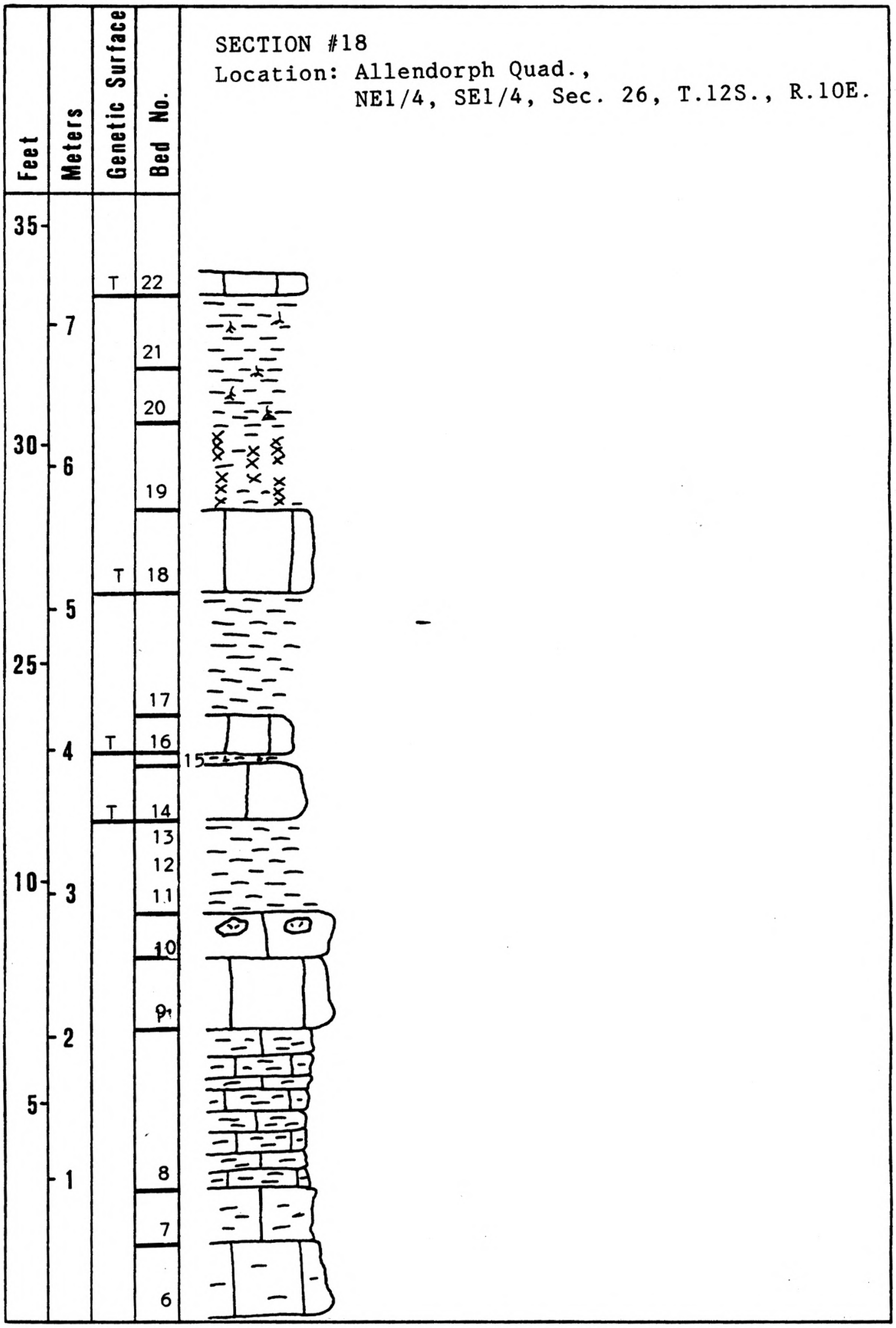
5. Howe Limestone: (1.8ft.; 0.56m.) light gray-brown (weathers pale orange-brown), blocky to massive, skeletal calcilutite (wackestone); with echinoid spines, productids, ostracodes (including Bairdia-like and Paraparchites), ramose bryozoans, crinoids, and coated grains (Osagia); basal contact sharp.

4. Bennett Shale: (4.0ft.; 1.22m.) COVERED.

3. Glenrock Limestone: (0.3ft.; 0.08m.) light gray-brown (weathers brown), massive, skeletal calcilutite to calcarenite (wackestone); fossiliferous; with (30-35%) fusulinids, Composita, Rhipidomella, productids, Crurithyris, Derybia, crinoids, Neospirifer, echinoid plates and spines, and ramose and fenestral bryozoans; basal contact sharp.

2. Glenrock Limestone: (0.7ft.; 0.20m.) light gray-brown (weathers pale orange-brown), massive, coarse skeletal calcarenite (wackestone); with intraclasts (3-4mm. in diameter, subrounded to subangular), productids, crinoids, and fossil fragments; basal contact sharp.

1. Johnson Shale: (2.5ft.; 0.76m.) light brown mottled dark gray (weathers brown), platy, slightly silty, mudstone; becoming more indurated upwards; with mudcracks, root traces, and ostracodes (including Bairdia-like) basally; basal contact covered.


SECTION #18
Location: Allendorph Quad.,
NE1/4, SE1/4, Sec. 26, T.12S., R.10E.
Feet
Meters
Genetic Surface
Bed No.
35
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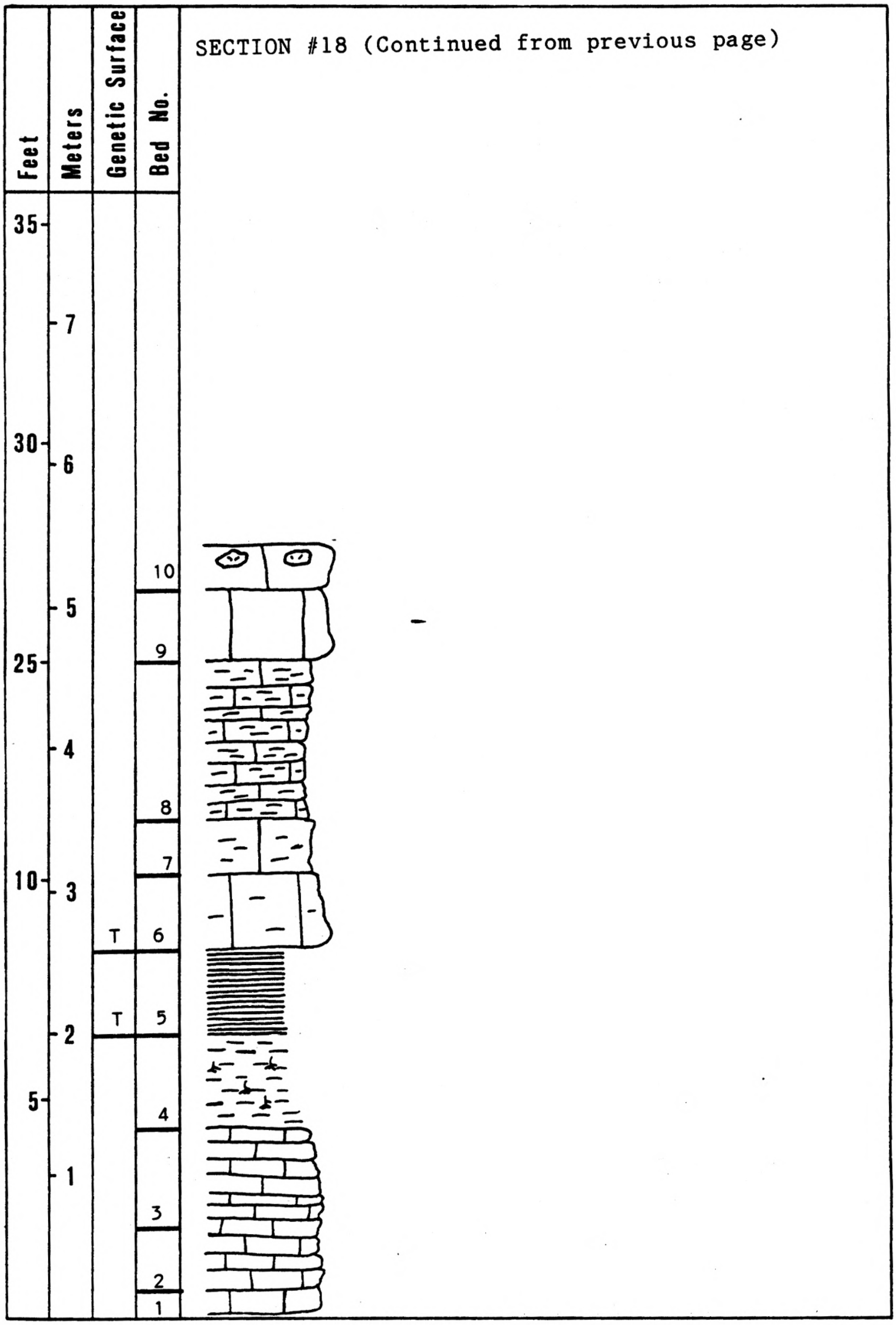
SECTION #18 (Continued from previous page)



SECTION #18 Alma Lake Spillway, Wabaunsee County, KS; Allendorph Quadrangle; NE1/4, SE1/4, SEC.26, T.12S., R.10E.; measured by Michael H. Clark (July 1987)

22. Sallyards Limestone: (0.5ft.; 0.15m.) medium gray (weathers gray-brown), slabby, slightly argillaceous, skeletal calcilutite (wackestone); with algal biscuits (Osagia), small bivalves, Aviculopecten, ostracodes, and productids; basal contact sharp.

21. Roca Shale: (1.7ft.; 0.51m.) light brown (weathers same), blocky-crumbly, slightly silty, mudstone; with root traces and iron stains; basal contact gradational.

20. Roca Shale: (1.3ft.; 0.41m.) dark gray (weathers light gray), blocky to crumbly, indurated, silty mudstone; with caliche nodules, microslickensides, and root traces; basal contact gradational.

19. Roca Shale: (2.0ft.; 0.61m.) light gray-brown (weathers same), massive, calcified ped horizon; weathers blocky and crumbly; with root traces; basal contact sharp.

18. Roca Shale: (1.8ft.; 0.53m.) light gray (weathers medium gray), slabby to blocky, calcilutite (mudstone); with fenestral fabric (1-2mm. in diameter sparite filled vugs); irregular upper contact; basal contact sharp.

17. Roca Shale: (0.3ft.; 0.08m.) light green (weathers greenish brown), blocky-crumbly, indurated, slightly silty, unfossiliferous mudstone; basal contact sharp.

16. Roca Shale: (2.5ft.; 0.76m.) brick-red (weathers reddish brown), blocky-crumbly, indurated, slightly silty, unfossiliferous mudstone; with microslickensides; basal contact gradational.

15. Roca Shale: (0.3ft.; 0.08m.) light green (weathers greenish brown), blocky-crumbly, indurated, slightly silty, unfossiliferous mudstone; with microslickensides; basal contact sharp.

14. Roca Shale: (0.8ft.; 0.25m.) light gray (weathers gray-brown), slabby, calcilutite (mudstone); thin-bedded; with mudcracks; basal contact sharp.

13. Roca Shale: (0.3ft.; 0.08m.) light olive-brown (weathers brown), blocky-crumbly, indurated, slightly silty, mudstone; with root traces and microslickensides; basal contact sharp.

12. Roca Shale: (1.3ft.; 0.38m.) light gray (weathers gray-brown), flaggy to slabby, calcilutite (mudstone); thin-bedded; with iron stains and mudcracks; basal contact sharp.

11. Roca Shale: (2.0ft.; 0.61m.) varigated (olive-green-brown-gray, weathers greenish brown), massive, slightly silty, unfossiliferous mudstone; basal contact sharp.

10. Howe Limestone: (1.0ft.; 0.30m.) light brown (weathers pale orange-brown), massive, skeletal calcarenite (packstone-grainstone); well sorted; with (60-80%) coated grains (Osagia), high-spired gastropods (pyramidellid-type), ostracodes (including Bairdia-like and Paraparchites), Nucula (some of which are replaced by celestite), and large (12-15cm. in diameter) hemispheroidal stromatolites; basal contact sharp.

9. Howe Limestone: (1.7ft.; 0.51m.) light gray-brown (weathers pale orange-brown), blocky, slightly argillaceous, skeletal calcilutite (wackestone); with echinoid spines, crinoids, ramose bryozoans, ostracodes (including Bairdia-like and Paraparchites), and productids; basal contact sharp.

8. Bennett Shale: (4.1ft.; 1.22m.) light olive-gray (weathers light brown), flaggy to slabby, very argillaceous, skeletal calcilutite (marlstone-mudstone); bioturbated; with echinoid spines and plates, Wellerella, Composita, Fenestrellina, crinoids, Hustedia, Linoproductus, Antiquatonia, productids, Aviculopecten, ramose, fenestral and encrusting bryozoans; basal contact gradational.

7. Bennett Shale: (1.2ft.; 0.36m.) light olive-gray (weathers light brown), massive, argillaceous, skeletal calcilutite (mudstone-wackestone); bioturbated; fossiliferous: ramose, fenestral, and encrusting bryozoans, crinoid columns, echinoid spines and plates, Wellerella, Neochonetes, Neospirifer, Composita, productids, and Hustedia; basal contact gradational.

6. Bennett Shale: (1.4ft.; 0.43m.) dark gray-brown (weathers brown), massive, argillaceous, skeletal calcilutite (mudstone-wackestone); bioturbated; with Orbiculoidea, Crurithyris, ostracodes, crinoid plates, and Fenestrellina; basal contact sharp.

5. Bennett Shale: (0.8ft.; 0.25m.) dark gray to black (weathers brown), platy, slightly silty, mudstone; with Orbiculoidea, Crurithyris, ostracodes, brachiopod spines, and fossil fragments; basal contact sharp.

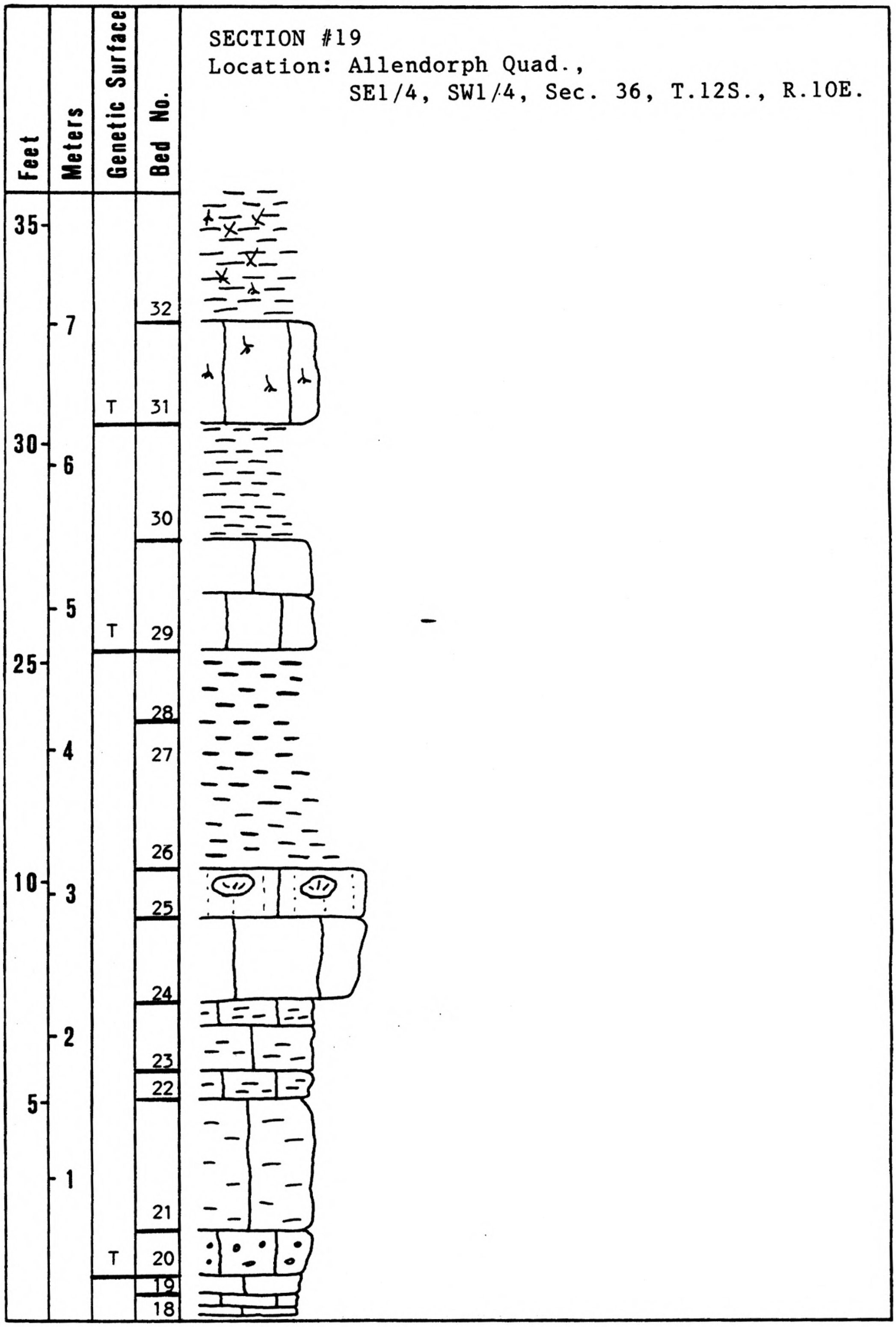
NOTE: Glenrock Limestone Member is missing at this locality.

4. Johnson Shale: (2.5ft.; 0.56m.) varigated (dark gray to light green, weathers medium brown), blocky-crumbly, indurated, root mottled, mudstone; with root traces, small (2-4cm. in diameter) celestite geodes; basal contact gradational.

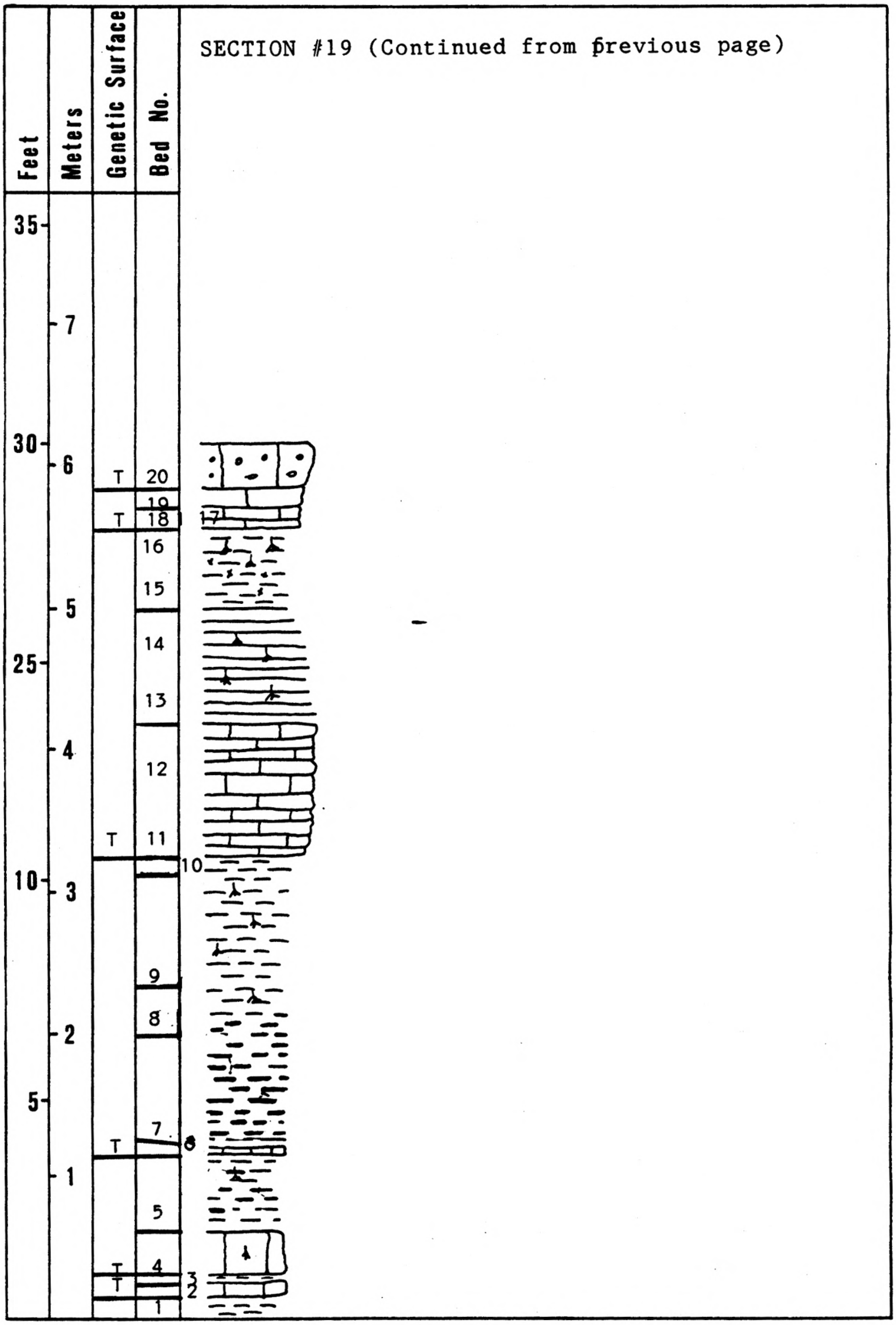
3. Johnson Shale: (2.6ft.; 0.79m.) medium brown (weathers light brown), platy to flaggy, slightly argillaceous, skeletal calcilutite (mudstone); with mudcracks and ostracodes (including Bairdia-like); basal contact gradational.

2. Johnson Shale: (1.3ft.; 0.41m.) medium brown (weathers light brown), flaggy, slightly silty, skeletal calcilutite (mudstone); with ostracodes and mudcracks; basal contact gradational.

1. Johnson Shale: (0.6ft.; 0.18m.) light gray (weathers brown), slabby, slightly argillaceous, skeletal calcilutite (mudstone), thin-bedded; with ostracodes (including Bairdia-like) and silty partings; basal contact covered.



SECTION #19
Location: Allendorph Quad.,
SE1/4, SW1/4, Sec. 36, T.12S., R.10E.
Feet
Meters
Genetic Surface
Bed No.
35
30
25
10
5
7
6
5
4
3
2
1
T
T
T
32
31
30
29
28
27
26
25
24
23
22
21
20
19
18



SECTION #19 (Continued from previous page)
Feet
Meters
Genetic Surface
Bed No.
35
30
25
10
5
7
6
5
4
3
2
1
T
T
T
T
T
T
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1

SECTION #19 southeast of Alma in a stream out in Mill Creek, Wabaunsee County, KS; Allendorph Quadrangle; SE1/4, SW1/4, SW1/4, SEC.36, T.12S., R.10E.; measured by Michael H. Clark (July 1987)

32. Roca Shale: (3.2ft.; 0.97m.) varigated (gray-maroon-green, weathers reddish brown), blocky-crumbly, indurated, calcareous, slightly silty mudstone; with root traces, intraclasts (3-4mm. in diameter, subrounded to subangular), microslickensides, caliche nodules, and calcareous peds; upper contact covered; basal contact sharp.

31. Roca Shale: (2.3ft.; 0.71m.) light gray-brown to light maroon-gray (weathers medium gray-brown), slabby, argillaceous, skeletal calcilutite (mudstone); with 10-15% ostracodes (including Bairdia-like), fenestral fabric (1-2mm. in diameter sparite filled vugs), and root traces; basal contact sharp.

30. Roca Shale: (2.5ft.; 0.76m.) brick-red (weathers reddish brown), blocky-crumbly, indurated, slightly calcareous, unfossiliferous, silty mudstone; basal contact gradational.

29. Roca Shale: (1.3ft.; 0.38m.) light gray-brown (weathers medium gray-brown), slabby, slightly argillaceous, algal laminated, skeletal calcilutite (mudstone); with fenestral fabric (1-2mm. in diameter sparite filled vugs) and abundant (20-30%) ostracodes (including Bairdia-like); basal contact gradational.

28. Roca Shale: (1.3ft.; 0.38m.) light gray-brown (weathers medium gray-brown), flaggy, argillaceous calcilutite (mudstone); basal contact sharp.

27. Roca Shale: (1.5ft.; 0.46m.) varigated (brick-red to dark olive-green, weathers reddish brown), slightly calcareous, slightly silty, unfossiliferous, varved, mudstone; basal contact sharp.

26. Roca Shale: (3.5ft.; 1.07m.) light green (weathers greenish brown), slabby, slightly calcareous, slightly silty, mudstone; with root traces; basal contact sharp.

25. Howe Limestone: (1.0ft.; 0.30m.) light brown (weathers pale orange-brown), massive, skeletal calcarenite (packstone to grainstone); well sorted; with coated grains (<u>Osagia</u>), ostracodes (including Bairdia-like and <u>Paraparchites</u>), high-spired gastropods (pyramidellid-like), and hemispheroidal stromatolites; basal contact gradational.

24. Howe Limestone: (1.8ft.; 0.56m.) light brown (weathers pale orange-brown), massive, slightly vuggy, skeletal calcarenite (packstone to grainstone); well sorted; with ostracodes (including Bairdia-like and Paraparchites), Crurithyris, coated grains (Osagia), high-spired gastropods, Nucula, and fossil fragments; basal contact sharp.

23. Bennett Shale: (1.5ft.; 0.45m.) medium brown (weathers light brown), massive (weathers platy), very argillaceous, skeletal calcilutite (marlstone-mudstone); with Derybia, productids, Aviculopecten, and crinoids; basal contact gradational.

22. Bennett Shale: (0.7ft.; 0.20m.) medium brown (weathers light brown), massive (weathers platy), very argillaceous, skeletal calcilutite (marlstone-mudstone); fossiliferous; with crinoids, Composita, productids, Wellerella, Hustedia, Neospirifer, Derybia, Aviculopecten, Enteletes?, echinoid plates and spines, and ramose and fenestral bryozoans; basal contact gradational.

21. Bennett Shale: (2.9ft.; 0.89m.) medium brown (weathers light brown), massive (weathers platy), very argillaceous, skeletal calcilutite (marlstone-mudstone); fossiliferous; with Derybia, productids, Aviculopecten, crinoids, ramose and fenestral bryozoans, echinoid plates and spines, Hustedia, and Composita; basal contact gradational.

20. Bennett Shale: (1.0ft.; 0.30m.) light gray-brown (weathers brown), slabby to blocky, slightly argillaceous, skeletal calcilutite (wackestone); fossiliferous; with Wellerella, Hustedia, productids, ramose and fenestral bryozoans, crinoids, fusulinids, echinoid spines, and Crurithyris; basal contact sharp.

19. Glenrock Limestone: (0.5ft.; 0.15m.) light gray-brown (weathers brown), slabby, slightly argillaceous, skeletal calcilutite (mudstone); with fecal pellets, ostracodes (including Bairdia-like), and brachiopod fragments; basal contact gradational.

18. Glenrock Limestone: (0.3ft.; 0.10m.) light gray-brown (weathers brown), platy to flaggy, argillaceous, skeletal calcilutite (mudstone); with ostracodes (including Bairdia-like), productids, crinoids, and fossil fragments; basal contact gradational.

17. Glenrock Limestone: (0.2ft.; 0.05m.) light gray (weathers light brown), slabby, slightly argillaceous, coarse skeletal calcarenite (wackestone to packstone); with intraclasts (2-4mm. in diameter, subrounded to subangular), ostracodes (including bairdia-like), high-spired gastropods (pyramidellid-like), and fossil fragments; basal contact sharp.

16. Johnson Shale: (1.8ft.; 0.56m.) dark olive-gray (weathers olive-brown), slightly calcareous, indurated, claystone; with root traces, root mottling, and intraclasts (3-4mm. in diameter, subrounded to subangular); basal contact gradational.

15. Johnson Shale: (1.2ft.; 0.36m.) dark olive-gray (weathers olive-brown), flaggy to slabby, slightly calcareous, mudstone; with mudcracks, ostracodes, and root traces; basal contact gradational.

14. Johnson Shale: (1.1ft.; 0.33m.) light brown (weathers same), flaggy to slabby, calcareous mudstone; with mudcracks, root traces, ostracodes, and iron stains; basal contact gradational.

13. Johnson Shale: (0.6ft.; 0.18m.) light brown (weathers same), flaggy to slabby, calcareous mudstone; with plant fragments on bedding surfaces, iron stains, and ostracodes; basal contact gradational.

12. Johnson Shale: (1.7ft. 0.51m.) medium brown (weathers light brown), flaggy, very argillaceous, skeletal calcilutite (mudstone); with ostracodes and mudcracks; basal contact gradational.

11. Johnson Shale: (1.3ft.; 0.41m.) medium brown (weathers light brown), flaggy, slightly argillaceous, skeletal calcilutite (mudstone); with ostracodes and mudcracks; basal contact sharp.

10. Johnson Shale: (0.3ft.; 0.10m.) light yellow-brown (weathers light brown), massive, unfossiliferous, mudstone; with gypsum filled vugs throughout; basal contact gradational.

9. Johnson Shale: (2.7ft.; 0.81m.) light maroon (weathers reddish brown), blocky, indurated, calcareous, slightly silty mudstone; with root traces; basal contact gradational.

8. Johnson Shale: (1.1ft.; 0.33m.) light green (weathers greenish brown), slightly indurated, slightly silty, mudstone; with root traces and root mottling; basal contact gradational.

7. Johnson Shale: (2.5ft.; 0.76m.) light yellow-brown to maroon (weathers reddish brown), slabby, very calcareous, mudstone; with root traces and slightly indurated; basal contact sharp.

6. Johnson Shale: (0.2ft.; 0.05m.) light gray-brown (weathers brown), argillaceous, skeletal calcilutite (mudstone); bioturbated; with fossil fragments; basal contact sharp.

5. Johnson Shale: (1.8ft.; 0.53m.) light gray-green (weathers greenish brown), slabby, slightly indurated, slightly silty, mudstone; with iron stains and root traces; basal contact sharp.

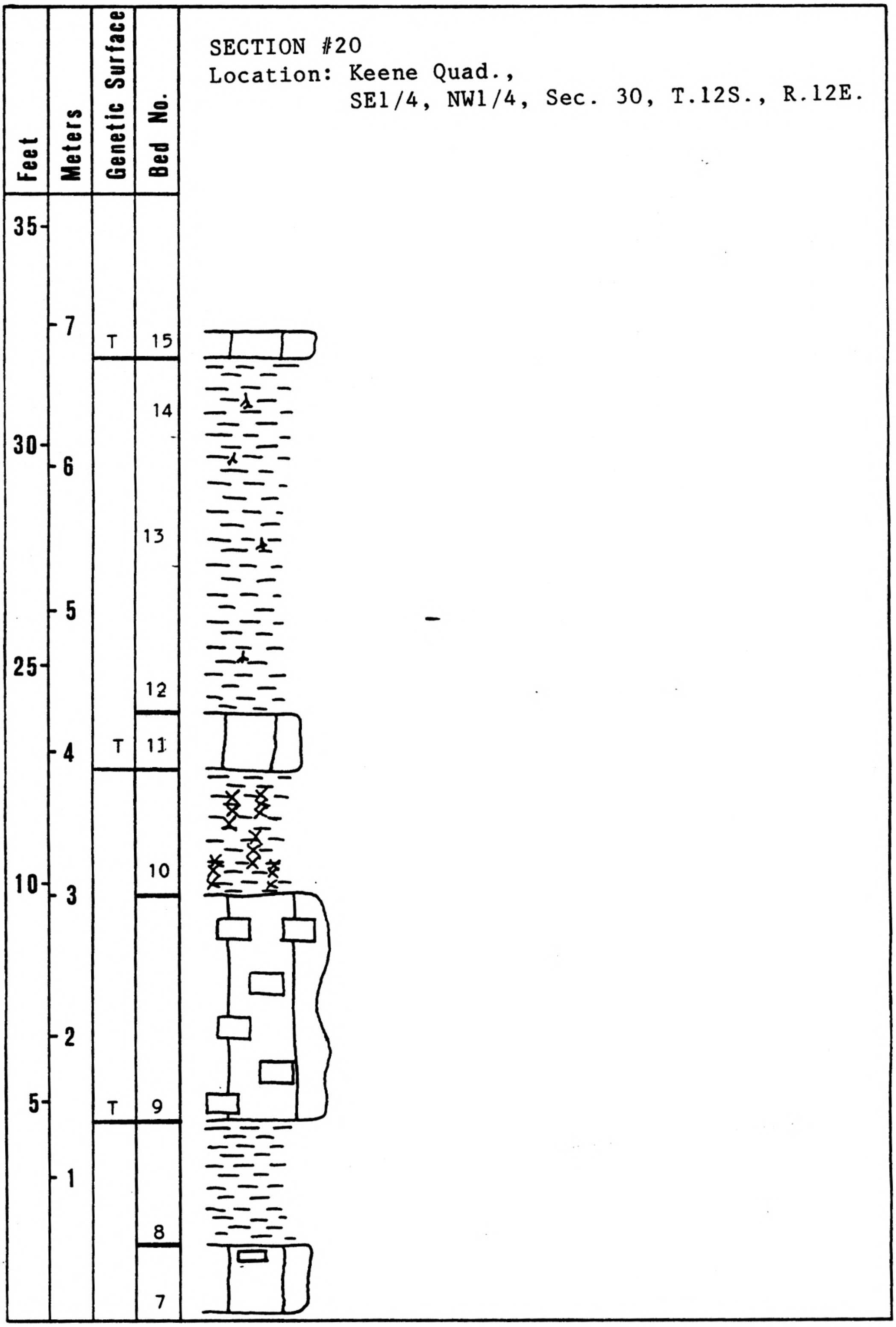
4. Johnson Shale: (1.0ft.; 0.30m.) light yellow-brown (weathers light brown), slabby, slightly argillaceous, calcilutite (mudstone); with iron stains and root traces; basal contact sharp.

3. Johnson Shale: (0.2ft.; 0.05m.) light brown (weathers same), platy, calcareous mudstone; with ostracodes; basal contact sharp.

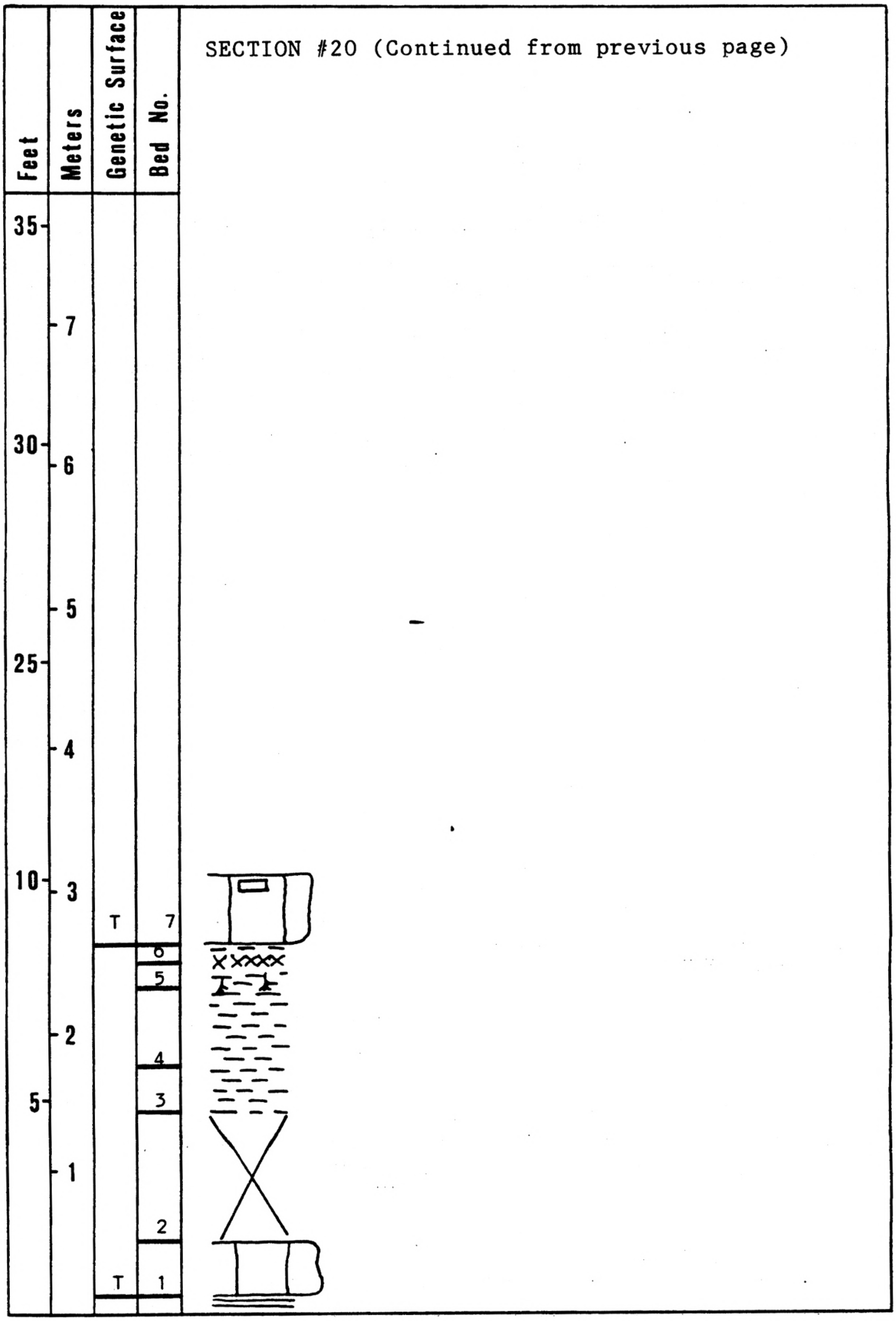
2. Johnson Shale: (0.3ft.; 0.10m.) dark olive-gray (weathers olive-brown), slabby, argillaceous, skeletal calcilutite (mudstone); with ostracodes and iron stains; basal contact sharp.

1. Johnson Shale: (0.5ft.; 0.15m.) light yellow-gray to light brown (weathers light brown), massive, slilghtly calcareous, unfossiliferous mudstone; basal contact covered.

SECTION #20
Location: Keene Quad.,
SE1/4, NW1/4, Sec. 30, T.12S., R.12E.



SECTION #20 (Continued from previous page)



SECTION #20 Old Quarry, Wabaunsee County, KS; Keene Quadrangle; SE1/4, NW1/4, SEC.30, T.12S., R.12E.; measured by Michael H. Clark (July 1987)

15. Sallyards Limestone: (0.6ft.; 0.18m.) light gray (weathers gray-brown), slabby, slightly argillaceous, skeletal calcilutite (wackestone); with algal biscuits (Osagia), Aviculopecten, large bivalves, productids, and Acanthopecten; basal contact sharp.

14. Roca Shale: (1.9ft.; 0.58m.) light yellow-brown (weathers light brown), blocky, slightly silty, mudstone; with iron stains and root traces; basal contact gradational.

13. Roca Shale: (3.1ft.; 0.94m.) varigated (light brown to light green, weathers greenish brown), blocky, calcareous, slightly silty, mudstone; with root traces, iron stains, and root mottling; basal contact gradational.

12. Roca Shale: (3.0ft.; 0.91m.) light olive-green (weathers olive-brown), blocky, calcareous, slightly silty, mudstone, with iron stains and rare root traces; basal contact sharp.

11. Roca Shale: (1.3ft.; 0.38m.) light gray (weathers light brown), slabby, skeletal calcilutite (mudstone); with ostracodes (including Bairdia-like) and high-spired gastropods (pyramidellid-like); basal contact sharp.

10. Roca Shale: (2.8ft.; 0.86m.) light green to gray (weathers light greenish brown), massive, rooted, calcified ped horizon; weathers blocky-crumbly, with microslickensides; basal contact sharp.

9. Roca Shale: (5.2ft.; 1.57m.) light gray (weathers gray-brown), massive (with very vuggy structure), boxwork calcilutite (mudstone); vugs are due to dissolution of evaporites; basal contact sharp.

8. Roca Shale: (2.8ft.; 0.86m.) varigated (light green to maroon, weathers reddish brown), blocky-crumbly, mudstone; with caliche nodules and root traces; basal contact sharp.

7. Roca Shale: (1.5ft.; 0.46m.) light gray-brown (weathers pale orange-brown), slabby, argillaceous, algal laminated, skeletal calcilutite (mudstone), the upper 10cm. very vuggy; with ostracodes (including Bairdia-like), high-spired gastropods (pyramidellid-like), and fossil fragments; basal contact sharp.

6. Roca Shale: (0.3ft.; 0.08m.) light brown (weathers same), blocky, calcareous, mudstone; with root traces and iron stains; basal contact sharp.

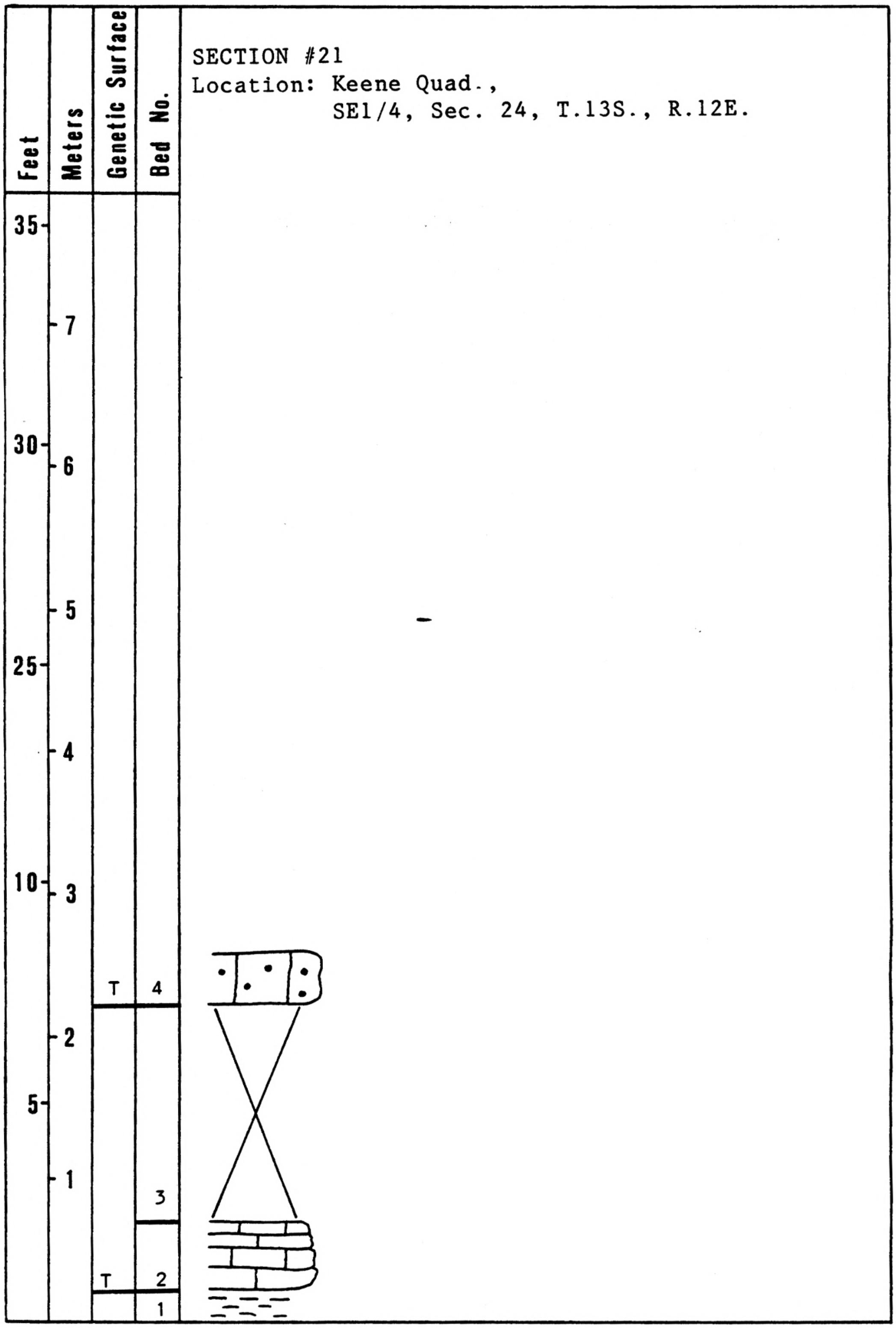
5. Roca Shale: (0.6ft.; 0.18m.) light brown to olive-brown (weathers same), calcrete; with sparite filled vugs, root traces, and root mottling; basal contact sharp.

4. Roca Shale: (1.9ft.; 0.58m.) light brown to gray (weathers brown), blocky, slightly calcareous, silty, mudstone; with root traces, root mottling, iron stains, and a thin (1cm. thick) caliche horizon 24cm. from the top of this unit; basal contact gradational.

3. Roca Shale: (1.1ft.; 0.33m.) light gray (weathers grayish brown), blocky, slightly silty, unfossiliferous mudstone; with iron stains; basal contact covered.

2. Roca Shale: (3.2ft.; 0.97m.) COVERED.

1. Howe Limestone: (1.3ft.; 0.38m.) light brown (weathers pale orange-brown), slabby to blocky, skeletal calcilutite (wackestone); highly weathered; with coated grains (Osagia), brachiopod fragments, ostracodes and hemispheroidal stromatolites; basal contact covered.


Feet
Meters
Genetic Surface
Bed No.
SECTION #21
Location: Keene Quad.,
SE1/4, Sec. 24, T.13S., R.12E.
35
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2
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SECTION #21 Keene, Wabaunsee County, KS; Keene Quadrangle; SE1/4, SEC.24, T.13S., R.12E.; measured by Michael H. Clark (July 1987)

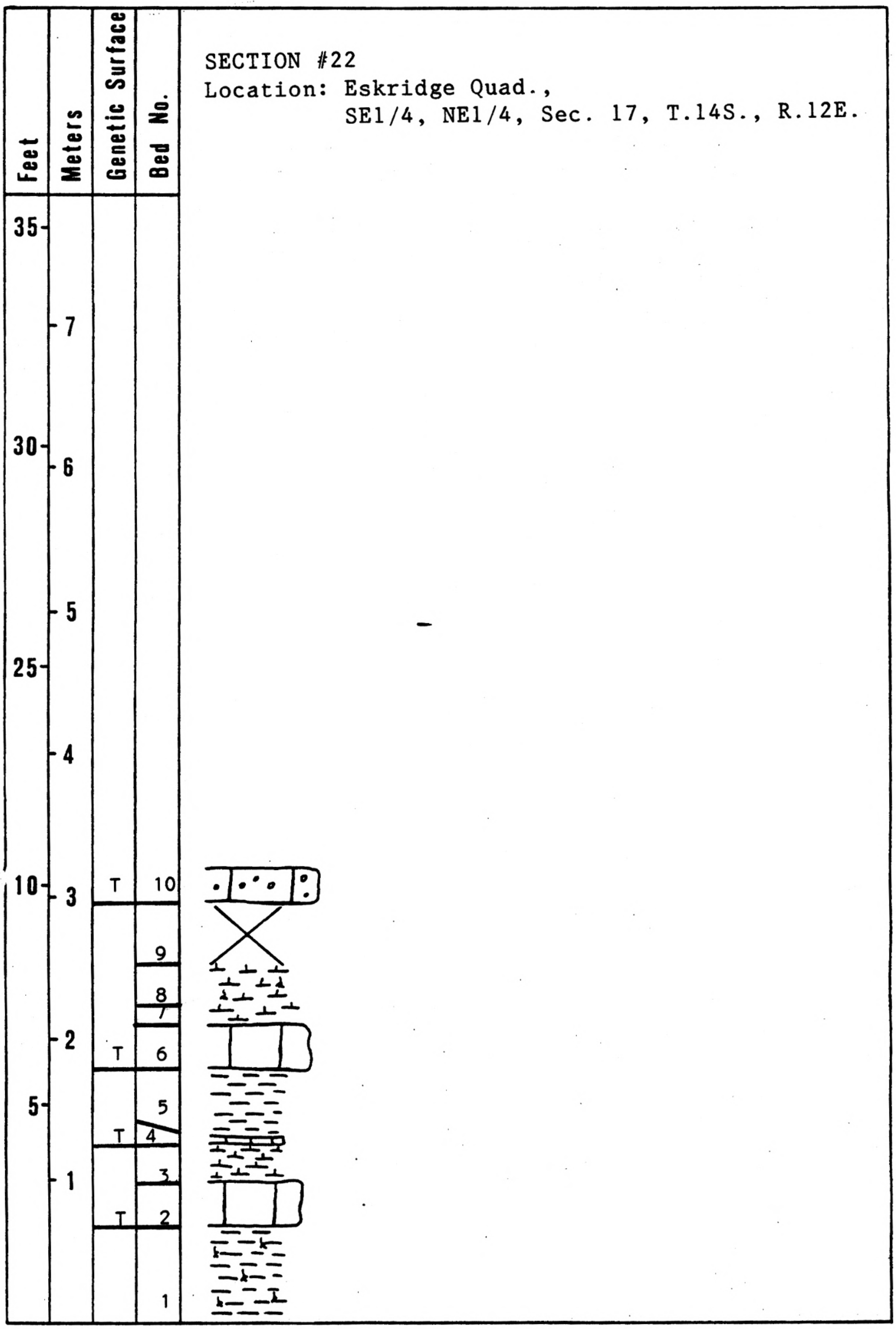
5. Bennett Shale: COVERED.

4. Glenrock Limestone: (1.2ft.; 0.36m.) light gray-brown (weathers pale orange-brown), massive, skeletal calcarenite to calcirudite (wackestone to packstone); with fusulinids, Aviculopecten, bryozoans, productids, intraclasts (2-3mm. in diameter, subrounded) and fossil fragments (brachiopod); basal contact sharp.

3. Johnson Shale: (5.0ft.; 1.52m.) COVERED.

2. Johnson Shale: (1,5ft.; 0.46m.) light gray-brown (weathers light brown), flaggy to slabby, slightly argillaceous, calcilutite (mudstone); thinly laminated; with mudcracks; basal contact covered.

1. Johnson Shale: (0.5ft.; 0.15m.) light green (weathers greenish brown), slightly calcareous, silty, unfossiliferous mudstone; basal contact covered.


Feet
Meters
Genetic Surface
Bed No.
SECTION #22
Location: Eskridge Quad.,
SE1/4, NE1/4, Sec. 17, T.14S., R.12E.
35
30
25
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7
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5
4
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SECTION #22 south of skridge, Wabaunsee County, KS; Eskridge Quadrangle; SE1/4, NE1/4, SEC.17, T.14S., R.12E.; measured by Michael H.Clark (July 1987)

10. Glenrock Limestone: (0.8ft.; 0.23m.) light gray-brown (weathers brown), massive, slightly argillaceous, skeletal calcarenite (wackestone-packstone); with fusulinids, ostracodes (including Bairdia-like), ramose bryozoans, intraclasts (2-4m . in diameter, subrounded to subangular), and brachiopod fragments; basal contact sharp.

9. Johnson hale: (1.3ft.; 0.43m.) COVERED AND HIGHLY WEATHERED.

8. Johnson Shale: (1.0ft.; 0.30m.) light brown (weathers same), platy to slightly indurated, calcareous mudstone; with mudcracks and root traces; basal contact gradational.

7. Johnson Shale: (0.5ft.; 0.15m.) light brown (weathers same), platy, calcareous mudstone; with mudcracks; basal contact gradational.

6. Johnson Shale: (0.9ft.; 0.28m.) light gray-brown (weathers light brown), flaggy to slabby, slightly argillaceous, laminated calcilutite (mudstone); with mudcracks; basal contact sharp.

5. Johnson Shale: (1.6ft.; 0.48m.) varigated (maroon-green-gray-brown, weathers reddish brown), blocky-crumbly, indurated, unfossiliferous, silty mudstone; with iron stains; basal contact sharp.

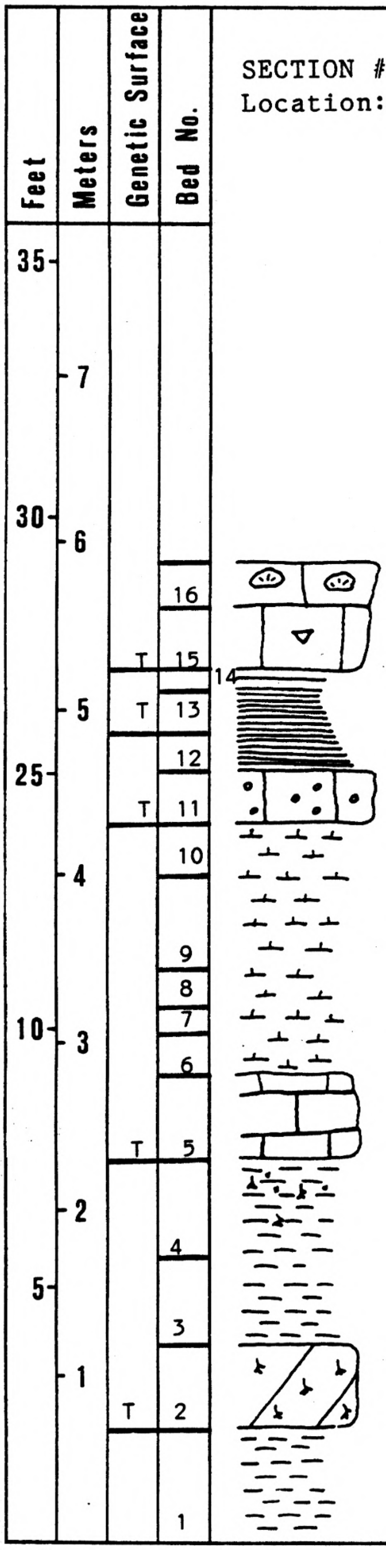
4. Johnson Shale: (0.2ft.; 0.05m.) light gray-brown (weathers light brown), flaggy, argillaceous calcilutite (mudstone); with iron stains; basal contact sharp.

3. Johnson Shale: (0.8ft.; 0.25m.) light yellow-gray (weathers light brown), massive, slightly silty, unfossiliferous, calcareous mudstone; slightly indurated; basal contact sharp.

2. Johnson Shale: (1.0ft.; 0.30m.) light green to brown (weathers greenish brown), slabby, argillaceous calcilutite (mudstone); with iron stains; basal contact sharp.

1. Johnson Shale: (2.0ft.; 0.61m.) light brown (weathers same), massive, calcareous, slightly silty, mudstone; with iron stains and root traces; basal contact covered.

SECTION #23
Location: Eskridge Quad.,
C., Sec. 36, T.14S., R.11E.



SECTION #23 southwest of Eskridge, Wabaunsee County, KS; Eskridge Quadrangle; C., SEC.36, T.14S., R.11E.; measured by Michael H. Clark (July 1987)

17. Roca Shale: COVERED

16. Howe Limestone: (0.9ft.; 0.28m.) light brown (weathers pale orange-brown), massive, skeletal calcarenite (wackestone to packstone); well sorted; with coated grains (Osagia), fossil fragments, ostracodes, hemispheroidal stromatolites; basal contact gradational.

15. Howe Limestone: (1.2ft.; 0.36m.) light brown (weathers pale orange-brown), massive, skeletal calcilutite (wackestone); with productids, large (5-7cm. in diameter;) chert filled burrows (Thalassinoides?), ostracodes, coated grains (Osagia), and fossil fragments; basal contact sharp.

14. Bennett Shale: (0.3ft.; 0.10m.) light gray to brown (weathers brown), platy, mudstone; with (20-30%) Orbiculoidea, ostracodes, productids, and fossil fragments; basal contact gradational.

13. Bennett Shale: (0.9ft.; 0.28m.) dark gray (weathers brown), platy, mudstone; with rare (10-15%) Orbiculoidea, sharks teeth, and ostracodes; basal contact sharp.

12. Bennett Shale: (0.8ft.; 0.23m.) black (weathers brown), fissile to platy shale/mudstone; with rare plant fragments; basal contact sharp.

11. Glenrock Limestone: (1.0ft.; 0.30m.) medium brown (weathers light brown), massive, skeletal calcarenite (wackestone to packstone); with fusulinids, Aviculopectens, productids, echinoid spines, intraclasts (2-4mm. in diameter, subrounded to subangular),and brachiopod fragments; basal contact sharp.

10. Johnson Shale: (1.1ft.; 0.33m.) light brown (weathers same), indurated, calcareous mudstone; with mudcracks; basal contact gradational.

9. Johnson Shale: (2.0ft.; 0.61m.) light gray (weathers light brown), flaggy to slabby, calcareous, mudstone; with mudcracks; basal contact gradational.

8. Johnson Shale: (0.8ft.; 0.23m.) light brown (weathers brown), flaggy, calcareous mudstone; with mudcracks; basal contact gradational.

7. Johnson Shale: (0.3ft.; 0.10m.) light gray (weathers brown), flaggy, calcareous mudstone; with mudcracks; basal contact gradational.

6. Johnson Shale: (0.8ft.; 0.25m.) light brown (weathers brown), slabby, calcarous mudstone; with mudcracks; basal contact sharp.

5. Johnson Shale: (1. ft.; 0.51m.) light gray (weathers light brown), skeletal calcilutite (mudstone); with ostracodes (including Bairdia-like); basal contact sharp.

4. Johnson Shale: (2.0ft.; 0.61m.) maroon (weathers reddish brown), massive, indurated, calcareous, mudstone; with intraclasts (4-5mm. in diameter, subrounded to subangular), and root traces; basal contact sharp.

3. Johnson Shale: (1.6ft.; 0.48m.) light brown to light olive-green (weathers olive-brown), massive to slightly indurated, unfossiliferous, calcareous mudstone; slightly silty; basal contact sharp.

2. Johnson Shale: (1.7ft.; 0.51m.) light brown to light green (weathers light brown), massive, root mottled, dololutite (mudstone); basal contact sharp.

1. Johnson Shale: (2.1ft.; 0.64m.) varigated (brown-olive-gray, weathers olive-brown), massive, slightly calcareous, unfossiliferous mudstone; basal contact covered.

HIERARCHAL GENETIC STRATIGRAPHY OF THE
RED EAGLE LIMESTONE AND ROCA SHALE FORMATIONS
(LOWER PERMIAN) IN NORTHEAST KANSAS

by

Michael H. Clark

B.S., Kansas State University, 1986

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AN ABSTRACT OF A THESIS

submitted in partial fullfillment of the

requirements for the degree

MASTER OF SCIENCE

(Geology)

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1989

## A B S T R A C T

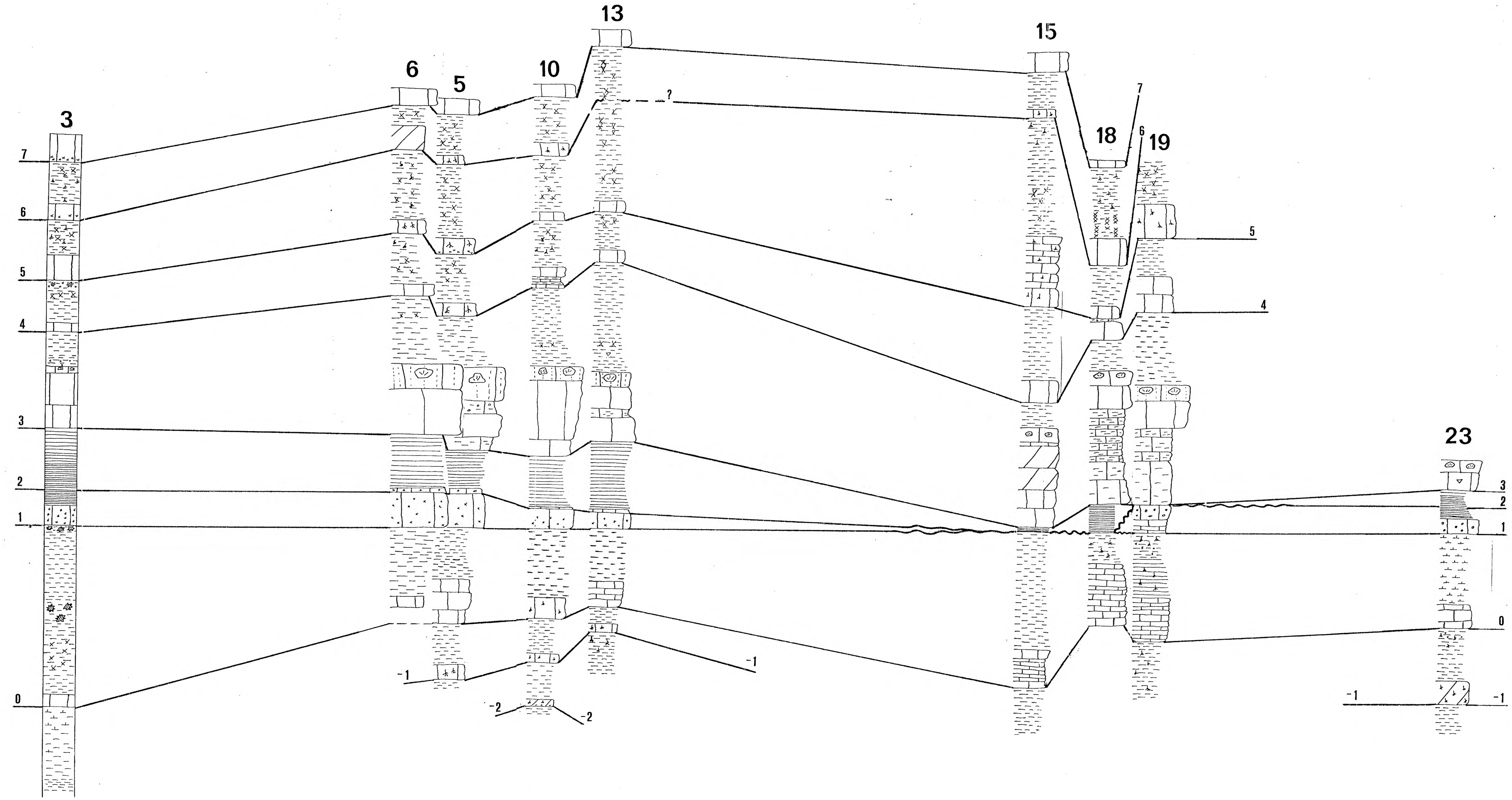
The Red Eagle Limestone and Roca Shale formations compose one net transgressive-regressive unit, that is equivalent to a fifth-order T-R unit of Busch and Rollins (1984), and represents an interval of about 300-500 Ka. This net transgressive-regressive (fifth-order) unit is composed of six smaller scale (sixth-order) T-R units, which are approximately one meter thick and shallow upwards. These "packages" are bounded by genetic surfaces (i.e., transgressive-regressive surfaces). The sixth-order T-R units are numbered from 1 at the base of the fifth-order T-R unit, through 6 at the top of the fifth-order T-R unit.

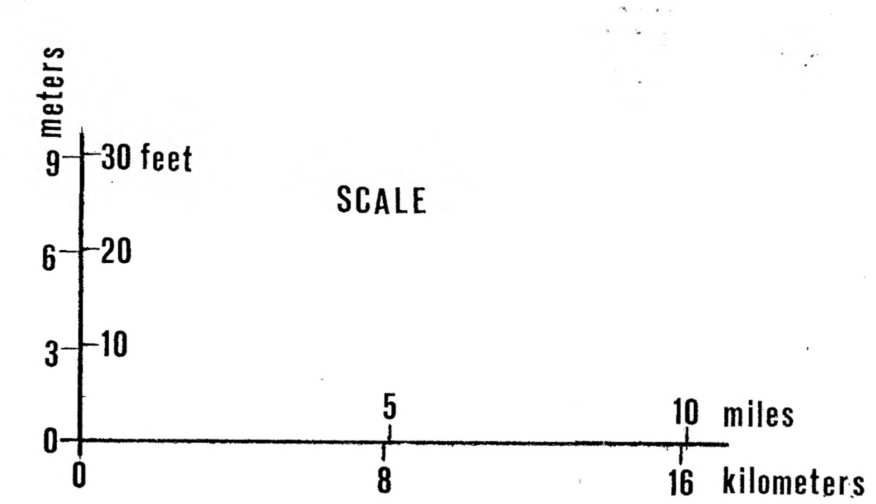
Detailed paleogeographic maps were constructed for the times of maximum transgression and regression of each sixth-order T-R unit. These paleogeographic reconstructions illustrate the development of the Red Eagle fifth-order T-R unit as a series of smaller scale (sixth-order) transgressive-regressive units. Temporally and spatially recurring facies changes allude to topographic "highs" and "lows", that were possibly structurally influenced and periodically reactivated, thus influencing sedimentation patterns.

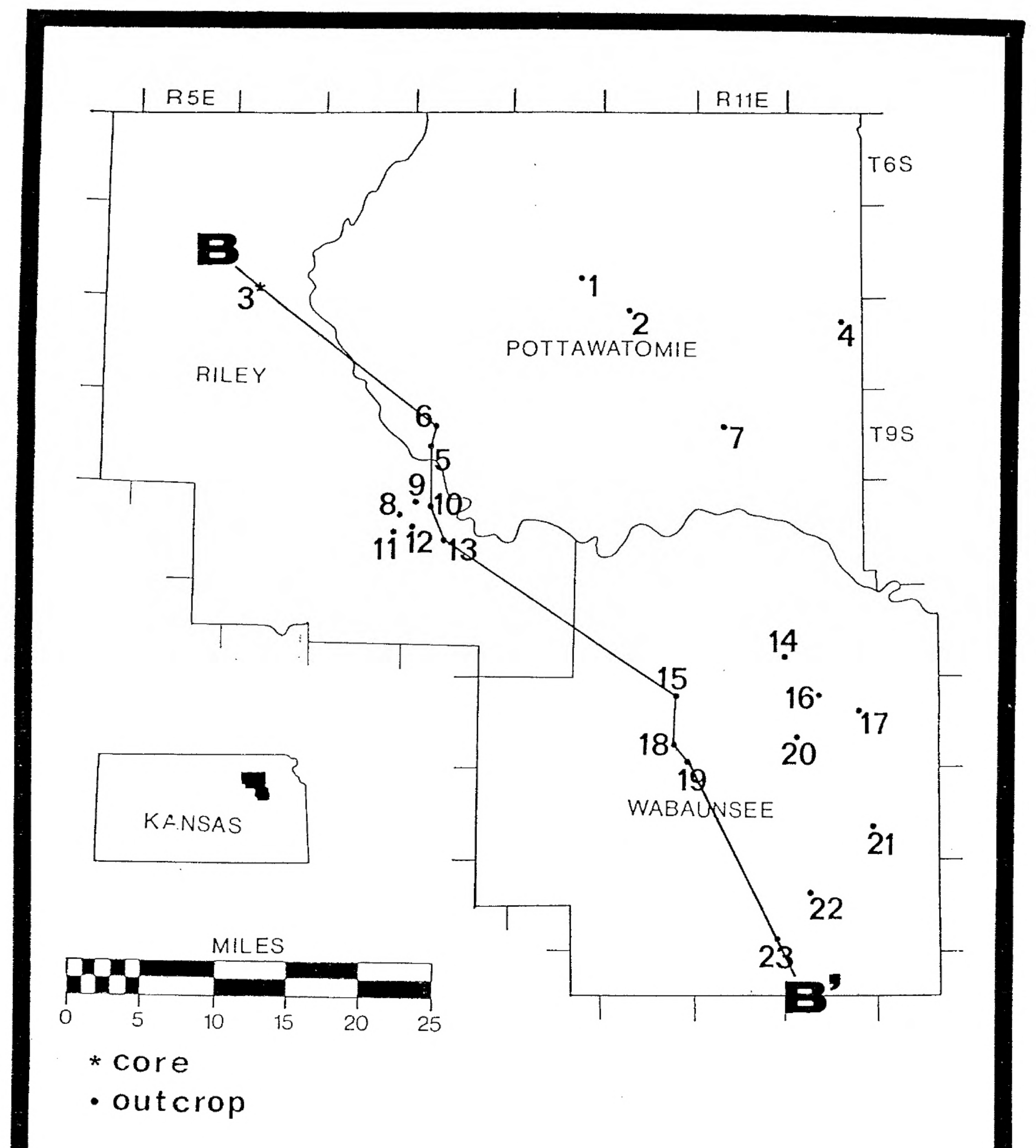
Two cross sections constructed in a northeast-southwest (A-A') and northwest-southeast (B-B') direction

show thinning and even nondeposition and/or erosion (i.e., subaerial exposure) over topographic highs. These cross sections also support the paleogeographic reconstructions and inferred topographic "highs" and "lows".

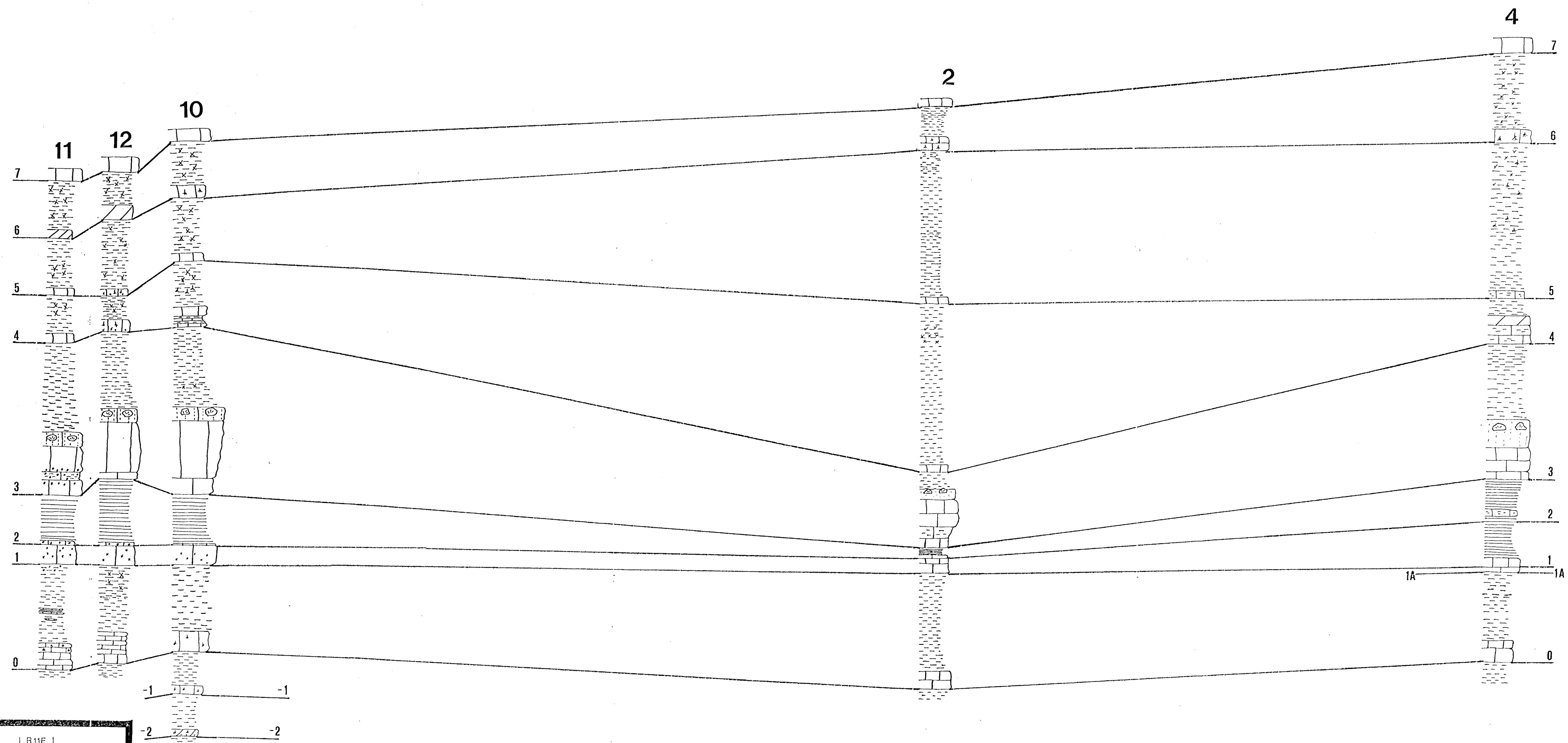
The sixth-order T-R unit #2 represents a time when the sea level stand and freshwater input into the basin were at their highest. These conditions were induced by a warm and humid (wet) climate (i.e., climate driven). High terrigenous influxs increased turbidity and "posioned" carbonate production. The freshwater influx also combined with normal temperature gradient to produce a strong density stratification, envoking anoxic conditions (i.e., black shale/mudstone - Bennett Shale). However, anoxic conditions were interrupted by periods of sediment oxygenation allowing for the establishment of infaunal organisms.

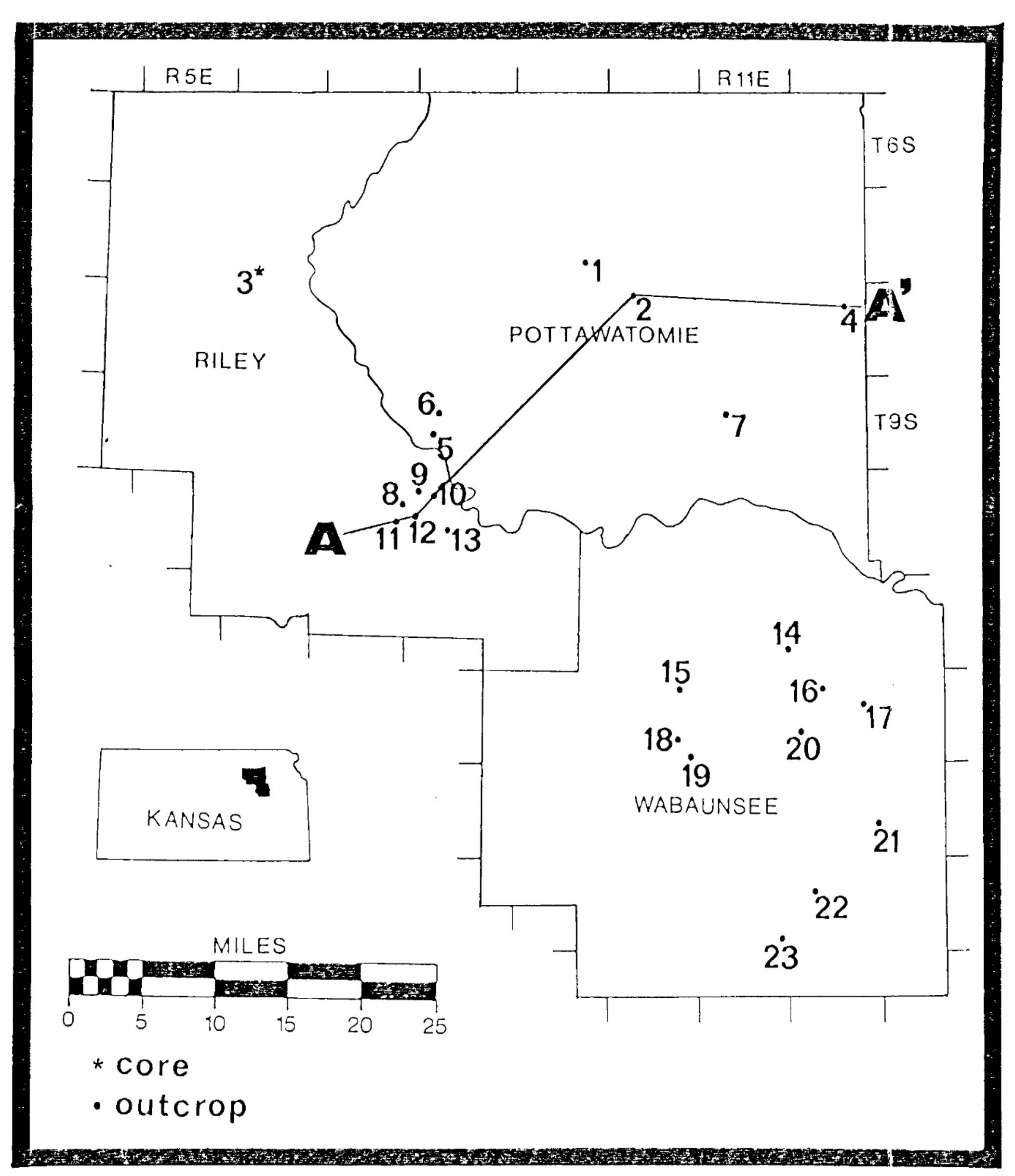


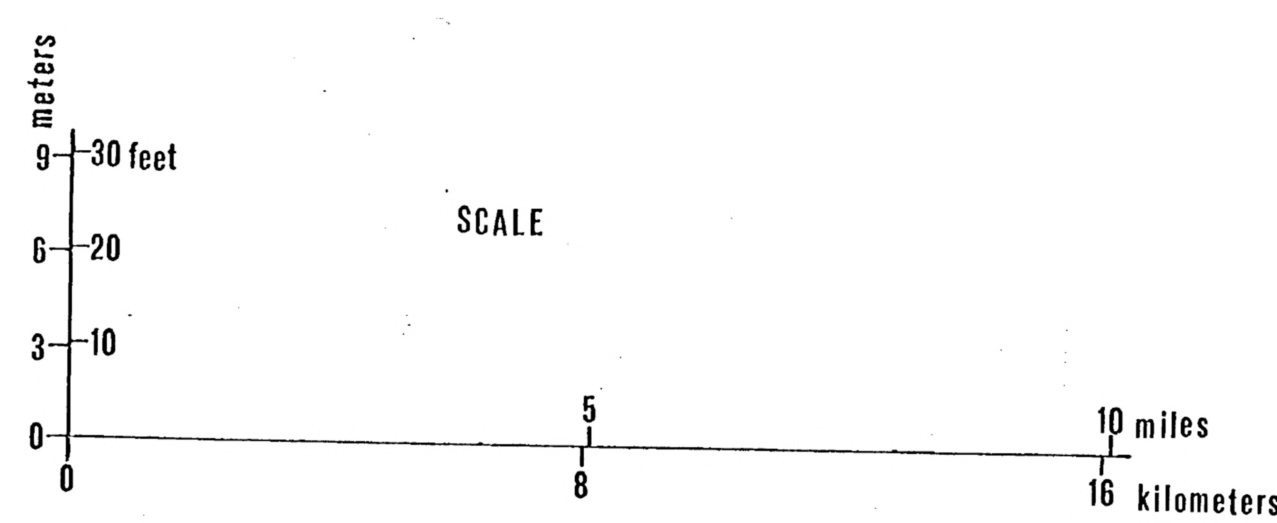




CORRELATION OF SIXTH-ORDER TRANSGRESSIVE-REGRESSIVE UNITS
OF THE RED EAGLE LIMESTONE-ROCA SHALE FORMATIONS

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