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CONODONT-BASED CORRELATION OF MAJOR CYCLOTHEMS IN LOWER CHEROKEE GROUP (LOWER DESMOINESIAN, MIDDLE PENNSYLVANIAN), OKLAHOMA TO IOWA

by

Thomas Robert Marshall

An Abstract

Of a thesis submitted in partial fulfillment
of the requirements for the Doctor of
Philosophy degree in Geoscience
in the Graduate College of
The University of Iowa

May 2010

Thesis Supervisor: Professor Philip H. Heckel

ABSTRACT

Three named major cycles of marine transgression and regression (cyclothems) in the lower Cherokee Group are recognized from the Arkoma Basin margin in east-central Oklahoma across the northern Midcontinent shelf, on the basis of distinctive conodont morphotypes. The lowest of these (McCurtain) is characterized by *Idiognathodus* cf. *praeobliquus* and absence of *I. obliquus* and *Idiognathoides*. The middle cyclothem (Doneley) is the first major cyclothem to yield *I. obliquus*. The uppermost (Inola) yielded abundant *Idiognathodus*, *Neognathodus* and *Idioprioniodus*, and sparse *Gondolella*, and is characterized by large numbers of *Idiognathodus podolskensis*. All three contain large numbers of *I. amplificus*. At the base of the succession, the genus *Idiognathoides* in three cores from northeastern Kansas to south-central Iowa confirms the presence of Atokan strata in the Forest City Basin.

The McCurtain cyclothem extends from Oklahoma to the Forest City Basin in northeastern Kansas. The Doneley and Inola cyclothems extend from Oklahoma into Iowa. The Inola Limestone of Oklahoma is equivalent to the Hackberry Branch Limestone of western Missouri. The Bluejacket Coal of Oklahoma, at the base of the Inola cyclothem, is likely equivalent to Bluejacket A Coal of Kansas, Weir B or C coals in Missouri, and a middle Laddsdale coal in Iowa. The Rowe Coal of Oklahoma, Kansas, and Missouri, at the base of the Doneley cyclothem, is likely equivalent to the Cliffland Coal of Iowa. Inconsistent marine lithofacies in all three cyclothems suggest a complex depositional history on irregular surfaces.

Abstract Approved: _____
Thesis Supervisor

_____
Title and Department

_____
Date

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Graduate College
The University of Iowa
Iowa City, Iowa

CERTIFICATE OF APPROVAL

PH.D. THESIS

This is to certify that the Ph.D. thesis of

Thomas Robert Marshall

has been approved by the Examining Committee
for the thesis requirement for the Doctor of Philosophy
degree in Geoscience at the May 2010 graduation.

Thesis Committee: _____
Philip H. Heckel, Thesis Supervisor

_____
E. Arthur Bettis

_____
Robert L. Brenner

_____
James Puckette

_____
Jeffry Schabilion

_____
Brian Witzke

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Kristy Hanley's work on the middle Cherokee Group provided the foundation for my project, and her work on the Upper Tiawah cyclothem helped me correlate the Inola cyclothem. She helped me in core sampling, describing sections, and field work and also provided measured sections, maps, and information on conodonts, making it possible for me to finish. John P. Pope went with me to outcrops, made suggestions to facilitate sample processing, and engaged in vigorous discussions on Cherokee stratigraphy. I look forward to working with him in future collaborations.

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ABSTRACT

Three named major cycles of marine transgression and regression (cyclothems) in the lower Cherokee Group are recognized from the Arkoma Basin margin in east-central Oklahoma across the northern midcontinent shelf, on the basis of distinctive conodont morphotypes. The lowest of these (McCurtain) is characterized by *Idiognathodus* cf. *praeobliquus* and absence of *I. obliquus* and *Idiognathoides*. The middle cyclothem (Doneley) is the first major cyclothem to yield *I. obliquus*. The uppermost (Inola) yielded abundant *Idiognathodus*, *Neognathodus*, *Idioprioniodus*, and sparse *Gondolella*, and is characterized by large numbers of *Idiognathodus podolskensis*. All three contain large numbers of *I. amplificus*. At the base of the succession, the genus *Idiognathoides* in three cores from northeastern Kansas to south-central Iowa confirms the presence of Atokan strata in the Forest City Basin.

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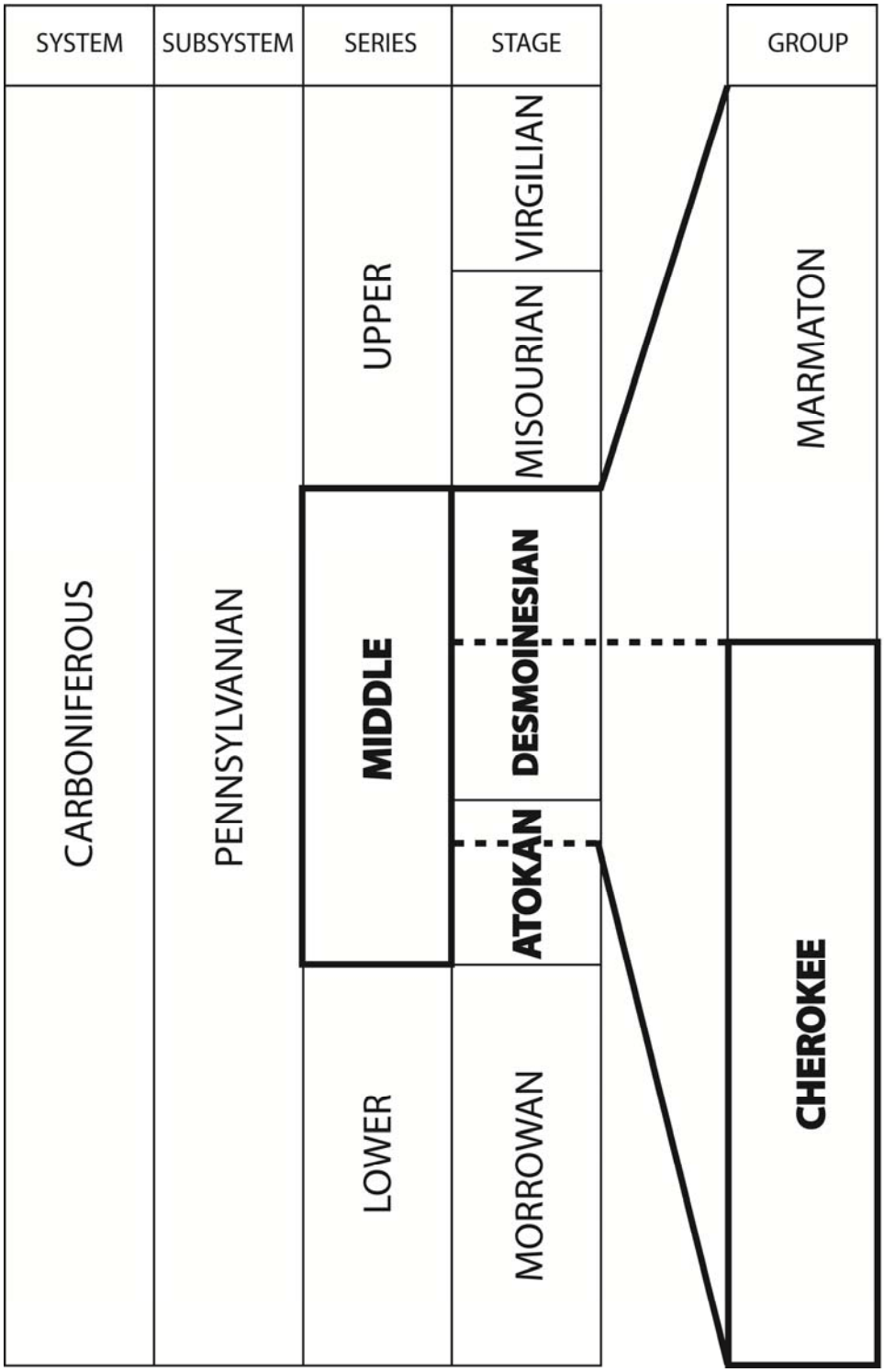
CHAPTER I

INTRODUCTION

Despite being noted for its highly repetitive sequences of sandstones, shales, limestones, underclays and importantly, coals, little recent work has been done on the sequence stratigraphy and biostratigraphic correlation of the lower Desmoinesian Cherokee Group. Most previous workers in the Cherokee Group (e.g. Abernathy, 1936; Searight and others, 1953) dealt with resolving issues of stratigraphic nomenclature rather than interpretive stratigraphy. More recent interpretative stratigraphic work (see Heckel, 2002) dealt only with upper Desmoinesian through lower Virgilian strata, leaving a significant gap in the lower Desmoinesian.

The Cherokee Group lies entirely within the Desmoinesian Stage in Oklahoma and within the Desmoinesian and Atokan stages in Kansas, Missouri, and Iowa; both stages are in the Middle Pennsylvanian Series, Pennsylvanian Subsystem, and Carboniferous System (Figure 1). The Cherokee Group overlies the Atoka Formation in the Arkoma Basin of east-central Oklahoma and Mississippian strata in Kansas and northward, and it is essentially conformable beneath the overlying Marmaton Group. In Oklahoma, Missouri, and Kansas, the Cherokee Group is divided into two subgroups: the Krebs and Cabaniss (Figures 2 and 3). In Oklahoma, the Cherokee Group is further divided into five formations in ascending order: Hartshorne, McAlester, Savanna, Boggy (in the Krebs Subgroup), and Senora (in the Cabaniss). The other states divide the Cherokee Group into a number of different formations, many of which are recognized only as members or beds in Oklahoma. In Iowa, the Cherokee Group is divided into the Kilbourn, Kalo, Floris, and Swede Hollow Formations.



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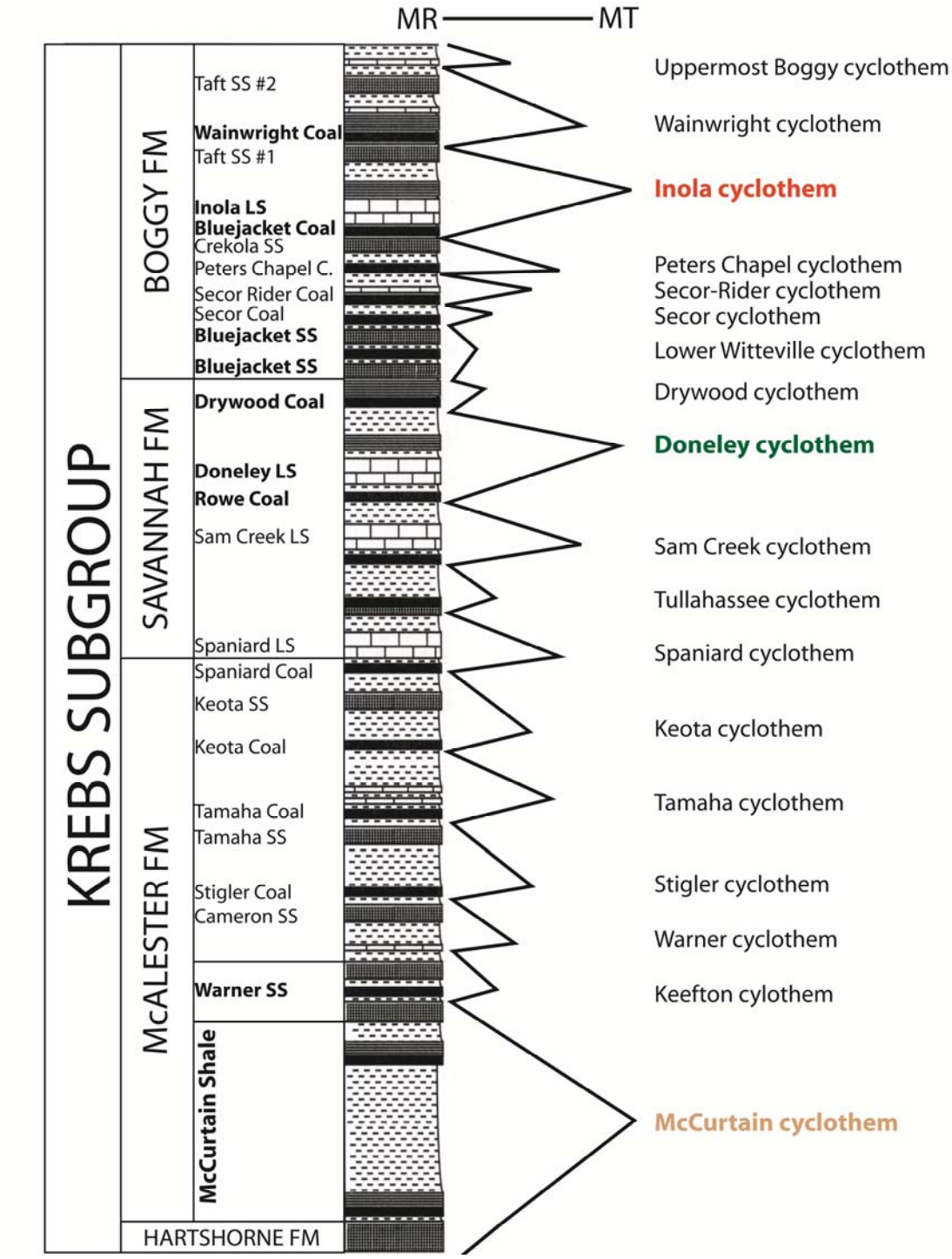


Figure 2. Marine transgressive-regressive cycles (cyclothems) recognized in lower Cherokee Group in eastern Oklahoma (Marshall, 2002) with sea-level curve modified from Boardman and others (2002) by Boardman and others (2004); colored names indicate units that have been thought to be regionally extensive, MR- maximum regression, MT-maximum transgression.

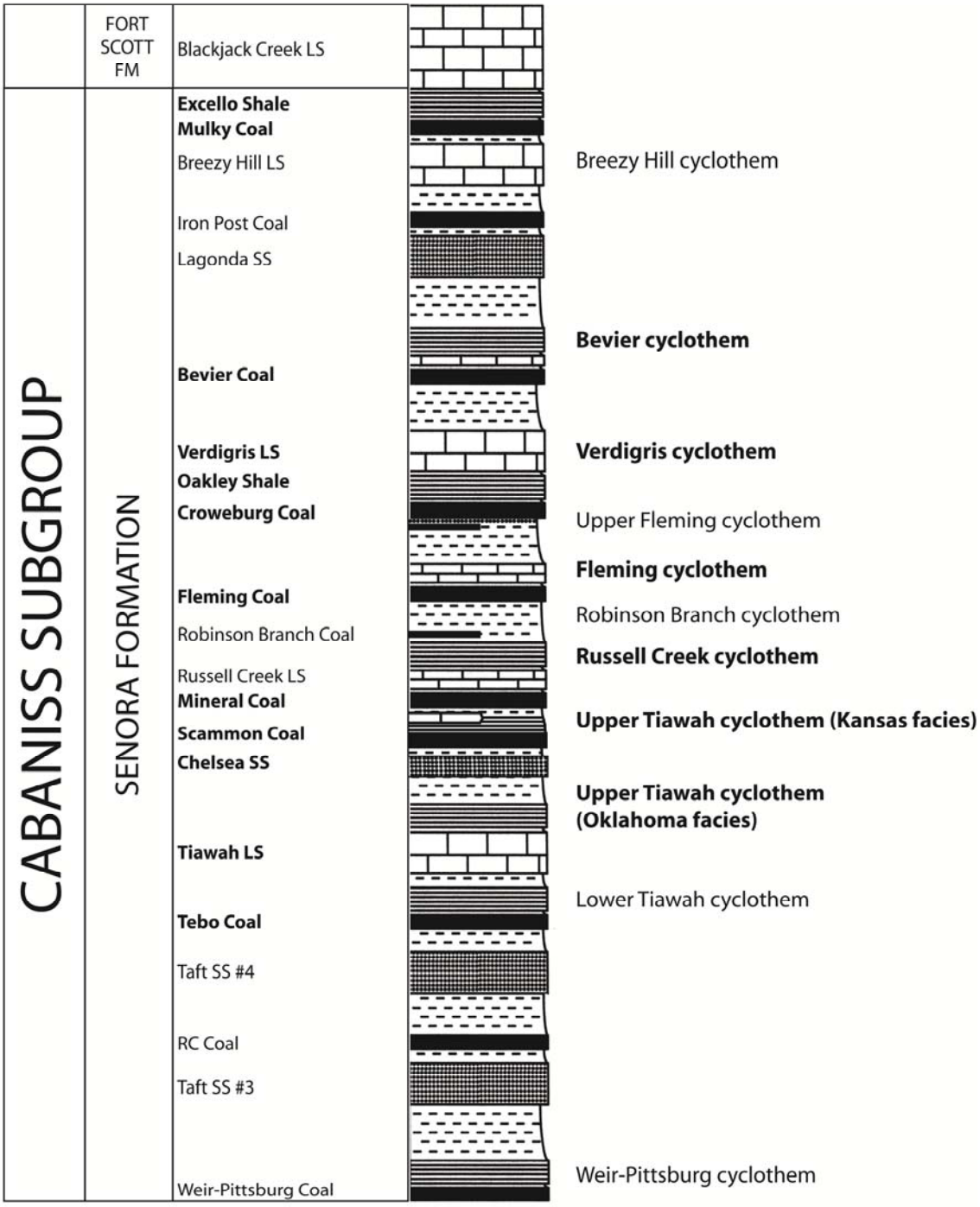


Figure 3. Composite section of marine transgressive-regressive cycles (cyclothems) recognized in middle and upper Cherokee Group in eastern Oklahoma and southeastern Kansas by Marshall (2002) and Hanley (2008); bolded names indicate units that are thought to be regionally extensive.

Previous Work

Describing a succession of coal, shale, limestone, sandstone, and fire clay near Peoria, Illinois, Udden (1912) was the first to denote the cyclical nature of the Midcontinent Pennsylvanian (Heckel, 1984, p. 535). Wanless and Weller (1932, p.1003) established the term cyclothem and attempted the first regional correlation of the cyclothems of Illinois, Iowa, western Missouri, eastern Kansas, and northeastern Oklahoma. Wanless and Shepard (1936) proposed as the drivers of cyclic deposition the growth and shrinkage of glaciers in the Southern Hemisphere resulting in eustatic sea-level changes. Moore (1936, p.24) established an "ideal cyclothem" of the Midcontinent Pennsylvanian, consisting initially of the following:

> ". 9. Shale (and coal).
> .8. Shale, typically with molluscan fauna.
> .7. Limestone, algal, molluscan, or with mixed molluscan and molluscoid fauna
> .6. Shale, molluscoids dominant.
> .5. Limestone, contains fusulinids, associated commonly with molluscoids.
> .4. Shale, molluscoids dominant.
> .3. Limestone, molluscan, or with mixed molluscan and molluscoid fauna.
> .2. Shale, typically with molluscan fauna.
> .1. *c*. Coal
> .1. *b*. Underclay
> .1. *a*. Shale, may contain land plant fossils.
> .0. Sandstone."

According to Moore (1936, p.25), the nonmarine portions of the cyclothem were members .0, .1, and .9, with .9 being part of the regressive phase, while members .2 to .8 were the marine portions, with .2 being part of the transgressive phase. Ferm (1970) proposed the hypothesis of 'delta switching' to explain Appalachian cyclothems. Heckel (1977) developed the concept that the black phosphatic shales (core shales) were

deposited during the deepest marine highstands. Swade (1985) described the conodont faunas of the upper part of the Cherokee Group, but used open nomenclature.

Haworth and Kirk (1894) established the name “Cherokee Shale” in southeastern Kansas. Early studies of the Cherokee Group centered on coal exploration and production (e.g., Chance, 1890, Taff, 1899, 1904; Hendricks and others, 1936; and Dane and others, 1938) in southeastern Oklahoma.

Abernathy (1936, p.60) recognized a more simplified Cherokee cycle by removing the two upper limestones (.5, .7) and most of the upper shales (.4, .6, and .8) from Moore’s “ideal cyclothem”. He divided the Cherokee Group into 15 cyclothems, separated by disconformities (1936, p. 61). It should be noted that Abernathy’s cyclothem better represents a “realistic” Cherokee cyclothem than does Moore’s “ideal cyclothem”.

Moore (1949) elevated the “Cherokee Shale” to “Cherokee Group”. Searight and others (1953), utilizing coal cycles, divided the Cherokee Group into 18 “formations” and also proposed dropping the term “Cherokee Group” in favor of the Krebs and Cabaniss Groups. However, according to Howe (1956), the term “Cherokee Group” was reinstated at a meeting in Lawrence, Kansas in 1955. Howe (1956) produced a seminal work describing and discussing many of the lithostratigraphic units of the Cherokee Group in Missouri, Kansas, and Oklahoma, and providing the basis for the current lithostratigraphic classification and nomenclature in Missouri.

Marshall (2002) recognized and described 28 separate units of marine transgressive-regressive (T-R) cycles within the Cherokee Group from the Arkoma Basin in southeastern Oklahoma to the Northern Oklahoma Shelf in extreme northeastern

Oklahoma and southeastern Kansas. These repeated T-R cycles are typically genetic coal-bearing cycles or cyclothems, bounded by exposure surfaces at the tops of paleosols or at the base of incisement surfaces. Utilizing these 28 T-R cycles, Boardman and others (2002) established a modern cyclothem succession and a sea-level curve for the most complete Cherokee succession in the Midcontinent, which was updated by Boardman and others (2004) (Figure 2).

The Study Area

The area of study for this project extends from the Arkoma Basin in east-central Oklahoma, through the shelf area in northeastern Oklahoma and southeastern Kansas, over the Bourbon Arch in east-central Kansas and western Missouri, and through the Forest City Basin in northeastern Kansas, northwestern Missouri, and southwestern Iowa to the northern shelf area in central Iowa (Figure 4). Due to the paucity of outcrops of long sections, most work involved long cores from Kansas, Missouri, and Iowa (Figure 4). However, outcrops with stratigraphic significance were included, particularly those in the type areas of major cyclothems: Inola Hill in Rogers County, Oklahoma, the type area for the Inola Limestone Member of the Boggy Formation; the type Doneley Limestone Member of the Savanna Formation in central Craig County, Oklahoma; the type McCurtain Shale in Pittsburg County, Oklahoma; the type locality of the Hackberry Branch Limestone in southwestern Vernon County, Missouri; and the type Laddsdale coal interval in Davis County, Iowa (Figure 4).

Figure 4. Locations of cores and outcrops used in this study. Dots indicate location of cores and triangles of significant surface exposures; gray shaded area indicates approximate outcrop belt of Cherokee Group. Tectonic features outlined in dark blue. Line of correlation in red.

Field Methods

Marshall (2002) studied the cyclothems in the entire Cherokee succession in northeastern Oklahoma, and the original purpose of the current work was to extend all this work northward. Initial work, however, showed that the Cherokee succession in Kansas, Missouri, and Iowa is far more complex than originally thought. Therefore, in order to ensure timely completion of research, the project was limited to the lower Cherokee (Krebs Subgroup) below the Weir-Pittsburg coal. K.D. Hanley (2008), another PhD student of P.H. Heckel, worked up the middle of the Cherokee Group from the Weir-Pittsburg coal to the Verdigris Limestone. The upper Cherokee interval from the Verdigris Limestone to the Fort Scott Limestone had already received extensive study by previous workers (see Brenner, 1989, 1995).

Because of the scarcity of Cherokee surface exposures, sampling was primarily from long cores at the Missouri Geological Survey in Rolla, the Kansas Geological Survey in Lawrence, and the Iowa Geological Survey in Iowa City. To supplement core data, additional conodont materials were collected from surface exposures in Craig and Rogers counties, Oklahoma, Vernon County, Missouri, and Davis and Mahaska counties, Iowa.

Because marine lithofacies are being used to correlate the cyclothems from Oklahoma to Iowa, only marine shales and limestones were sampled for detailed processing. These units were identified in cores by their marine fossil assemblages, particularly crinoids, ostracodes, foraminifers, and brachiopods. Standard sampling intervals are every six inches (15 cm) except for limestones and shales thinner than six inches (15 cm). Furthermore, if a shale or limestone exhibited significant lithologic

changes on a finer scale, sampling intervals were every 1 to 4 inches (2.5 to 10 cm); the thicker, more uniform black shales were sampled every foot (30.5 cm). Most units, marine and nonmarine, were thoroughly described in terms of grain size, sedimentary structures, bedding, diagenetic features, and fossil content, and assigned a Munsell® color value. Ultimately, this data was used to create handwritten graphic logs of some of the cores and entered into Microsoft Excel™ to be converted into digital stratigraphic sections. Some cores (such as the Cooper CW-1, Rose Hill, and Hinthorn CW-1) were previously excellently described and logged by students at the Kansas Geological Survey; therefore, no hand drawn core logs were created, although their data was still entered into Microsoft Excel™. The databases with the stratigraphic descriptions in addition to tops of units were imported into a drafting program called Strater™. Using this program, digital stratigraphic columns were created and imported into Adobe Illustrator™. Once in Illustrator, diagrams were created showing the cyclothem correlations among the long cores and surface exposures.

Laboratory Methods

Marine shales and limestones were disaggregated for microfossil extraction. Initially, all shales were dried in oven until free water was removed, soaked in Stoddard Solvent for one to two days, followed by decantation of the solvent and soaking in hot water, to disaggregate the clays within the shales. Any organic material in the shale that did not break down in Stoddard Solvent followed by water, was treated with bleach and in some cases hydrogen peroxide or Oxy-Clean™. Any remaining clay material was easily removed with boiling in a mixture of water and Calgon™ for approximately four

hours. Limestones and calcareous portions of shales were digested in formic acid diluted to about 7%.

The resulting residue was wet-washed through 1000-, 125-, and 63-micron sieves, and microfossils were extracted from the 125-micron residue. Any conodonts in the 63-micron residue are simply too small or fragmented to be properly compared with conodonts from elsewhere. The number of elements, genera, species (if possible), and type of element (i.e. Pa, S, and M) of conodonts was noted for each conodont-bearing 125-micron residue. This information was entered into a database created in Microsoft Excel™ which was incorporated with drafted core sections created in Strater™. Abundances of conodonts were calculated for platform elements per kilogram by extrapolating the weight of the bulk sample minus that of the 1000-micron residue, yielding the number of Pa elements in a 125-micron residue; other elements, such as ramiforms, were not calculated per kilogram since they could not be identified to species.

Conodont photomicrographs provide visual support for the correlation. Individual conodont photographs were taken in two sessions at the Central Microscopy Research Facility at the University of Iowa. The first set of photographs was taken May 2008 using a Hitachi S-4800 SEM at the Eckstein Medical Research Building with the help of Diane Ramirez, a geoscience graduate student at Iowa. The conodonts for this set were gold coated. Working with Jonas Baltrusaitis of the Central Microscopy Research Facility, the second set of conodont photographs were taken February 2010 using a Hitachi S-3400N SEM, housed in the Geoscience Department. The conodonts for this session were photographed in their natural state without any carbon/gold coating. The

photographs were saved in TIFF format and were later edited in Photoshop and Paint Shop Pro.

Rationale for Correlation

Correlation of the lower Cherokee Group northward was conducted by tracing distinctive conodont faunas from the marine units. Conodont faunas obtained from localities in Oklahoma (Marshall, 2002), where the succession is more complete, were used as reference points for comparison with the conodont succession from the rest of the Midcontinent. Several distinct morphotypes of conodonts (particularly of *Idiognathodus*) were recognized in several of the cyclothems, which differ from proceeding and succeeding cyclothems. As a result, each significant cyclothem of the Cherokee Group can be identified or "tagged" with a distinctive conodont species or group of morphotypes. Northward persistence of some of these distinctive morphotypes allow for tracing of major cyclothems into northern Kansas, Missouri, and Iowa.

Geologic Setting

The Cherokee Group of the Midcontinent extends from the Arkoma Basin in east-central Oklahoma (where it is thickest) through the basin-marginal Northern Oklahoma Shelf ("Cherokee Basin") in northeastern Oklahoma and southeastern Kansas (Brenner, 1989; Charpentier, 1995), over the Bourbon Arch in eastern Kansas and western Missouri, and into the Forest City Basin of northeastern Kansas, northwestern Missouri, and southwestern Iowa (Figure 5). Its northernmost extent is the shelf area of west-central to south-central Iowa. The Arkoma Basin is a foreland basin caused by downwarping of the North American Plate (Rascoe and Adler, 1983, p. 982) and extends from east-central Oklahoma eastward to west-central Arkansas. It is bounded on the

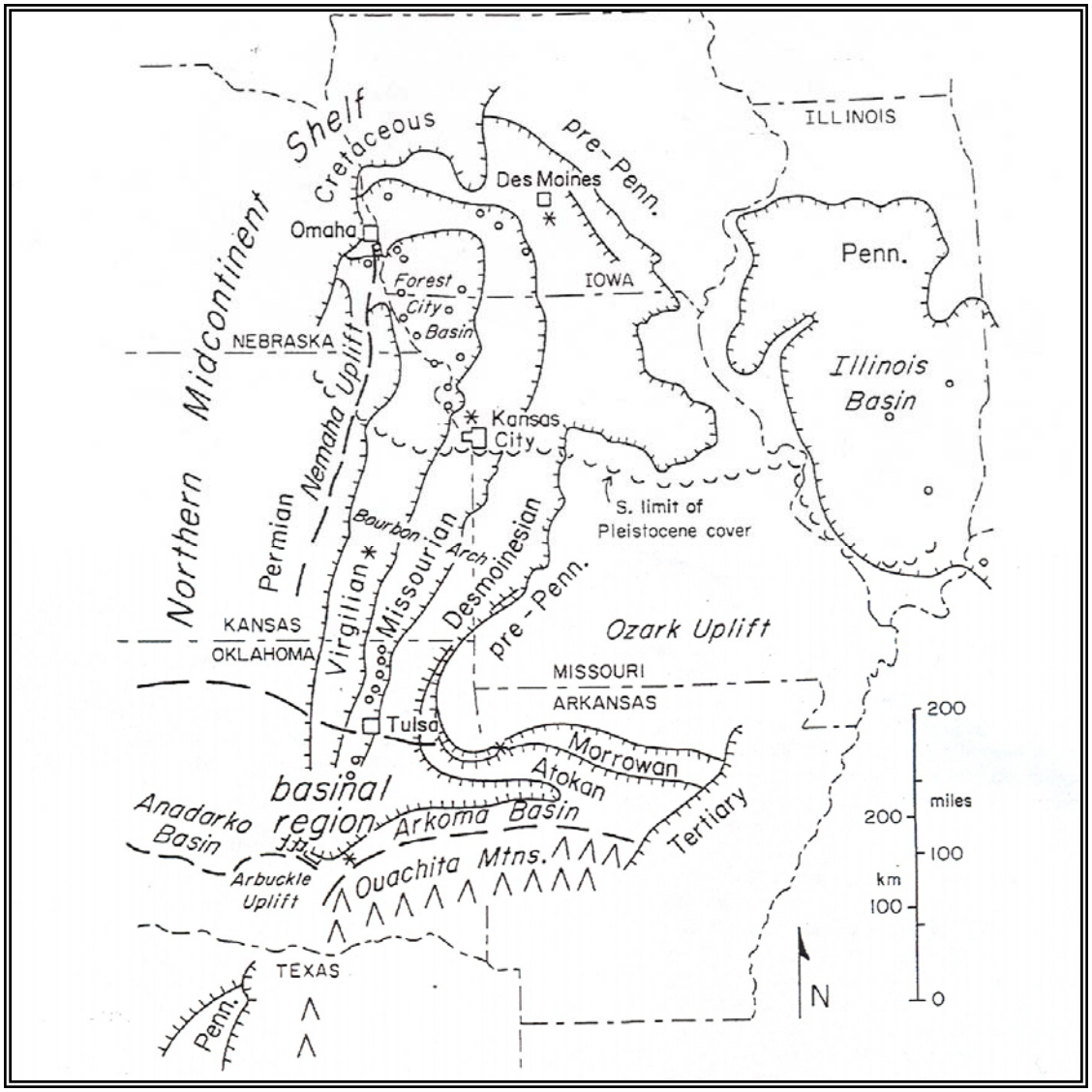


Figure 5. Regional tectonic setting of Midcontinent with outcrop belts of individual Pennsylvanian stages outlined (from Heckel, 2002).

south by the Ouachita Mountains, on the northwest by the Central Oklahoma Platform and Nemaha Ridge, on the northeast by the Ozark Uplift, on the southwest by the Arbuckle Uplift and Tishomingo anticline, and on the north by the Northern Oklahoma Shelf (Henk, 1981, p. 12). The hinge line between the Arkoma Basin and Northern Oklahoma Shelf may have run along what is now the Arkansas River in Muskogee County (Rascoe and Adler, 1983).

Northward, the Northern Oklahoma Shelf, also known as the Cherokee "Basin" in Kansas, extends from northeastern Oklahoma into southeastern Kansas and southwestern Missouri and is separated from the Forest City Basin to the north by a broad low divide known as the Bourbon Arch (Lee, 1943), which extends from Coffey County in eastern Kansas to Vernon County in southwest Missouri (Figures 4, 5). The Bourbon Arch served as an effective divide between the Forest City Basin to the north and the Northern Shelf/Cherokee Basin to the south. However, while it appears that several of the minor to intermediate Cherokee marine cyclothems in Oklahoma were unable to breach the Bourbon Arch and extend northward, major cyclothems are found in the Forest City Basin and Iowa shelf area.

The Forest City Basin covers parts of northeastern Kansas, northwestern Missouri, southwestern Iowa, and a small portion of southeastern Nebraska (Figure 5). Downwarping of the erosional surface on Mississippian rocks by renewed uplift of the Nemaha Ridge led to the formation of the Forest City Basin (Lee, 1943). Major marine transgressions during Cherokee deposition probably entered the Forest City Basin between the west end of the Bourbon Arch and the Nemaha Uplift as evidenced by data

from subsurface logs from Lyon County, Kansas (W. L. Watney, personal communication to P.H. Heckel, 2005).

From Oklahoma to Iowa, the thickness of the Cherokee Group varies depending upon the amount of accommodation space offered by each tectonic province. In the Arkoma Basin, it ranges from 7000 to 10,000 feet (2100 to 3000 meters) thick (Oakes, 1953), which is by far the thickest interval of Cherokee Group in the Mid-Continent. It thins considerably to 400 to 500 feet (120 to 150 meters) at the Oklahoma-Kansas border on the Northern Oklahoma Shelf and further to 300 to 400 feet (91 to 120 meters) over the Bourbon Arch. The Cherokee Group thickens again to over 700 feet (210 meters) in the Forest City Basin, although recent studies indicate that the Cherokee may be thinner than shown by Moore (1949). In its northernmost extension in Iowa, Ravn and others (1984) reported a thickness of approximately 500 feet (152 meters), reduced from the previous estimate of 755 feet (230 meters) in the 1968 Stratigraphic Column of Iowa. However, Witzke and others (2003, p. 21) reported that full well penetrations on the downthrown side of the Thurman-Redfield Fault in southwest Iowa yielded a thickness between 100 and 750 feet (30 and 230 meters) for the Cherokee Group.

Geologic History

Mississippian carbonate deposition over Midcontinent North America was followed by broad epeirogenic uplift across the central part of the continent (Saunders and Ramsbottom, 1986), which caused karst development over the entire region. During early Pennsylvanian (Morrowan) time, suturing of the North and South American plates produced the Amarillo-Wichita highlands. During late Morrowan through Atokan time, downwarping of North America under the overriding Gondwana supercontinent created

the Arkoma Basin (Rascoe and Adler, 1983, p. 982; Johnson, 2004, p. 8). The greatest subsidence during the Atokan resulted in 20,000 feet (6006 meters) of sediment from nearby deltas and uplands (Branan, 1968, p. 1616) with turbidites along the southern margin of the basin (Rascoe and Adler, 1983) (Figure 6), yet by early Desmoinesian time, the Arkoma Basin may have been nearly completely filled with sediments (Oakes, 1953).

Subsidence in the Forest City Basin began concurrently with that in the Arkoma Basin (Johnson, 2004, p. 8). Uplift during this time also brought the Nemaha Ridge from southeastern Nebraska through east-central Kansas several hundred feet above the downwarping Forest City Basin, resulting in a high escarpment along the west side of the basin (Lee, 1943). The Nemaha Ridge remained a positive topographic feature during Desmoinesian time (Figure 6) until flooding during the Missourian (Johnson, 2004, p. 8).

During late Atokan and early Desmoinesian time, continued subduction resulted in northward migration of the hinge line between the Arkoma Basin and North Oklahoma Shelf (Rascoe and Adler, 1983). Johnson (2004) noted that Morrowan sediments onlapped the Northern Oklahoma Shelf and Bourbon Arch from the Arkoma Basin on the south, and Atokan and younger sediments onlapped from the Forest City Basin on the north. Continued subsidence of the Arkoma Basin, coupled with glacial-eustatic marine transgressions, and regressions and highstand and regressive deltaic sedimentation, contributed to the great thickness of the Cherokee Group in the basin (Boardman and others, 2002). During Desmoinesian time, buildup and melting of glaciers situated on

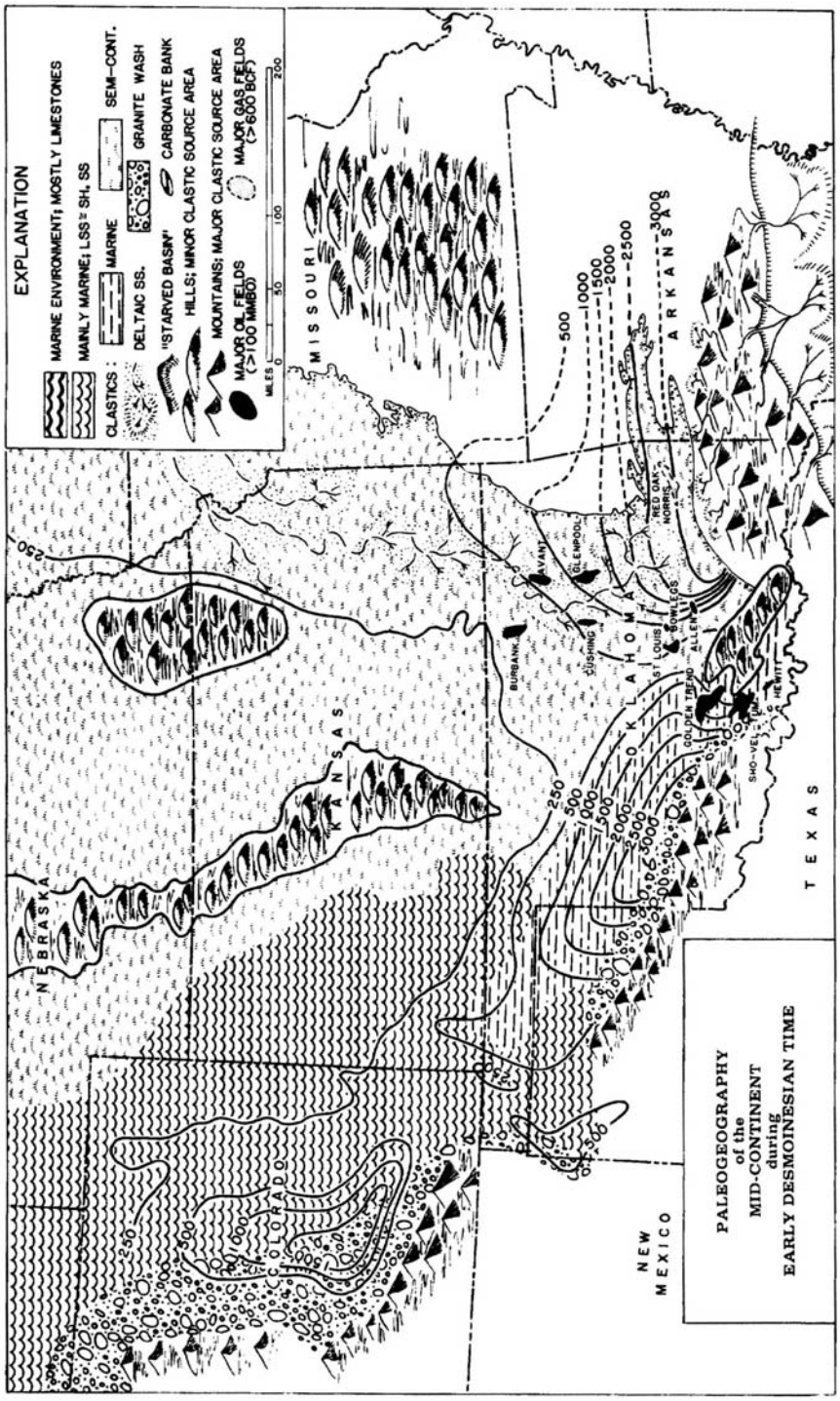


Figure 6. Paleogeographic reconstruction of Midcontinent during Early Desmoinesian, illustrating general depositional environments during lower stands of sea level during early Cherokee time (from Rascoe and Adler, 1983).

Gondwanaland resulted in eustatic changes of sea-level during much of Pennsylvanian deposition in Midcontinent North America (see Heckel, 1994, 2002, 2008), leading to a series of transgressions and regressions of the Midcontinent Sea affecting eastern Oklahoma, Kansas, western Missouri, and Iowa. This buildup and melting of Gondwana glaciers were likely driven by Milankovitch cycles, periodic variations in Earth's orbital parameters. As the glaciers melted, leading to sea-level rise or transgression, most of the area was covered by the sea, and, as the glaciers built up again, leading to sea-level fall or regression, the area was emergent and subject to terrestrial processes (Rascoe and Adler, 1983).

As sea-level rose, lime mud and marine silt and clay were deposited. The deepening sea caused most of the sediments to be primarily deposited near the receding shorelines, leading to a starved basin offshore. At times of maximum transgression, when sea level was at its highest over many parts of the Midcontinent, organic-rich black clay was deposited, and the slow rate of deposition allowed for the accumulation shells, bone, and other hard parts. During periods of glacial buildup, sea level fell over the Midcontinent resulting in regressive deposits of nearshore, shoreline, and terrestrial silt, clay, and sand and the formation of exposure surfaces. When sea level was at its lowest level, at maximum lowstand, large channels (Figure 6) developed across the emergent surface, within which many Cherokee sand bodies were deposited. Some of the larger channels incised deeply into underlying units. Ancient soils (paleosols) continued to develop on the subaerially exposed surface, and, as sea-level began to rise during the next transgression, coals were often deposited at the leading edge of the transgression upon the former exposure surface (Heckel, 1995).

Significance of This Study

Biostratigraphic correlation was used to delineate how the Oklahoma cyclothem succession changes across the Bourbon Arch, into the Forest City Basin, and then finally shelfward to exposures in central Iowa. Finally, there is much confusion concerning the stratigraphic nomenclature of the Cherokee Group across the Midcontinent, as the same units often have different names in different states. Establishing equivalency of certain marine units in each state will clarify some of the stratigraphic confusion and make it possible to establish a more unifying nomenclature system for the Midcontinent Cherokee Group.

CHAPTER II

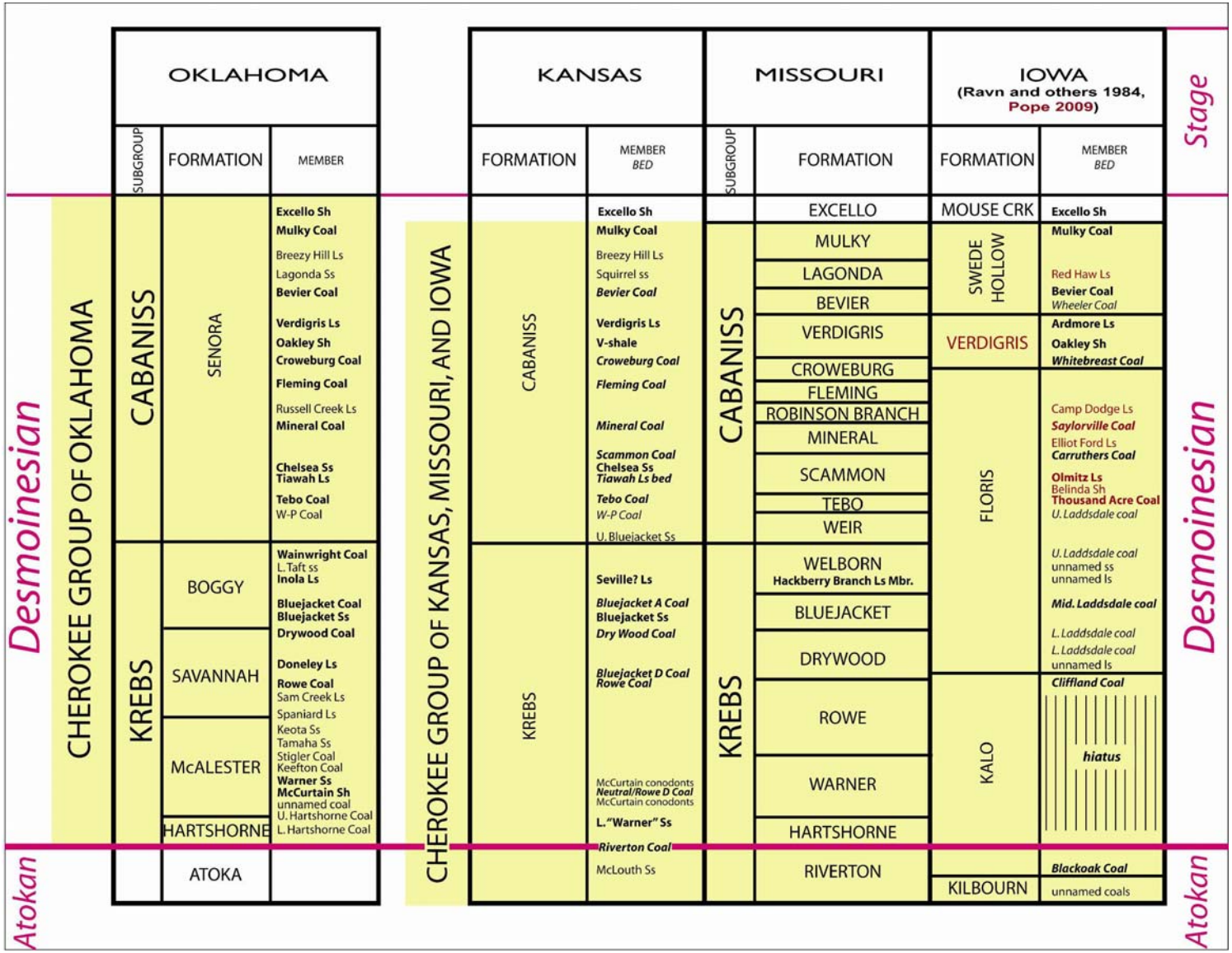
STRATIGRAPHY

Introduction

The lithostratigraphy of the Cherokee Group differs from state to state. The Oklahoma Geological Survey bases most of its formational divisions upon conspicuous lithic units not recognized to the north, rather than on cyclothems. The Missouri Survey recognizes cyclic successions but defines its formations from the top of a coal bed to the top of the next higher coal bed, splitting the early transgressive marine phase off from the remainder of its genetic cyclothem unit, placing it into the underlying cyclothem. The Kansas Survey's lithostratigraphy is generally similar to Oklahoma's. The Iowa Geological Survey uses formation names not recognized in Kansas, Missouri, or Oklahoma.

Because Haworth and Kirk (1894) recognized the "Cherokee Shales" in southeastern Kansas as extending from the base of the Fort Scott Limestone to the top of the Mississippian, the Kansas, Missouri, and Iowa geological surveys placed the base of the Cherokee Group at the top of the Mississippian. Therefore, the lowest Cherokee in these states is likely within the Atokan Stage (Figure 7). However, the Oklahoma Geological Survey placed the base of the Cherokee Group at the top of the Atoka Formation and the Atokan Stage (Figure 7). Furthermore, at the upper boundary, the Oklahoma Survey includes the Excello Shale within the Cherokee Group while the Kansas, Missouri, and Iowa surveys place it within the higher Marmaton Group (Figure 7). For the above reasons, a unifying nomenclature scheme would be useful for the Midcontinent Cherokee.

Figure 7. Stratigraphic classification and nomenclature of Cherokee Group used in different states of Midcontinent. Nomenclature based on Oakes (1953) for Oklahoma, Searight and others (1953), Howe (1956), and Zeller (1968) for Kansas, Searight and others (1953) and Gentile and Thompson (2004) for Missouri, and Ravn and others (1984) for Iowa with updates by Pope (2009) as reported in Pope and Marshall (2009) highlighted in red color. Carruthers Coal is correlated with Scammon Coal at base of Upper Tiawah cyclothem by Hanley (2008). A middle Laddsdale coal and Cliffland Coal are correlated with units to the south as discussed in Chapter IV. Bold names indicate units updated by author to be regionally extensive.


OKLAHOMA
SUBGROUP
FORMATION
MEMBER
CHEROKEE GROUP OF OKLAHOMA
CABANISS
SENORA
Excello Sh
Mulky Coal
Breezy Hill Ls
Lagonda Ss
Bevier Coal
Verdigris Ls
Oakley Sh
Croweburg Coal
Fleming Coal
Russell Creek Ls
Mineral Coal
Chelsea Ss
Tiawah Ls
Tebo Coal
W-P Coal
KREBS
BOGGY
Wainwright Coal
L. Taft ss
Inola Ls
Bluejacket Coal
Bluejacket Ss
Drywood Coal
SAVANNAH
Doneley Ls
Rowe Coal
Sam Creek Ls
Spaniard Ls
McALESTER
Keota Ss
Tamaha Ss
Stigler Coal
Keefton Coal
Warner Ss
McCurtain Sh
unnamed coal
U. Hartshorne Coal
HARTSHORNE
L. Hartshorne Coal
ATOKA
Desmoinesian
Atokan
CHEROKEE GROUP OF KANSAS, MISSOURI, AND IOWA
KANSAS
FORMATION
MEMBER
BED
CABANISS
Excello Sh
Mulky Coal
Breezy Hill Ls
Squirrel ss
Bevier Coal
Verdigris Ls
V-shale
Croweburg Coal
Fleming Coal
Mineral Coal
Scammon Coal
Chelsea Ss
Tiawah Ls bed
Tebo Coal
W-P Coal
U. Bluejacket Ss
KREBS
Seville? Ls
Bluejacket A Coal
Bluejacket Ss
Dry Wood Coal
Bluejacket D Coal
Rowe Coal
McCurtain conodonts
Neutral/Rowe D Coal
McCurtain conodonts
L. "Warner" Ss
Riverton Coal
McLouth Ss
MISSOURI
SUBGROUP
FORMATION
EXCELLO
CABANISS
MULKY
LAGONDA
BEVIER
VERDIGRIS
CROWEBURG
FLEMING
ROBINSON BRANCH
MINERAL
SCAMMON
TEBO
WEIR
KREBS
WELBORN
Hackberry Branch Ls Mbr.
BLUEJACKET
DRYWOOD
ROWE
WARNER
HARTSHORNE
RIVERTON
IOWA
(Ravn and others 1984, Pope 2009)
FORMATION
MEMBER
BED
MOUSE CRK
Excello Sh
SWEDE HOLLOW
Mulky Coal
Red Haw Ls
Bevier Coal
Wheeler Coal
VERDIGRIS
Ardmore Ls
Oakley Sh
Whitebreast Coal
FLORIS
Camp Dodge Ls
Saylorville Coal
Elliot Ford Ls
Carruthers Coal
Olmitz Ls
Belinda Sh
Thousand Acre Coal
U. Laddsdale coal
U. Laddsdale coal
unnamed ss
unnamed ls
Mid. Laddsdale coal
L. Laddsdale coal
L. Laddsdale coal
unnamed ls
KALO
Cliffland Coal
hiatus
KILBOURN
Blackoak Coal
unnamed coals
Stage
Desmoinesian
Atokan

Lithostratigraphy

Oklahoma

The subdivisions of the Cherokee Group are the most detailed in Oklahoma, generally because the increased accommodation space of the Arkoma Basin allowed deposition of the thickest and most complete succession of Cherokee sediments. Taff (1899, 1901) named the Hartshorne, McAlester, Savanna, Boggy, and Senora Formations in Oklahoma. Oakes (1953) divided the Cherokee Group into the Krebs and overlying Cabaniss Subgroups. The Krebs Subgroup includes the four lower formations of Taff: Hartshorne, McAlester, Savanna, and Boggy in ascending order (Figure 7). Furthermore, the Cabaniss Subgroup was divided by Oakes (1953) upward into the Thurman Sandstone, Stuart Shale, and the Senora Formation, but because the Thurman Sandstone and Stuart Shale are present only in the southern Arkoma Basin, the Cabaniss comprises only the Senora Formation in the study area. Each of the formations is further subdivided into numerous member units, most of which are not regionally extensive. However, a few of these units may be continuous from Oklahoma to Iowa, and hence are of interest to this study, all in ascending order: the McAlester Formation includes the McCurtain Shale, Warner Sandstone, and Tamaha Sandstone; the Savanna Formation includes the Sam Creek Limestone, Rowe Coal, the Doneley Limestone, and possibly the Drywood Coal; and the Boggy Formation includes the Bluejacket Sandstone, Bluejacket Coal, Inola Limestone, and Wainwright Coal (Figure 7). Members of the Senora Formation were dealt with by Hanley (2008) and are outside the scope of this study.

Nevada, Missouri Conference

Geologic Survey representatives from the five Midcontinent states of Iowa, Nebraska, Missouri, Kansas, and Oklahoma, met in Nevada, Missouri in 1953 to resolve stratigraphic issues of the Cherokee Group. At that conference they divided the Cherokee into formations utilizing its repetition of cyclicity (Searight et al., 1953) because…

> "Coal beds are regarded as the most persistent units in the succession. Divisions of formational rank as adopted include beds from the top of a coal bed, to the top of the next higher coal bed…." (ibid., p. 2747).

In addition, they reclassified the Cherokee Group as the Krebs and Cabaniss Groups. On this basis, they divided the lower Cherokee (the Krebs Group) into six formations:

Seville Formation
Bluejacket Formation
Dry Wood Formation
Rowe Formation
Warner Formation
Riverton Formation

Of these, the Warner, Rowe, Drywood, and Bluejacket were recognized in Oklahoma. In the states to the north, lithic nomenclature has evolved to various extents.

Missouri

Currently, Missouri still recognizes the Cherokee formations from the Nevada, Missouri conference, though with some modifications. Missouri recognizes the Krebs and Cabaniss as subgroups of the Cherokee Group (Figure 7). Based upon conodont data, Thompson (1979) dated the Riverton as middle to late Atokan, and removed it from the Cherokee Group. Later, Thompson (1995) tentatively assigned a suite of sandstones, shales, and red shale between the Warner and Riverton Formations to the Hartshorne

Formation (Figure 7). Gentile and Thompson (2004) updated Howe's work on Missouri lithostratigraphy.

Gentile and Thompson (2004) noted that Searight based his correlation of a limestone in the Cherokee Basin in southwestern Missouri with the Seville Limestone of the Illinois Basin upon the last appearance of the brachiopod *Mesolobus striatus*. However, the type Seville is at the base of the Desmoinesian in Illinois (Hopkins and Simon, 1975), and Gentile and Thompson (2004) believed that the last appearance of this brachiopod did not occur at the same time in both basins. Further noting that several different thin limestones throughout Missouri have been identified as the Seville, Gentile and Thompson (2004) renamed the Seville Limestone of Vernon and adjacent counties in southwestern Missouri as the Hackberry Branch Limestone Member of the Welborn Formation in the Krebs Subgroup (Figure 7).

Kansas

Howe (1956) summarized in detail the presence of the formations of Searight et al. (1953) in Kansas. However, since mapping the formations proved difficult, Jewett (1959) simply divided the Cherokee into the Krebs and Cabaniss Formations (Figure 7). Later, Jewett, O'Connor, and Zeller (1968) recognized several members and beds within the Krebs Formation: the Riverton Coal bed, Warner Sandstone Member, Neutral Coal bed, Rowe Coal bed, Dry Wood (sic) Coal bed, and Bluejacket Sandstone Member, of which the Neutral was revived from older work (Figure 7). Furthermore, they recognized the limestone above the Bluejacket Sandstone in eastern Crawford County that Howe (1956, p.44) had tentatively correlated with the Seville Limestone of Illinois. In 2006, the Kansas Geological Survey formed a Stratigraphic Nomenclature Committee to

address and incorporate any stratigraphic changes since Jewett et al. (in Zeller, 1968) (http://www.kgs.ku.edu/General/Strat/index.html). Most likely, recent changes in Cherokee lithostratigraphy will be updated as well.

Iowa

In the 1930s, Cline and Stookey (unpublished) attempted to subdivide the Cherokee of Iowa (Ravn et al., 1984). Gleim (1955) applied the Krebs and Cabaniss Groups to Cherokee exposures in southeastern Iowa, but neither of these subdivisions has been used subsequently in Iowa. Because the formations established at the 1953 Nevada Conference were not identified in Iowa, Ravn et al. (1984) divided the entire Cherokee into four formations: Kilbourn, Kalo, Floris and Swede Hollow, in ascending order (Figure 7). They further noted (p. 23-25) that the Atokan-Desmoinesian boundary lies between the Blackoak and Cliffland coals within the Kalo Formation, based on palynological correlation with coals in Illinois. Therefore the Iowa Geological Survey placed the Atokan/Desmoinesian boundary at the base of the Cliffland Coal. This boundary was used by Lambert (1992, p. 113) to establish the age of the conodonts he described from exposures of the marine units above the Cliffland Coal in Iowa. At least the basal portion of the Kalo Formation is Atokan in age. The overlying Floris Formation has two named coal units: the Laddsdale at the base and the Carruthers above the middle (Ravn et al., 1984). Forming the lower Floris Formation, the Laddsdale Member contains as many as six coals. Pope (2009, p. 45) designated several new members for the Floris Formation above the Laddsdale: the Thousand Acre Coal, Belinda Shale, Olmitz Limestone, Elliot Ford Limestone, Saylorville Coal, and Camp Dodge Limestone (Figure 7). He further (p. 54) split the Oakley Shale and Ardmore Limestone Members from the

base of the Swede Hollow Formation to form a fifth formation for Iowa, the Verdigris Formation, which has been recognized in states to the south. However, the Whitebreast Coal was retained in the underlying Floris Formation, thus separating the early transgressive marine units of the Verdigris cyclothem from its highstand units. As discussed below, some of the upper Laddsdale coals are equivalent to middle Cherokee units farther south (Hanley, 2008). Therefore, in Iowa, the lower Cherokee interval of the current study comprises the upper Kalo and lower Floris Formations.

Genetic Stratigraphy

Marshall (2002) recognized 28 transgressive-regressive cycles and described the cyclothems in the entire Cherokee succession in eastern Oklahoma and southeastern Kansas. Each of these cyclothems was defined to extend vertically from the top of the paleosol underlying a coal bed with overlying marine strata, to the top of the next paleosol beneath a coal bed with overlying marine strata. Each of these comprises an entire marine transgressive-regressive sequence. In the current study, minor cyclothems that contain coal beds overlain by only terrestrial or only sparsely fossiliferous marginal marine strata are delineated in the Appendix, but not emphasized in the correlation. Three major lower Cherokee cyclothems, which exhibit relatively distinct conodont faunas, appear to be continuous across the Midcontinent.

McCurtain Cyclothem

The McCurtain Shale Member of the McAlester Formation of Oklahoma was named by Wilson (1935, p. 508) from the town of McCurtain in Haskell County, which was built upon this shale. He placed the McCurtain Shale as the lowest unit of the McAlester Formation, below the Warner Sandstone, and possibly including the Riverton

Coal. Oakes and Knetchel (1948, p. 31) identified a calcareous fossiliferous zone within the McCurtain Shale about 1.5 miles (2.4 km) north of McCurtain, Oklahoma.

Marshall (2002) recognized two cyclothems within the McCurtain Shale: the Post-Upper Hartshorne cyclothem and the Post-Brushy Mountain cyclothem. Later, Boardman and others (2004) recognized that these two units are parts of the same cyclothem and renamed it the McCurtain cyclothem. The presence of conodont-rich black phosphatic shale in its type region in east-central Oklahoma qualifies the McCurtain as a major cyclothem. In Oklahoma, the McCurtain cyclothem extends from the subaerial exposure surface at the base of the uppermost coal in the Hartshorne Formation, upward to the subaerial exposure surface just below the Keefton Coal in the Warner Sandstone Member of the McAlester Formation (Boardman et al., 2004).

The McCurtain cyclothem contains the uppermost Hartshorne coal of the Hartshorne Formation as well as the entire McCurtain Shale Member of the McAlester Formation. Within this shale, there are two coal beds whose identity has not been properly constrained. Pierce and Courtier (1937, p.62) identified a coal in Craig County as the Riverton Coal named nearby in Kansas. Hemish (1987, p.9) named the Brushy Mountain Coal in southeastern Muskogee County. However, the lateral extent and correlation of these coals is not known, and they may represent just minor cycles associated with the major McCurtain cyclothem. Since the Keefton Coal is considered to be a bed within the Warner Sandstone Member of the McAlester Formation of Oklahoma (Hemish, 1998), the McCurtain cyclothem contains the lowermost sandstones of the Warner in that region.

Sam Creek Cyclothem

In 1932, Lowman named the Sam Creek Limestone Member of the Boggy Formation from exposures at Sam Creek in Muskogee County (Wilson, 1935, p. 504, 510). He recognized it as lying below the Bluejacket Sandstone and above the Warner Sandstone. The type locality of the Sam Creek is approximately 2.5 miles (4.0 km) south of Muskogee, Oklahoma and half a mile (0.81 km) west of present-day US 64, center west half, east half Sec. 15, T14N, R18E (Wilson, 1935, p. 504). The Sam Creek Limestone is very fossiliferous, and Lowman described it as rich in the brachiopod *Marginifera muricata*, almost a coquina (Wilson, 1935, p. 510). Fossils identified from the Sam Creek Limestone include the horn coral *Campophyllum*, the brachiopods *Mesolobus* and *Spirifer*, and the fusulinid *Fusulinella*.

Marshall (2002, p. 53) defined the Sam Creek cyclothem to extend from the top of the subaerial exposure surface below the Sam Creek Coal to the top of the subaerial exposure surface below the Rowe Coal. Marshall (2002, p.55) identified the Sam Creek cyclothem at a stream exposure on the Davis Airfield in Muskogee County, Oklahoma (NW-NW-SW-NW Sec. 26, T14N, R18E) and in a shale pit in Wagoner County, Oklahoma (NE-NE-NE Sec. 1, T15N, R17E and SW-SE-SE-SE Sec. 36, T16N, R17E).

At the Davis Airfield locality (roughly two miles south of the type Sam Creek locality), the southernmost known extent of the Sam Creek cyclothem, the Sam Creek Limestone Member is a medium dark gray (N4) and light brown (5YR 5/6), brachiopod-rich packstone; in outcrop, the unit is 0.3 feet (9 cm) thick, ferruginous, dense, hard, and nodular. A high abundance and diversity of fossil material includes productid

brachiopods, fish vertebrae and teeth, echinoid plates, poorly preserved calcareous (possibly *Tetrataxis*) and encrusting foraminifers, and the conodont, *Idiognathodus* (Marshall, 2002, p. 339). Brown fissile silty shale capped by underclay below the Rowe Coal bed overlies the Sam Creek Limestone.

At the Wagoner County locality, the Sam Creek Limestone consists of two beds. The lower Sam Creek limestone bed is a 0.7 foot- (21 cm-) thick dark gray (N3) ferruginous impure packstone. This bed is very micaceous with angular silt-sized quartz grains; it is also very fossiliferous with gastropod and pelecypod fragments, brachiopods, fish debris, ostracodes, and numerous conodonts, mainly *Idiognathodus*. While the faunal diversity of the Davis Airfield Sam Creek Limestone bed is higher, the lower bed of the Sam Creek Limestone in the Wagoner County shale pit yielded a higher number of conodont platform elements per kilogram (hundreds per kilogram) despite the presence of siliciclastics. However, the most interesting feature is numerous rounded intraclasts in the lower part of the limestone bed, some of which range up to 0.5 inches (1.3 cm) in diameter. The upper Sam Creek limestone bed is 0.6 foot- (18 cm-) thick medium dark gray (N4) wackestone. Like the lower bed, it is ferruginous, very impure, dense, and fossiliferous, and has a nodular appearance in outcrop. Seven feet (2.1 meters) of dark gray silty fissile shale overlie the Sam Creek, and contain only a few plant stem fragments at the upper contact.

North of Wagoner County, Oklahoma, the extent of the Sam Creek cyclothem is unclear. Branson and others (1965, p.11) placed the northernmost extent of the Sam Creek Limestone in Craig County, Oklahoma. Searight et al. (1953) recognized the Rowe Formation from the top of the Neutral Coal to the top of the Rowe Coal, which may

correspond closely with the Sam Creek cyclothem. However, the lowermost carbonate unit within the Rowe Formation may be equivalent to the higher Doneley Limestone (Howe, 1956, p. 35), as discussed in greater detail in the following section on the Doneley cyclothem. Although conodont faunas similar to that of the Sam Creek have been found in Kansas and Iowa, the overlying Doneley cyclothem shares similar fauna. As discussed below, the Doneley cyclothem, rather than the Sam Creek, likely extends north of Oklahoma.

Doneley Cyclothem

A six-inch (15.2 cm) fossiliferous limestone bed was identified above a “lower Boggy” coal by Wilson and Newell (1937). Branson (1952) named a limestone occupying this stratigraphic position the Doneley, after the Doneley School four miles north of Vinita in Craig County, Oklahoma. He established the type locality about a mile (1.6 km) north of the school in a north-facing creek bank 100 feet (30 meters) east of a section-line road in NW Sec. 16, T26N, R20E. At its type locality, Branson (1952, p.192) described the Doneley Limestone as a three-inch- (7.6-cm-) thick, calcareous clay ironstone about eight inches (20.3 cm) above a thin coal with a paleosol underclay.

Marshall (2002, p.56) described the Doneley cyclothem from an exposure on the southeastern slope of Hensley Mountain (SW-SE-NE and NW-NE-SE Sec. 4 T10N R19E) in Muskogee County, Oklahoma. At this locality, the Doneley Limestone Member is an eight-inch (2.1-cm) ferruginous brachiopod-rich packstone overlain by 20 feet (6 meters) of black shale. He defined the Doneley cyclothem from the top of the subaerial exposure surface below the Rowe Coal to the top of the subaerial exposure surface below the Drywood Coal. The Doneley Limestone Member overlies the Rowe

Coal bed, although it is absent between the Rowe Coal and a higher black fissile phosphatic shale at the Davis Airfield locality (NW-NW-SW-NW Sec. 26, T14N, R18E), indicating that it is discontinuous. At Hensley Mountain, black phosphatic fissile shale with sparse conodonts lies ten feet (3.33 meters) above the Doneley Limestone Member (Marshall, 2002, p. 346). At the Davis Airfield locality, similar shale is approximately seven feet (2.1 meters) above the Rowe Coal bed (Marshall, 2002, p. 339).

Howe (1956, p. 35) described a six-inch, impure, ferruginous, brachiopod-rich limestone, which he placed as the lowermost unit of the Rowe Formation. He also believed that this limestone might be equivalent to the Doneley Limestone Member of Oklahoma (Howe, 1956, p.35). While the Doneley Limestone Member at Hensley Mountain is similar to Howe's Doneley Limestone in Kansas, there is an issue with stratigraphic position. In Oklahoma, the Doneley is above the Rowe Coal, whereas in Kansas what Howe identified as Doneley is above the Neutral Coal but *below* the Rowe Coal. If the Doneley Limestone Member is the same as Howe's Doneley Limestone, then the Neutral Coal bed of Kansas could be equivalent to the Rowe Coal bed of Oklahoma.

As previously mentioned, the Doneley and the Sam Creek cyclothems share similar conodont faunas. In the KGS Cooper CW-1 long core from Labette County, Kansas, conodonts similar to those of the Sam Creek/Doneley have been found in an interval nine feet thick with two limestones, 39 feet (11.7 meters) above a coal identified as the Rowe and 15.5 feet (4.6 meters) below a coal identified as the Drywood. The lower limestone is a brown wackestone with brachiopods and bryozoans. The upper limestone is a brown packstone with bioclasts. However, the limestones are separated by dark gray sideritic silty shale and gray to light brown sandstone with silty laminations and

wavy bedding. The silty shale has been interpreted by Lange (2003) as offshore and the sandstone as a tidally-influenced crevasse splay (strongly suggesting) that both limestones are part of the same cycle. Farther north in the southern edge of the Forest City Basin, two zones, 0.5 feet (15 cm) above an unnamed coal, yielded conodonts similar to those of the Sam Creek/Doneley at 932.4 to 933.4 feet and 935 to 935.6 feet in the KGS Edmonds 1A long core in Leavenworth County, Kansas. While it is tempting to assign the lower conodont-bearing zone to the Sam Creek cyclothem and the upper one to the Doneley cyclothem, both zones are within a grayish black fissile, highly fossiliferous shale and thus part of the same cycle. Finally, in Lucas County in south-central Iowa in the IGS CP-79 long core, Sam Creek/Doneley-type conodonts have been identified in a limestone above the Cliffland Coal bed of the Kalo Formation.

The above-mentioned marine zones are most likely part of the Doneley cyclothem for several reasons. Unlike the Sam Creek Limestone, which Branson et al. (1955) believed to have its northern limit in Craig County, Oklahoma, Branson (1952, p. 192) believed that the Doneley Limestone is traceable over the Kansas border, and Howe (1956, p.35) noted the possible presence of the Doneley in east-central Kansas. Heckel (1986, 1994) defined a major cyclothem as one that extends over the entire northern Midcontinent shelf and noted that it typically contains high conodont abundance, widespread black fissile phosphatic shale facies, and deep-water conodonts (*Idioprioniodus* and *Gondolella*) in addition to the more common *Idiognathodus*.

At the Davis Airfield locality, the Sam Creek Limestone yielded five *Idiognathodus* Pa elements per kilogram whereas the black fissile phosphatic shale of the Doneley cyclothem yielded 125 *Idiognathodus* Pa elements, 208 *Idiognathodus* juveniles,

and 56 *Idioprioniodus* per kilogram. Northward, the conodont abundance of the Sam Creek Limestone increases dramatically as it yields hundreds of *Idiognathodus* elements per kilogram at the Wagoner County shale pit. At the type Doneley section, the highstand of the Doneley cyclothem yielded only eight *Idiognathodus* Pa elements, two *Idiognathodus* juveniles, and four *Idioprioniodus* per kilogram. Based strictly upon conodont abundances at one locality, the Sam Creek would appear to be the major cyclothem.

However, the highstand of the Sam Creek cyclothem at the Wagoner County shale pit is probably a winnowed limestone, in which the mechanically concentrated conodonts are more characteristic of an intermediate cyclothem (Heckel, 1994). In contrast, the highstand of the Doneley cyclothem is deeper-marine black fissile phosphatic shale, which does not show evidence of winnowing. Furthermore, the highstand of the Doneley cyclothem yielded the deeper-water conodont *Idioprioniodus* at the Davis Airfield locality. Northward, black shale in one core locality in northeast Kansas (Edmonds) and above the Cliffland Coal in the Lakonta strip pit in Iowa yielded *Idioprioniodus* in the same stratigraphic position, indicating a widespread distribution for this facies. The presence of the below-wave base black shale, *Idioprioniodus*, and widespread distribution of the black phosphatic shale facies demonstrate that the Doneley cyclothem is more likely the major cyclothem that extends from Oklahoma into Iowa.

Inola Cyclothem

Lowman (1932) named the Inola Limestone from an outlier on Inola Hill about half a mile (0.8 km) east of Inola in Rogers County, Oklahoma in Sec. 10, T19N, R17E. Wilson (1935, p. 511) described the Inola Limestone of Muskogee County as a 10-inch

(25.4-cm) dark blue bed with large sponges. Tillman (1952, p. 32) measured an outcrop approximately 12 miles (19.2 km) northeast of Inola Hill (NE-NW-NW Sec. 18, T21N, R18E) with four limestones designated as “upper Inola”, “second Inola”, “third Inola”, and “lower Inola”. Because each limestone was part of a separate cyclothem, Branson (1954, p. 192) designated Tillman’s “lower Inola” as the type. Hemish (1990c), however, designated the upper limestone at Inola Hill as closest to Lowman’s original concept, and established a principal reference section for the Inola Limestone Member on the northeast slope of Inola Hill (NE-NW Sec. 10 T19N R17E).

The Inola Limestone has yielded fossils that have potential biostratigraphic utility. Wilson and Newell (1937, p. 56) reported the sponge *Heliospongia* from the Inola Limestone. Furthermore, the Inola has yielded a diverse assemblage of fusulinids (Branson, 1952; and Alexander, 1954), from a locality in SE Sec. 7, T21N, R18E, near Tillman’s 1952 measured sections. Boardman and others (2004) noted distinctive conodonts, *Idiognathodus podolskensis* and *Neognathodus asymmetricus*, from the Inola Limestone at Inola Hill.

Branson (1954, p. 6) described a coal cycle containing the Inola Limestone and extending from the base of the Inola Limestone to the top of an underclay above the Inola Limestone, which included only the highstand and regressive limb of a typical Cherokee cyclothem. Marshall (2002, p. 64) described the complete Inola cyclothem from an exposure on the southwest slope of Inola Hill (NE-SW-NW Sec. 10, T19N, R17E). He defined the cyclothem from the subaerial exposure surface below the Bluejacket Coal upward through the Inola Limestone to the subaerial exposure below the Wainwright Coal, to provide a more complete genetic unit than Branson’s definition. At its principal

reference section on Inola Hill, this cyclothem exhibits both a transgressive limestone and overlying black phosphatic shale. In addition to containing brachiopods, echinoids, bryozoans, and corals, the limestone yielded hundreds of *Idiognathodus* conodont platform elements per kilogram and *Idioprioniodus*. The overlying black phosphatic shale yielded *Idiognathodus*, *Neognathodus*, *Idioprioniodus* and the genus *Gondolella*. Swade (1985) interpreted *Idioprioniodus* and *Gondolella* as offshore, deep-dwelling conodonts and that the deeper-water (core) shales of younger cyclothems yielded *Idiognathodus*, *Neognathodus*, *Idioprioniodus*, and *Gondolella*.

CHAPTER III

RECOGNITION OF CONODONT MORPHOLOGY AND TAXONOMY

Introduction

Early conodont biostratigraphic work by Swade (1985) on the Midcontinent Cherokee Group focused on the Verdigris Limestone at the base of the upper Cherokee, and younger cyclothems. Hanley (2008) summarized morphotypes and their distribution in the middle Cherokee (Weir-Pittsburg through Fleming cyclothems). Marshall (2002) worked on the conodont biostratigraphy of the most complete Cherokee succession from the Arkoma Basin margin to Cherokee Shelf in eastern Oklahoma and southeastern Kansas. Because some conodont morphotypes underwent relatively rapid evolutionary changes throughout the Cherokee, Marshall (2002) was able to "tag" each of the major T-R cycles with a distinctive morphotype, allowing regional correlation for these cycles. The lower Cherokee Group yielded *Neognathodus*, *Adetognathus*, *Idioprioniodus*, *Gondolella*, and *Idiognathodus* (see Appendix B). *Adetognathus* was sparse in the materials studied. *Idioprioniodus* was identified from all major cyclothems northward into Iowa. *Gondolella* was identified from black phosphatic shale above the Inola Limestone at Inola Hill and in three cores in Kansas. The majority of biostratigraphic work focused on *Neognathodus* and *Idiognathodus*, for which the abundance and quality of preservation facilitated enough recognition for correlation. Morphotypes were identified to species mainly by determining closeness to holotypes, as elaborated below. *Idiognathoides* is also discussed because it is a biostratigraphic marker for the underlying

Atokan stage, and has been identified in the KGS Edmonds 1A and Hopp #1-16 long cores in the Forest City Basin of Kansas and the CP-78 long core in Iowa.

Recognition of Conodont Morphotypes

Genus *Idiognathoides* Harris and Hollingsworth 1933

The platform is generally subsymmetrical, lanceolate, and ridged. The most prominent feature of this genus is a deep anteriorly-plunging medial channel or furrow that extends from approximately three-fourths down the platform posteriorly to the anterior terminus of the platform. The channel is lined by corrugated or denticulated rims but not crests or parapets. The unchanneled posterior tip exhibits transverse ridges. The free blade is very short and heavily denticulated. The genotype is *Idiognathoides sinuata*. The *Idiognathoides* found in this study have not yet been identified to species (Figure 8-23 & 8-24).

Genus *Gondolella* Stauffer and Plummer 1932

Gondolella is easily identifiable by its platform, which is narrow and gondola-shaped. It has minimal to no free blade, and there is a prominent reclined cusp near the posterior termination. The denticled carina is present at the anterior end of the platform. While an important biostratigraphic marker in major cyclothems in the middle and upper Cherokee, *Gondolella* has only been sporadically encountered in the lower Cherokee in the black fissile phosphatic and other shale facies of the Inola cyclothem. At Inola Hill in Rogers County, Oklahoma, *Gondolella* was identified within a foot above the Inola Limestone. The platform of the Inola form is wide and curved with a smooth upper surface, and the platform posterior is sharply bent upward. The curvature of the platform becomes more pronounced towards its posterior end, while the anterior end is relatively

straight. The carina is strongly denticled with six to seven large, nodular denticles. Boardman and others (2004) identified this specimen as *G*. aff. *laevis*.

The other specimens of *Gondolella* in the Inola cyclothem were encountered in the Cooper, Rose Hill, Spencer, and Hopp cores. In the Cooper, Spencer, and Hopp, only one juvenile per core was identified (Figure 8-8 & 8-9). In the Rose Hill, a small Pb element was present. Therefore, a useful comparison with the Inola form or species identification was not possible.

Genus *Idiognathodus* Gunnell 1931

The free blade and platform of *Idiognathodus* are equal or nearly equal in length. The platform element is usually asymmetrical, although some species do have nearly symmetrical platforms; some platforms exhibit a bend or curve along the axis from the free blade. The platform shape is ovoid, spade-like, lanceolate, or knife-like. The platform oral surface bears nodes and ridges. Strong transverse ridges are usually present on the posterior portion of the platform. The carina is minor or absent.

Idiognathodus is the most abundant genus encountered in the lower Cherokee of the Midcontinent. Because it also yielded the most diverse and distinctive morphotypes through time, this genus provides the primary biostratigraphic marker species for the lower Cherokee. Based upon the conodont successions illustrated by Marshall (2002), Boardman and others (2004) recognized three main conodont morphotypes in the lower Cherokee Group in Oklahoma and southeastern Kansas in ascending order: *Idiognathodus praeobliquus*, *I. obliquus*, and *I. podolskensis*. These conodont morphotypes have been recognized and described from the Moscow and Donets Basins. Kossenko and Kozitskaya (1978) described *Idiognathodus obliquus* from the

Dobropolsky Kapitalny mining district in the Donets Basin of Ukraine. Goreva (1984) described *I. podolskensis* from several mid-Moscovian units in the Moscow and Donets Basins: upper Kashira, Podolsk, and lower Myachkovo horizons. Nemyrovska, Perret-Mirouse, and Alekseev (1999) described *I. praeobliquus* from early to middle Moscovian units in the Moscow and Donets Basin: the uppermost Vereya and Kashira horizons in Russia in the Donets Basin. In Iowa, Lambert (1992) recognized two stratigraphically important species in the lower Cherokee around the Atokan/Desmoinesian boundary: *Idiognathodus amplificus* and *I. gibbus*. He described *I. amplificus* from a marine unit above the Cliffland Coal in an abandoned strip pit in Mahaska County, Iowa, and *I. gibbus* from a marine unit above the Blackoak Coal in the CP 6 long core, Davis County, Iowa and the CP 37 long core in Clarke County, Iowa. In this study, *I. amplificus* is found to be a fourth major morphotype in the lower Cherokee.

The following species are also discussed in this chapter, as they have been identified in the lower Cherokee, but are not major faunal constituents. More common to the middle Cherokee, a form similar to *I. robustus* has been encountered locally in the Inola and Doneley intervals. Morphotypes resembling *I. crassadens* and *I. iowaensis* have been identified from the Inola cyclothem at Inola Hill and in southeastern Kansas. Because some lower Cherokee conodont morphotypes from Missouri, Kansas, and Iowa appear similar to *Idiognathodus mundulus* described by Youngquist and Downs (1949) from Pennsylvanian shales in the vicinity of Knoxville, Iowa, now known to belong to the Verdigris cyclothem (J.P. Pope and P.H. Heckel, personal communication), it also is included.

Idiognathodus obliquus Kossenko and Kozitskaya 1978

(Figure 8-11, 8-12, 8-13. & 8-14)

Diagnosis: Diagnostic characteristics include strongly oblique transverse ridges, long, flaring adcarinal ridges, and a sigmoidal profile in the oblique inner view. *Idiognathodus obliquus* has a lanceolate, bent platform with a narrow, sharp posterior tip. The transverse ridges are thin, parallel, and strongly oblique at an angle up to 45° to 60° to the longitudinal axis of the platform, numbering from eight to nineteen.

Description: If present, the carina is small to absent and delineated from adcarinal ridges by adcarinal grooves. There are two large accessory lobes on the anterior end of the platform, which are delineated from the adcarinal ridges by small grooves. The carina is higher and more serrated while the adcarinal ridges are lower and nodose. The adcarinal ridges flare anteriorly and downward; they parallel the carina at the anterior end of the platform, then flange the free blade for a third of its length before merging with it. The inner accessory lobe is larger, rounded, and carries two to four rows of nodes that are curved toward the platform axis. The outer accessory lobe is longer, convex, and the rows of nodes are less distinct. The oral surface of the platform's anterior edge is convex in cross-section while the oral surface of the platform's posterior edge is flat or slightly concave on smaller specimens. The free blade is slightly shorter than the platform.

Kossenko and Kozitskaya (1978) reported a wide variation in the extent in the amount of bending of the platform, number and obliquity of transverse ridges, and the number of rows of nodes on the accessory lobes. *Idiognathodus obliquus* differs from *I. sinuatus* by the occurrence of the outer accessory lobe, wider anterior portion of the platform element, and more oblique transverse ridges. *I. obliquus* differs from *I. delicatus*

by the curvature of the platform, the shape of the outer accessory lobe, the less-developed carina, and the more oblique transverse ridges.

Hanley (2008, p.47-48) reported *I.* cf. *obliquus* from the Upper Tiawah cyclothem, but it is more elongate than the holotype. Moreover, the transverse ridges on the specimens Hanley identified as *I* cf. *obliquus* exhibit a medial groove or furrow, and thus are closer to the transverse ridges of *I. podolskensis* in appearance. Boardman and others (2004) reported *I. obliquus* from the Sam Creek and the Doneley limestone members of the Savanna Formation of Oklahoma. Forms that I assigned to *I. obliquus* have blunter posterior tips and less flared adcarinal ridges.

Idiognathodus podolskensis Goreva 1984

(Figure 8-1, 8-2, 8-3, 8-4, & 8-5)

Diagnosis: Diagnostic characteristics include a medial furrow in the transverse ridges, flared adcarinal ridges, and accessory lobes with randomly-oriented nodes on the outer lobe and concentric rows of nodes paralleling the arcuate adcarinal ridge on the inner lobe.

Description: *Idiognathodus podolskensis* has a platform that is blade- or knife-like in oral outline with a bent axis and sharp, pointed posterior tip. The length of the platform element is twice that of its width, and the widest part of the platform is in its anterior third. The inner and outer accessory lobes are subequal, convex, and decorated with rounded nodes. The posterior half of the platform exhibits eight to fifteen oblique transverse ridges, which typically have a medial groove or furrow that becomes more pronounced toward the posterior tip of the platform. The carina is very short to nearly absent. Adcarinal ridges flare anteriorly and downward from the axis of the carina and

merge with the free blade at about the midway point. The adcarinal ridges delineate the anterior half of the lateral accessory lobes, and deep grooves delineate the posterior half of the free blade. *I. podolskensis* is reported to have a wide variety in the width of the platform element and the length to width ratio. The platforms of adult specimens are proportionally broader than juveniles, subsymmetrical, wider in the anterior third, and have up to fifteen transverse ridges. *Idiognathodus podolskensis* is close in appearance to *I. obliquus* but differs by the shape of the platform element, the more random orientation of the nodes on the outer lobe, and the medial furrow in the transverse ridges. Boardman and others (2004, fig. 2, specimens 1, 3-5) reported the first appearance of *Idiognathodus podolskensis* in the North American Midcontinent from the Inola Limestone Member of the Boggy Formation of Oklahoma. Although they also reported *I. podolskensis* from the higher Russell Creek Limestone and post-Fleming marine unit, specimens they illustrated as *I. podolskensis* (fig. 3, specimens 12-13) and as *I.* cf. *podolskensis* (fig. 3, specimens 1-7) have fewer, coarser, and more slightly nodose transverse ridges than *I. podolskensis* in the Inola. Hanley (2008) reported no *I. podolskensis* in the interval she studied up to the Verdigris Limestone. Forms that I assign as *I. podolskensis* have more spade-shaped platforms and lower length-to-width ratios, less-flared adcarinal ridges, and slightly more lineated and less curved nodes on the accessory lobes.

Idiognathodus amplificus Lambert 1992

(Figure 8-6, 8-15, 8-19, & 8-20)

Diagnosis: Diagnostic characteristics include an elongated, posterior platform exhibiting often disrupted transverse ridges and accessory lobes that drape around the distal anterior portion of the platform, especially in sinistral elements. Dextral elements have less-

developed accessory lobes that do not extend posteriorly. The platforms of *Idiognathodus amplificus* are narrow with pointed posterior tips and relatively flat-lying transverse ridges. The carina is minor to absent; the adcarinal ridges are also short and terminate abruptly at the anterior-most transverse ridge.

Description: The free blade is much shorter than the platform. The inner accessory lobe is usually present, and some specimens may have both inner and outer lobes. The accessory lobe extends from the adcarinal ridge to the midpoint of the inner margin of the platform and is decorated by rows of nodes. The outer margin of the platform may also be covered by rows of nodes that extend from the anterior end of the adcarinal ridge to about a quarter of the way down on the platform. The transverse ridges are not always continuous across the platform and often break up into smaller segments; the breaks frequently line up parallel to the platform axis. An incipient trough is sometimes present across the posterior-most quarter of the platform although some specimens may have the trough across the entire platform. The platform has a high side profile, and the cavity on the aboral surface is asymmetrical, narrow, and deep. Lambert (1992) noted some variability among different specimens of *I. amplificus*, although overall general appearances are the same.

I. amplificus can be distinguished from *I. obliquus* by the narrowness and high profile of the platform, shorter adcarinal ridges, and the lack of pronounced obliquity in the transverse ridges. *I.* sp. C of Boardman and others 2004 is also similar to *I. amplificus*, but the platform has a more ovoidal, straighter platform outline, the carina and adcarinal ridges are longer, the accessory lobes are smaller and do not drape around the platform, and the transverse ridges are straighter, coarser, and less disrupted across

the platform. Forms that I assign as *I. amplificus* have more nodose outer and inner accessory lobes and less interruption of the transverse ridges.

Idiognathodus praeobliquus Nemyrovska, Perret-Mirouse, and Alekseev 1999

(Figure 8-16, 8-17, 8-18, & 8-22)

Diagnosis: Diagnostic characteristics include slightly oblique transverse ridges exhibiting a furrow toward the posterior tip. The platform of *Idiognathodus praeobliquus* is triangular with an inward posterior curve. There are six to eight transverse ridges, but some larger specimens can have up to ten to twelve. The accessory lobes are unequal.

Description: The inner accessory lobe is larger than the outer lobe. There are several concentric rows of nodes on the inner lobe. The outer accessory lobe is not as well developed and has one row of nodes. The carina is short but prominent, occupying approximately a third of platform length. The adcarinal ridges are also short, extending from the anterior edge of the platform to about a third of the length of the free blade, flaring out only slightly.

I. praeobliquus was originally identified as *I. obliquus*, but has a smaller number of transverse ridges on the platform, which are not as obliquely oriented to the platform element axis. *I. praeobliquus* differs from *I. podolskensis* in the lack of the medial furrow in the transverse ridges, the shorter and less flared adcarinal ridges, and the concentric orientation of the nodes on the accessory lobes.

While I have identified forms that are very similar to *I. praeobliquus* in the McCurtain and Doneley cyclothems, they are different enough from the holotype to make

a positive identification difficult. Therefore, I decided to assign these forms as *I*. cf. *praeobliquus*.

One specimen of *I.* sp. A of Boardman and others (2004, fig. 2, specimen 29) from the Sam Creek Limestone is similar to *I. praeobliquus* in platform shape, slight obliquity of the transverse ridges, concentric rows of nodes on the accessory lobes, and short adcarinal ridges and thus could be construed as *I.* cf. *praeobliquus*. However, *I.* sp. A, Boardman and others 2004, exhibits the beginning of a medial furrow in the posterior-most three to six transverse ridges indicating a possible transition from *I. praeobliquus* to *I. podolskensis*.

I. cf. *praeobliquus* has also been identified in the Iowa CP-78 coal project core at the same level as *Idiognathoides*.

Idiognathodus iowaensis Youngquist and Heezen 1948

Diagnostic characteristics include an expanded inner accessory lobe along the anterior half of the platform. The inner accessory lobe is nodose. The platform is asymmetrically lanceolate. The five to six moderately-arched transverse ridges are coarser than those in most of the idignathodids of the lower Cherokee. Hanley (2008, p. 40) reported that the transverse ridges of the holotype are quite irregular. Forms similar to *I. iowaensis* have been identified above the Inola Limestone at Inola Hill, which I assigned to *I.* cf. *iowaensis*.

Idiognathodus mundulus Youngquist and Downs 1949

Diagnosis: Diagnostic characteristics include a narrow ovoid platform with subdued lobes, four arcuate grooves separating the adcarinal ridges from the carina and from the

narrow rows of nodes in the position of the accessory lobes. The carina is short with two arcuate sulci on each side, and extends from the blade nearly halfway onto the platform.

Description: The blade and platform of *Idiognathodus mundulus* are subequal in length. The platform is slightly bowed, arched, and narrowly ovoid in oral outline. The platform anterior margins are nodose. The adcarinal ridges are parallel to the carina and extend very little distance along the blade. Seven or eight transverse ridges are present on the posterior half of the platform. The lateral accessory lobes are minor with one or two sinuous rows of nodes. *Idiognathodus mundulus* superficially resembles *I. podolskensis* but can be distinguished by a narrower platform, straighter axis, lack of medial furrow in the transverse ridges, much smaller accessory lobes with more sinuous rows of nodes that extend more posteriorly, shorter, less-flared adcarinal ridges, and narrower platform. *I. mundulus* was named from shales northwest of Knoxville, Iowa which Boardman and others (2004) believed are most likely in the Verdigris cyclothem, more recently confirmed by field work led by J.P. Pope and P.H. Heckel. Boardman and others (2004) noted that many specimens illustrated by Stamm and Wardlaw (2003) as *I. ignisitus* may actually be *I. mundulus*. *I.* sp. C of Boardman and others 2004, can be assigned as *I.* cf. *mundulus*, but has no outer lobe, hence no fourth groove between it and the outer adcarinal ridge.

<u>*Idiognathodus robustus* Kossenko and Kozitskaya 1978</u>

Diagnosis: Diagnostic characteristics include lack of an accessory lobe, concave platform anterior half, raised upper edges of the platform anterior half that carry large nodes which sometimes morph into transverse ridges, and coarse, sparse (two to six) transverse ridges.

Description: The platform is oblong and lanceolate. The morphotype that Hanley (2008)

assigned to *I*. cf. *robustus* exhibits more transverse ridges than the holotype described by Kossenko and Kozitskaya (1978), but is very similar to forms identified as *I. robustus* by Stamm and Wardlaw (2003). Hanley (2008, p. 43) reports that *I. robustus* along with *I.* cf. *robustus* and *I*. sp. A are the most common idignathodid morphotypes in the middle Cherokee. In southeastern Kansas, a form that I assign to *I*. cf. *robustus* was encountered in the Cooper and Spencer 2-6 long cores and in Iowa the CP-79 coal project core.

Idiognathodus gibbus Lambert 1992

(Figure 8-25)

Diagnosis: Diagnostic characteristics include a moderately long carina and adcarinal ridges that join the distal platform obliquely, and transverse ridges that exhibit a groove or furrow to the outer side, in addition to an incipient posterior trough. The outer accessory lobe is usually absent with only a few nodes on the outer side. The carina is relatively longer than in most other species of *Idiognathodus* and terminates at the anterior-most transverse ridge.

Description: The Pa element of *Idiognathodus gibbus* has an asymmetrical, spade-like oral outline with a sharp to blunt posterior tip; the platform and free blade are of nearly equal length. The adcarinal ridges are long and nodose, paralleling the carina for over one-third to one-half of total platform length. The adcarinal ridges are delineated by shallow sulci. The inner accessory lobe is very nodose with nodes in random orientation. Nine to ten transverse ridges are present on the posterior two-thirds of the platform. The transverse ridges exhibit very slight obliquity. A groove or furrow is present in the transverse ridges, becoming more prominent toward the posterior tip. An incipient sub-central trough may develop across the transverse ridges of some specimens. Dextral

elements usually have shorter carinas and adcarinal ridges, and the transverse ridges show greater variability in their complexity. On some specimens, the outer margin of the transverse ridges aligns with the outer adcarinal ridge to form a continuous prominence down the outer side of the platform.

I. gibbus is similar to *I. podolskensis* in having a furrow or groove in the transverse ridges, but can be differentiated by having a squatter shape that is widest near the posterior end, only one well-developed accessory lobe, and straighter adcarinal ridges.

Idiognathodus crassadens Stamm and Wardlaw 2003

(Figure 8-10)

Diagnosis: Diagnostic characteristics include a narrow, straight platform with a slight downward and inner deflection of the posterior one-third, a narrow inner lobe with irregular, stout denticles, and a serrated lateral upper margin of the platform. The posterior platform is strongly ridged with five to ten thin, widely-separated transverse ridges. In some cases, the posterior platform is ornamented with short ridges or fused denticles.

Description: The adcarinal ridges are moderately developed, curved inward, and consist of small fused denticles, and the inner adcarinal ridge is more curved than the outer. The four to five denticles of the inner lobe are stout, wedge-like, and arrayed in straight to curved lines. The anterior-most denticles of the inner lobe may fuse with the adcarinal denticles. Conodonts similar to *Idiognathodus crassadens*, which I designated as *I.* cf. *crassadens*, were identified within the Inola cyclothem at 577 to 577.5 feet in the KGS Cooper CW-1 long core.

Genus *Neognathodus* Dunn 1970

The platform of *Neognathodus* is pectinate and equal in length to the free blade. The carina is well-developed and extends nearly to the posterior tip of the platform. One or both sides of the platform are flanked by transverse ridge-bearing parapets, which are delineated from the carina by deep adcarinal grooves. Dunn (1970) reassigned several common species of the genus *Gnathodus*, such as *G. bassleri* and *G. roundyi*, into *Neognathodus*. The genotype is *Neognathodus bassleri*.

Neognathodus is not as common as *Idiognathodus* in the lower Cherokee Group. However, Boardman and others (2004) noted three morphotypes found in lower Cherokee marine units from Oklahoma that are possibly useful for correlation: *Neognathodus bothrops* from the McCurtain Shale Member, *Neognathodus* cf. *asymmetricus* from the Sam Creek Limestone Member, and *Neognathodus asymmetricus* from the Inola Limestone Member. Lambert (1992) added *Neognathodus caudatus* as another taxon for marking the Atokan/Desmoinesian boundary in Iowa. Therefore, species of *Neognathodus* may serve as secondary biostratigraphic markers for the lower Cherokee Group.

Neognathodus asymmetricus (Stibane 1967)

Figure (8-7)

Diagnosis: Diagnostic characteristics include a free blade and platform of equal length with two nodose parapets, the outer one merging with the carina at about the third-most posterior node.

Description: Reassigned from *Gnathodus asymmetricus* by Stamm and Wardlaw (2003, p. 118), the platform is spade-like with a moderately-pointed to blunt tip. The outer

parapet is lower on its anterior end than its posterior end. The inner parapet is better-developed than the outer, but is lower than the carina. Pointed wedge-shaped nodes are found along the height of the inner parapet on the anterior transverse ridges. The outer platform margin merges with the carina near the third-most posterior node. Stamm and Wardlaw (2003, p. 119) assigned all *Neognathodus* species with the outer parapet merging with the carina, including *N. medadultimus* and *N. medexultimus*, into *N. asymmetricus*. *N. asymmetricus* is found in the Inola Limestone, and in the middle Cherokee, in the Lower and Upper Tiawah cyclothems and in a post-Fleming marine unit (Hanley, 2008).

Neognathodus cf. *asymmetricus* of Boardman, Heckel, and Marshall 2004

Diagnosis: Boardman, Heckel, and Marshall (2004) recognized a variety of *N. asymmetricus* with a very strongly convex inner platform margin, more so than in other varieties of *N. asymmetricus*. The inner platform margin joins with the carina about a short distance from the posterior tip.

Description: Narrow and leaf-like Pa element platform and a very pointed posterior tip. The free blade is shorter than the platform and extends toward the posterior tip of the platform as a nodose carina. The inner parapet is well-developed with fan-like, wedge-shaped nodes that terminate at the carina. The outer parapet is slightly nodose.

Boardman and others (2004) identified *N.* cf. *asymmetricus* from the Sam Creek Limestone of Oklahoma, in the *Idiognathodus obliquus* faunal zone within the lower Cherokee Group. I identified forms construed as *N.* cf. *asymmetricus* from the Doneley

interval of KGS Spencer and Hopp cores and IGS CP-79 core and Inola interval of KGS Deffenbaugh and Edmonds cores and IGS CP-78 core.

Neognathodus bothrops Merrill 1972

Diagnosis: Diagnostic characteristics include a relatively symmetrical shape, straight nodose carina, inner and outer parapets that parallel the carina without flaring away from or merging with it, and thick, wedge-shaped nodes on the platform margins, particularly the outer one.

Description: The Pa element of *Neognathodus bothrops* is spade-like in oral profile. The free-blade is long, straight, denticled and extends toward the posterior tip of the platform as a strongly-nodose carina. The nodes on the carina are rounded to slightly compressed. The platform is widest in its anterior one-third. Platform margins are lined with an outer and inner row of nodes; nodes are wedge-shaped and are delineated from the carina by adcarinal grooves. The wedge-shaped nodes, particularly the inner row, are strongly reminiscent of transverse ridges producing a radial fan-like pattern. The outer and inner rows of nodes merge near the posterior tip at the terminus of the carina. The parapets formed by the inner and outer row of nodes are very high, as high as or higher than the carina and are slightly curled at their tops. The form I assigned to *N. bothrops* has a less nodose carina and a greater separation between the wedge-shaped nodes on the platform margins. Boardman and others (2004) placed *N. bothrops* within the *Idiognathodus praeobliquus* faunal zone of the lower Cherokee Group of the southern Midcontinent.

Neognathodus caudatus Lambert 1992

(Figure 8-21)

Diagnosis: Diagnostic characteristics include triangular platform shape, and an elevated, nodose carina that extends to the posterior tip. *Neognathodus caudatus* has a distinctive Pa element oral outline with a flat-topped, triangular wedge-shaped platform and long free blade. The free blade displays strong denticles and frequently tilts in a nearly 20° angle from the element axis.

Description: The free blade extends to the posterior tip of the platform as a strongly-nodose and sometimes elevated carina. Transverse ridges start at the platform margin and terminate at the carina without any delineation by adcarinal grooves. The transverse ridges on the inner parapet extend downward to the anterior platform margin normally having a 30° deflection from the free blade; the transverse ridges on the outer parapet do not have as great an anterior extent.

Forms that I assign to *N. caudatus* have more pointed, oblique, horn-like anterior margins of the parapets, a carina that does not extend to the posterior tip, and transverse ridges that are delineated from the carina by adcarinal grooves except at the anterior margin. *N. caudatus* was found in the McCurtain cyclothem in Pittsburg County, Oklahoma. According to Lambert (1992), the stratigraphic range of *N. caudatus* extends from marine units above the Cliffland Coal in the Kalo Formation to marine units above the basal Laddsdale or a lower coal and shares a similar range with *Idiognathodus amplificus*. However, first appearance of *N. caudatus* and *Idiognathodus amplificus* in the McCurtain cyclothem in Oklahoma is below the first appearance of *I. obliquus* in the Sam Creek cyclothem there.

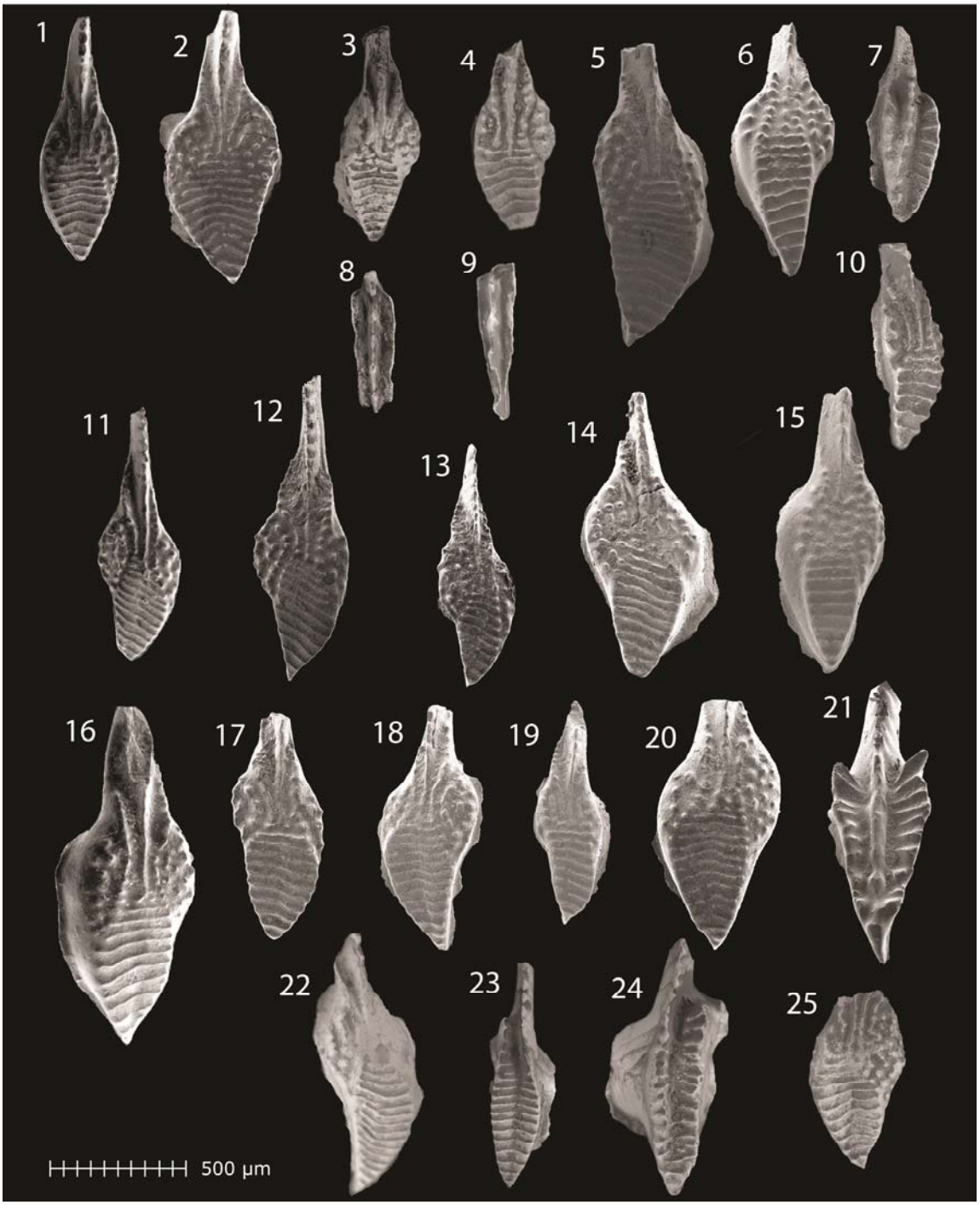
Figure 8. Lower Cherokee conodonts. All specimens magnified 65X.

Inola cyclothem
1. *Idiognathodus podolskensis*, Inola Hill, Rogers Co., OK, Boardman and others (2004)
2. *I. podolskensis*, KGS Rose Hill 1-6, 840-840.5, Miami Co., KS
3. *I. podolskensis*, Type Hackberry Branch Ls locality, Vernon Co., MO
4. *I. podolskensis*, Type Laddsdale locality, Davis Co., IA
5. *I. podolskensis*, KGS Edmonds 1A, 908-908.5, Leavenworth Co., KS
6. *I. amplificus*, Type Hackberry Branch Ls locality, Vernon Co., MO
7. *Neognathodus asymmetricus*, Inola Hill, Rogers Co., OK, principal reference section of Hemish (1998)
8. *Gondolella* sp., KGS Cooper CW-1, 577-577.5, Labette Co., KS
9. *Gondolella* sp., KGS Spencer 2-6, 848.5-848.9, Franklin Co., KS
10. *I.* cf. *crassadens*, KGS Cooper CW-1, 577-577.5, Labette Co., KS

Doneley cyclothem
11. *I. obliquus*, Davis Airport locality, above the Rowe Coal, Muskogee Co., OK, Boardman and others (2004)
12. *I. obliquus*, KGS Spencer 2-6, 881.5-882, Franklin Co., KS
13. *I. obliquus*, KGS Edmonds 1A, 932.4-933.4, Leavenworth Co., KS
14. *I. obliquus*, IGS CP-79, 389.5-399, Lucas Co., IA
15. *I. amplificus*, Type Doneley locality, Craig Co., OK

McCurtain cyclothem
16. *I.* cf. *praeobliquus*, Brushy Creek Tributary, Pittsburg Co., OK, Boardman and others (2004)
17. *I.* cf. *praeobliquus*, KGS Cooper CW-1, 805.9-806.5, Labette Co., KS
18. *I.* cf. *praeobliquus*, KGS P & M 7, 389-389.3, Cherokee Co., KS
19. *I. amplificus*, Brushy Creek Tributary, Pittsburg Co., OK
20. *I. amplificus*, KGS P & M 7, 389-389.3, Cherokee Co., KS
21. *N. caudatus*, Brushy Creek Tributary, Pittsburg Co., OK

Atokan interval
22. *I.* cf. *praeobliquus*, KGS Hopp 1-16, 1685-1685.5, Doniphan Co., KS
23. *Idiognathoides* sp., IGS CP-78, 524.8-525.25, Wayne Co., IA
24. *Idiognathoides* sp., IGS CP-78, 525.25-525.7, Wayne Co., IA
25. *I.* cf. *gibbus*, IGS CP-78, 525.25-525.7, Wayne Co., IA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CHAPTER IV

BIOSTRATIGRAPHY AND CORRELATION OF MAJOR LOWER CHEROKEE GROUP CYCLOTHEMS

Most of the correlation of lower Cherokee major cyclothems was done biostratigraphically with conodonts. However, in some instances, the marine zone did not yield conodonts, and correlation was conducted based upon stratigraphic position in relation to the Inola cyclothem as explained below. A high abundance of morphotypes of the conodont *Gondolella* has been found in shales associated with the younger Tiawah Limestone, which Hanley (2008) called the "major *Gondolella* zone" and utilized as the biostratigraphic marker for the Upper Tiawah cyclothem in the lower part of the middle Cherokee. In Oklahoma, there are several minor and intermediate cyclothems below the Upper Tiawah and above the uppermost major cyclothem in the lower Cherokee, the Inola, in ascending order: the Wainwright, Uppermost Boggy, Weir-Pittsburg, RC, and Lower Tiawah cyclothems. Of these five cyclothems, all are minor except for the Wainwright and Lower Tiawah cyclothems, which are intermediate. However, Marshall (2002) determined that the Inola is the only cyclothem in the lower Cherokee to yield even sparse *Gondolella*. Since *Gondolella* has now been identified in a major marine interval below Hanley's "*Gondolella* zone" in four cores, this interval is likely the Inola. Furthermore, the persistence of this marine zone across the Midcontinent makes the Inola cyclothem the ideal datum on which to position the biostratigraphic correlation of cyclothems in the lower Cherokee Group. Correlation of the Doneley and McCurtain cyclothems was done based on their positions relative to the Inola cyclothem, with some help from conodont abundance patterns and species distributions. The correlation of

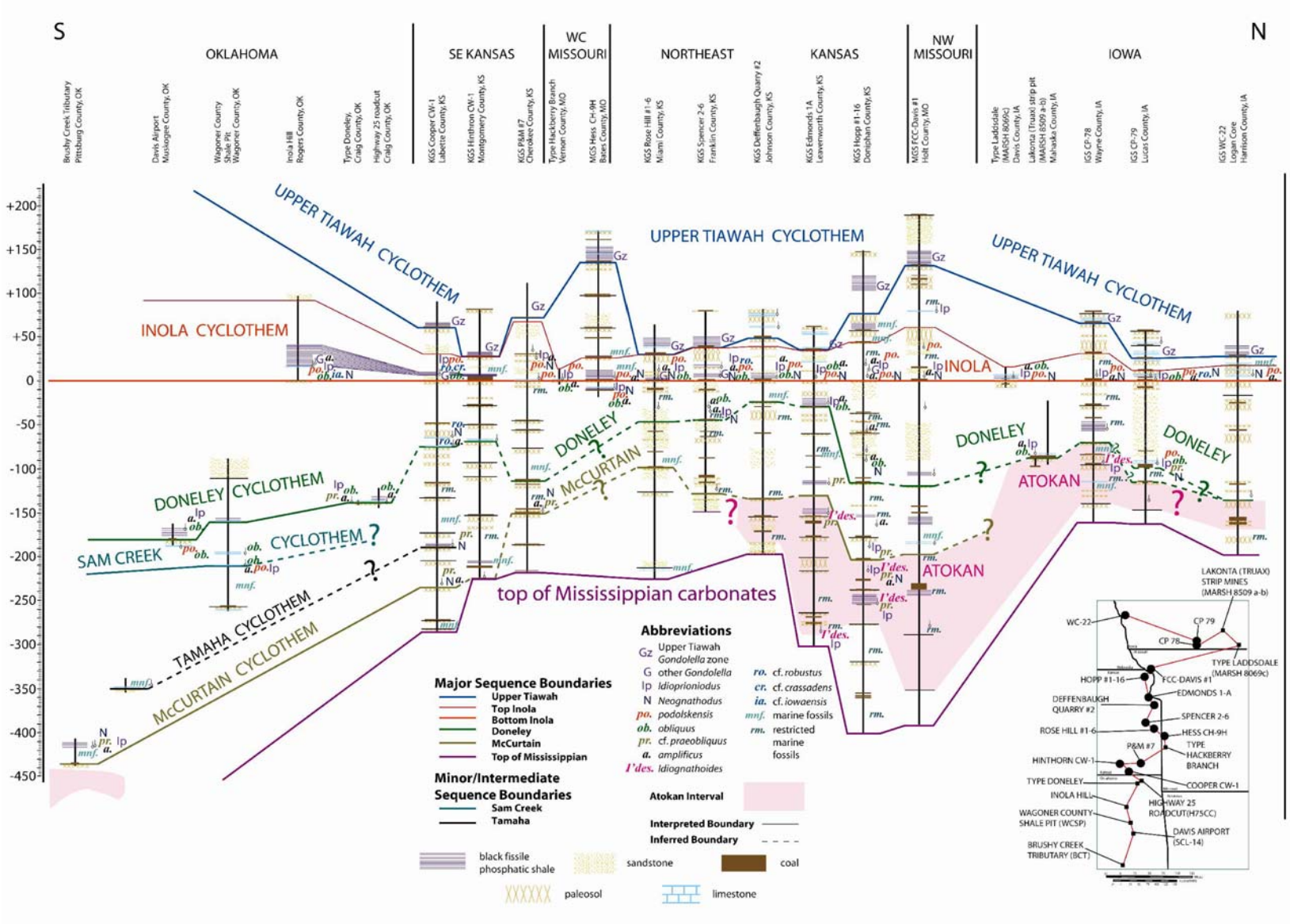
lower Cherokee cyclothems utilized several conodont morphotypes including *Idiognathodus podolskensis*, *I. obliquus*, *I.* cf. *praeobliquus*, *Idiognathoides*, *Idioprioniodus*, and *Gondolella*. *Idiognathodus amplificus* is the most abundant and cosmopolitan species within the lower Cherokee Group, as it is found in all three major cyclothems. The two uppermost cyclothems, the Inola and Doneley, have a dominance of *I. amplificus* over *I. podolskensis* and *I. obliquus*, respectively. The distribution of these morphotypes within each lower Cherokee cyclothem is provided below, along with the reasoning as to how they were correlated in Plate 1 and Figure 9.

Inola Cyclothem

At the type section of the Inola cyclothem at Inola Hill, the two most common species of *Idiognathodus* encountered are *I. amplificus* and *I. podolskensis*, but *I. obliquus* is also present. Boardman and others (2004) reported the first appearance of *I. podolskensis* from the Inola Limestone. A form more common to the middle and upper Cherokee, *I.* cf. *iowaensis* was found in the black fissile phosphatic shale above the Inola Limestone. *Neognathodus* species include *N. asymmetricus*, *N. cf. asymmetricus*, and *N. caudatus*. The black fissile phosphatic shale above the Inola Limestone is the highstand of the cycle as indicated by the deep-water *Idioprioniodus* and *Gondolella*, along with high abundance of conodonts at approximately 4600 *Idiognathodus* platforms and 350 *Idioprioniodus* elements per kilogram.

Northward from Oklahoma into Iowa, as previously mentioned, a marine interval just below, or one cycle below the Upper Tiawah cyclothem consistently yields relatively abundant deep-water conodonts. *Idioprioniodus* was identified in all cores and outcrops at this interval, except for IGS WC-22 and Hinthorn (for which the black

Figure 9. Correlation of lower Cherokee succession using base of Inola cyclothem as datum. Short brown lines represent coals, light blue lines are limestones, dark orange XX mark paleosols, dark yellow dots mark sandstones, purple lines mark dark phosphatic shales. Thick dark blue lines mark base of Upper Tiawah cyclothem. Thin red lines mark assumed top of Inola cyclothem. Other thick colored lines represent correlations based on good biostratigraphic data and/or position relative to Inola cyclothem above. Dashed lines are inferred correlations. Pink zones denote Atokan strata. 'mnf' denotes marine fossils, 'rm' denotes restricted marine fossils, purple 'Gz' denotes position of *Gondolella* zone of Hanley (2008), purple 'G' denotes *Gondolella* found in the Inola cyclothem, purple 'Ip' denotes *Idioprioniodus*, dark blue 'N' denotes *Neognathodus*, and pink 'I'des' denotes *Idiognathoides*. Please refer to key included on figure for symbols used on diagram for various species of *Idiognathodus*.


S
N
OKLAHOMA
SE KANSAS
WC MISSOURI
NORTHEAST
KANSAS
NW MISSOURI
IOWA
UPPER TIAWAH CYCLOTHEM
INOLA CYCLOTHEM
DONELEY CYCLOTHEM
SAM CREEK CYCLOTHEM
TAMAHA CYCLOTHEM
McCURTAIN CYCLOTHEM
DONELEY
McCURTAIN
INOLA
ATOKAN
top of Mississippian carbonates
Major Sequence Boundaries
Upper Tiawah
Top Inola
Bottom Inola
Doneley
McCurtain
Top of Mississippian
Minor/Intermediate Sequence Boundaries
Sam Creek
Tamaha
Abbreviations
Gz Upper Tiawah Gondolella zone
G other Gondolella
Ip Idioprioniodus
N Neognathodus
po. podolskensis
ob. obliquus
pr. cf. praeobliquus
a. amplificus
I'des. Idiognathoides
ro. cf. robustus
cr. cf. crassadens
ia. cf. iowaensis
mnf. marine fossils
rm. restricted marine fossils
Atokan Interval
Interpreted Boundary
Inferred Boundary
black fissile phosphatic shale
sandstone
coal
paleosol
limestone
LAKONTA (TRUAX) STRIP MINES (MARSH 8509 a-b)
WC-22
CP 79
CP 78
TYPE LADDSDALE (MARSH 8069c)
HOPP #1-16
FCC-DAVIS #1
EDMONDS 1-A
DEFFENBAUGH QUARRY #2
SPENCER 2-6
ROSE HILL #1-6
HESS CH-9H
P&M #7
TYPE HACKBERRY BRANCH
HINTHORN CW-1
TYPE DONELEY
COOPER CW-1
INOLA HILL
HIGHWAY 25 ROADCUT(H75CC)
WAGONER COUNTY SHALE PIT (WCSP)
DAVIS AIRPORT (SCL-14)
BRUSHY CREEK TRIBUTARY (BCT)

shale noted by Lange (2002) was missing in the core box). *Neognathodus* is present in this interval in all but three cores and outcrops, and the species of *Neognathodus* identified throughout the Midcontinent are the same as those found at Inola Hill. *Neognathodus bothrops* is present at this interval in the Hess core. *Gondolella* was identified in the Cooper, Rose Hill, Spencer, and Hopp cores. Furthermore, *Idiognathodus amplificus* and *I. podolskensis* are present in this marine interval in every core and outcrop studied. This marine interval also yielded *I. obliquus* in lesser numbers in about half the cores. The conodont content, particularly the common occurrence of *Idioprioniodus* and *Neognathodus*, the sole occurrence of *Gondolella*, the abundance of *I. podolskensis* and *I. amplificus*, along with stratigraphic position, readily allows this marine interval to be correlated with the Inola cyclothem as defined in Oklahoma. This includes the type locality of the Hackberry Branch Limestone and associated shales in Vernon County, Missouri, where this limestone yielded *I. podolskensis* and *Idioprioniodus*.

Although Hemish (1990c, p.12) noted that the Inola Limestone is not continuous north of the Oklahoma-Kansas border, the biostratigraphic correlation establishes equivalency between the Inola cyclothem and the Hackberry Branch Limestone, formerly misidentified Seville (see Gentile and Thompson, 2004) of Vernon and Barton Counties of southwestern Missouri. It also establishes equivalency of coals at its base: Bluejacket Coal of Oklahoma, Bluejacket A Coal in southeastern Kansas, a coal in the Weir Formation, the ‘Tebo’ Coal of the Spencer 2-6, Rose Hill, and Deffenbaugh Quarry cores in northeastern Kansas, and a middle Laddsdale coal in Iowa. On a regional extent, the Inola cyclothem includes the middle Boggy Formation (Bluejacket Coal and Inola

Limestone) of Oklahoma; the uppermost Krebs Formation and probably part of the basal Cabaniss Formation as currently identified in Kansas; Welborn Formation and part of basal Weir Formation of Missouri; and middle part of the Laddsdale Member at the base of the Floris Formation in Iowa.

Cyclothems Below the Inola Cyclothem

Atokan Interval

Two marine intervals in the lower Edmonds and Hopp cores and one in the CP-78 core yielded mostly the conodont genus *Idiognathoides*, as well as some *Idiognathodus* cf. *praeobliquus*, *I. amplificus*, and *Idioprioniodus*. Previous workers have determined that the upper range of *Idiognathoides* is within the Atokan, based upon biotic associations of other fossil groups as well as conodonts (Landing and Wardlaw, 1981; Grayson, 1984; Grubbs, 1984, Barrick and others, 2004). Therefore, these marine intervals are considered to be Atokan in age (Figure 9).

In the Edmonds core, Peppers and Brady (2007) confirmed an unnamed coal between 1164.3 to 1164.6 (354.9 to 355.0 m) as Atokan (early Westphalian B) by being within the lower part of the *Microreticulatisporites nobilis-Endosporites globiformis* (NG) Spore Assemblage Zone of the Illinois Basin. This is consistent with the appearance of *Idiognathoides* in this core between 1047.5 (319.3 m) and 1173.4 (357.7m). Although *Idiognathoides* is not reported from the lower parts of the Spencer, Rose Hill, and P&M 7 cores below the McCurtain cyclothems, these intervals might also be Atokan by position below the correlated McCurtain cyclothem, but definite biostratigraphic evidence is lacking.

Based upon palynological data, such as *Dictyotriletes bireticulatus*, the Atokan/Desmoinesian boundary was placed at the base of the higher Cliffland Coal within the Kalo Formation (Ravn, 1986). Lambert (1992) noted that *I. obliquus*, *I. amplificus*, and *Neognathodus caudatus* could serve as a marker for the base of the Desmoinesian at the Atokan/Desmoinesian boundary in Iowa. However, in the Hopp core, *I.* cf. *amplificus* has been tentatively identified in Atokan strata. If this identification is correct, *I. amplificus* would have first appeared in the Atokan. *I.* cf. *gibbus* has been tentatively identified in the CP-78 core in association with *Idiognathoides*, which is consistent with its occurrence only in Atokan strata as noted by Lambert (1992).

McCurtain Cyclothem

Idiognathodus cf. *praeobliquus* seems to the most common morphotype found within the McCurtain cyclothem. *I. amplificus* is also found but, unlike the Inola and Doneley, it is not always the abundant form in the McCurtain.

The McCurtain Shale in Pittsburg County, Oklahoma contains a conodont fauna dominated by *Idiognathodus amplificus* and *praeobliquus* and also has *Idioprioniodus*, *Ellisonia*, *Neognathodus bothrops*, and rare *N. caudatus*. The McCurtain Shale in the locality studied has a condensed-section yielding nearly 2200 *Idiognathodus* platform elements and 1050 *Idioprioniodus* per kilogram.

Farther north, the McCurtain can be correlated by identification of a marine interval containing *I. amplificus* and *I.* cf. *praeobliquus* but lacking *Idiognathoides* and *I. obliquus*. However, conodonts compatible with the McCurtain Shale of Oklahoma have been identified in Kansas only in the Cooper, P&M, Edmonds, and Hopp long cores.

From Oklahoma to southeast Kansas, this interval consistently yielded *N. bothrops* in addition to the idignathodids. Unlike the Inola cyclothem, the McCurtain yielded only rare *Idioprioniodus*, in the Hopp core. In some cases, the McCurtain can only be correlated positionally, because cores such as the Hinthorn and Davis yielded only *Ellisonia* and fragments, respectively, in the stratigraphic position of the McCurtain. Since McCurtain strata have not been identified in Iowa in the studied cores, it may extend only to the southern part of the Forest City Basin (Figure 9). Further study is needed.

Although the Riverton Coal has been traditionally considered to be Atokan, and older than the other units, inclusion of coals identified as Riverton within the McCurtain cyclothem indicates unclear stratigraphic relationships between units that have been identified as the Riverton Coal, Warner Sandstone, Neutral Coal, Rowe Coal, and Rowe D in Kansas. For example, coal identified as Riverton in one part of Kansas may be equivalent to the Neutral Coal or Rowe Coal in another part of Kansas. Because the type Warner Sandstone forms the uppermost part of the type McCurtain cyclothem in Oklahoma, then the sandstone identified as Warner below the McCurtain cyclothem must be older than the type Warner Sandstone in Oklahoma.

Doneley Cyclothem

The Doneley cyclothem is dominated by *I. amplificus* and less commonly by *I. obliquus* and *I.* cf. *praeobliquus*. It is characterized by the lowest appearance of *I. obliquus*. *Idioprioniodus* occurs in the Hess, Spencer, Edmonds, and CP-79 long cores and the Lakonta strip pit in Davis County, Iowa. *Neognathodus* has been found in the Cooper, Hess, Spencer, Hopp, and CP-79 long cores (Figure 9).

Unfortunately, *I. obliquus* does not appear in every marine interval at the Doneley position, and some marine units, such as a fossiliferous shale above a possible Rowe Coal split in the P & M core did not yield any conodont material at all. In Oklahoma, *I. amplificus*, *I. obliquus*, and *Idioprioniodus* occur above a coal identified as the Rowe. A black silty shale immediately above a coal identified as the Bluejacket D and 20 feet (6.1 m) above a coal identified as the Rowe in the Spencer core yielded *I. amplificus*, *I. obliquus*, *Neognathodus* cf. *asymmetricus*, a juvenile *Neognathodus* (possibly *caudatus*), and *Idioprioniodus*. Doneley-compatible conodonts were found above an unnamed coal in the Edmonds core. In Iowa, *I. amplificus*, *I. obliquus*, and *Idioprioniodus* were identified above a Cliffland coal in the Lakonta strip pit and in CP-79. In the other cores or outcrops, other conodonts, such as *I.* cf. *robustus* in the Cooper, or no conodonts were encountered in the position of the Doneley, leaving gaps in its definite distribution. In these cases, correlation was conducted strictly on stratigraphic position (Figure 9).

On a regional extent, the Doneley cyclothem forms part of the upper Savanna Formation, from the top of the paleosol below the Rowe Coal bed to the top of the paleosol below the Drywood Coal bed of Oklahoma. Northward, it includes the middle part of the Krebs Formation of Kansas, the Rowe Coal in southeastern Kansas, a coal identified as Bluejacket D in east-central Kansas, possibly the Drywood Coal of the Rose Hill core, and an unnamed coal in the southern part of the Forest City Basin. The Doneley cyclothem appears to include the upper part of the Rowe Formation (the Rowe Coal) plus the overlying Drywood Formation of Missouri. At its northernmost extent, the Doneley includes the Cliffland Coal and overlying marine unit in the lowermost Floris Formation of Iowa. In the CP-78 core, the Doneley cyclothem is actually below what was identified

as the Cliffland and includes what was identified as the Blackoak Coal. However, since there are two Clifflands and two Blackoaks in this core, coal misidentification is probable. It is possible, for now, to establish probable equivalency at least between the Rowe Coal of Oklahoma and southeastern Kansas and the Cliffland Coal of Iowa.

Lambert (1992) believed that *I. obliquus* could serve as a marker for the base of the Desmoinesian at the Atokan/Desmoinesian boundary for Iowa due to its distinctive appearance, cosmopolitan distribution, and short taxonomic range. However, this would only hold true in Iowa where the McCurtain cyclothem has not been recognized. In Oklahoma, where the lower Cherokee is more complete, *Idiognathodus obliquus* first appears well above the Atokan/Desmoinesian boundary.

In CP-79 core, a form that I assigned as *I.* cf. *podolskensis* was identified in the black shale. At the Davis Airfield locality, the Sam Creek Limestone also yielded *I.* cf. *podolskensis*. If these identifications are correct, they would extend the range of *I. podolskensis* downward in the Midcontinent Cherokee Group, whereas Boardman and others (2004) noted its first appearance only at the Inola Limestone.

Intermediate and Minor Cyclothems

Besides the previously-mentioned major cyclothems, there are numerous intermediate and minor lower Cherokee cyclothems that were defined in east-central Oklahoma but not traced northward. They are briefly mentioned below because there is a possibility that at least some of them may be equivalent to some of the minor cycles between the major cycles in Kansas and northward, but are not able to be correlated northward by means of the fossils currently available.

Between Upper Tiawah and Inola

In Oklahoma, the Wainwright, Uppermost Boggy, Weir-Pittsburg, RC, and Lower Tiawah cyclothems (in ascending order) occupy the interval between the Upper Tiawah and Inola cyclothems. All are recognized as minor because they are represented mainly by coal above paleosols except for the Wainwright and Lower Tiawah cyclothems, both of which contain a substantial marine unit above the coal. Hanley (2008) split Marshall's (2002) Tiawah cyclothem into the Upper and Lower Tiawah cyclothems on the basis of an intraformational conglomerate within the type Tiawah Limestone, which is below the *Gondolella*-bearing Upper Tiawah black shale and above another conodont-bearing black shale that lacks *Gondolella* and is termed Lower Tiawah. Hanley (2008) reported *Idiognathodus crassadens*, *I. ignisitus*, and *I. attenuatus* from the Lower Tiawah. The type Wainwright cyclothem contains black phosphatic shales and limestones that yielded *Idioprioniodus* and a species of *Idiognathodus* that resembles *I. robustus*, based on illustrations in Boardman and others (2004). Neither Boardman and others (2004) nor Hanley (2008) encountered *I. amplificus* or *I. podolskensis* in the Wainwright or Lower Tiawah cyclothems. Since at least one cycle separates the Upper Tiawah from the Inola in some of the cores studied, it might be either the Wainwright or Lower Tiawah of Hanley (2008) that extends partially northward.

Between Inola and Doneley/Sam Creek

In Oklahoma, there are five cyclothems between the Doneley and the Inola (in ascending order): Drywood, Lower Witteville, Secor, Secor Rider, and Peters Chapel cyclothems. The highstands of the Drywood Coal, Secor Rider, and Peters Chapel cyclothems are black fissile phosphatic shale yielding *Idiognathodus*. The highstand of

the Secor Rider cyclothem also yielded *Idioprioniodus*. *Idiognathodus* was found in silty blocky sideritic shale ten feet (3.05 m) above the Secor Coal. Because they are conodont-bearing, the Drywood, Secor, Secor Rider, and Peters Chapel cyclothems are considered intermediate while the Lower Witteville cyclothem is minor. While it may be tempting to identify these cyclothems in the cores where there are several paleosols and sequence boundaries between the Inola and Doneley cyclothems, there is no way to be certain.

Between McCurtain and Doneley/Sam Creek

The seven cyclothems in the interval between the Sam Creek and McCurtain cyclothems are, in ascending order: Keefton, Warner, Stigler, Tamaha, Keota, Spaniard, and Tullahassee cyclothems. All have coals, but only the Tamaha and Spaniard are overlain by substantial marine units. Hence all are minor except for the Tamaha and Spaniard cyclothems, which are conodont-bearing and thus considered intermediate.

At its type locality, the Tamaha cyclothem exhibits a high abundance and diversity of marine fossils, including productid brachiopods, ramose bryozoans, gastropods, crinoids, ostracodes, and the foram *Endothyra*. A dark gray silty fissile calcareous shale above the Tamaha Coal yielded crinoid cups, columnals, and arm fragments. The shale also yielded a conodont morphotype that has been tentatively identified as *I*. cf. *praeobliquus*. In the Cooper core, there are two marine intervals yielding *I*. cf. *praeobliquus*: 764.8 to 765 (233.11 to 233.17 m), above a coal identified as the Neutral, and 805.9 to 806.5 (242.01 to 242.19), ten feet (3.05 m) above a sandstone identified as the Warner. It is possible that the upper “cf. *praeobliquus* zone” above the Neutral may be a northern extension of the Tamaha cyclothem above the lower “cf.

praeobliquus zone", which was identified as the McCurtain cyclothem (Figure 9). Both upper and lower Spaniard limestones in the Spaniard cyclothem yielded *Idiognathodus*, and it is possible that one of the cycles above the possible Tamaha in the Cooper and Hinthorn cores are correlative.

There is a possibility that the Sam Creek cyclothem extends northward. However, the lack of a second *I. obliquus* zone makes it uncertain because the major unit in this position in southern Kansas cores is considered to be Doneley as explained in the section on genetic stratigraphy.

Other Possible Controls Over Minor Cyclothems

More northward, in Kansas, Missouri, and Iowa, several minor to intermediate cycles are found between the lower Cherokee major cyclothems. While it is tempting to assume that these cycles are the northernmost expressions of the minor and intermediate cyclothems of the lower Cherokee in Oklahoma, there are other possibilities to consider. Many of these cycles may be a succession of minor reversals of sea level within the major transgression or regression that produced the traceable major cyclothem. These minor T-R events would produce marine sediments and coals that would be splayed outward northward as separate minor cycles but would merge southward with the major cyclothem. This pattern is documented in younger cyclothems. For example, the Pawnee cyclothem in the Marmaton Group splits into two traceable cyclothems north of the Kansas-Oklahoma border (Price, 1981, 1984; Bisnett and Heckel, 1996). In the younger Missourian Dennis cyclothem, the core black phosphatic Stark Shale splays black shales northward into the regressive Winterset Limestone in what is termed by Felton and Heckel (1996) "phased regression". In some areas, autocyclic processes such as localized

tectonics and delta switching could account for some of the minor or even intermediate cyclothems. Resolution of whether these minor cycles are the northernmost extensions of intermediate Oklahoma cycles, or minor reversals of sea level that produced regressive (or transgressive) splays of minor cycles off of the major identifiable Oklahoma cyclothems will require much further study. Moreover, the occurrences of different numbers of minor cycles between two major cycles in different cores (e.g., one between the Doneley and Inola in Edmonds core versus two between Doneley and Inola in Hopp core, see Figure 9) could have resulted from removal of minor cycles by erosion of the section, as represented in the Edmonds core, or from autocyclic processes. The present data are too sparse to resolve these possibilities.

CHAPTER V

DEPOSITIONAL FACIES AND BRIEF DEPOSITIONAL HISTORY

Depositional history is summarized from facies present only in the major cyclothems that are more confidently correlated northward from Oklahoma.

McCurtain Cyclothem

In Oklahoma, early transgression is represented by either an upper Hartshorne coal or an unnamed coal at the base of the McCurtain Shale (Plate 1). In Kansas, an unnamed coal in the basal Krebs Formation, very carbonaceous shale, and coals that have been identified as the Neutral or even the Riverton Coal mark the beginning of the transgression. Later transgression is recorded by a brachiopod and pelecypod-rich ferruginous grainstone directly above the uppermost Hartshorne Coal in southern Muskogee County, Oklahoma. Other transgressive deposits include clay shale with conodonts and ammonoids at the Brushy Creek tributary locality in Pittsburg County, Oklahoma. Late transgressive and highstand deposits are represented by black phosphatic conodont-rich fissile shales in Oklahoma, and calcareous dark fissile shales with conodonts in Kansas (Cooper core). Some of these shales also contain brachiopods, other pyritized fossil debris, and encrusting foraminifers. Regressive and lowstand deposits are represented by silty clay shales and the lower part of the Warner Sandstone in Oklahoma, and by silty shales with plant debris, paleosol underclays, and unnamed sandstone beds in Kansas. This cyclothem is capped by the paleosol underclays below the Keefton Coal in Oklahoma and by paleosols beneath the Rowe Coal and an

unidentified coal, possibly the Tamaha, in Kansas. The McCurtain cyclothem has not been definitely identified in Missouri or Iowa (Figure 9 and Plate 1).

Doneley Cyclothem

In Oklahoma, early transgression within the Doneley cyclothem is marked by the coal bed identified as the Rowe. Further transgression is represented as the brachiopod-rich Doneley Limestone, overlain by dark clay shale with marine fossils (brachiopods, ostracodes, nautiloids, gastropods, crinoids, and foraminifers). In some places, a very thin, impure, brachiopod-rich transgressive wackestone to packstone is present. Maximum transgression is represented by black fissile shale in Oklahoma, which is sparsely to moderately fossiliferous with brachiopods, crinoids, pelecypods, gastropods, foraminifers, and the conodonts *Idiognathodus* and *Idioprioniodus*. Early regressive deposits include dark micaceous calcareous shale with ostracodes, orthid brachiopods, foraminifers, *Idiognathodus*, and some *Idioprioniodus*; dark fissile shale with pyritized brachiopods and pelecypods; and ironstones with impressions of brachiopods and pelecypods. In a few places a very thin, silty, regressive brachiopod- and pelecypod-rich mudstone to wackestone yielding crinoids and possibly nautiloids is present. Late regression is represented by dark siltstone with carbonized leaf impressions and silty to sandy dark shale with siderite or iron oxide stringers and nodules. Lowstand deposits include the underclay below the Drywood Coal bed. However, at Hensley Mountain, the Drywood Coal and its paleosol underclay are absent, and the regressive silty shale of the Doneley cyclothem grades into the overlying Bluejacket Sandstone.

In southeastern Kansas, early transgression is represented in the Cooper core by carbonaceous shale with brachiopods and bryozoans followed upward by shale with

crinoids and conodonts. The coal identified as the Rowe lower in this core (Lange, 2003) may not be a part of the Doneley cyclothem, because two paleosols lie between it and the marine unit. A brown bioclastic wackestone with a diverse fauna including echinoderm fragments, bryozoans, brachiopods, fish debris, gastropods, foraminifers, and *Idiognathodus* may be the highstand of this cyclothem in the Cooper core. Above this limestone, there is dark gray silty shale and interlaminated micaceous sandstone and siltstone. An overlying brown packstone represents a second rise in sea level, yielding echinoderm fragments, fish debris, and fewer conodonts (*Idiognathodus*, *Adetognathus*, and *Neognathodus*). Carbonaceous pyritic slickensided mudstones overlain with rooted and pedogenically altered mudstones constitute the regressive sequence, and the paleosol below the Drywood Coal forms the top of this cyclothem.

In northeastern Kansas, a coal identified as the "Rowe" in the Spencer core (Johnson, 2004) is separated from a marine interval yielding *I. obliquus* (hence identified as Doneley) by coals identified as the "Drywood" and "Bluejacket D". Rooted sandstones and paleosols between the "Rowe", "Drywood", and "Bluejacket D" coals may represent a possible coastal floodplain with periodic minor transgressions. Above the highest ("Bluejacket D") coal, transgression deposited grayish black (N2) carbonaceous silty shale with plant fossils and *Lingula*. Highstand is represented by black silty calcareous shale yielding crinoids, brachiopods, fish teeth, *Idiognathodus* (including *I. obliquus*), *Idioprioniodus*, and *Neognathodus*. Regressive deposits include dark gray silty shale, siltstones, and paleosols. A thin unnamed coal approximately eighteen feet above the highstand deposits may represent a minor transgression in the regressive limb of the cycle. Late regression is represented by a rooted heterolithic,

possibly tidal, sandstone above the unnamed coal. Lowstand is marked by the pedogenically altered and rooted upper Bluejacket Sandstone (Plate 1).

In the Forest City Basin of northeastern Kansas and northwestern Missouri, an unidentified coal marks the beginning of transgression in the Doneley cyclothem, and early transgression is represented by thin carbonaceous shale. The transgressive limb of the Doneley is complex with interspersed sandstones, paleosols, and coals, which may be an overprinting of smaller magnitude, higher frequency sea-level fluctuations. Silty shales mark further transgression, and the highstand is represented by black fissile shale yielding a high diversity of marine fossils. Conodonts include *Idiognathodus*, *Idioprioniodus*, and sparse *Adetognathus.* In the Hopp core, silty shale with siderite stringers yielding brachiopods, crinoids, abundant *Idiognathodus* (~960 elements per kilogram), and *Neognathodus* marks the highstand of the cyclothem. The regressive limb is also complex with interspersed sandstones, shales, and occasional coals, including a five-foot, cross-bedded, possibly deltaic sandstone. Late regressive deposits include siltstones and silty shales. Lowstand deposits are marked by slickensided, rooted paleosol underclays below the next higher coal (Plate 1).

In Iowa, early transgression of the Doneley cyclothem is represented by the Cliffland Coal bed in the Lakonta pit and CP-79 core. However, in the CP-78 core, it is marked by a coal apparently misidentified as the Blackoak by the Iowa Geological Survey. Transgressive deposits include dark shaly carbonaceous, pyritiferous limestone yielding ostracodes and gastropods. Highstand in the Lakonta pit and CP-79 core is marked by dark gray argillaceous wackestone with crinoids, brachiopods, gastropods, rugose corals, ostracodes, fish teeth, and the conodonts *Idiognathodus* (especially *I.*

obliquus), *Neognathodus*, *Idioprioniodus*, and sparse *Adetognathus*. In the CP-78 core, transgression is represented by heterolithic, possibly tidal, sandstone followed by dark gray, fissile, micaceous shale. Although fossiliferous, this shale yielded only spores, gastropods, ostracodes, bivalves, and *Adetognathus* suggesting a restricted marine environment. Thin heterolithic bioturbated sandstone with large mica flakes may indicate a return to tidal conditions. The lowstand is represented by a yellowish gray, rooted, locally calcareous, argillaceous sandstone yielding sparse plant material. A very thin coal identified as the Cliffland overlies this sandstone (Plate 1).

The inconsistent and scattered nature of facies within the Doneley cyclothem indicates a very complex depositional history resulting from differences in accommodation space and detrital influx. Relatively thick regressive sandstones have been found only in the Davis and CP-79 cores and may have resulted from localized filling of paleovalleys. Marine lithofacies are also discontinuous. Black fissile phosphatic shales yielding *Idiognathodus*, *Idioprioniodus*, and sometimes *Neognathodus* have been encountered only in Oklahoma, in the Edmonds and Davis cores in the Forest City Basin, and CP-78 core in Iowa, whereas limestones are present only in Oklahoma, and the Cooper and Hinthorn cores in Kansas, the Lakonta strip pit and CP-79 core in Iowa (Figure 9 and Plate 1). As sea transgressed northward, it may have filled paleovalleys of differing elevations. Some areas had valleys deep enough for the deposition of deep-water clay, while other areas were shallower with less detrital influx and conducive to the deposition of localized lime muds. Still other areas were high enough that only nearshore sediments lacking the full complement of open marine faunas were deposited.

Inola Cyclothem

Early transgression of the Inola cyclothem is represented by the Bluejacket Coal in Oklahoma and at the type Hackberry Branch locality in Missouri, a Bluejacket A coal in southeastern Kansas, a coal in the Weir Formation in southwestern Missouri, a coal identified as the "Tebo" in the southern margin of the Forest City Basin, an unnamed coal in the upper Krebs Formation in Kansas, and a middle Laddsdale coal in the Floris Formation in Iowa. In the Cooper and Spencer cores, early transgression was followed by deposition of sand. At Inola Hill, Cooper core, type Hackberry Branch locality, Edmonds and Hopp cores, continued transgression deposited silty, locally carbonaceous, dark silts and clays containing plant fragments in the Cooper core, brachiopods and possible crinoid stems at the Hackberry Branch locality, and foraminifers, ostracodes, and brachiopods in the Hopp core. In Iowa, continued transgression following the middle Laddsdale coal formed thin black shale in the type Laddsdale locality and CP-79 core, which yielded abundant conodonts (~220 *Idiognathodus* platform elements per kilogram) in the CP-79 core. In the Logan core, early transgression is represented by light gray, clayey, brachiopod-bearing shale overlying a paleosol (Plate 1).

Later transgression is marked by the Inola Limestone in Oklahoma, the equivalent Hackberry Branch Limestone in Missouri, and an unnamed limestone above a middle Laddsdale coal in south-central Iowa. In the IGS Logan core, a paleosol above an equivalent limestone indicates a reversal of sea level. All of these limestones yield conodonts, typically in great abundance, indicating their position as condensed intervals in a major cyclothem. Highstand is represented by dark phosphatic shales with sparse *Gondolella* at Inola Hill and northward through most cores into northeastern Kansas

(Cooper, Hinthorn, Rose Hill, Spencer, and Deffenbaugh cores) and dark phosphatic shale without *Gondolella* in west-central Missouri (Hess core). In the Hinthorn, Hess, Rose Hill, and Deffenbaugh cores, the dark phosphatic shale directly overlies the coal. In the Forest City Basin, highstand is represented by a calcareous brachiopod-rich siltstone or silty shale (Edmonds core) and dark shale with siderite stringers (Hopp core).

In Iowa, the highstand facies are complex and vary among the outcrops and cores studied, probably representing different elevations on the depositional surface. At the type Laddsdale locality in Davis County, Iowa, highstand is represented by dark, silty, calcareous, and carbonaceous shale yielding crinoids, echinoderm debris, fusulinids, foraminifers, and conodonts (*Idiognathodus*, *Neognathodus*, *Idioprioniodus*, sparse *Adetognathus*). Westward, in the CP-78 core, black silty shale with gastropods, spores, foraminifers, bivalves, ostracodes, and a few conodonts (*Idiognathodus*, *Neognathodus*, and *Ellisonia*) directly overlying a coal identified as the Laddsdale, represents deposition in a nearshore to restricted marine environment. North of the CP-78 core, the CP-79 core exhibits a complex transgressive sequence. Above the early transgressive Laddsdale Coal and carbonaceous and silty shales, a second coal (also identified as Laddsdale) separates the early transgressive phase from the highstand phase. Following the second Laddsdale coal, dark fissile fossiliferous shale yielding echinoderm debris and *Idiognathodus* constitutes the highstand of the Inola cyclothem. Farther westward in Harrison County, the Inola highstand in the Logan core is represented by an argillaceous wackestone yielding brachiopod, fish debris, foraminifers, *Idiognathodus podolskensis*, and *Neognathodus*.

The deepest deposition during maximum transgression apparently was limited to two regions, northeastern Oklahoma into southeastern Kansas (south of the Bourbon Arch) and in Miami, Franklin, and Johnson counties, Kansas and Bates County, Missouri (north of the Bourbon Arch). In the P & M, Rose Hill, and Spencer cores in southeastern and east-central Kansas, there are two conodont-bearing marine zones separated by sandy to silty beds and thin paleosols in the Inola cyclothem (Figure 9), indicating two transgressive pulses within the Inola interval. A silty sandstone identified as Upper Bluejacket lies between these two zones in the P & M core. The lower zone yielded *Gondolella* in the Rose Hill and Spencer cores, and thus may have been deposited in deeper water than the upper zone.

Early regressive deposits include silts and clays containing siderite, along with gray to black silts and clays, with varying amounts of plant material. Sandstones, siltstones, and heterolithic sandstones and siltstones are common in many of the outcrops and cores studied. Some sandstones and siltstones yielded plants and sparse fusulinids. Regressive limestones with sparse marine fossils are present in the Edmonds core, type Laddsdale locality, CP-79, and Logan cores. Lowstand deposits are represented by fluvial sandstones (termed the lower Taft Sandstone on Inola Hill) and the succession of paleosol underclays below the next higher coal (Plate 1).

Unlike the Doneley cyclothem, the Inola cyclothem has been positively identified across the Midcontinent and has a more persistent dark phosphatic shale lithofacies from Oklahoma to at least northeastern Kansas. However, there is variation within the Inola cyclothem in thickness and types of lithofacies, reflecting more subtle differences in accommodation space and detrital influx. The thickness of the Inola cyclothem decreases

northward from Inola Hill in Oklahoma to Iowa as accommodation space decreased. The Inola is thickest with abundant siltstones and sandstones in the P & M and Davis cores (Figure 9) possibly as a result of increased localized detrital influx. The Inola cyclothem thins again northward from the Davis core onto the Iowa shelf (Figure 9). The dark phosphatic shale above the Inola Limestone thins from northeastern Oklahoma to southeastern Kansas, possibly from an increase in the elevation of the depositional surface. This lithofacies may have disappeared over the Bourbon Arch as the elevation may have been high enough to prevent its deposition, but it reappeared in some of the cores north of the Bourbon Arch area, possibly in deeper paleovalleys or deeper parts of the basin. Thin transgressive and regressive limestones are present, but only in a few cores and outcrops, indicating that some areas had less detrital influx and shallower water depths than others, to allow the concentration of localized carbonate material.

In Iowa, there was probably great variation in the depth and elevation of paleovalleys. Dark open marine shale and a regressive limestone is present in the CP-79 core but not in the CP-78 core, ten miles to the south. The Inola cyclothem is thicker in the CP-78 core (Figure 9) and silts and clays were probably deposited in a more marginal sea with higher siliciclastic influx, as evidenced by less open marine fossil assemblages, than in either the CP-79 core or type Laddsdale locality. The Inola cyclothem is dominated by paleosols and limestones in the Logan core, where it was probably at the edge of the transgressing sea.

As the sea regressed basinward, there were fluctuations in sea-level resulting in transgressive and regressive pulses that possibly filled some of the deeper paleovalleys, as evidenced by the second conodont zone in some of the cores discussed previously.

Sands and silts were probably deposited in deltas fringing the regressing sea. The sea regressed to southeastern Kansas and northeastern Oklahoma leaving behind the exposure surface found at the top of the Inola cyclothem from the Hinthorn core northward, except for the P & M core (Plate 1). There, a conglomerate at the top of the Inola cyclothem suggests the removal of the typical lowstand paleosol lithofacies by later erosion. After further regression into Oklahoma, channel sands were locally deposited upon the exposure surface that developed after the deposition of the Inola cyclothem sediments, as evidenced by discomformable lower Taft sandstone at Inola Hill.

CHAPTER VI

CONCLUSIONS AND SUGGESTIONS FOR FUTURE WORK

Conclusions

It is unlikely that inconsistencies in the lower Cherokee Group stratigraphic nomenclature from Oklahoma to Iowa will ever be resolved by lithostratigraphy alone. However, correlation using unconformity-bounded units or synthems (and recognizing the lithostratigraphic units as facies of the synthem) of the Midcontinent Cherokee Group would clear up some of the confusion. While the Missouri Geological Survey bases its formational nomenclature upon cyclothems, the early transgressive coals are grouped with the underlying lowstand and earlier marine strata, thus separating the early transgressive coals from the overlying part of the same transgression that formed a unitary cyclothem. In contrast, this research correlates the lower Cherokee across the Midcontinent based on individual cyclothemic units extending from unconformity to unconformity (top of paleosol to top of paleosol). Recognition of Cherokee cyclothems as synthems lays the foundation for a system of allostratigraphic nomenclature based upon more meaningful genetic stratigraphy involving the entire marine-associated part of a cyclothem.

Work on this project has led to the following conclusions:

1. Unlike the upper and middle Cherokee, most marine units in the lower Cherokee are less easily characterized by consistent lithic and biotic components. Most minor units are sporadic and laterally discontinuous. While numerous lower Cherokee cyclothems are recognized and named in the Arkoma Basin region of eastern

Oklahoma, only three major ones have been found to extend northward out of Oklahoma, in ascending order: McCurtain, Doneley, and Inola. Furthermore, these three cyclothems can be correlated by dominance or first appearance of three distinctive conodont morphotypes: *Idiognathodus* cf. *praeobliquus*, *I. obliquus*, and *I. podolskensis* respectively. The McCurtain cyclothem can be correlated in many areas based upon the predominance of *I.* cf. *praeobliquus* and presence of *I. amplificus*, in conjunction with the lack of *Idiognathoides* and *I. obliquus*. The Doneley can be correlated by the first appearance of *I. obliquus*.

2. The Inola cyclothem is the key to the biostratigraphic correlation of the lower Cherokee of the Midcontinent. It contains the only *Gondolella*-bearing zone in the lower Cherokee, has a consistent and relatively greater abundance of deeper-water conodonts (*Idioprioniodus*, *Idiognathodus*, and *Neognathodus*), and has been identified in every core studied (Figure 9 and Plate 1). However, the marine strata in the Inola cyclothem are not lithologically consistent. Limestones have only been found at Inola Hill, type Hackberry Branch, and type Laddsdale exposures, and in the P & M and WC-22 cores. Black phosphatic shale has been encountered in northeastern Oklahoma and southeastern Kansas, south of the Bourbon Arch, and less continuously in Bates County, Missouri and Miami, Franklin, and Johnson counties in Kansas, north of the Bourbon Arch, but in only half the localities in Iowa. Yet, since the persistence of the Inola cyclothem means that both bounding unconformities can be identified across the Midcontinent, it can be extended laterally as an unconformity-bounded unit.

3. Conodonts compatible with the McCurtain and Doneley have not been found in the stratigraphic positions of their respective cyclothem in every core studied (Plate 1). The correlation of these two cyclothems was based upon both biostratigraphy and position relative to the Inola cyclothem (Plate 1). The Doneley cyclothem has been correlated well into Iowa, but the McCurtain cyclothem seems to extend only into the Forest City Basin in northeastern Kansas and northwestern Missouri.
4. Minor and intermediate cycles between the major cyclothems may either be northern extensions of minor and/or intermediate cycles in Oklahoma, or possibly minor reversals of sea-level trends during transgressions and regressions within the major cyclothem, which splay outward away from the major cyclothem northward, and merge with the major cyclothem southward. Two intermediate cyclothems, the Sam Creek and Tamaha, may extend at least into extreme southeastern Kansas (Plate 1).
5. Unfortunately, biostratigraphic correlation of the major lower Cherokee cyclothems has not resolved all of the stratigraphic issues. For example, there is still confusion as to what exactly are the commonly used terms Riverton Coal, Neutral Coal, and Warner Sandstone away from their type areas in Kansas and Oklahoma. Despite this, the biostratigraphic framework of this project has led to the recognition of several correlations:
    i. The Inola Limestone is equivalent to the Hackberry Branch Limestone of western Missouri, which was formerly misidentified as the Seville Limestone (named in western Illinois).
    ii. The Bluejacket Coal of Oklahoma is likely equivalent to a Bluejacket A coal of Kansas, a Weir B or C coal in Missouri, and a middle Laddsdale coal

at the type section of the Laddsdale interval in Iowa, by their positions at the base of the Inola cyclothem.

iii. The Rowe Coal, where it has been correctly identified in Oklahoma, Kansas, and Missouri at the base of the Doneley cyclothem, is equivalent to the Cliffland Coal of Iowa, which also is at the base of the Doneley cyclothem, based on first appearance of *I. obliquus*.

6. The conodont *Idiognathoides* is known only below the top of the Atokan (e.g. Landing and Wardlaw, 1981; Grayson, 1984; Grubbs, 1984, Barrick and others, 2004). Therefore its presence low in the Edmonds, Hopp, and CP-78 cores has strengthened the identification of pre-Desmoinesian strata in the northern Midcontinent from northeastern Kansas into Iowa. In previous work, Peppers and Brady (2007) identified Atokan spores at the same interval in the Edmonds core that yielded *Idiognathoides*. Although Keyes (1893) defined the Desmoinesian Series from the base of the "great limestone of the Winterset" (now Bethany Falls Limestone) to the base of the Pennsylvanian in Iowa, Ravn (1986) identified a spore assemblage low in the CP-6 core from Davis County as suggestive of the Caseyville of Illinois, which is Morrowan, and Lambert (1992) identified *Idiognathoides* above the higher Blackoak Coal. In the CP-78 core, *Idiognathoides* was encountered below a second Blackoak Coal, which provides more data to extend Atokan strata from at least the Forest City Basin in northeastern Kansas into Iowa.

Future work

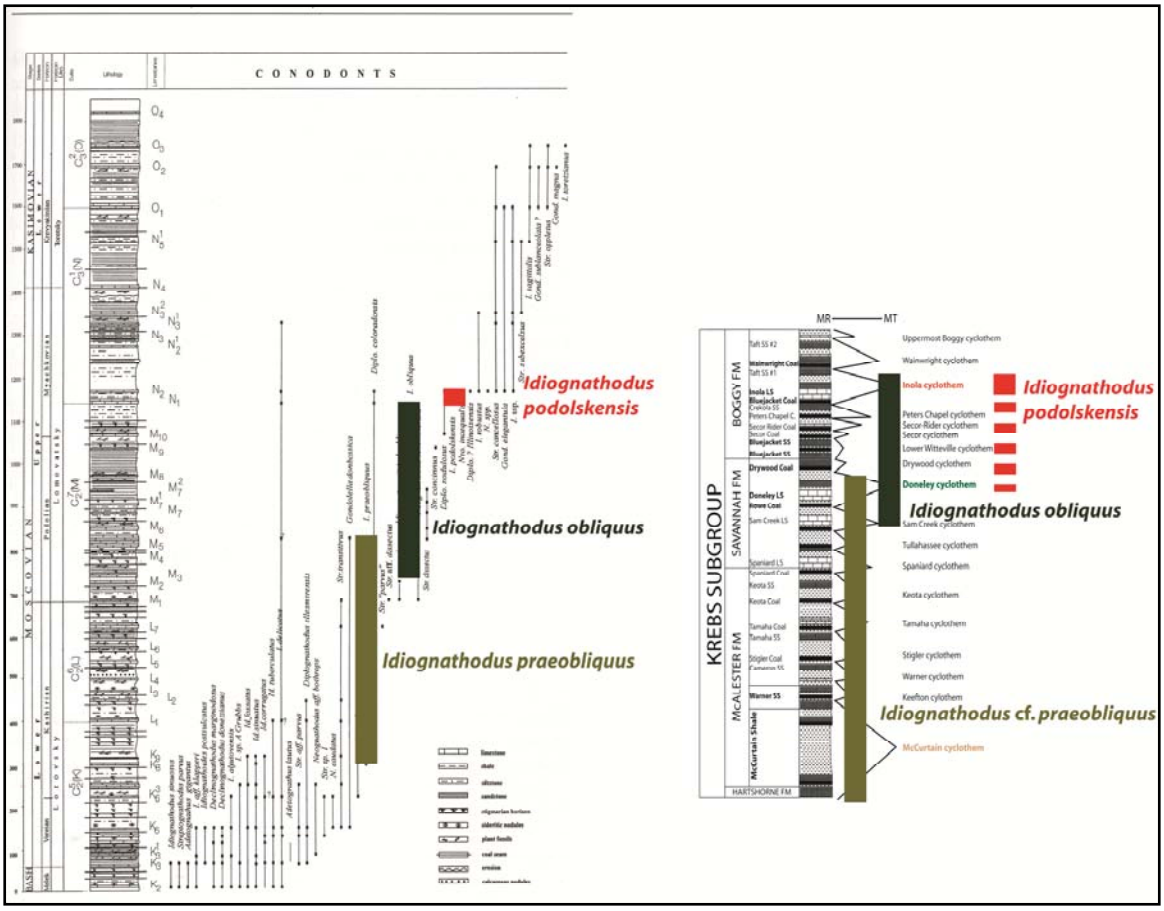
Because of the relatively low number of data points, more work is needed to fill in the gaps in the correlation. In Iowa, other coal projects cores should be sampled for

conodonts including marine intervals not seen in CP 78, 79 and Logan cores. In Kansas, comparison of long cores used in this study with their corresponding gamma logs will help identify the subsurface signatures of the major cyclothems. Once that is accomplished, correlation can be conducted with both biostratigraphy and subsurface data. While the extent of the Inola cyclothem across the Midcontinent is relatively certain, the exact distributions of the Doneley and McCurtain cyclothems and the Atokan interval are still unclear. More data points will better constrain the Doneley and determine the relationship of the McCurtain with the Atokan from northwestern Missouri/northeastern Kansas into south-central Iowa.

More work is still needed on conodont taxonomy by specialists, both to confirm or update the identifications made in the study, and to identify the unknown conodonts. Better delineation of the conodont species can strengthen the correlation framework. Furthermore, more study of marine lithofacies in the Inola cyclothem is needed to determine if *Gondolella* can be identified at that level in Missouri and Iowa. Beyond the Midcontinent, proper conodont identifications may extend the correlations into the Illinois Basin and perhaps even to the Appalachian region. Since *Idiognathodus praeobliquus*, *I. obliquus*, and *I. podolskensis* were first identified from the Donets Basin and Moscow Basin, correlation between Midcontinent North America and Eastern Europe may be possible, because their stratigraphic distribution appears to be similar (Figure 10).

With more data points, subsurface data, and better delineated conodont morphology and taxonomy, correlation of the lower Cherokee can be extended beyond

Figure 10. Stratigraphic distribution of *Idiognathodus podolskensis*, *I. obliquus*, and *I. praeobliquus* in Donets Basin compared with stratigraphic distribution of *I. podolskensis*, *I. obliquus*, and *I.* cf. *praeobliquus* in Midcontinent North America.


CONODONTS
Idiognathodus podolskensis
Idiognathodus obliquus
Idiognathodus praeobliquus
KREBS SUBGROUP
BOGGY FM
SAVANNAH FM
McALESTER FM
HARTSHORNE FM
Idiognathodus podolskensis
Idiognathodus obliquus
Idiognathodus cf. praeobliquus

the initial line of correlation, and fence diagrams can be created. Adjusted for elevation, the tops and bottoms of each cyclothem can be plugged into ArcMap software to create digital three-dimensional models of the lower Cherokee in the Midcontinent. Finally, this work should lead to the establishment of the systems-tract architecture and sequence stratigraphy, in addition to a unifying nomenclature of the Midcontinent lower Cherokee Group. The genetic stratigraphy can then be interpreted in a time-constrained as well as depositionally meaningful fashion, putting the facies patterns of the rock units into a more coherent, comprehensive framework. A better constraint on the sequence stratigraphy might lead a more accurate model of the patterns of resource distribution and reservoirs within the lower Cherokee. Eventually, this project might be used as a tool to better predict the occurrence of hydrocarbons in new areas, such as oil and natural gas in Iowa.

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APPENDIX A

MEASURED SECTIONS

Locations of Cores and Outcrops Studied

The detailed locations of each of the cores and outcrops are listed in order of their measured sections found later in this appendix.

1. Brushy Creek Tributary (BCT), Pittsburg County, OK, SW-SW-SE-SW Sec. 19, T5N, R17E, and NW-NW-NE-NW Sec. 30, T5N, R17E (Figure A3)
2. Davis Airfield (SCL-14), Muskogee County, OK, NW-NW-SW-NW Sec. 26, T14N, R18E (Figure A4)
3. Wagoner County Shale Pit (WCSP), Wagoner County, OK, NE-NE-NE Sec. 1, T15N, R17E, and SW-SE-SE-SE Sec. 36, T16N, R17E, (Figure A5)
4. Inola Hill, Rogers County, OK, NE-SW-NW Sec. 10, T19N, R17E (Figure A6)
5. Type Doneley section, Mill Creek, Craig County, OK, SW-NW-NW Sec. 16, T26N, R20E (Figure A7)
6. Roadcut of Doneley section on Highway 25 (H75 CC), Craig County, OK, NW-NW-NE Sec. 30, T27N, R21E (Figure A8)
7. KGS Cooper CW-1, Labette County, KS, SE-SW-SW Sec. 11 T35S, R18E (Figure A9)
8. KGS Hinthorn CW-1, Montgomery County, KS, SE-SE-SE Sec. 14, T32S, R16E (Figure A10)
9. KGS P & M #7, Cherokee County, KS, SE-SE Sec. 6, T32S, R22E (Figure A11)
10. Type Hackberry Branch section, Vernon County, MO, NE-NE-NW Sec. 29, T35N, R32W (Figure A12)
11. MGS Hess CH-9H, Bates County, MO, Sec. 4, T38N, R33W (Figure A13)

12. KGS Rose Hill #1-6, Miami County, KS, NE-SE-SW Sec. 6, T16S R24E (Figure A14)
13. KGS Spencer 2-6, Franklin County, KS, SE-SW-NE Sec. 6, T18S, R21E (Figure A15)
14. KGS Deffenbaugh Quarry #2, Johnson County, KS, NW-SW SE Sec. 1, T12S, R23E (Figure A16)
15. KGS Edmonds 1A, Leavenworth County, KS, NW-SW Sec. 35, T9S, R22E (Figure A17)
16. KGS Hopp #1-16, Doniphan County, KS, N1/2 SW-SE-SE Sec. 16, T2S, R19E (Figure A18)
17. MGS FCC-Davis #1 (Forest City Core), Holt County, Missouri, SE-NW Sec. 4, T59N, R38W (Figure A19)
18. Type Laddsdale section, Soap Creek, Davis County, IA, Center Sec. 7, T70N, R12W (Figure A20)
19. Strip pit 0.8 miles southwest of Lakonta (Truax), lower section, Mahaska County, IA, SW-NW Sec. 29, T74N, R16W (Figure A21)
20. Strip pit 0.8 miles southwest of Lakonta (Truax), upper section, Mahaska County, IA, SW-NW Sec. 29, T74N, R16W (Figure A22)
21. IGS CP 78, Wayne County, IA, SW-NE-NE Sec. 12, T70N, R22W (Figure A23)
22. IGS CP 79, Lucas County, IA, NE-NE-NE Sec. 12, T71N, R22W (Figure A24)
23. IGS WC-22 (Logan Core), Harrison County, IA, NW-SE-NE-NE Sec. 19, T79N, R42W (Figure A25)

Figure A1. Location of cores and outcrops used in study with line of correlation drawn in.

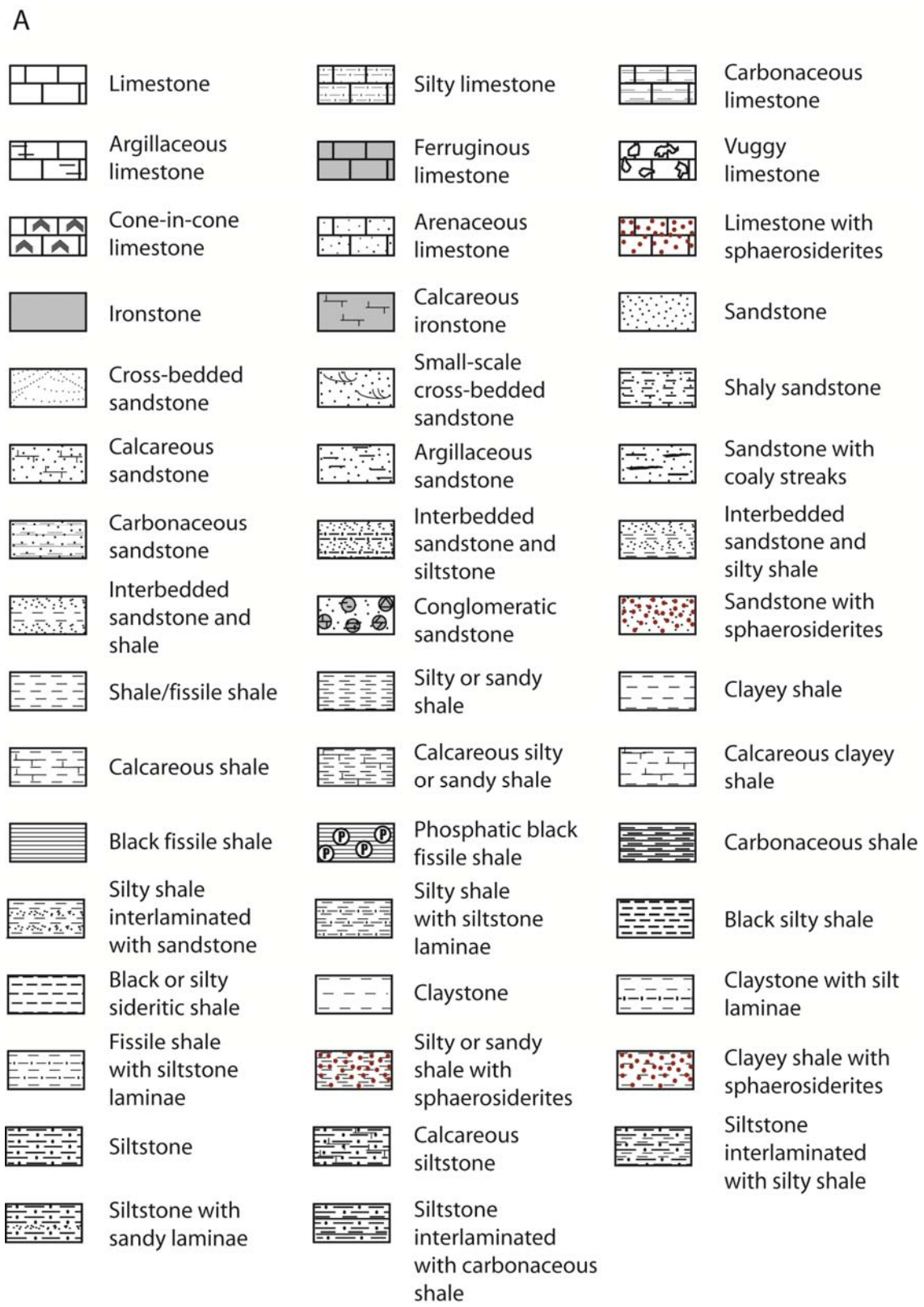
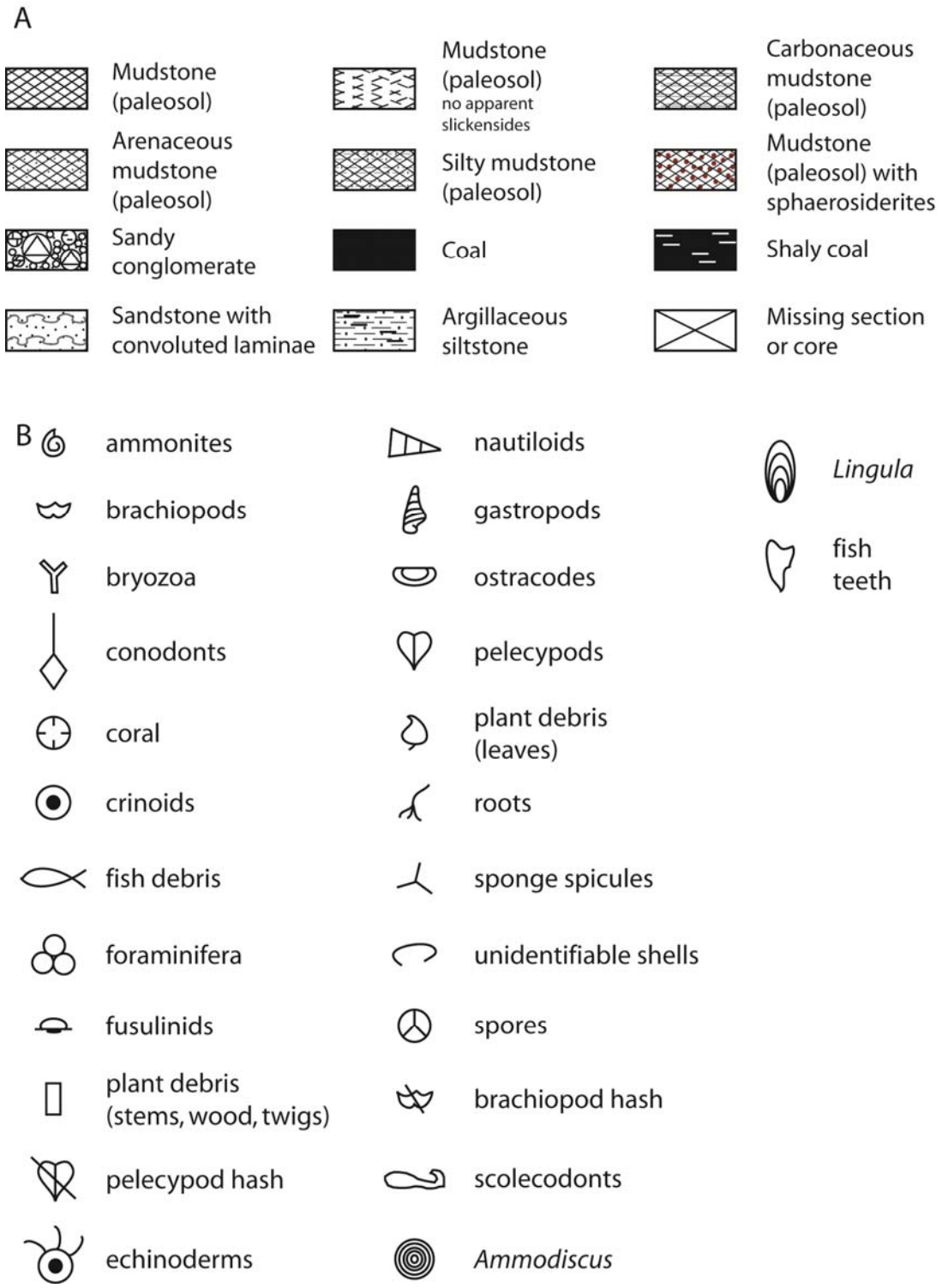


Figure A2. Explanation of symbols used in measured sections.

A. Lithology symbols used for measured sections.



B. Fossil symbols used for measured sections.

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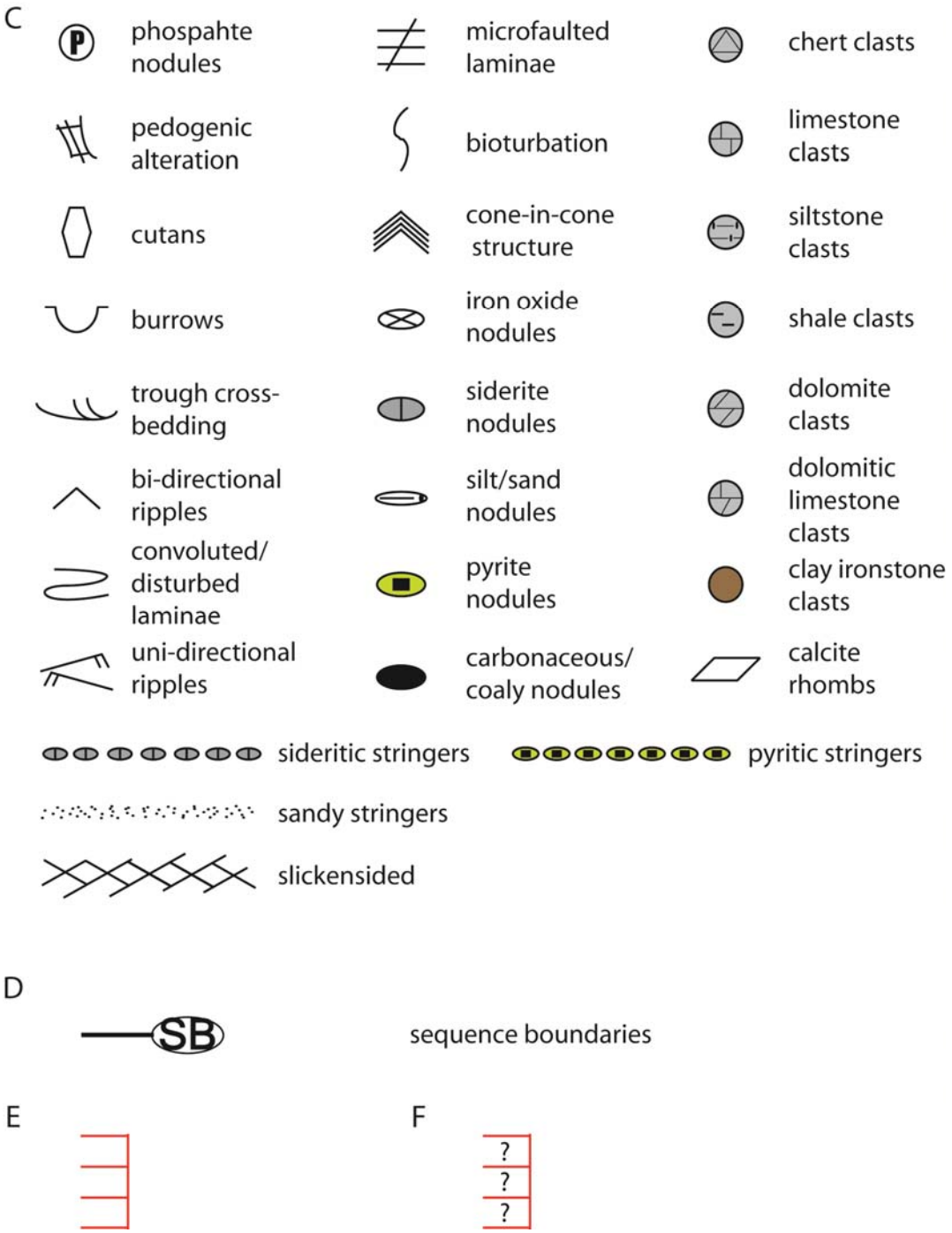


C. Sedimentary structure, nodule, clast, and diagenetic symbols used for measured sections, D. Sequence boundary labels for measured sections. Minor and major sequence boundaries not differentiated, E. Red lines on right side of sections show position of samples collected for conodonts, F. Red lines on right side of sections with question marks indicate samples collected but not picked for conodonts (measurements of core sections on left side of section in feet).

Figure A2. continued.

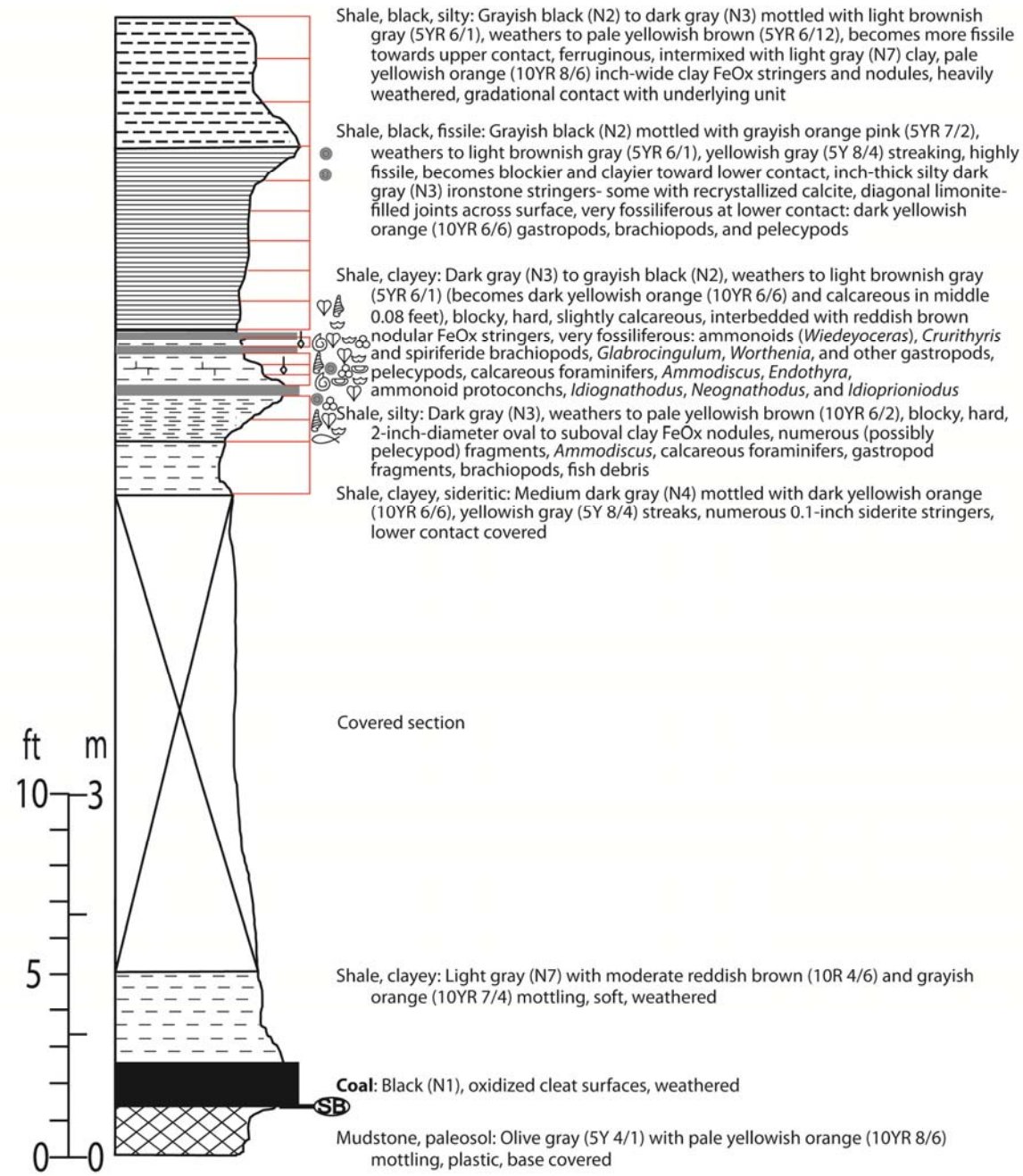


Figure A3. Exposure of upper marine band of McCurtain Shale Member of McAlester Formation (McCurtain cyclothem) measured in roadcut west of bridge over Brushy Creek, two miles (3.2 km) west of Jones Academy and two miles (3.2 km) north of Haileyville, Pittsburg County, OK, SW-SW-SE-SW Sec. 19., T5N, R17E, and NW-NW-NE-NW Sec. 30, T5N, R17E, from Marshall (2002).

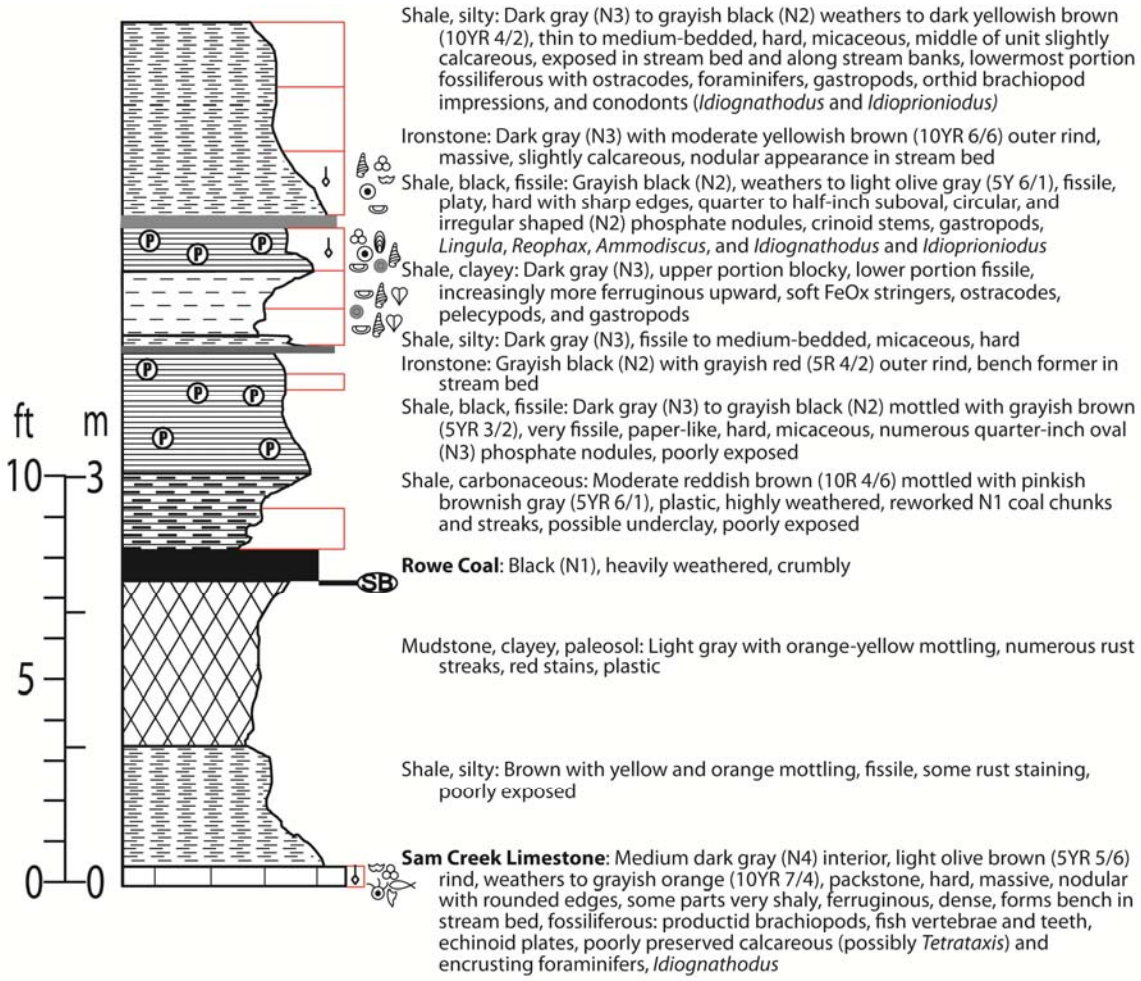


Figure A4. Sam Creek and overlying Doneley cyclothems at Davis Airfield, 4 miles (6.4 km) south of Muskogee, Muskogee County, OK, NW-NW-SW-NW Sec. 26, T14N, R18E, measured along stream bed directly east of Highway 64, modified from Hemish, L.A., 1998, *Coal Geology of Muskogee County, Oklahoma*, Measured Section 74.

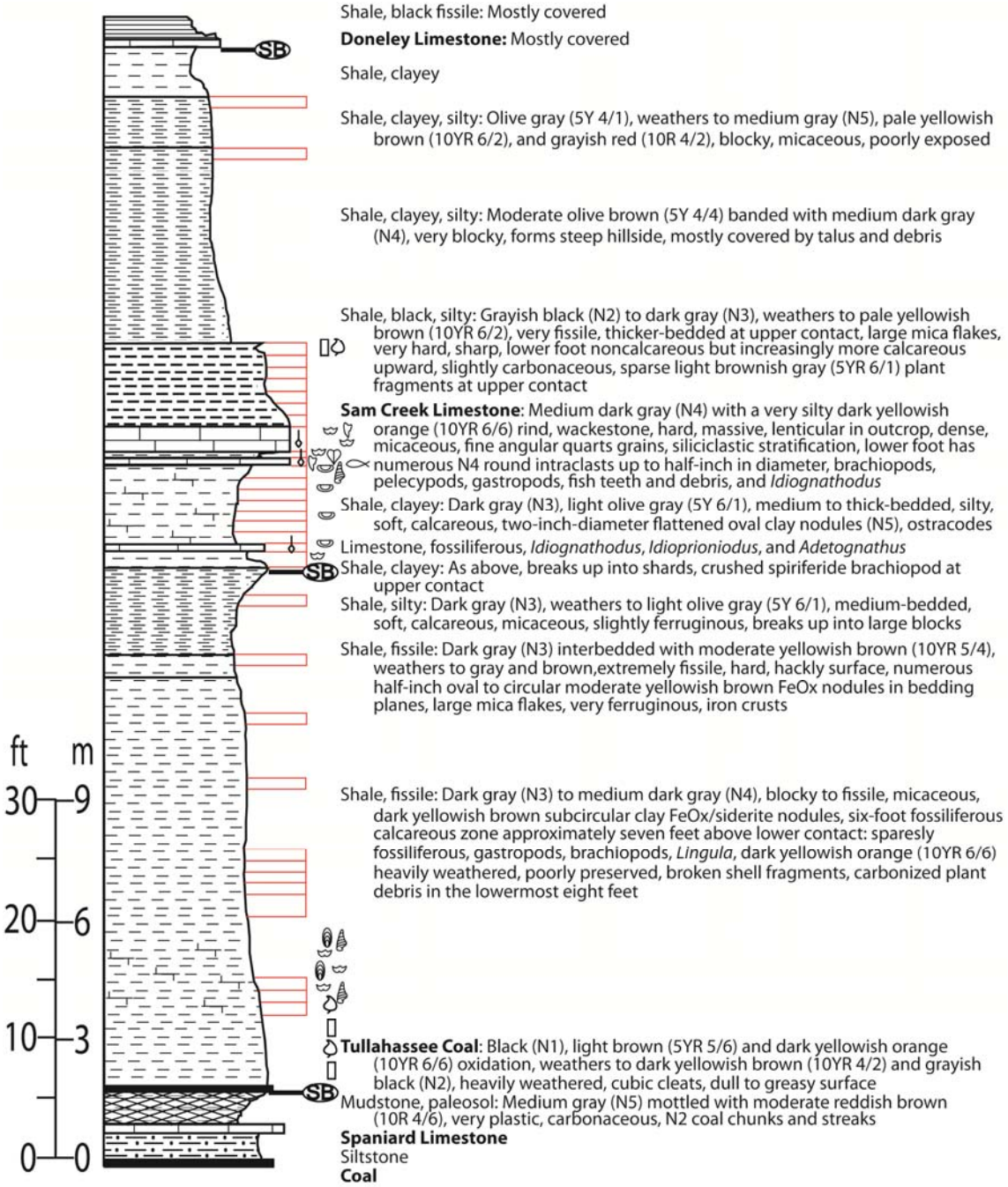
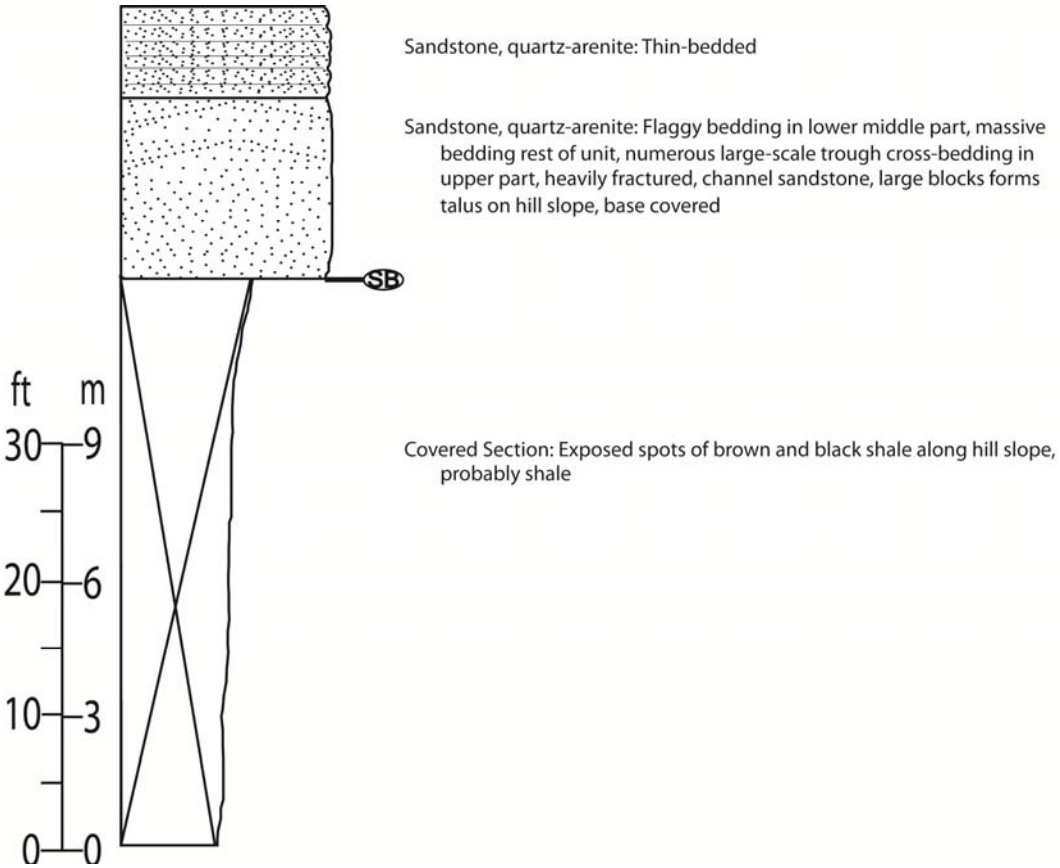


Figure A5. Wagoner County shale pit exposure (Sam Creek and possibly Doneley cyclothems) measured from creek bed, up hillside, and across road to top of hill, one mile (1.6 km) north of Arkansas River, Wagoner County, OK, NE-NE-NE Sec. 1, T15N, R17E, and SW-SE-SE-SE Sec. 36, T16N, R17E, from Marshall (2002).



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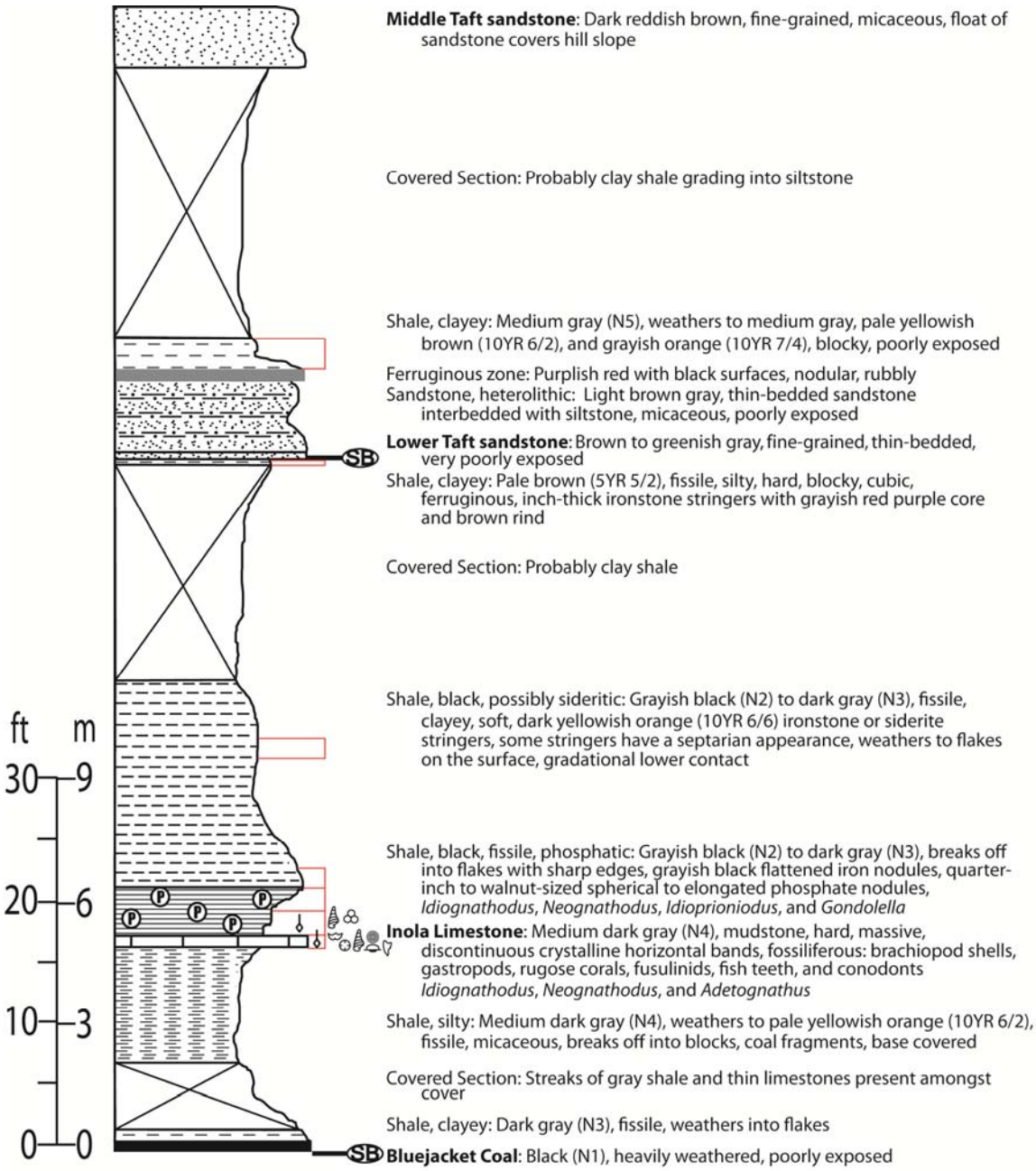


Figure A6. Exposure of Inola cyclothem, southwest slope of Inola Hill, Rogers County, Oklahoma, NE-SW-NW Sec. 10, T19N, R17E, measured with Alan Bennison, from Marshall (2002), some section based on Hemish, L.A., 1990c, Oklahoma Geology Notes, v. 50, pp. 4-23.

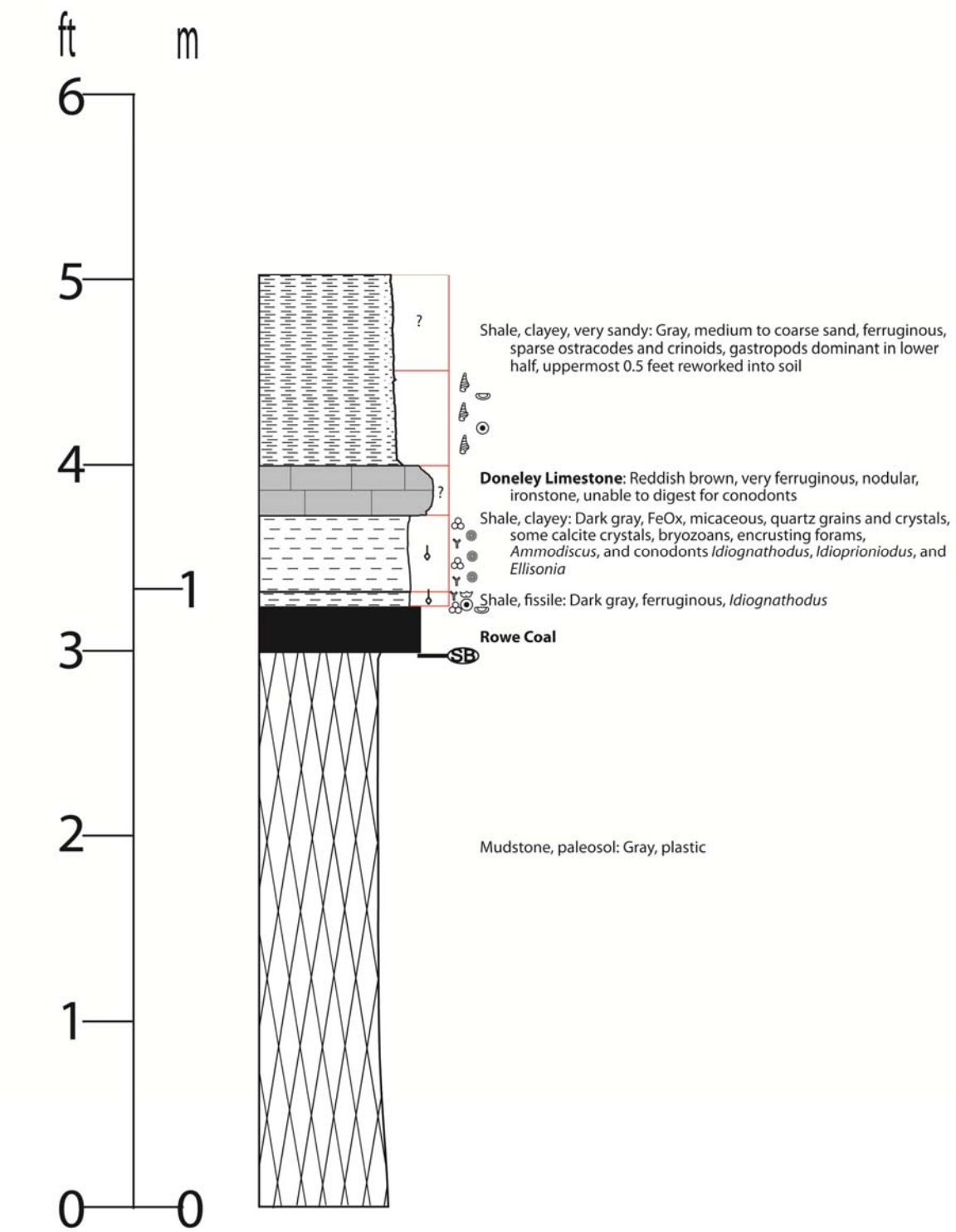


Figure A7. Type Doneley locality (Doneley cyclothem), measured on north-facing bank of Mill Creek, Craig County, Oklahoma, SW-NW-NW Sec. 16, T26N, R20E.

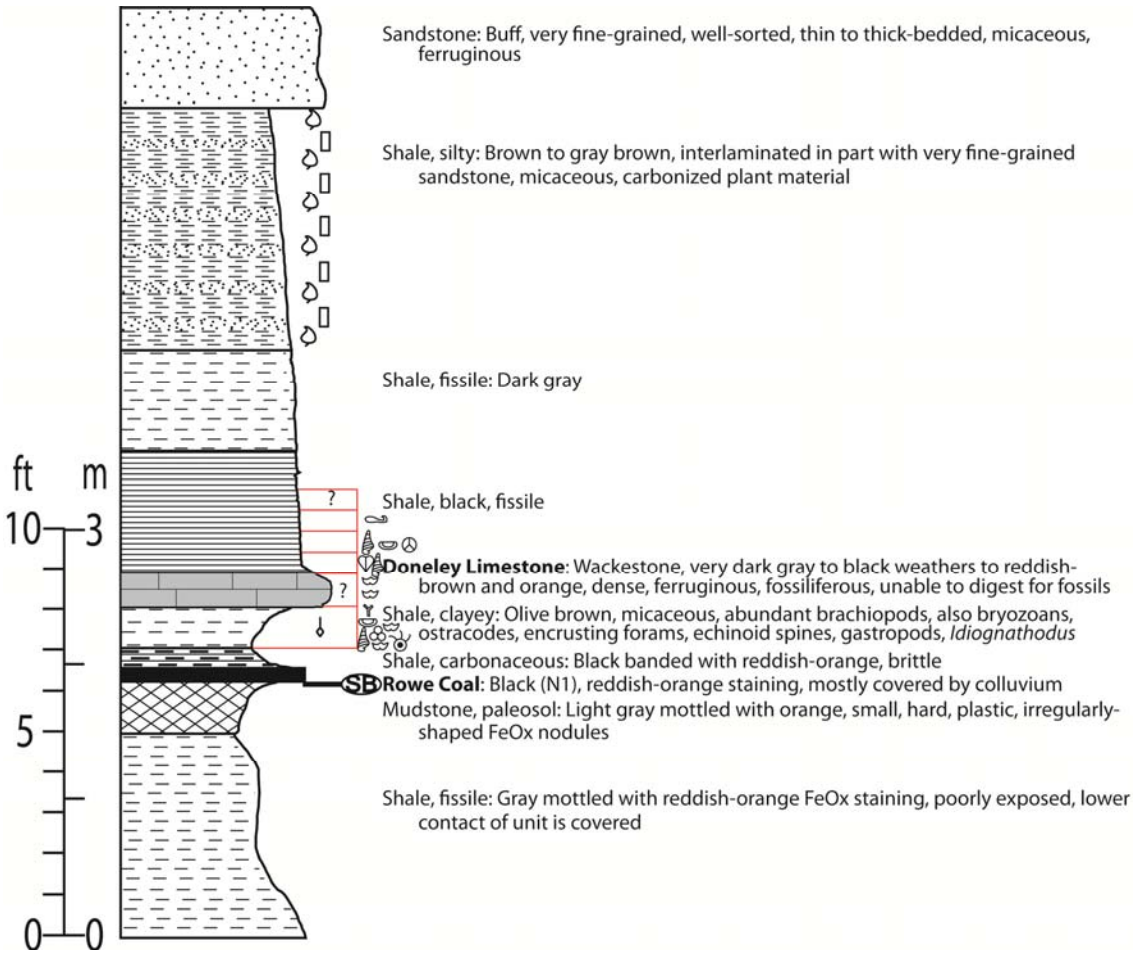


Figure A8. North-facing roadcut of Doneley cyclothem 1.5 miles west of Bluejacket, Craig County, Oklahoma, OK Highway 25, NW-NW-NE Sec. 30, T27N, R21E, from Hemish, 1986, *Coal Geology of Craig County and eastern Nowata County, Oklahoma*, Measured Section 75.

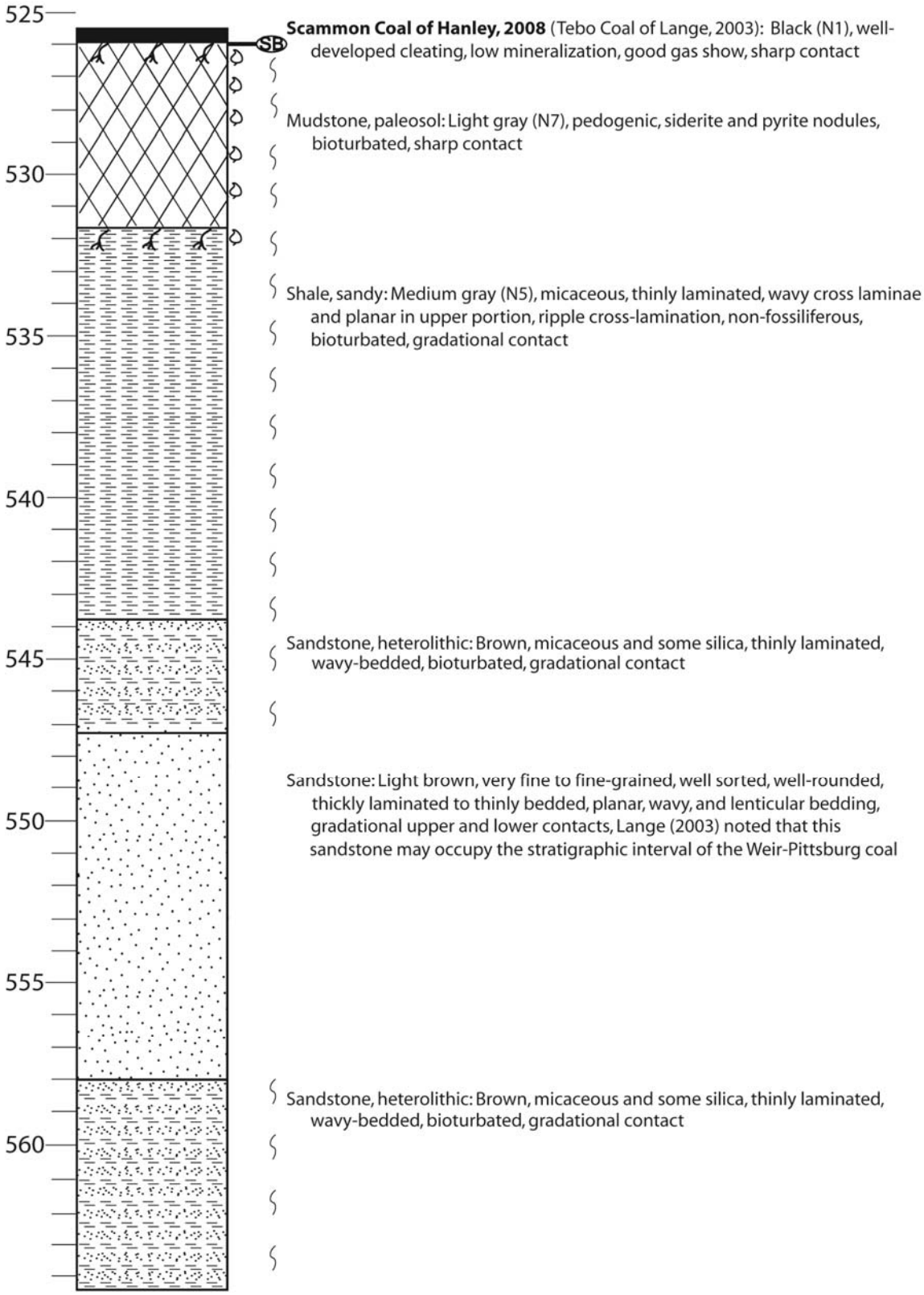
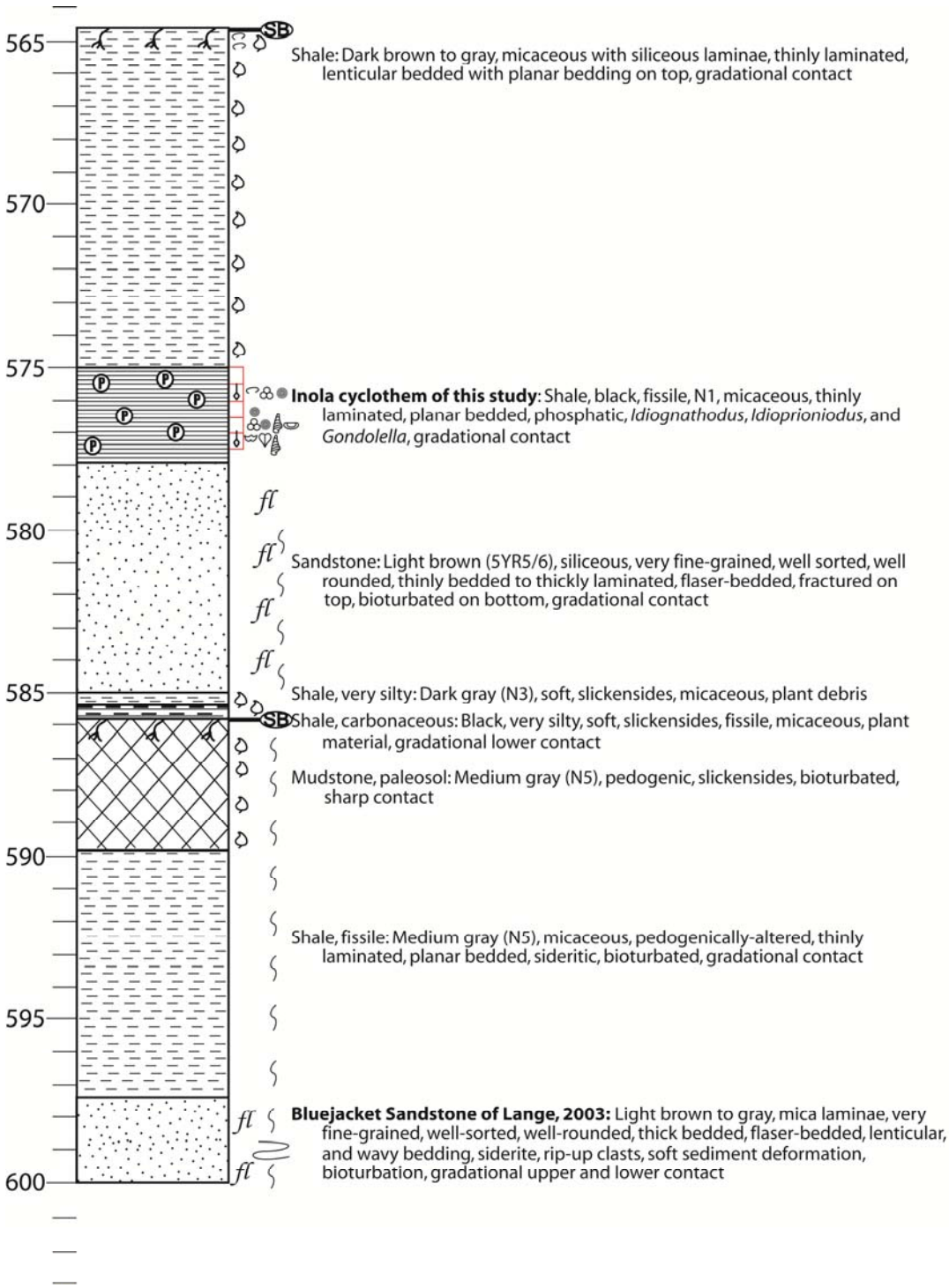


Figure A9. KGS Cooper CW-1 core description, Labette Co., KS, from previous description by J. Lange (2003).



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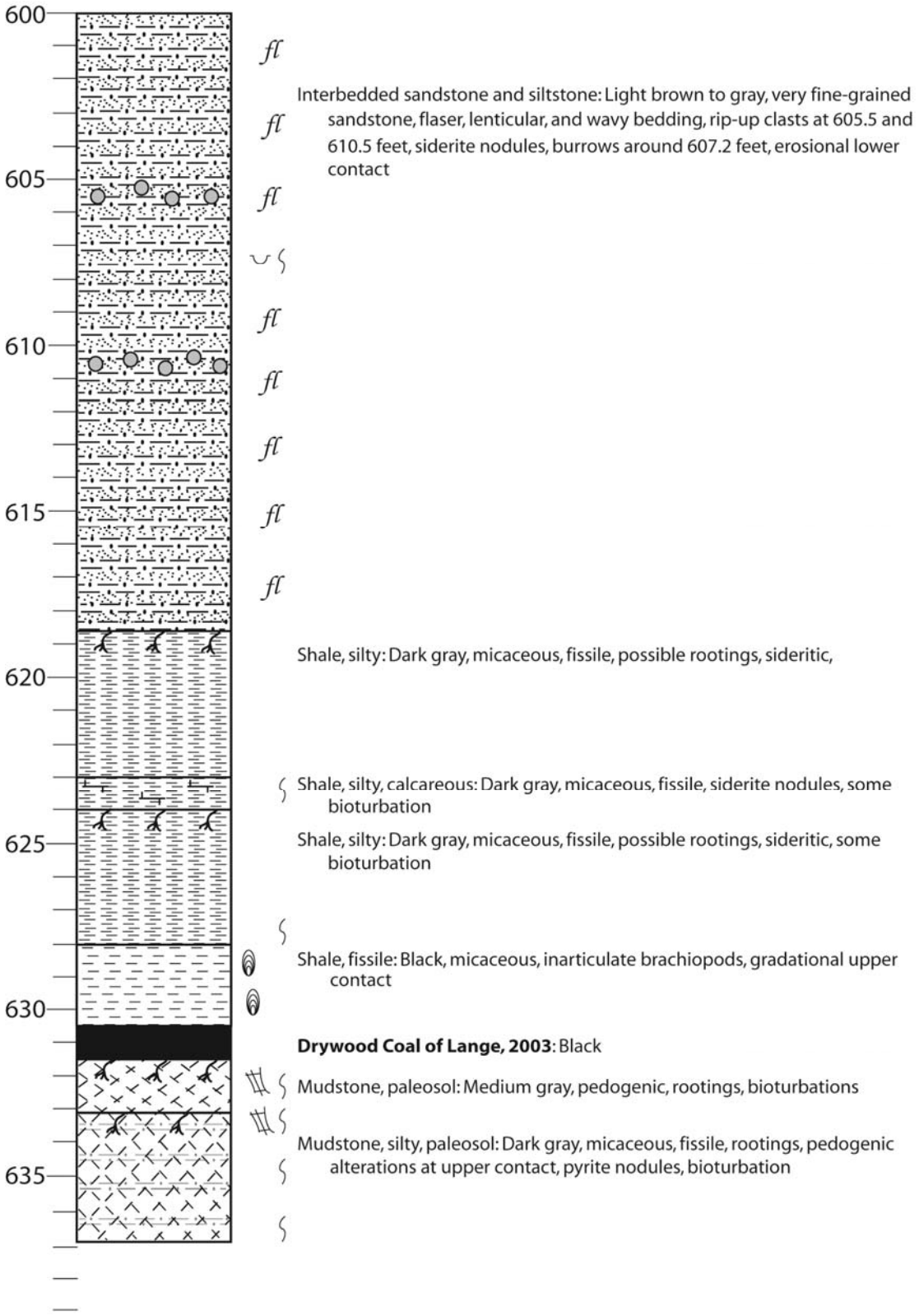

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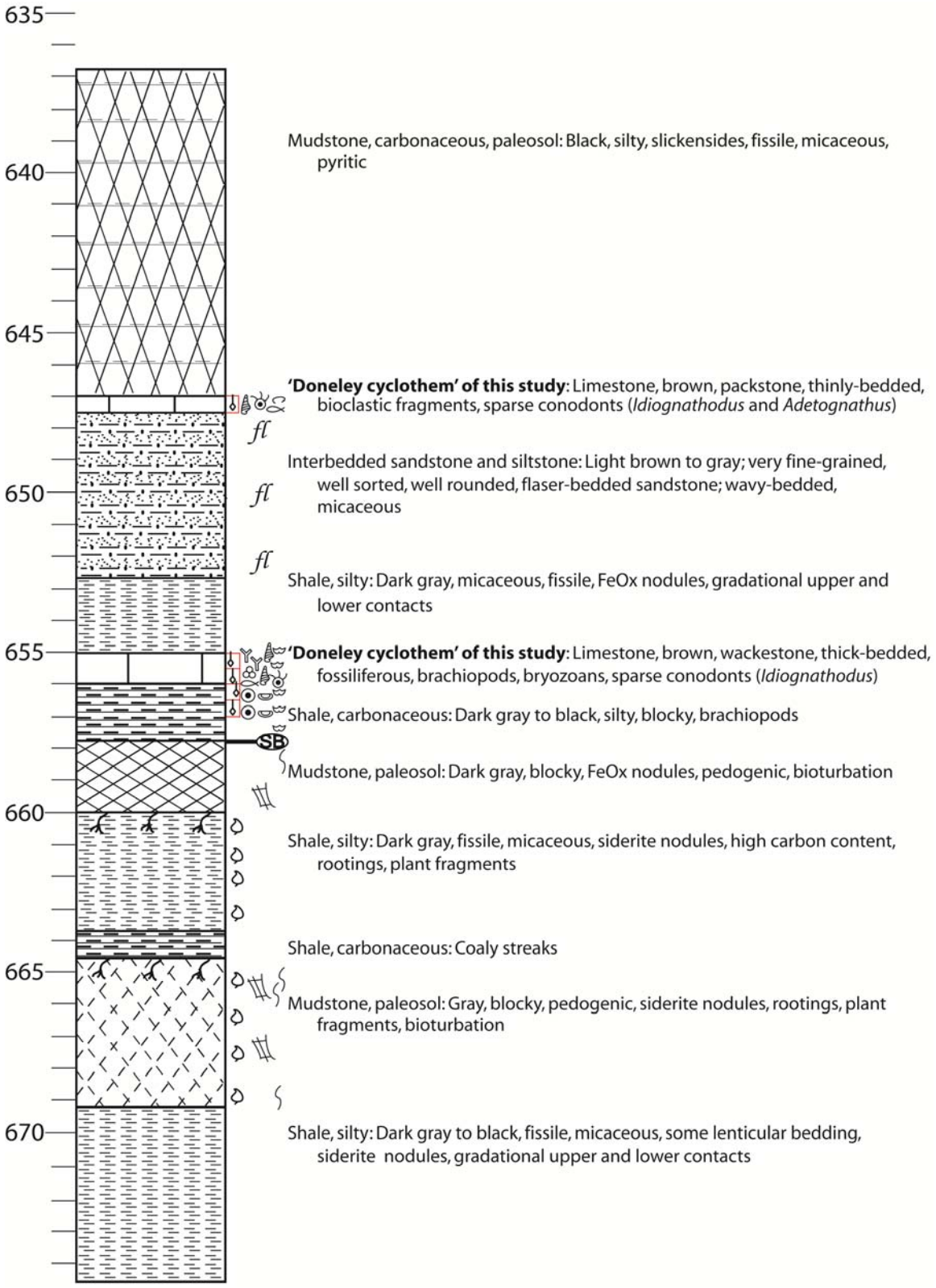

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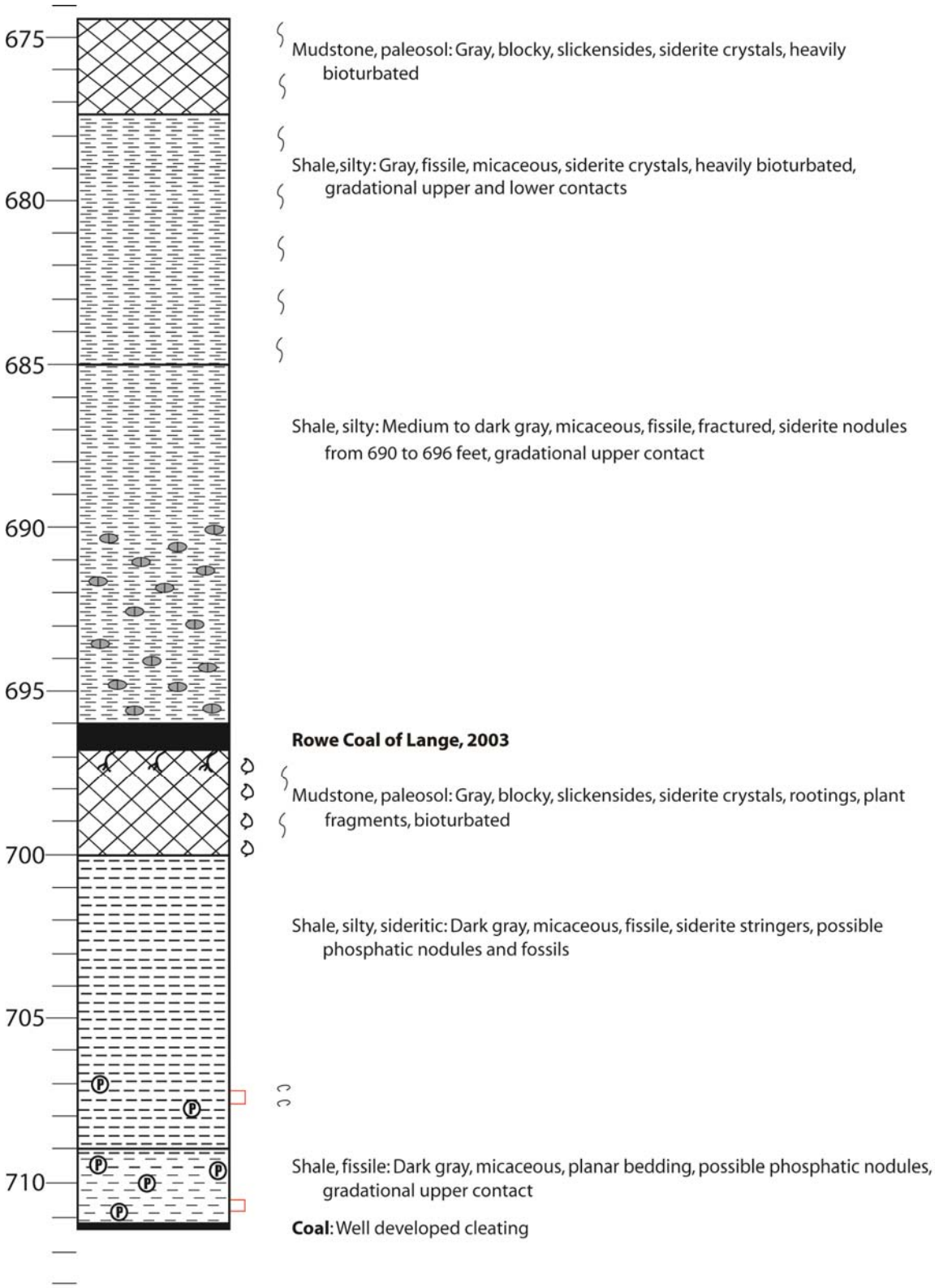

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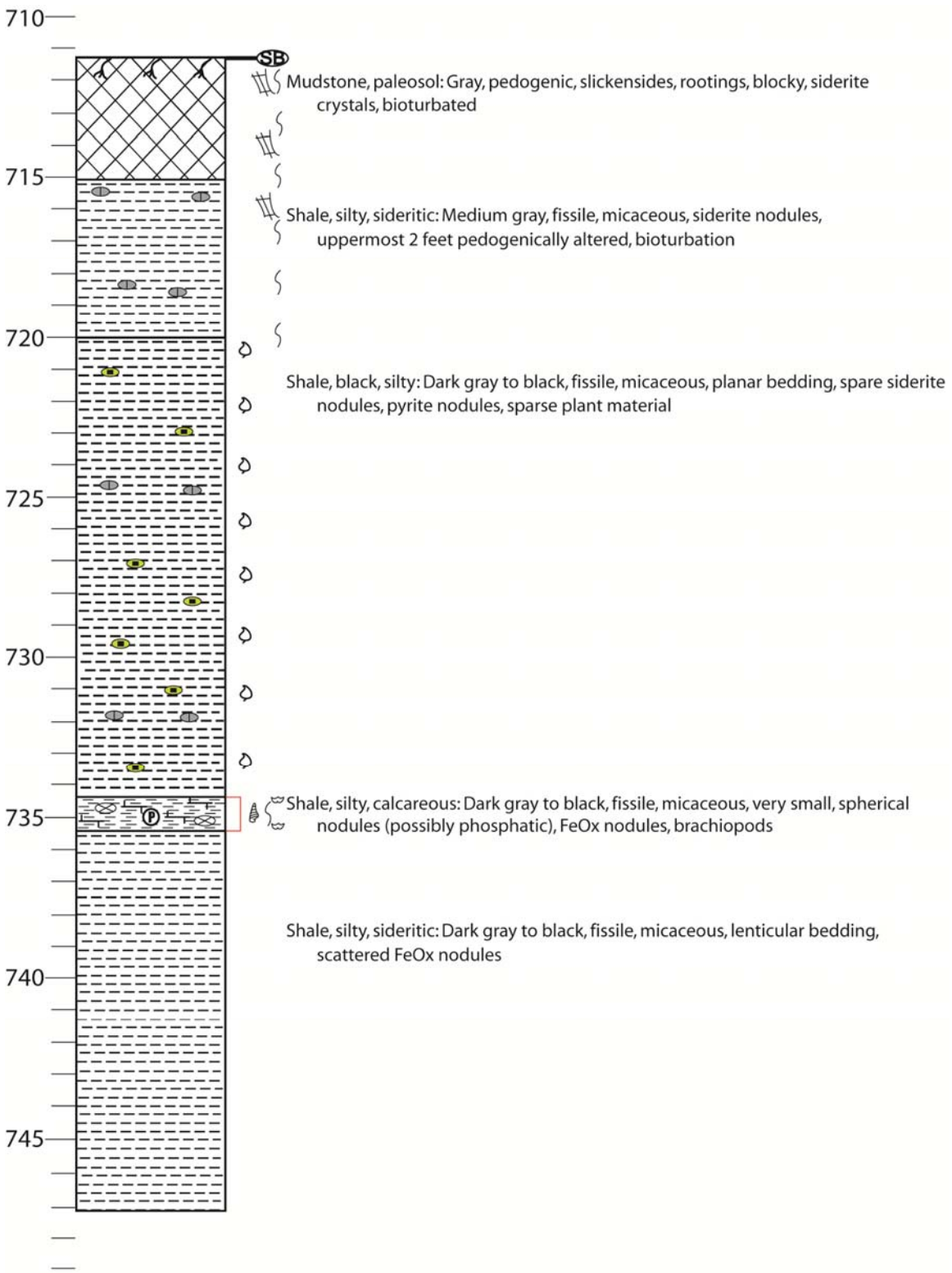

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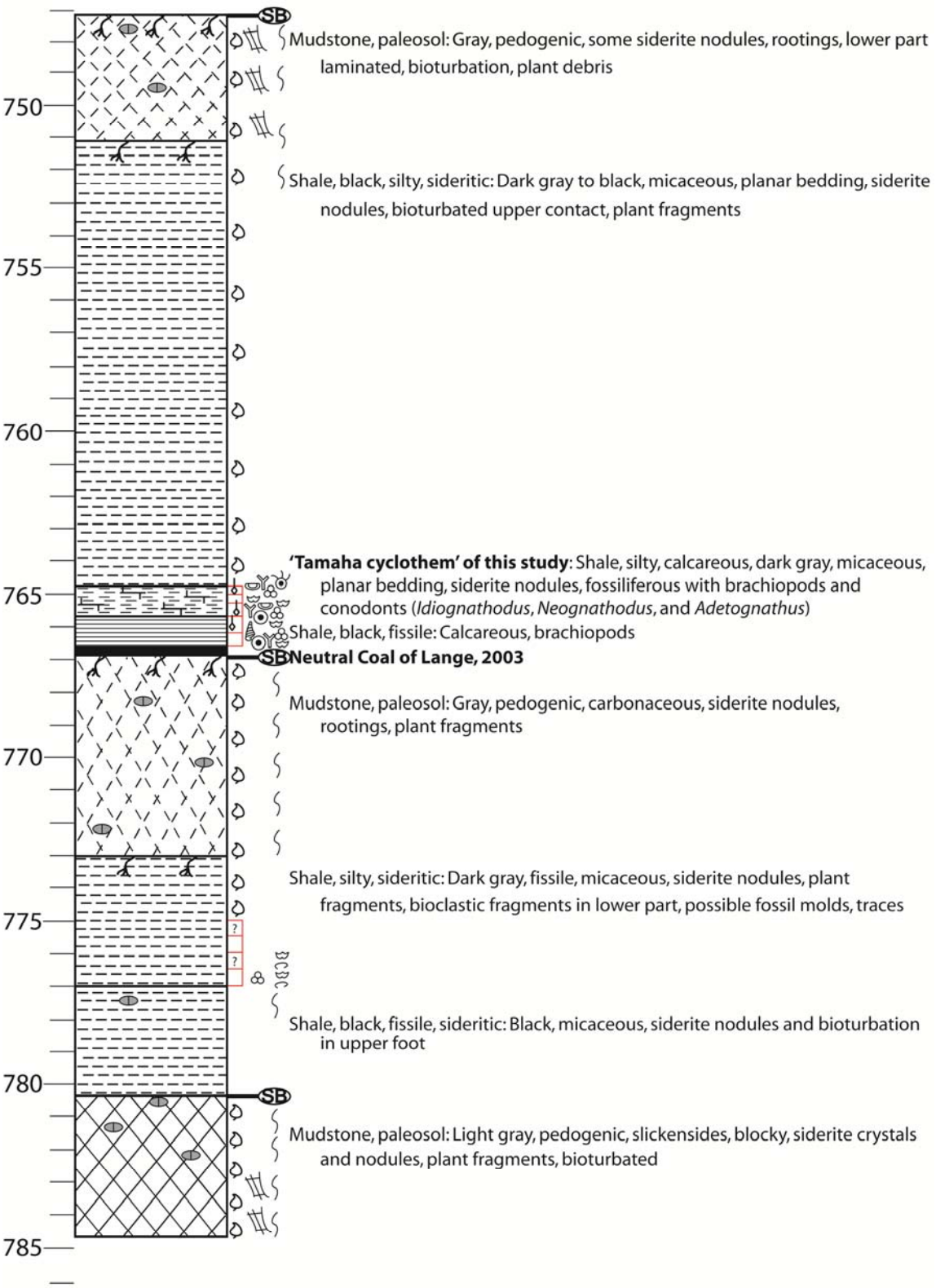

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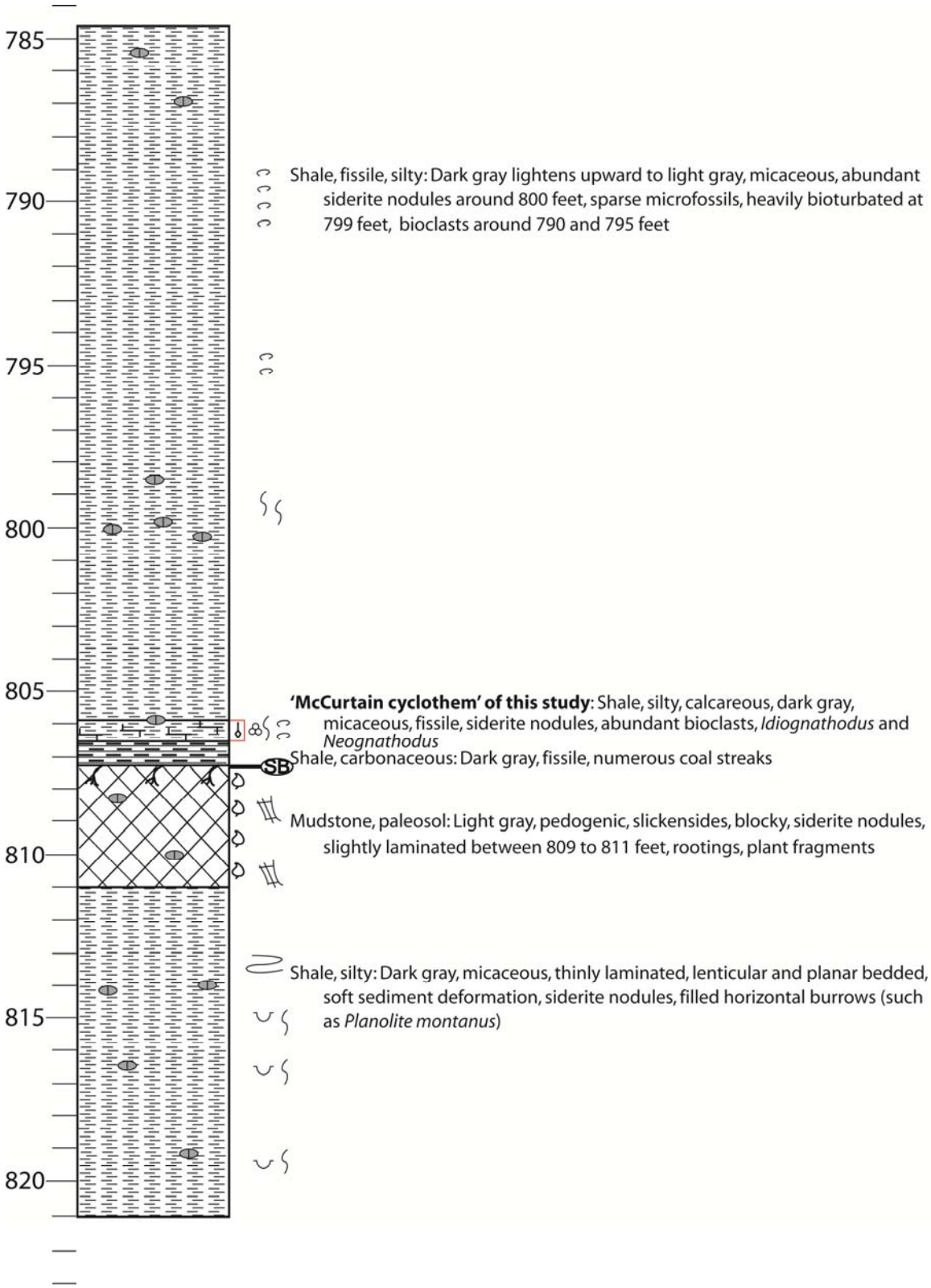

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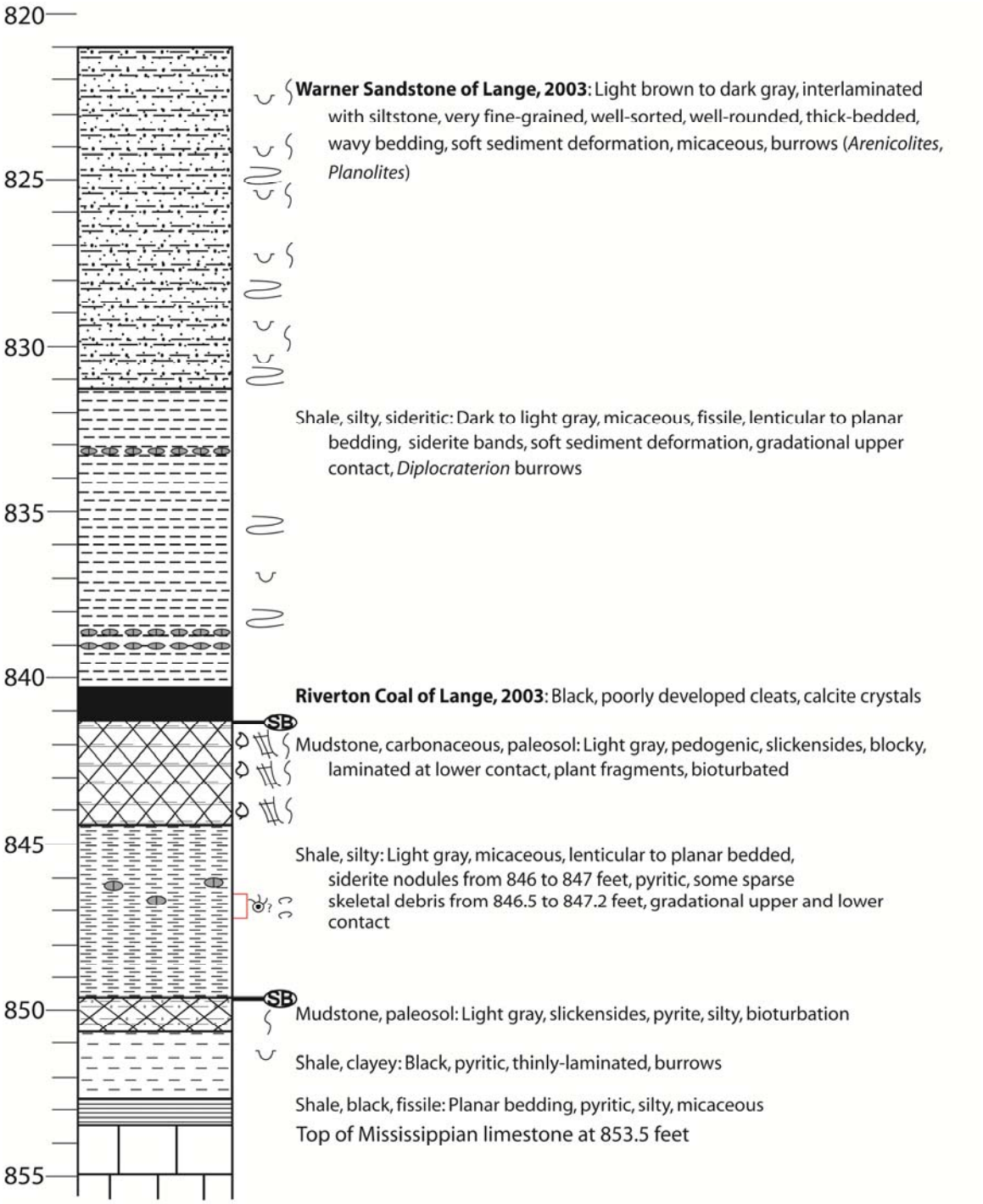

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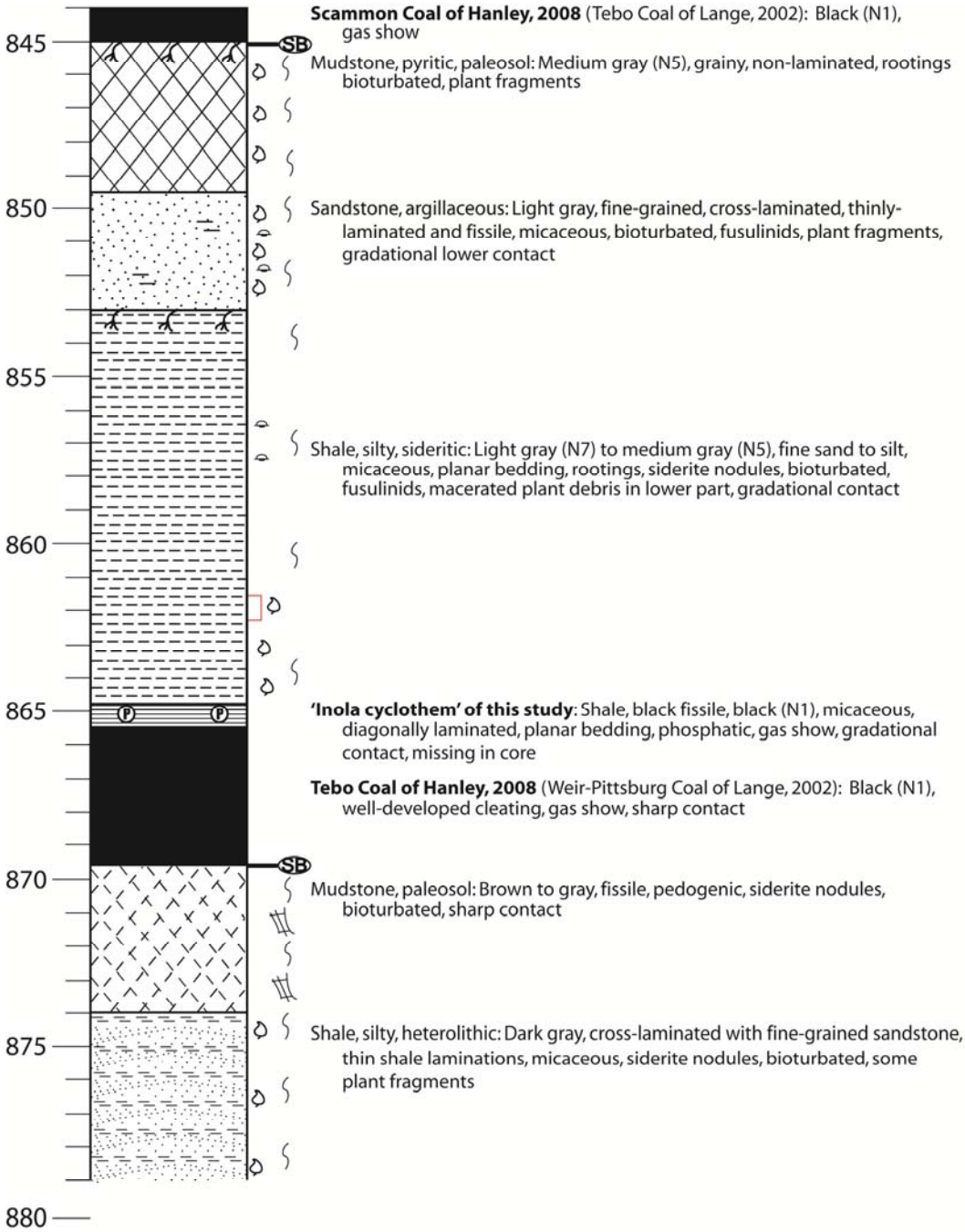
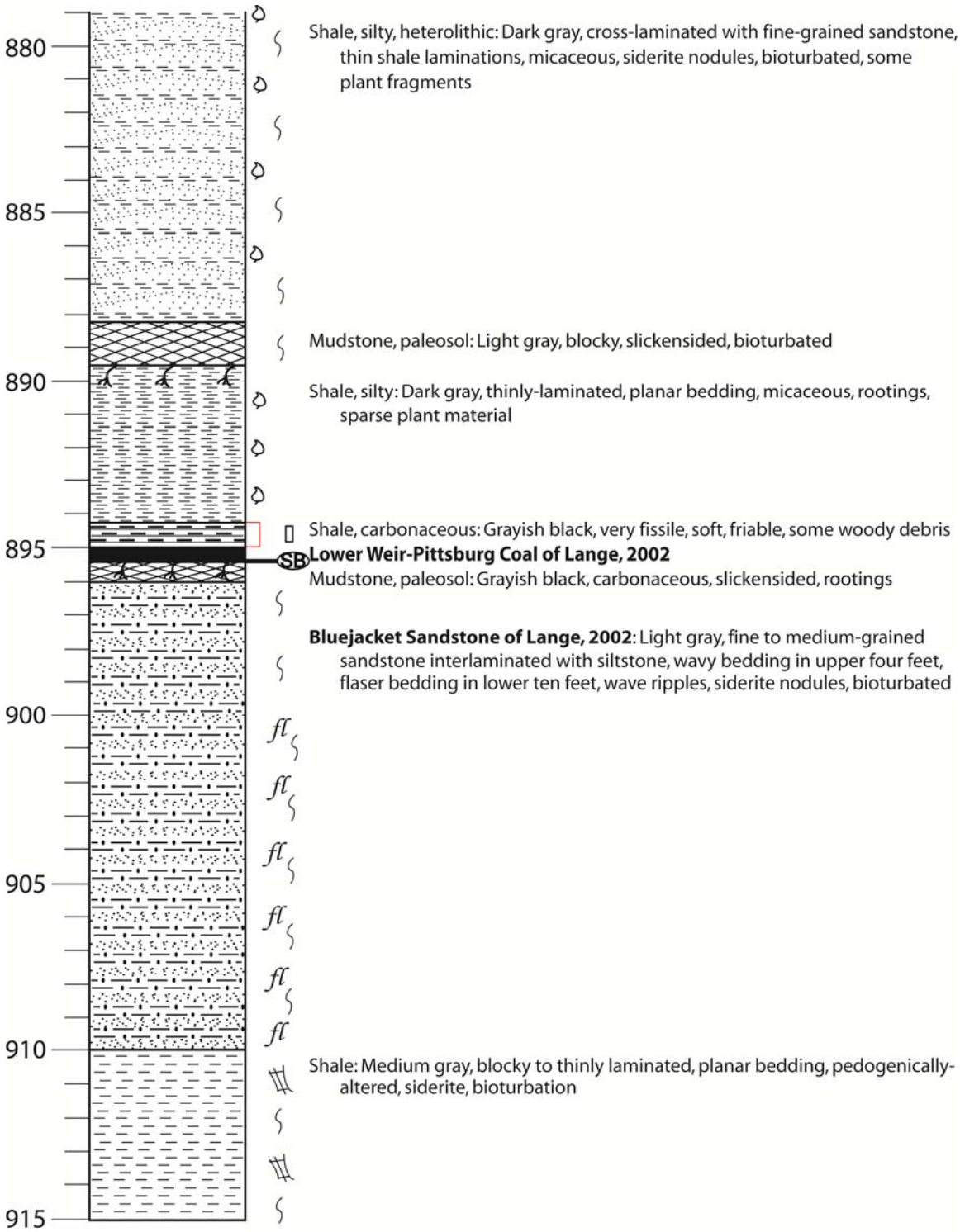


Figure A10. KGS Hinthorn CW-1 core description, Montgomery Co., KS, from previous descriptions by J. Lange (2002).



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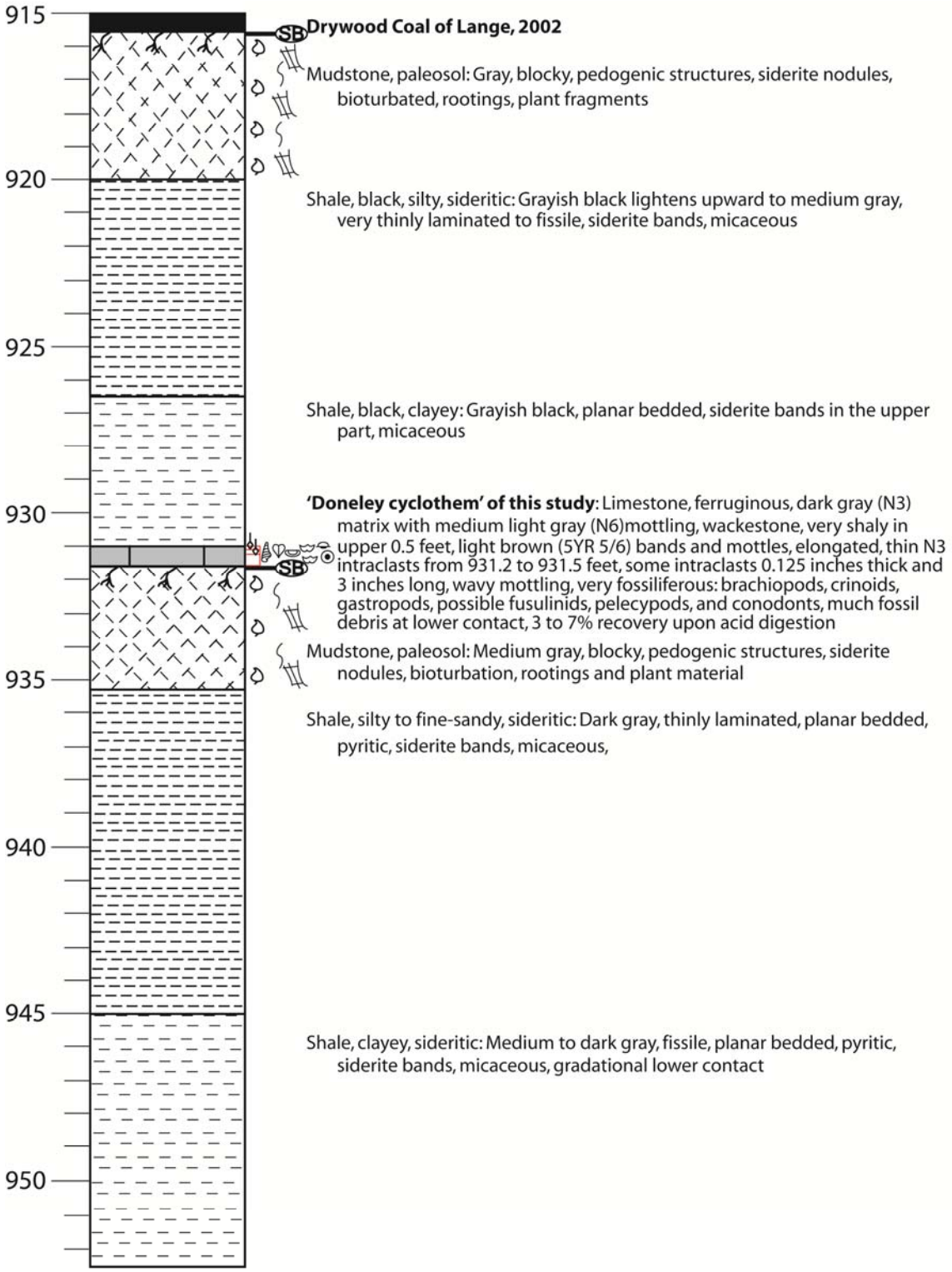

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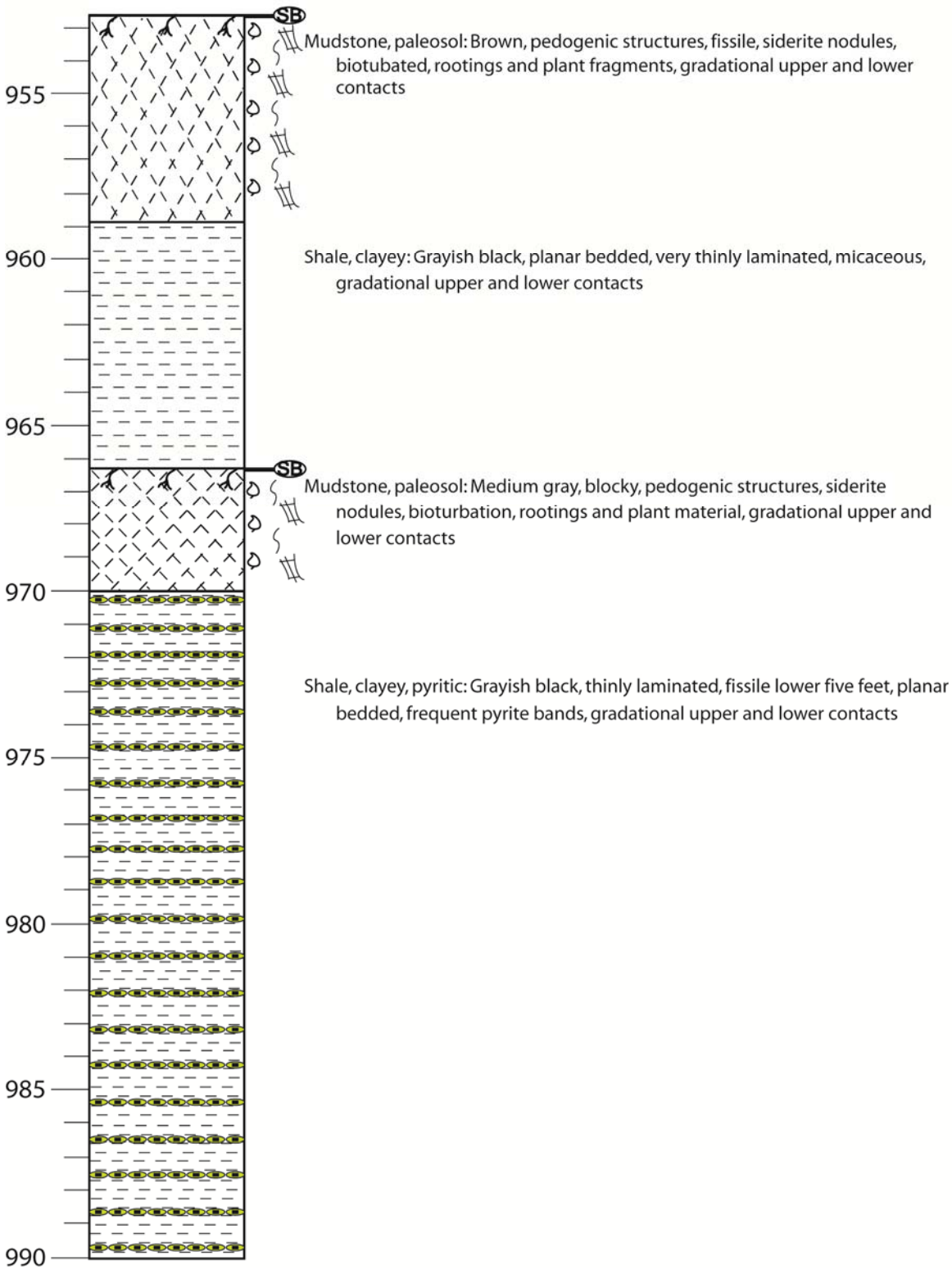

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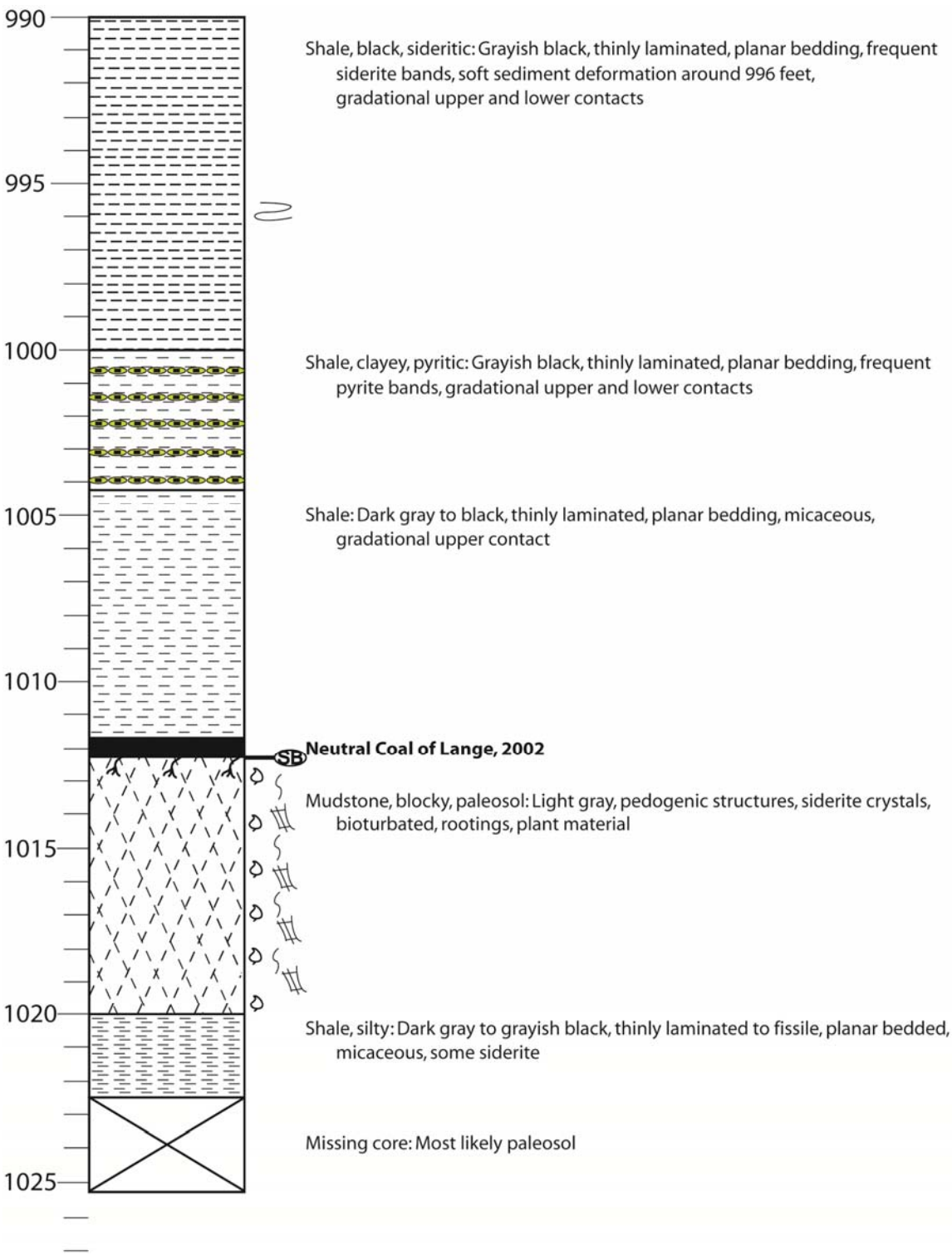

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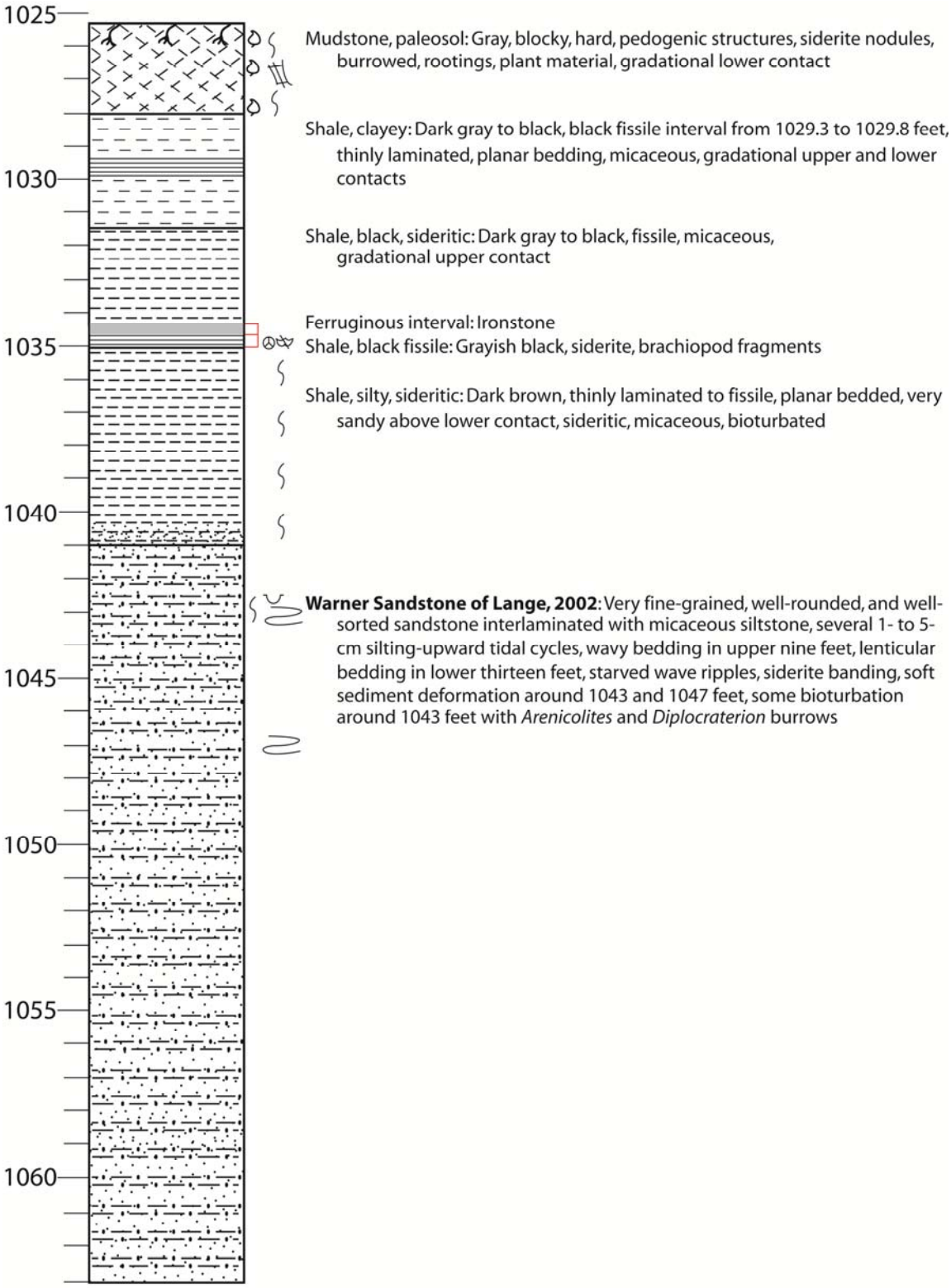

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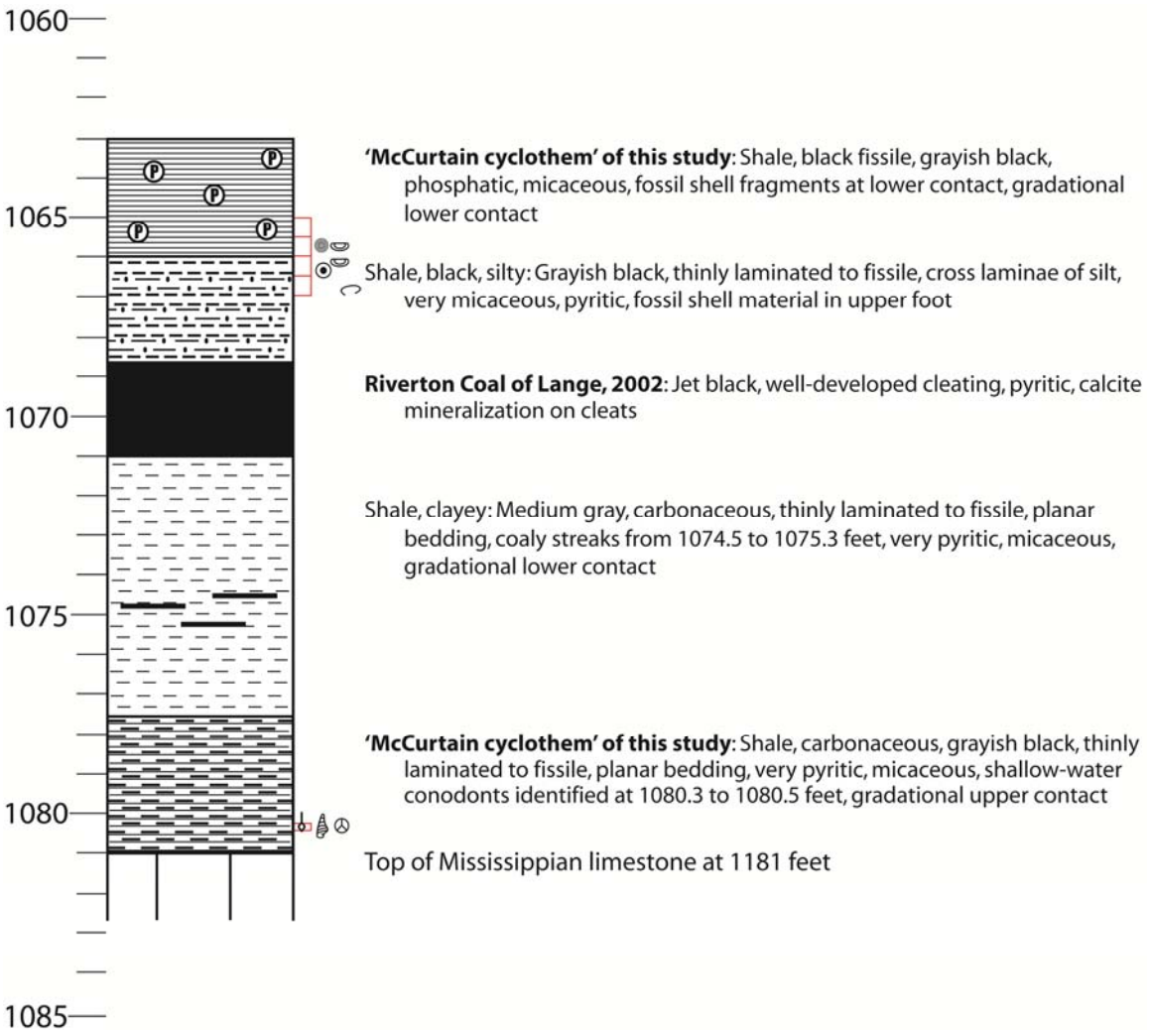

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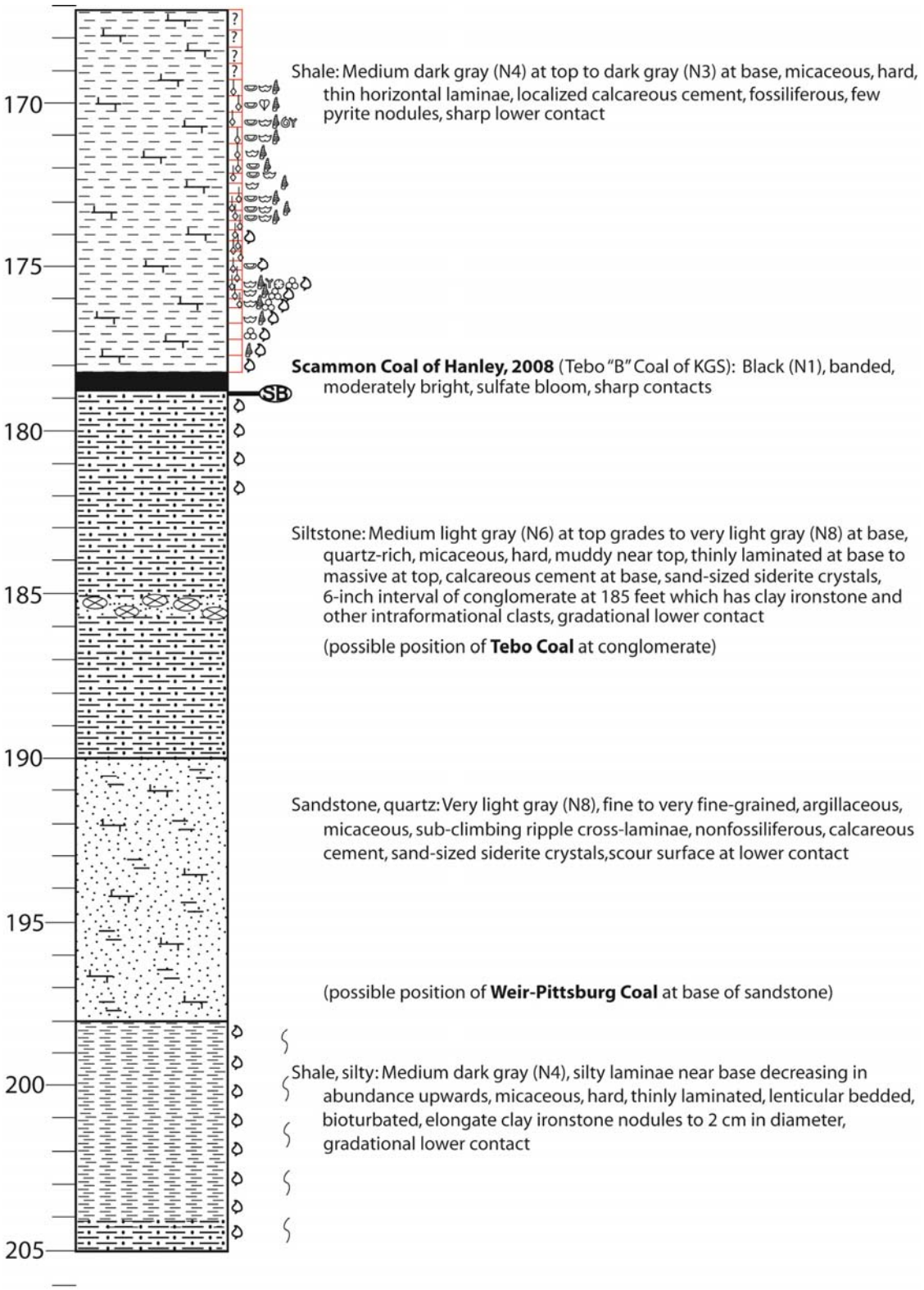
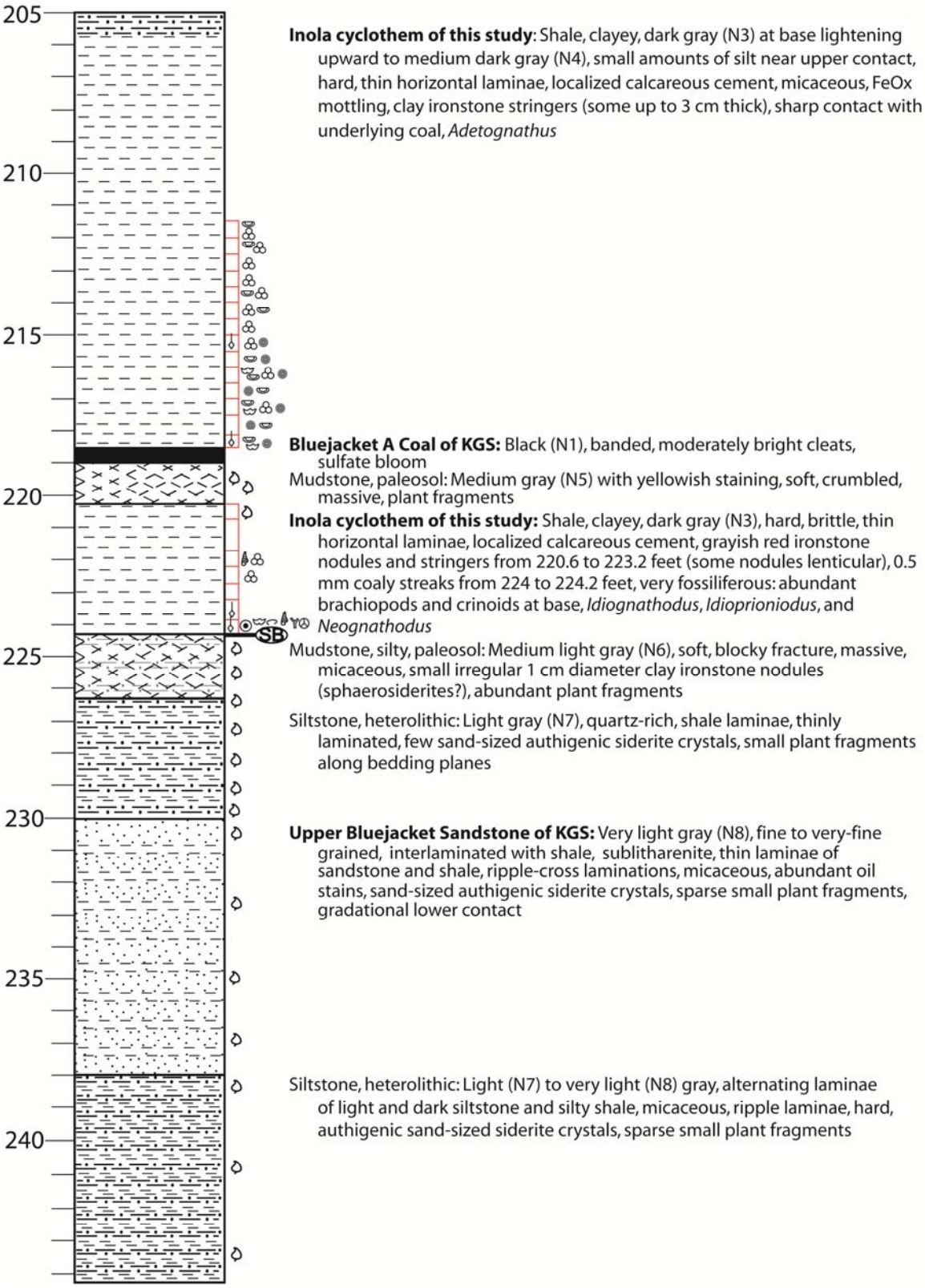


Figure A11. KGS P & M #7 core description, Cherokee Co., KS, previously described by John Harris and Michael Roberts (descriptions taken from Harris with additional notes by author).



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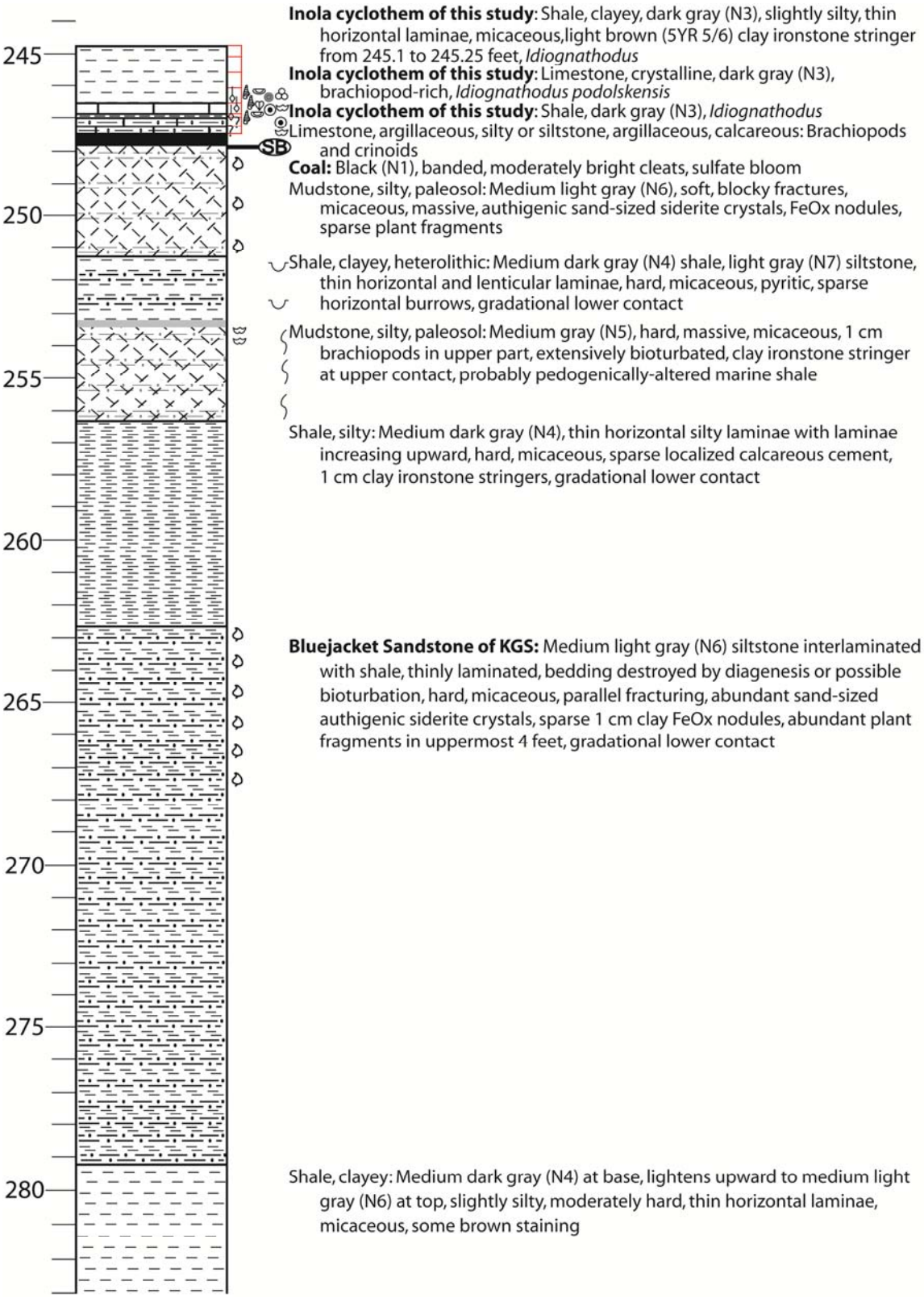

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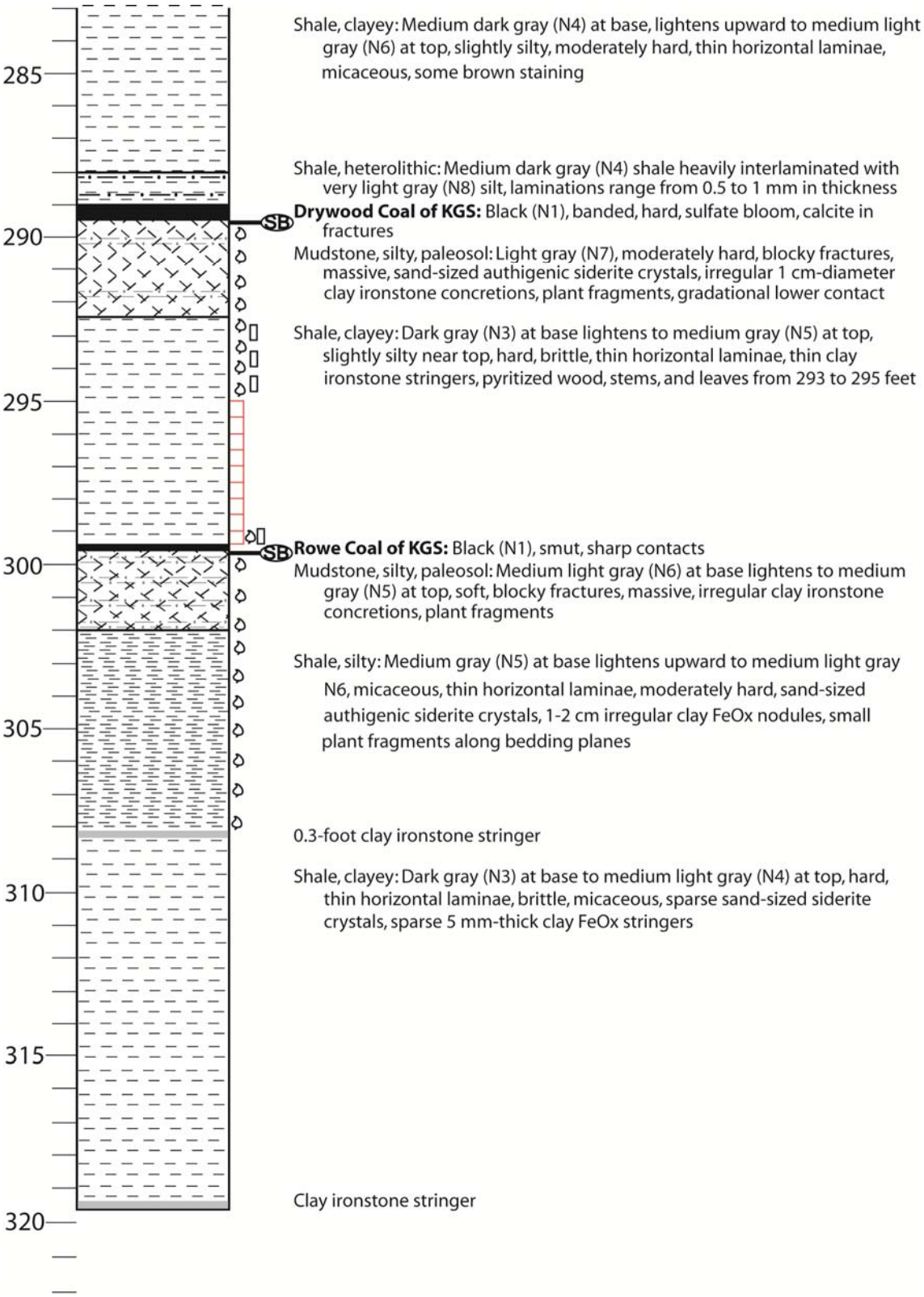

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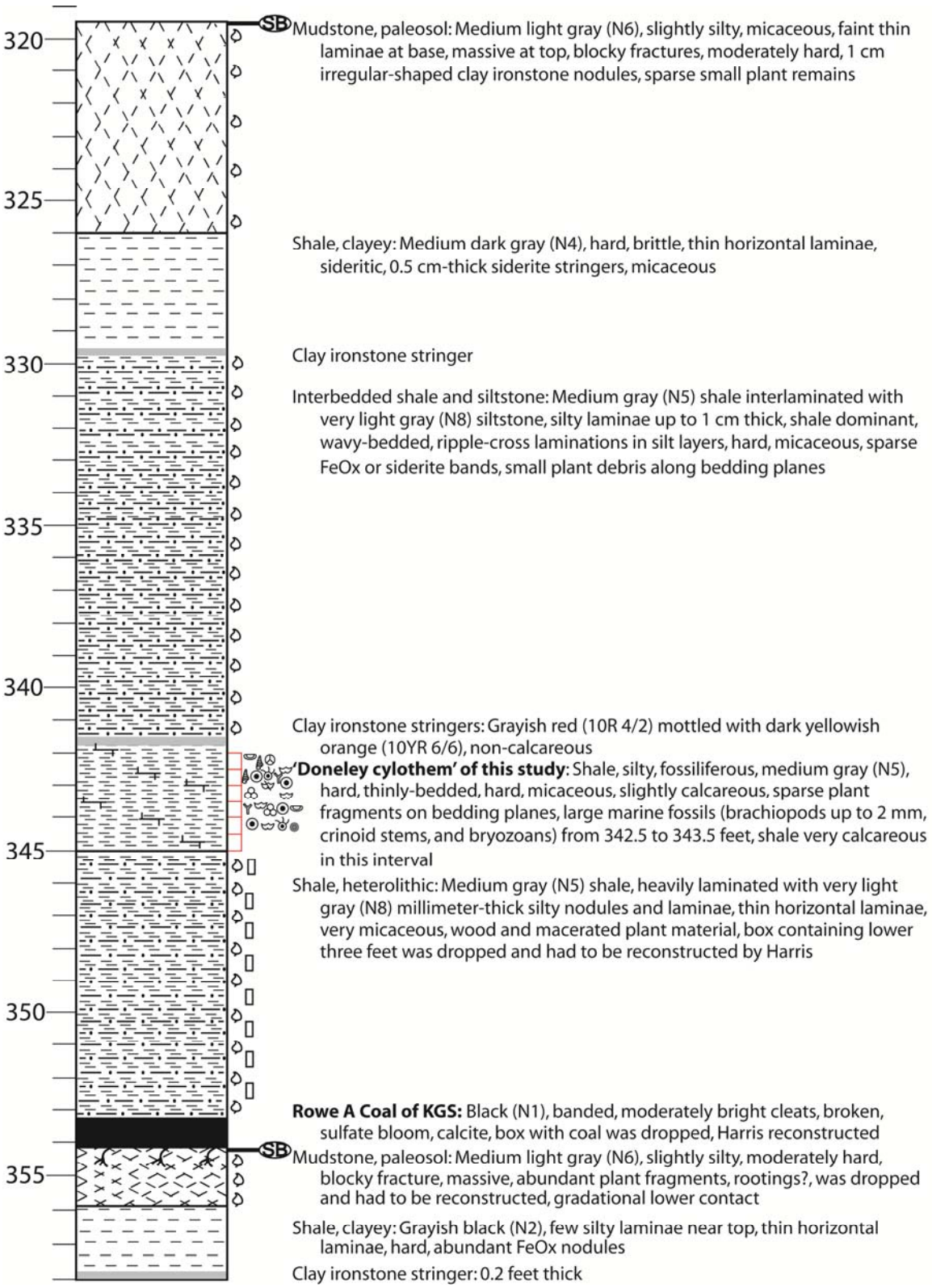

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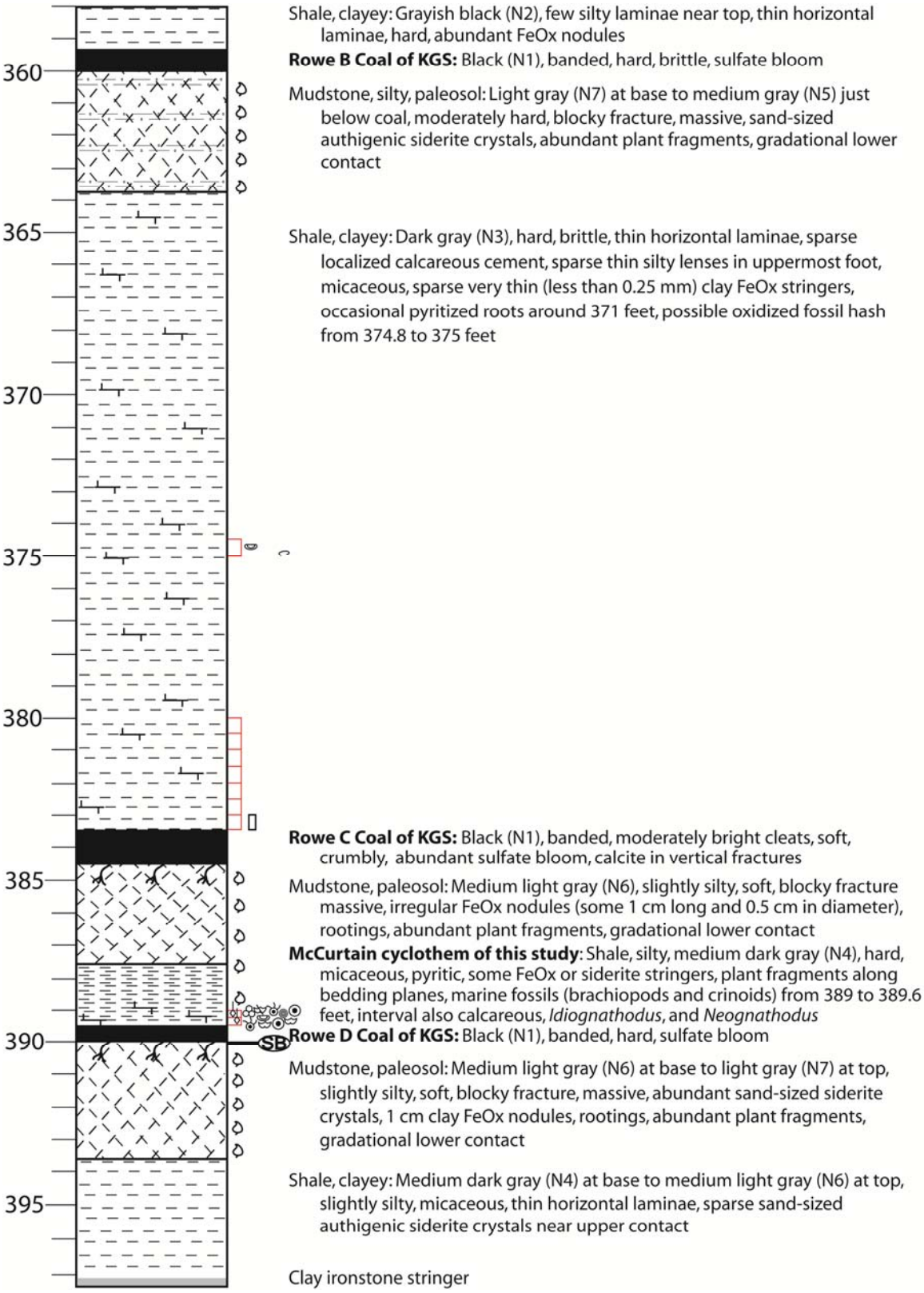

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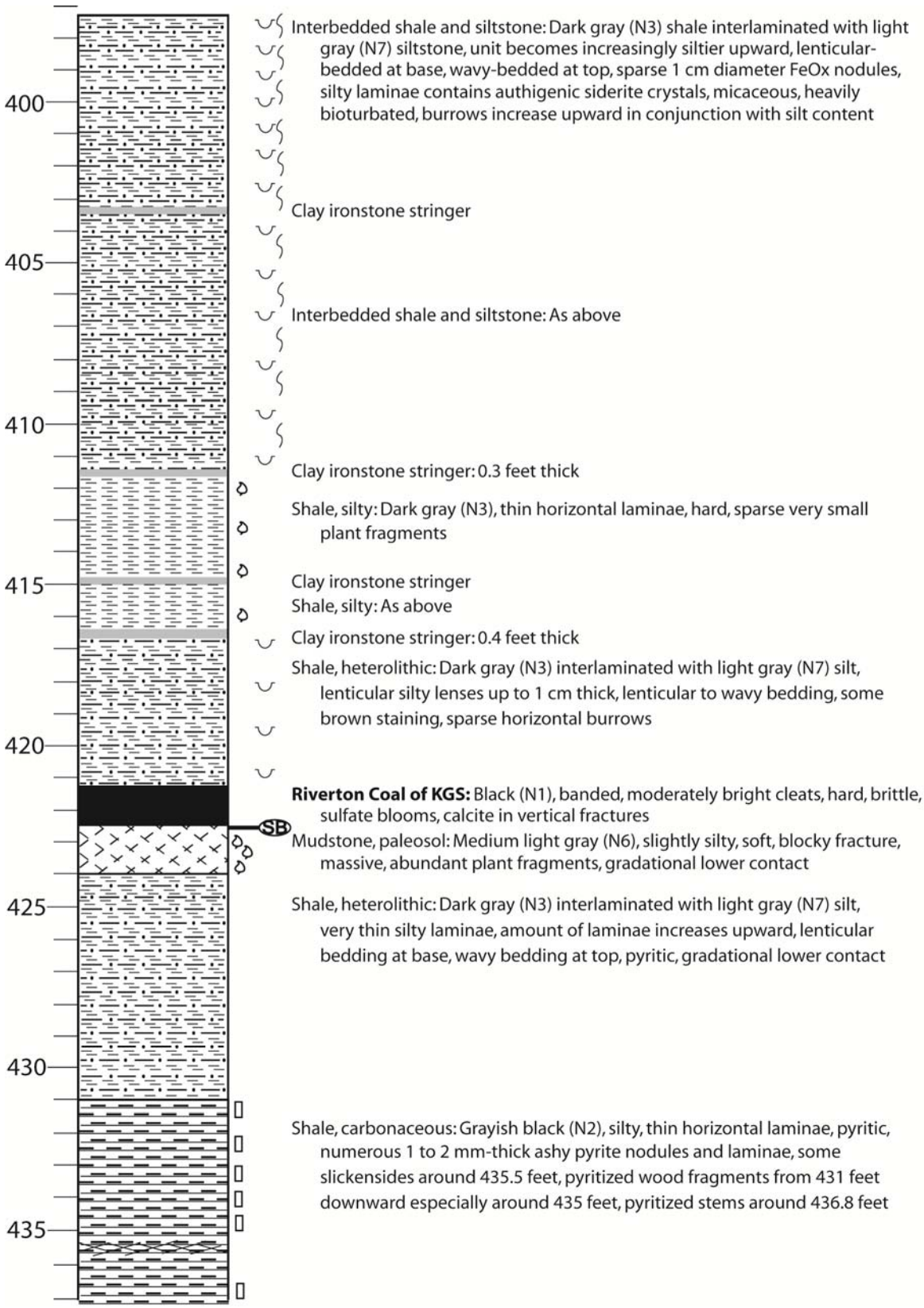

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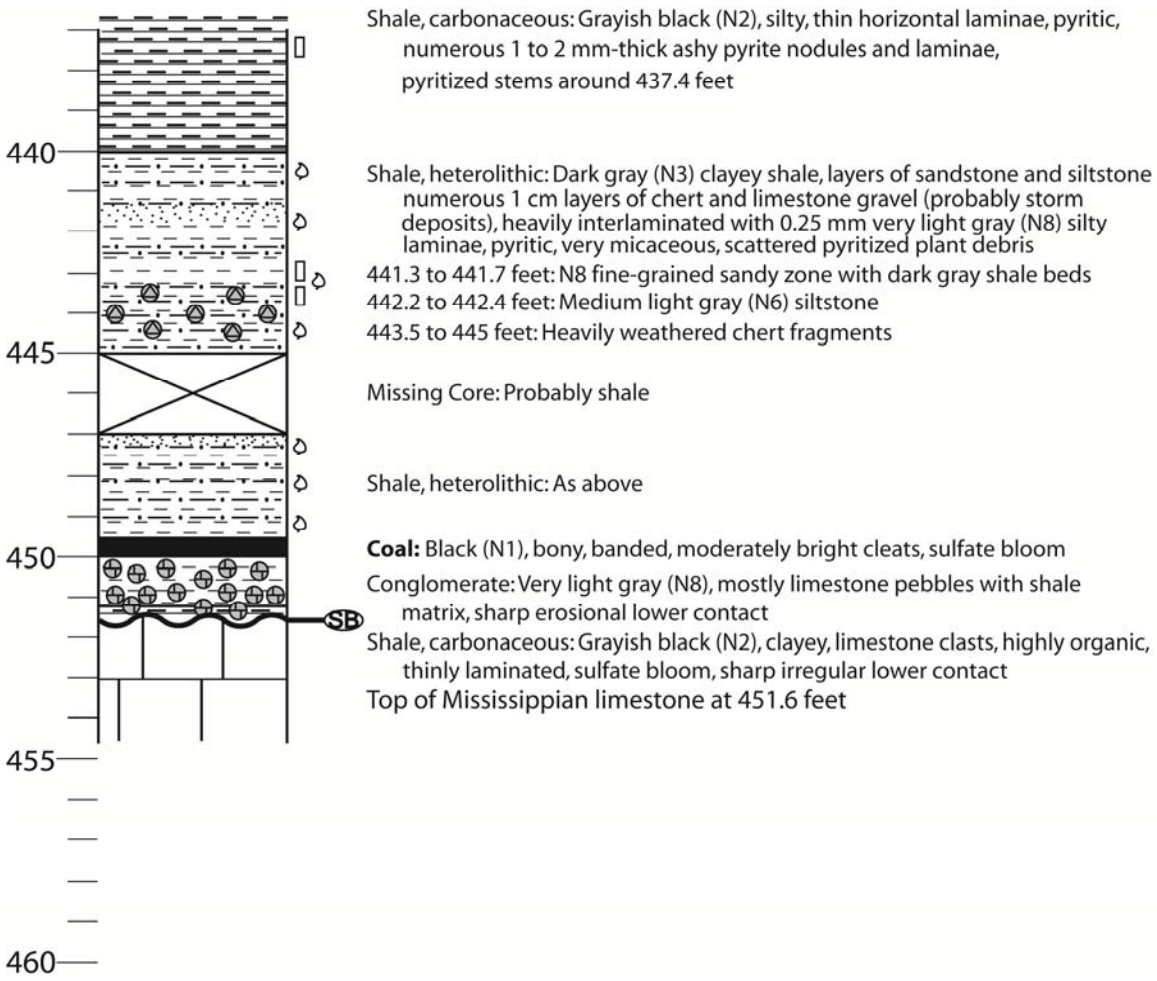

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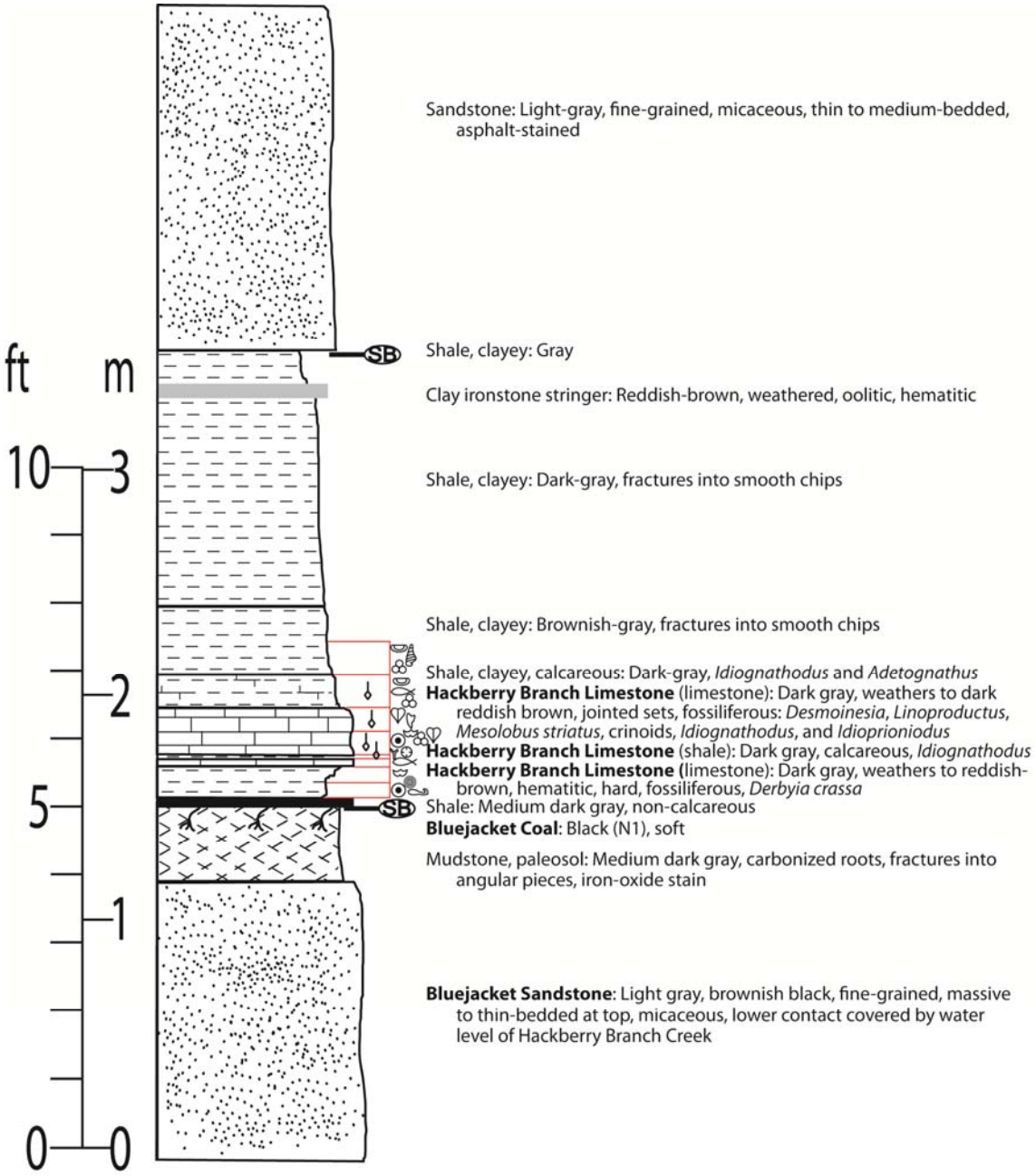


Figure A12. Type Hackberry Branch Limestone, Vernon County, Missouri (Inola cyclothem), NE-NE-NW Sec. 29, T35N, R32W (formerly misidentified as Seville Limestone in Missouri), based upon R.J. Gentile's 1964 and 2001 measured sections.

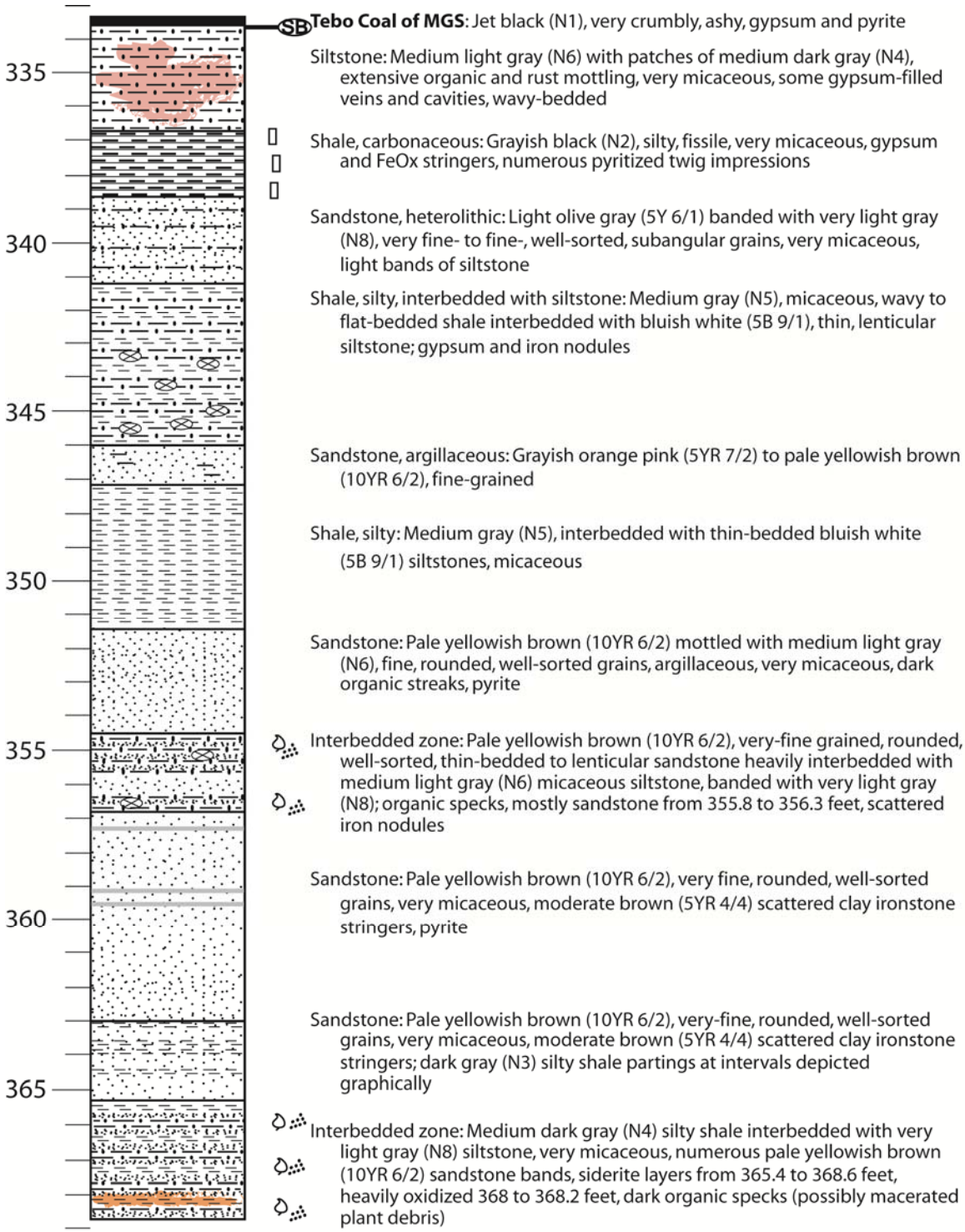
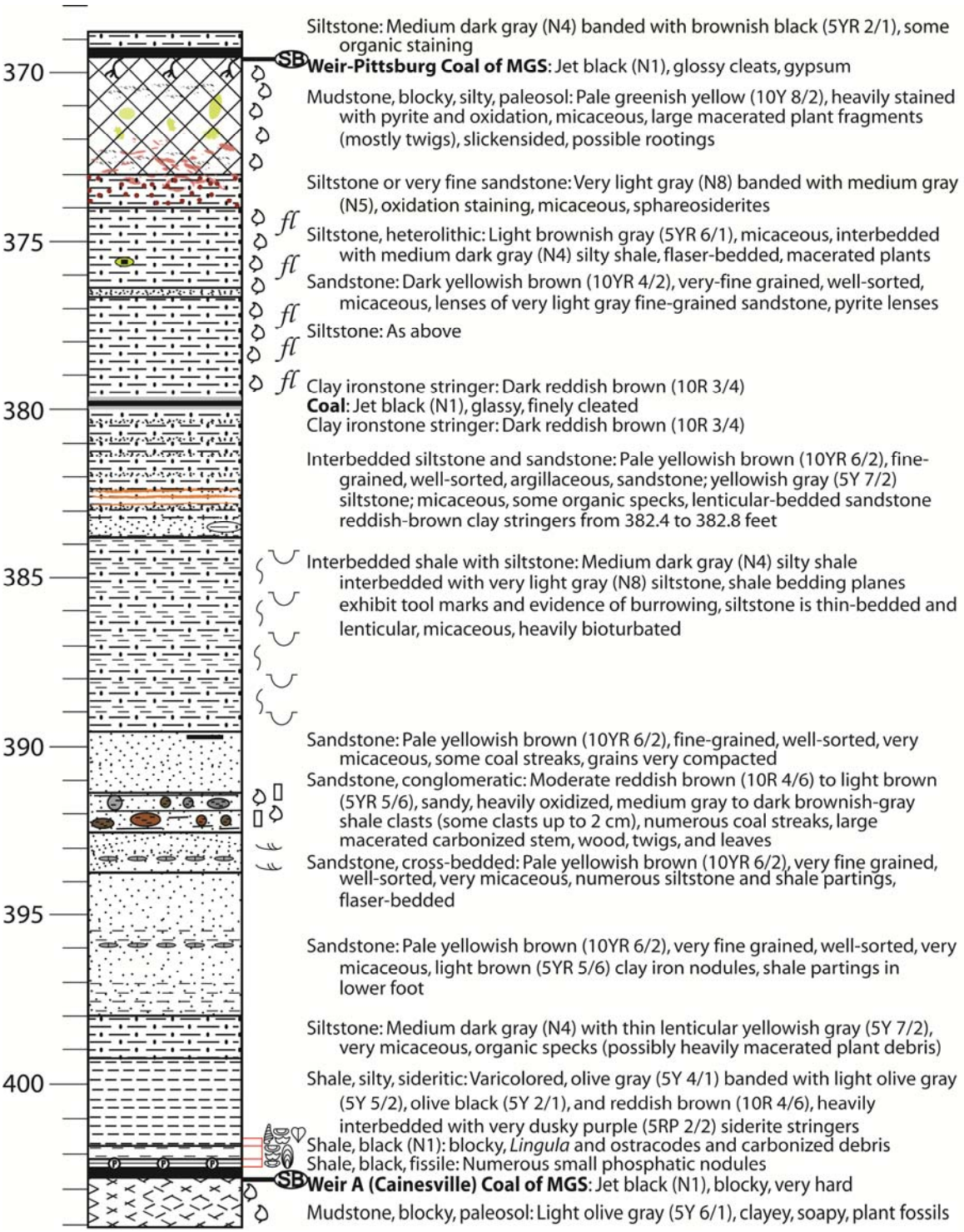


Figure A13. MGS Hess CH-9H core description, Bates Co., MO.



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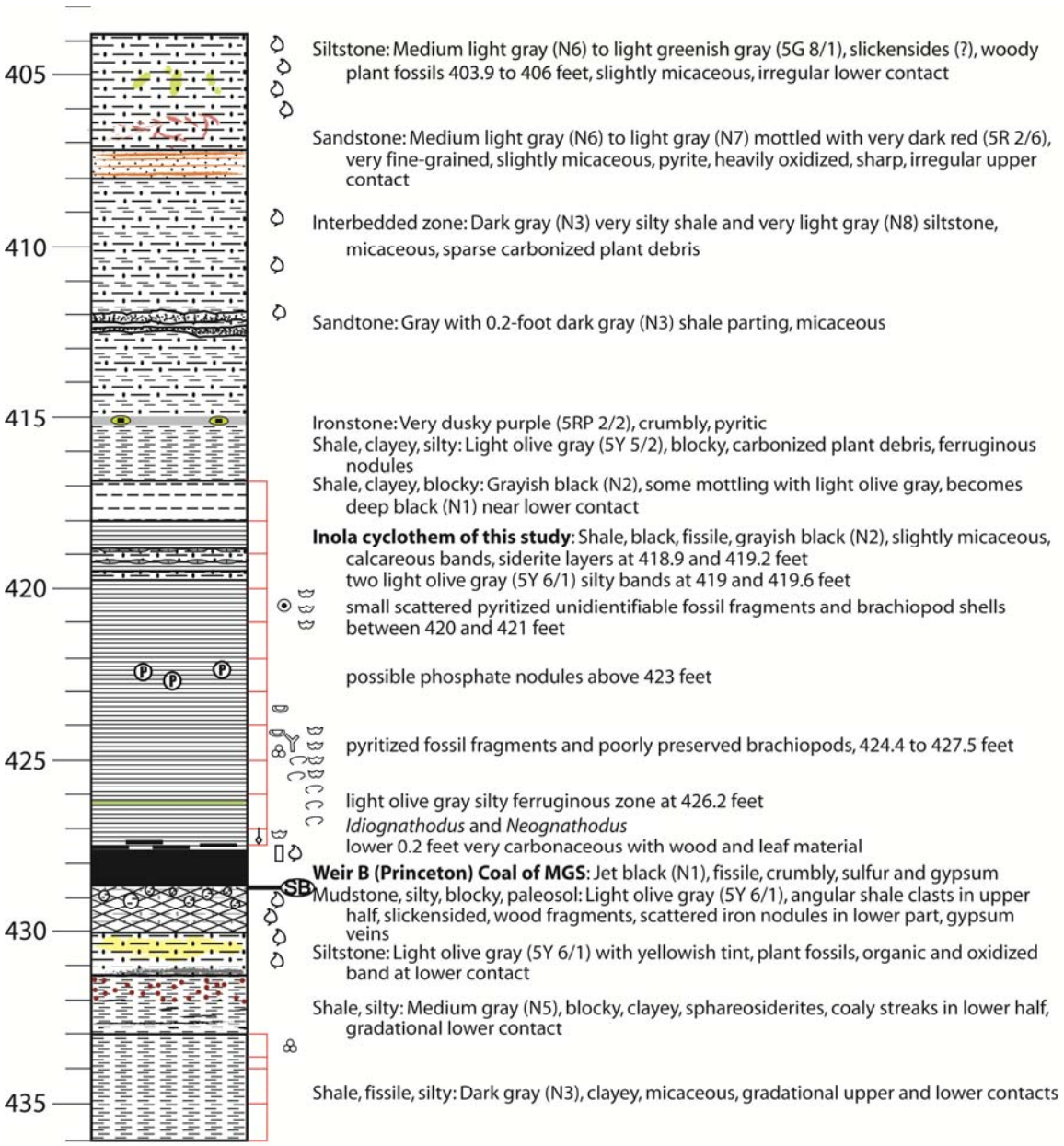

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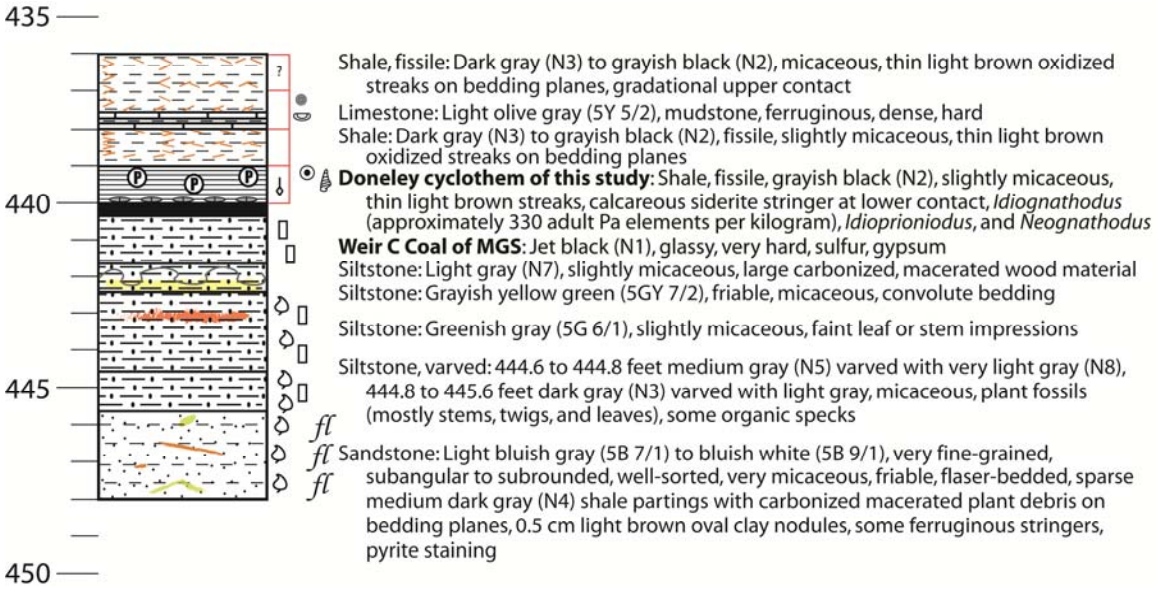

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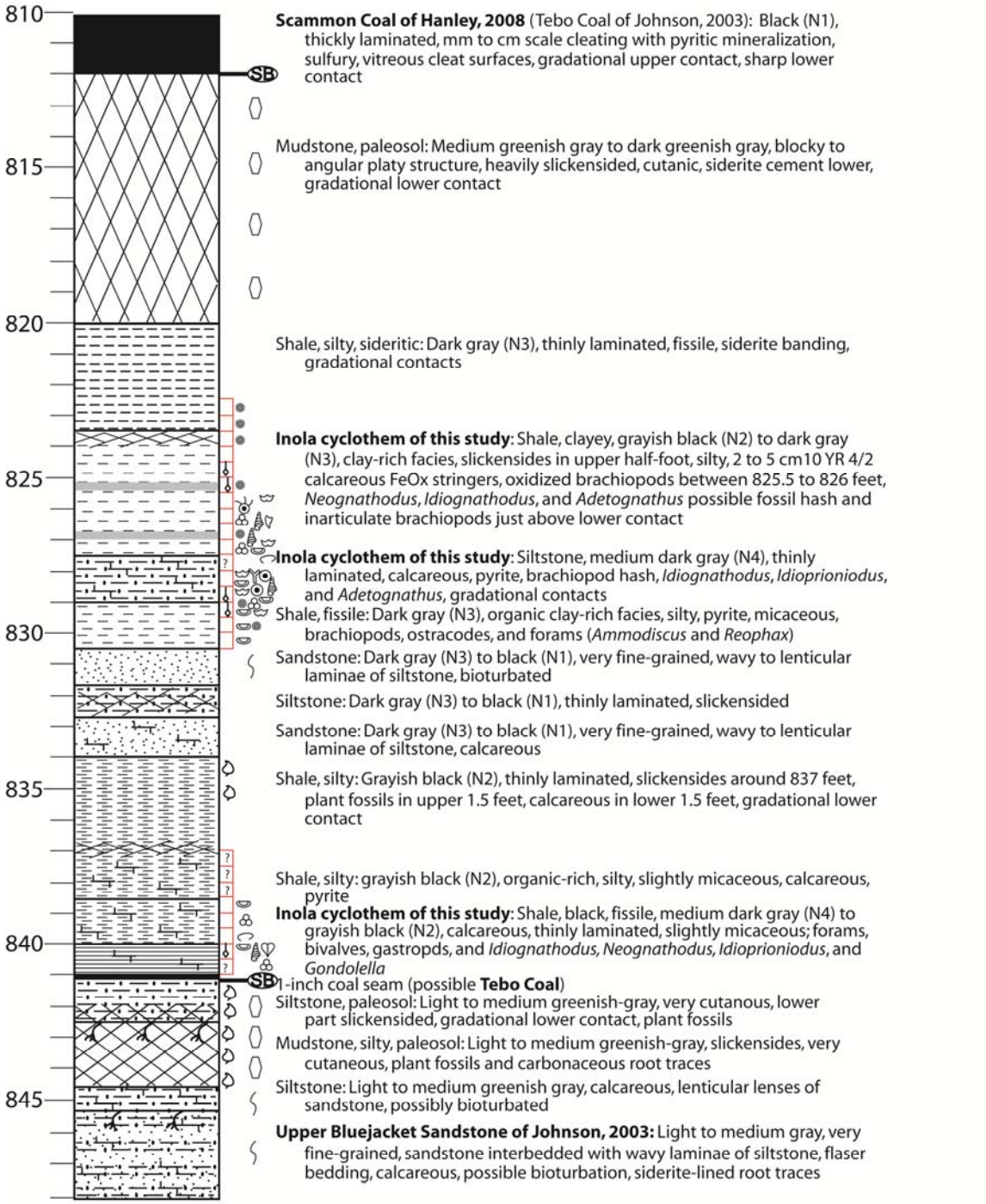
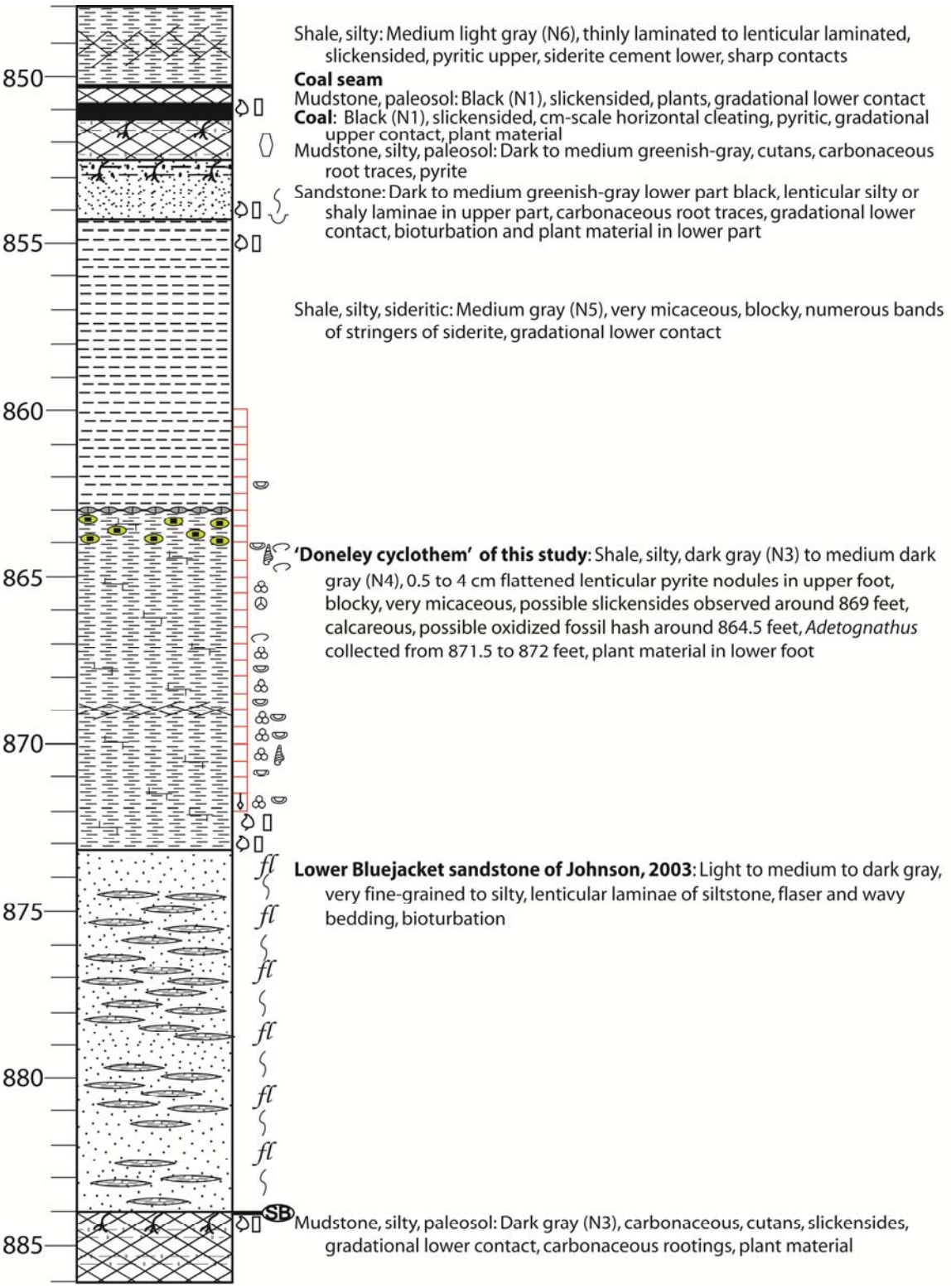


Figure A14. KGS Rose Hill #1-6 core description, Miami Co., KS, previously described by Johnson (2003).



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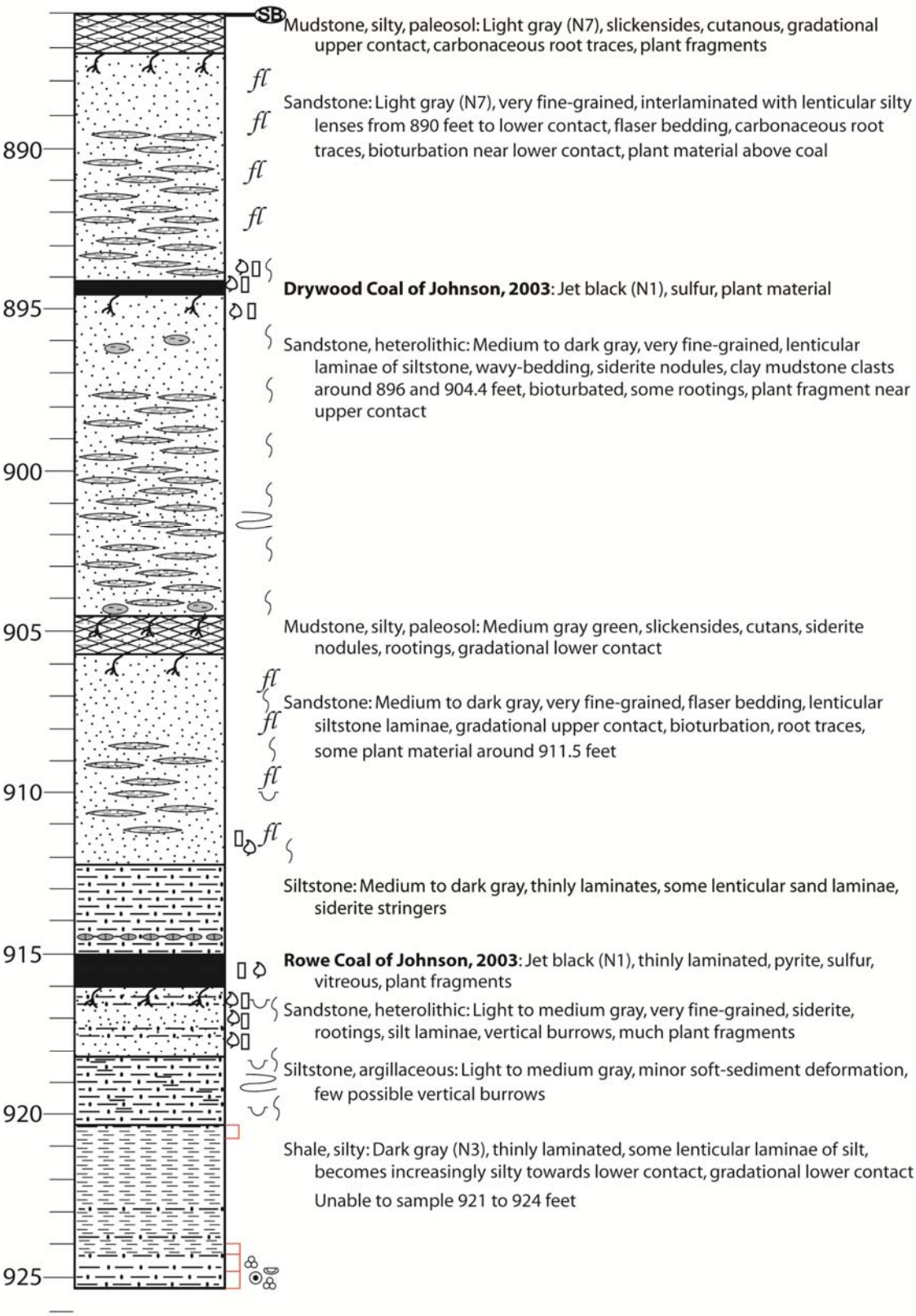

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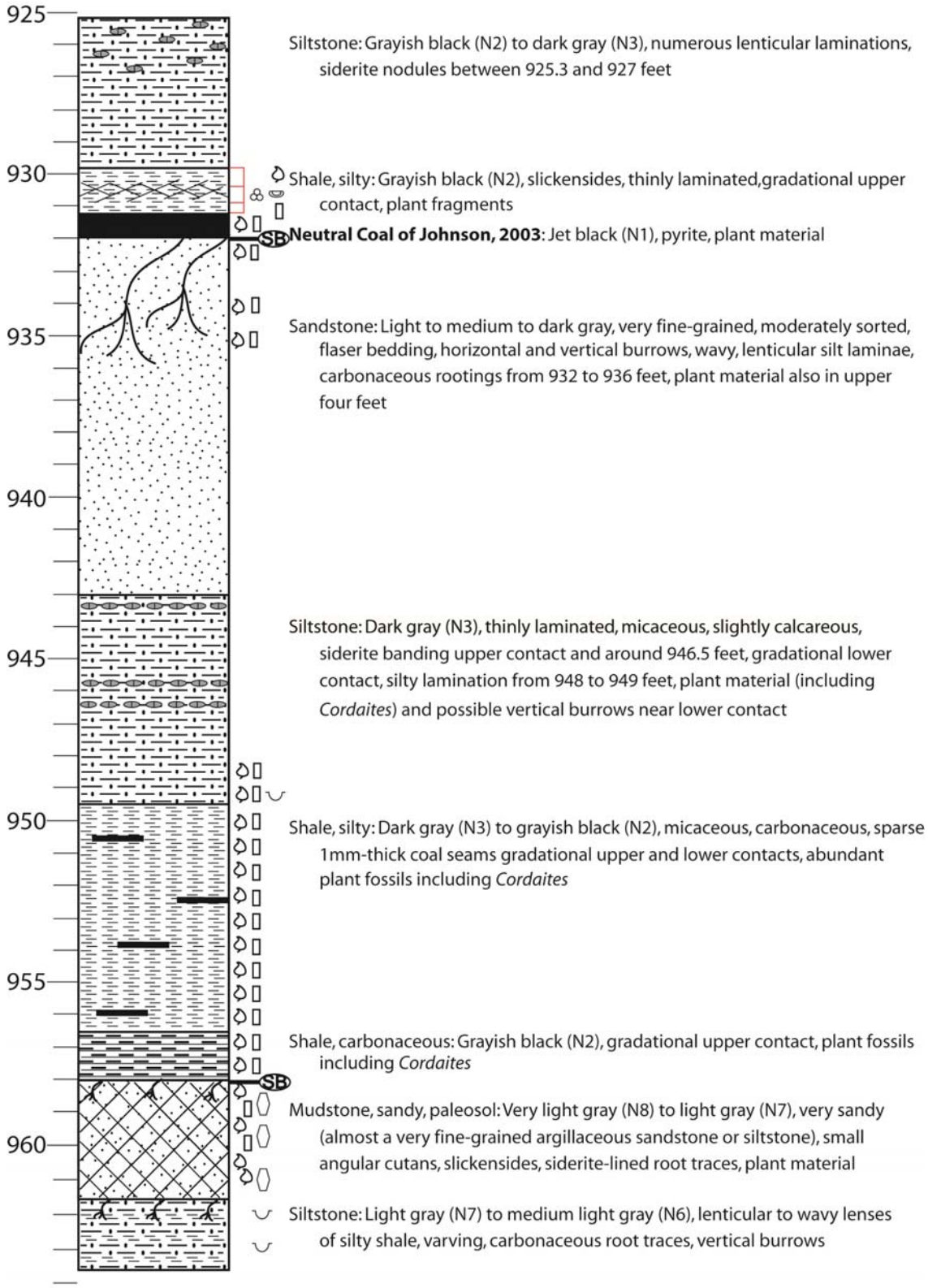

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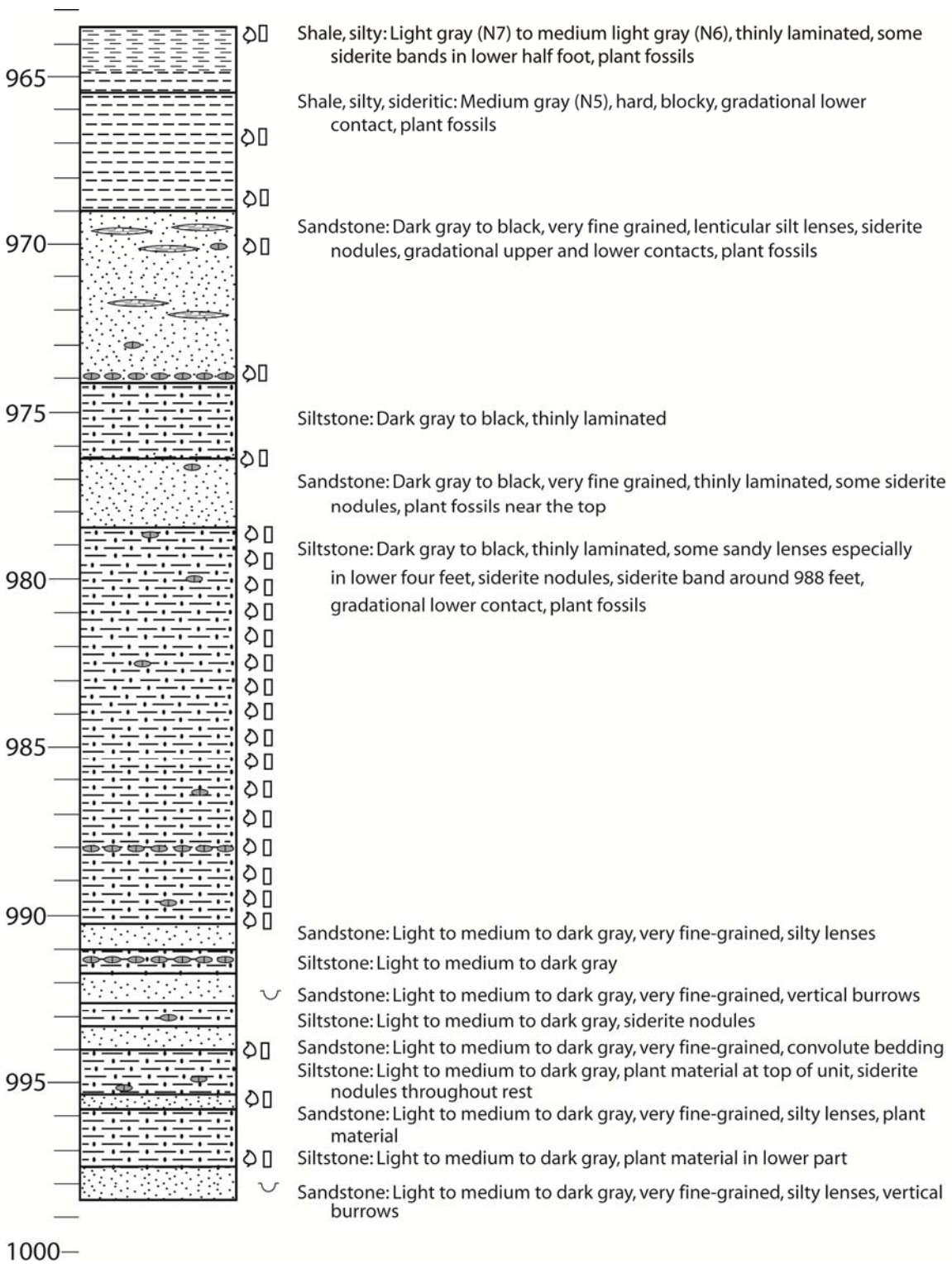

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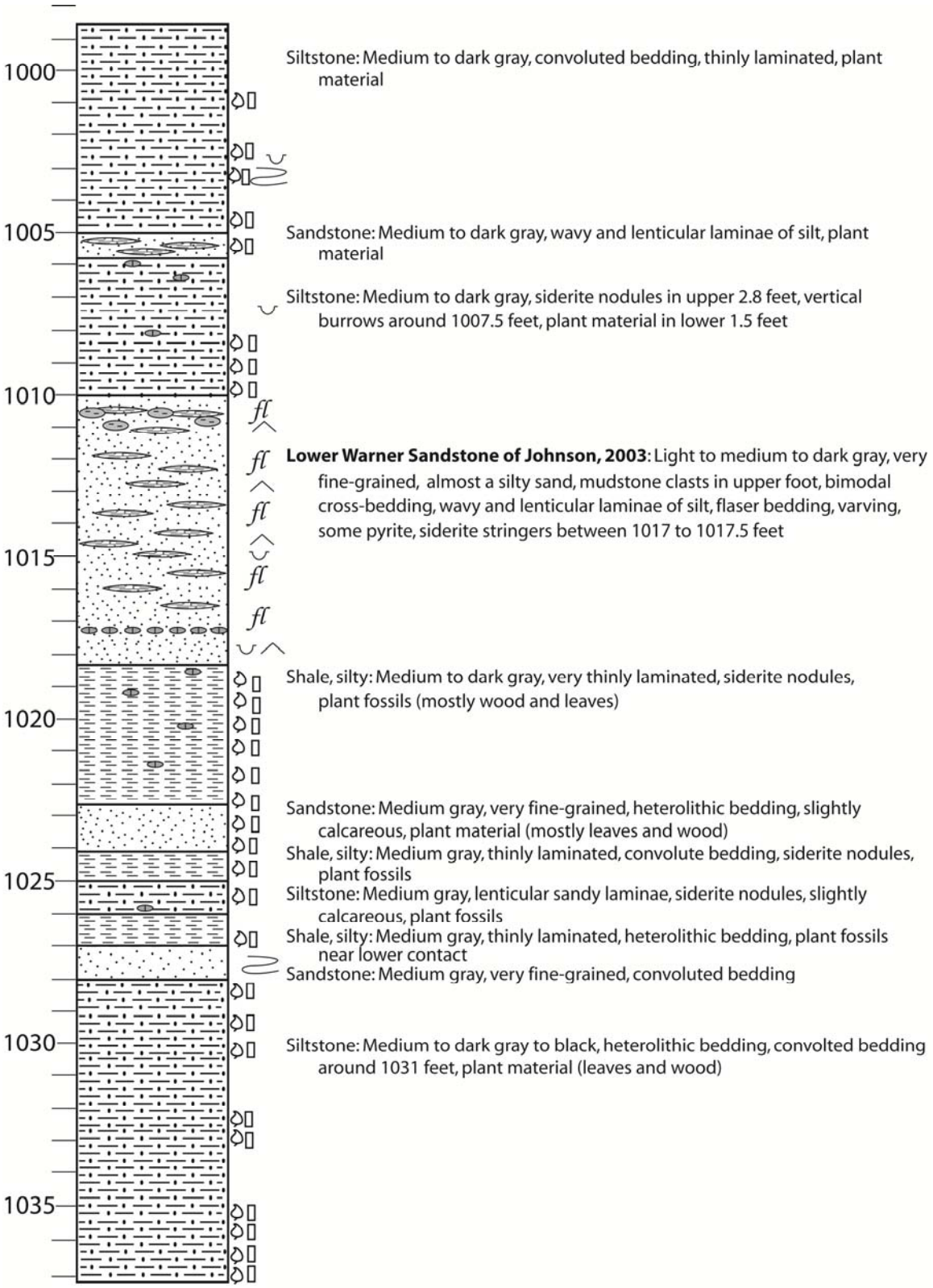

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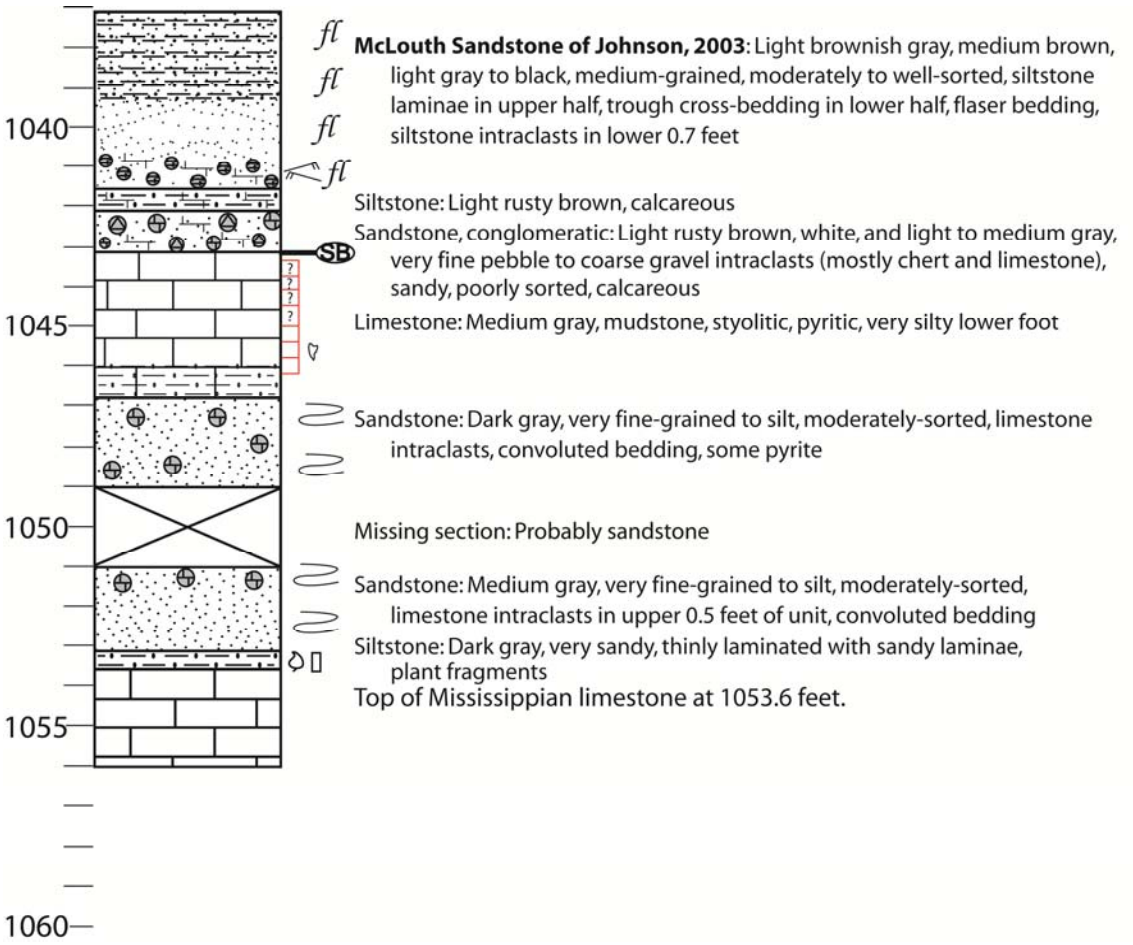


Figure A14. continued.

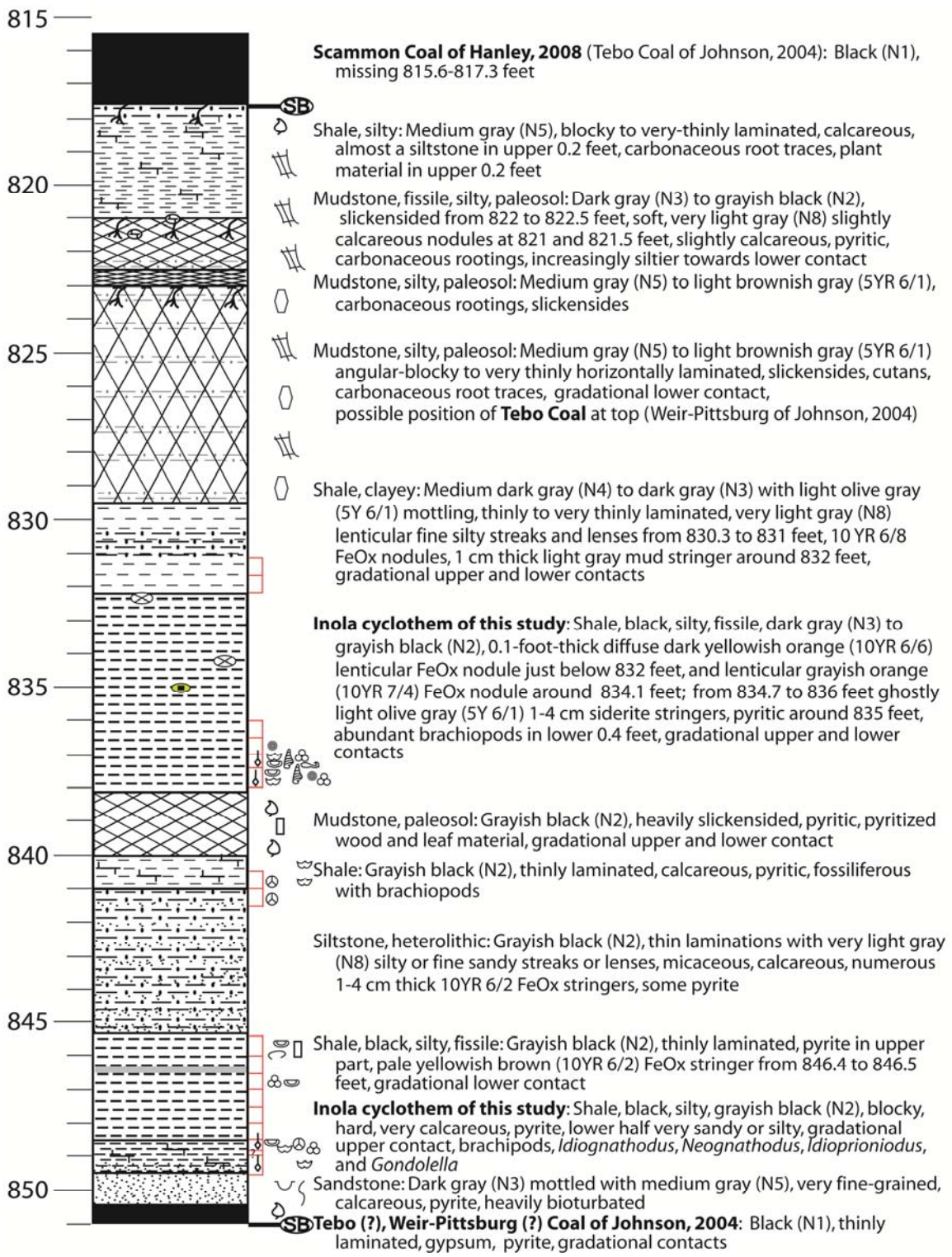
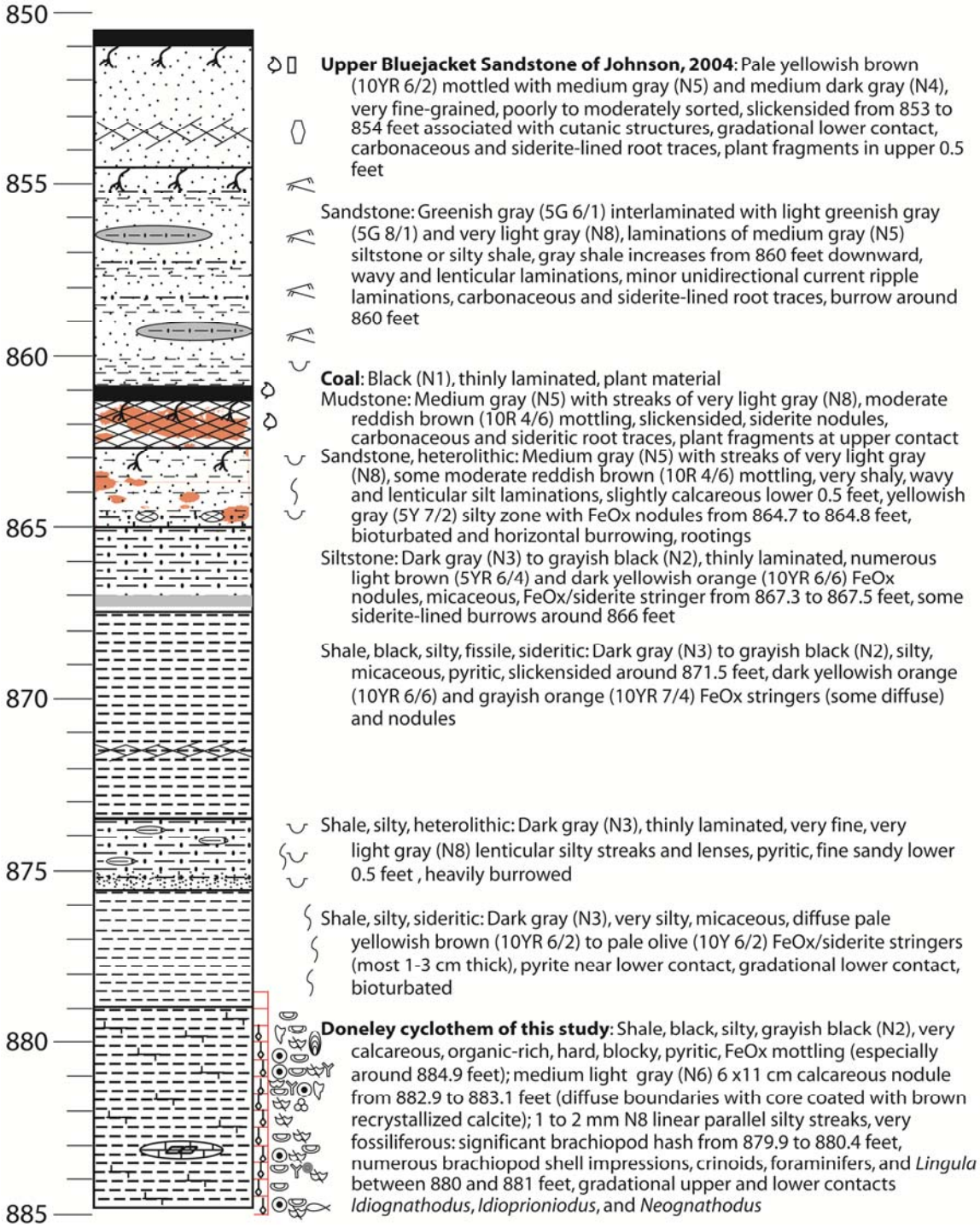


Figure A15. KGS Spencer #2-6 core description, Franklin Co., KS, previously described by Johnson (2004) (descriptions are from Johnson with some additional notes from author).



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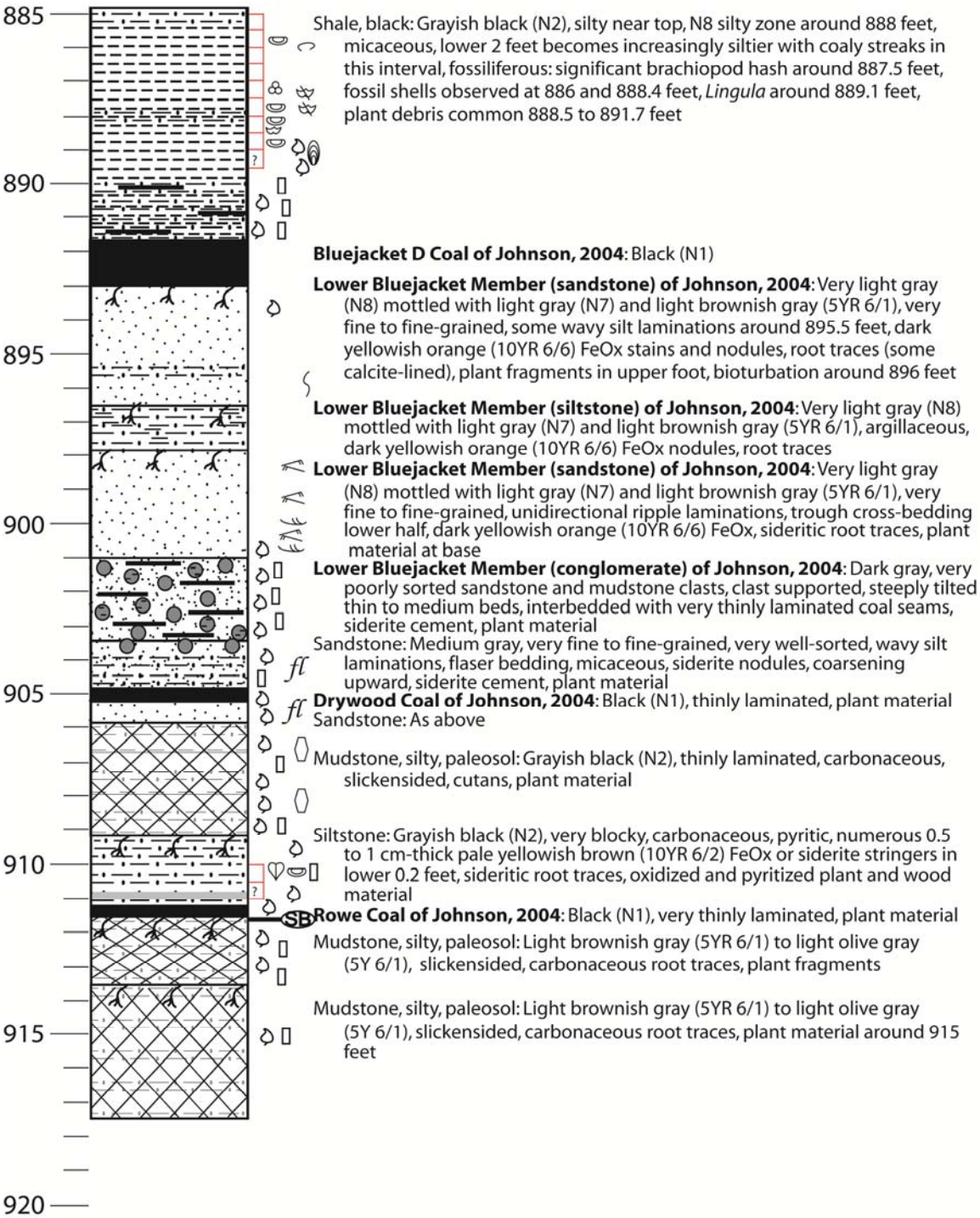

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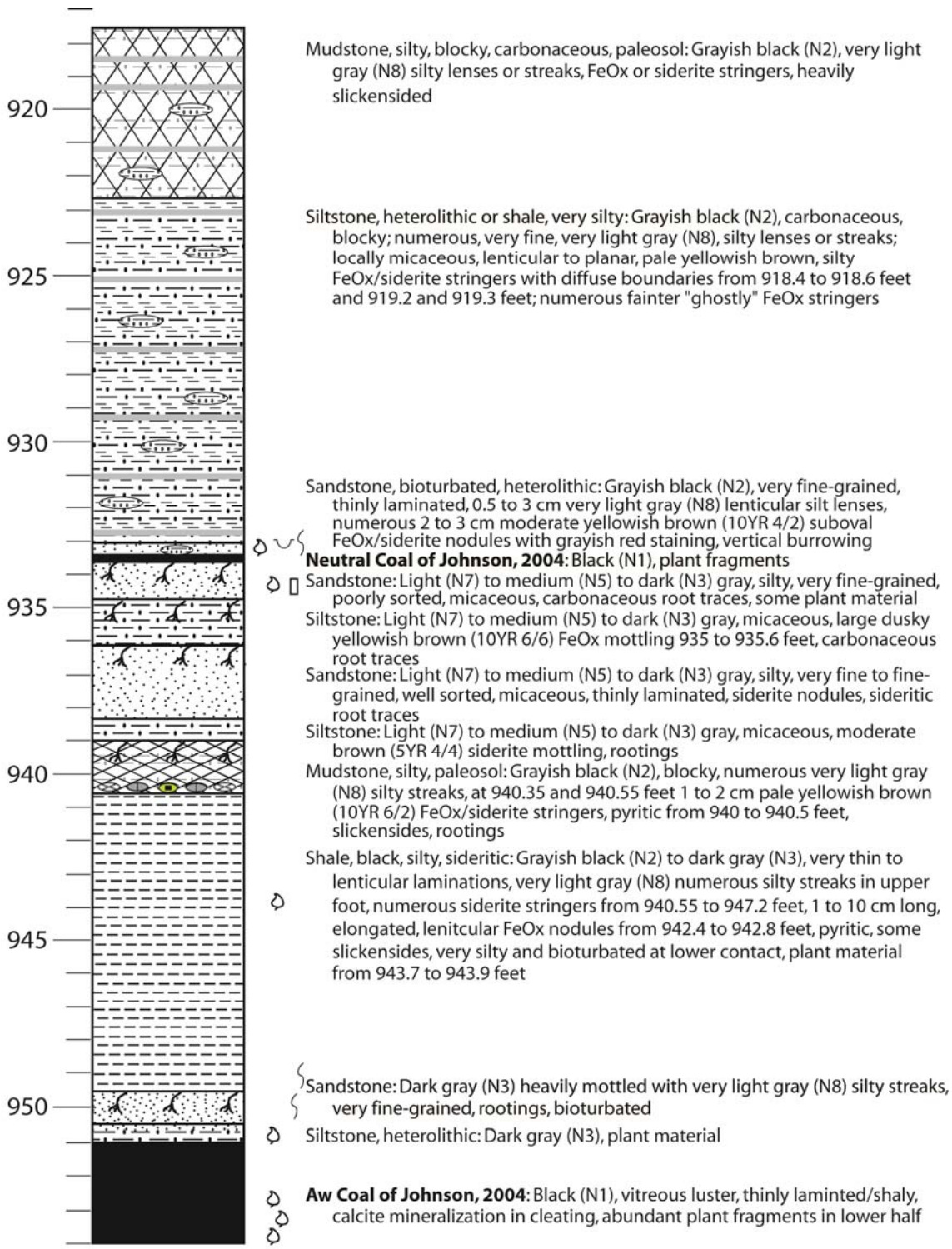

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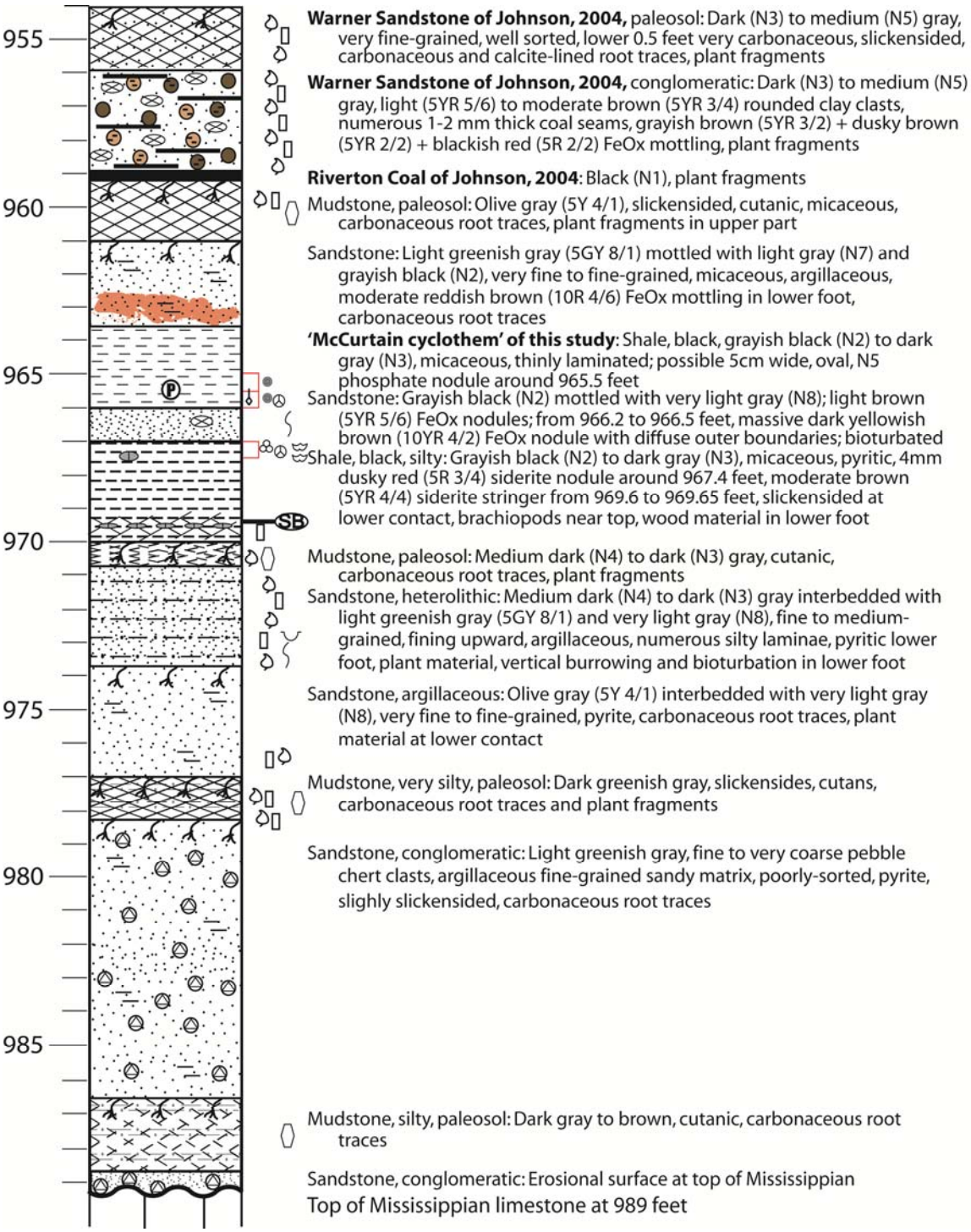

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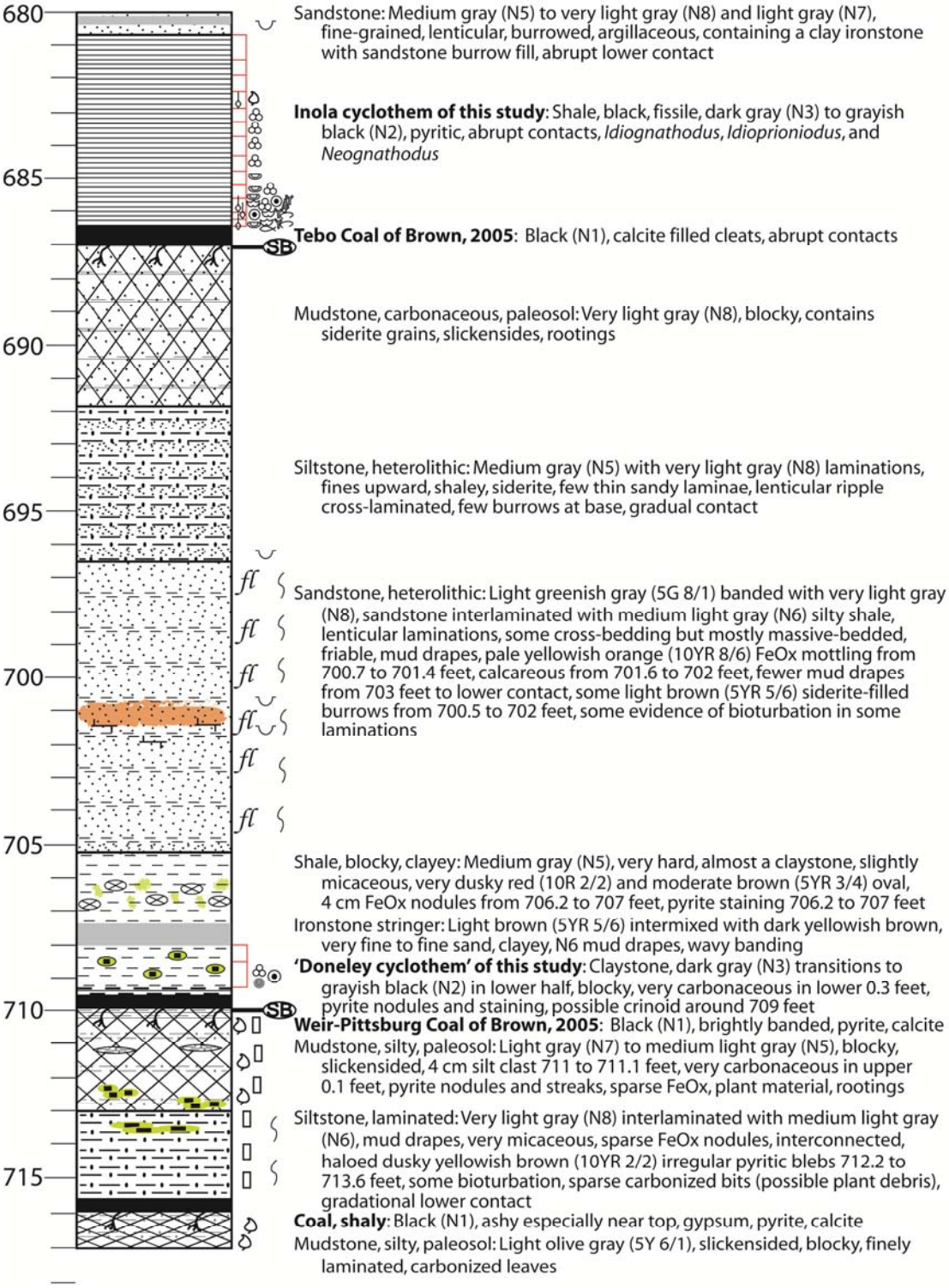


Figure A16. KGS Deffenbaugh Quarry #2 core description, Johnson Co., KS, previously described by W. M. Brown (2005).

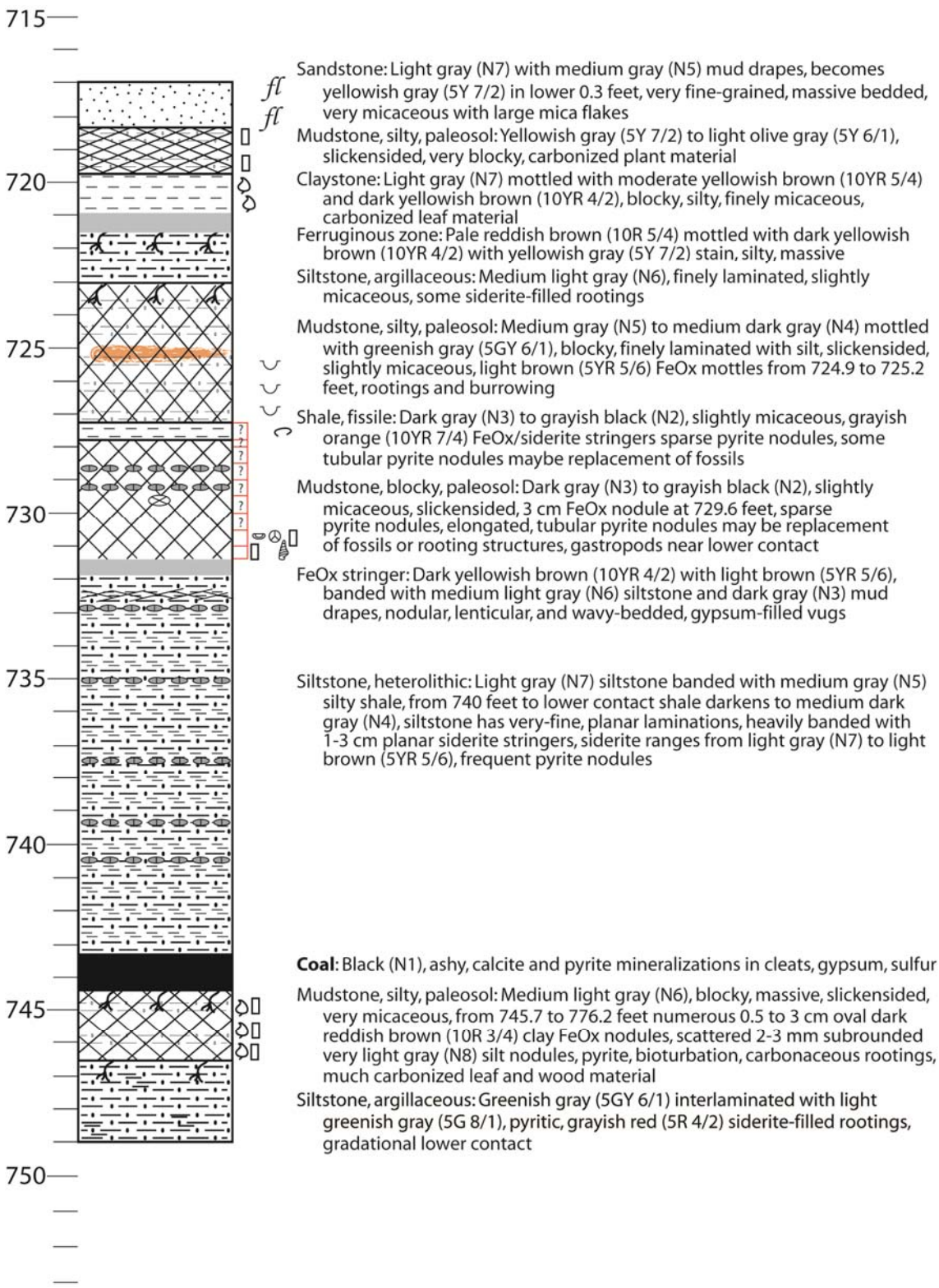
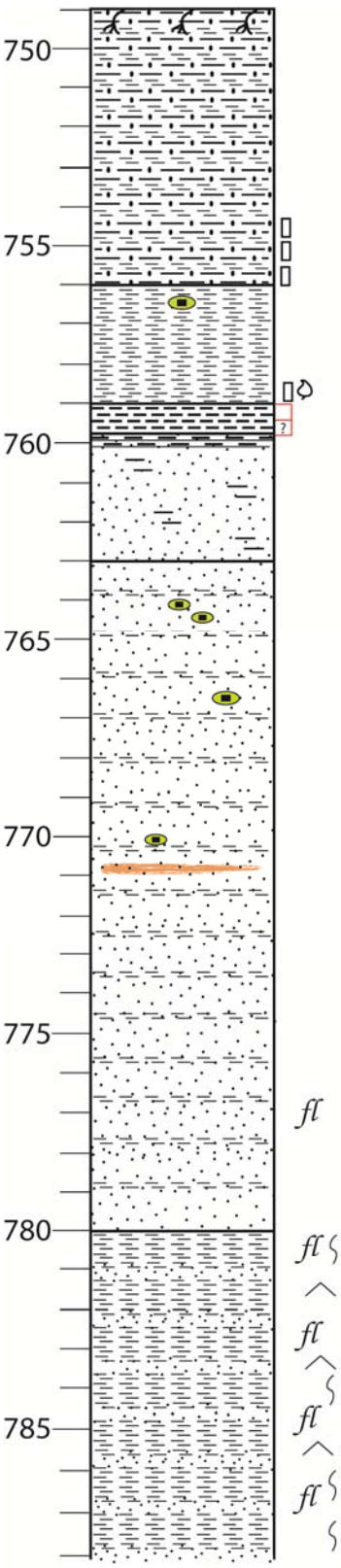


Figure A16. continued.



Siltstone, heterolithic: Greenish gray (5GY 6/1) siltstone interbedded with dark gray (N3) silty shale, shale amount increases downward, lenticular and wavy-bedded laminations, mud drapes, micaceous, pyritic (some nodules up to 5 cm), grayish red siderite-filled rootings in upper foot, carbonized wood material in lower 1.5 feet, gradational contacts

Shale, silty: Medium dark gray (N4), very blocky, finely micaceous, pyritic in lower 1.5 feet, 6 cm subcircular pyrite nodule 756.3 to 756.4 feet, 2 mm spherical nodules on bedding planes, oxidized plant debris above lower contact, gradational lower contact

Shale, black, silty: Grayish black (N2), blocky, finely laminated with very light gray (N8) silty streaks, increasingly siltier downward, waxy, finely micaceous gradational upper contact

Sandstone, argillaceous: Light greenish gray (5GY 8/1) with medium light gray (N6) mud drapes, carbonaceous shale in upper 0.2 feet, lenticular and wavy-bedded

Sandstone, heterolithic: Yellowish gray (5Y 7/2) sandstone interlaminated with dark gray (N3) silty shale, lenticular and wavy-bedded shale, very thin mud drapes and sparse flaser beds around 777 feet, some light brown FeOx staining above 771 feet, pyritic in upper 7 feet, large pyrite nodule at 766.5 feet, gradational lower contact

Shale, silty, heterolithic: Medium dark gray (N4) with very light gray (N8) silty streaks and lenses, interlaminated with very light gray sandstone laminae, bi-directional current ripples, mud drapes and double mud drapes, wavy-bedded silt laminations, flaser bedding, bioturbation, gradational upper contact

Figure A16. continued.

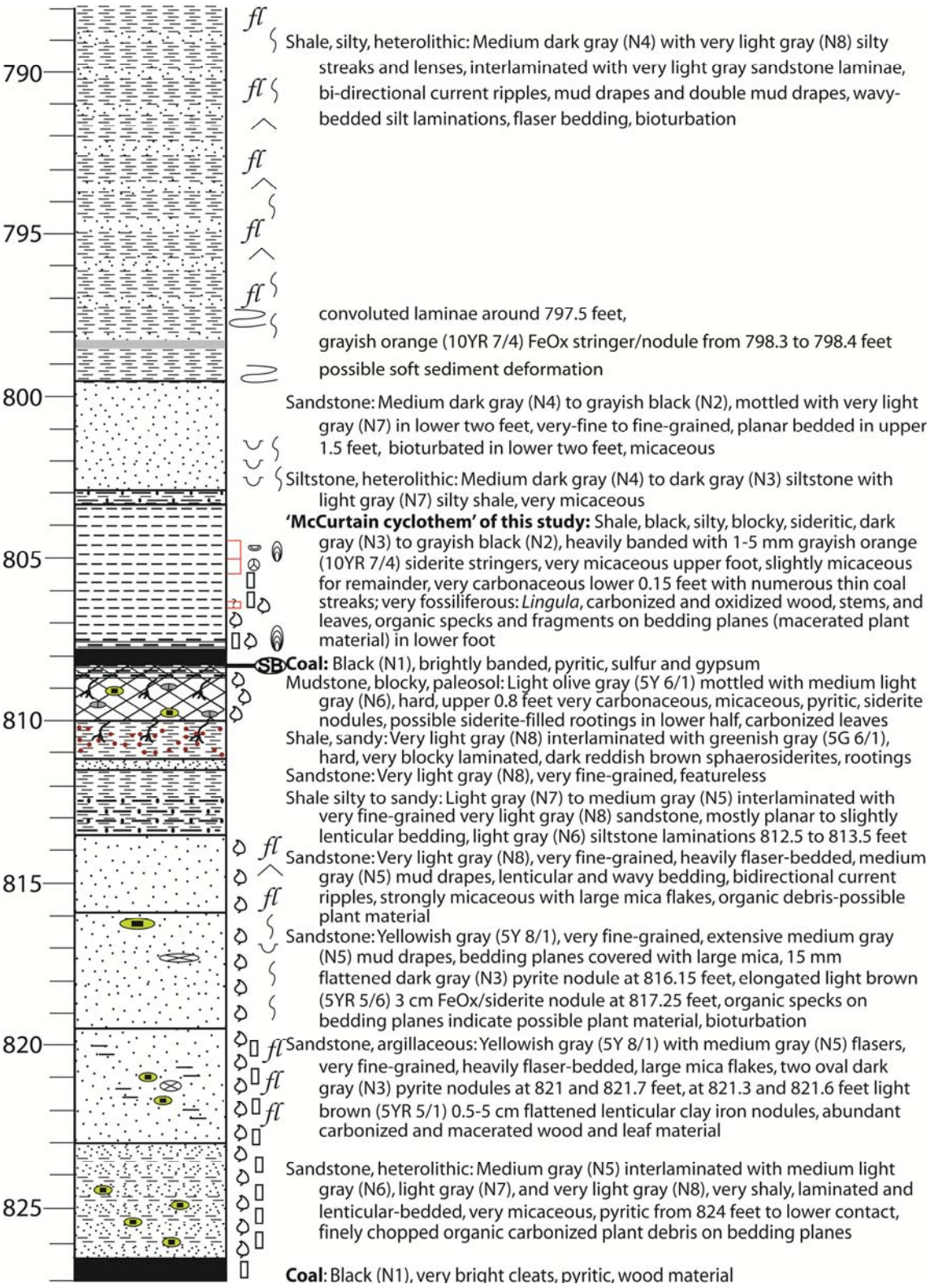


Figure A16. continued.

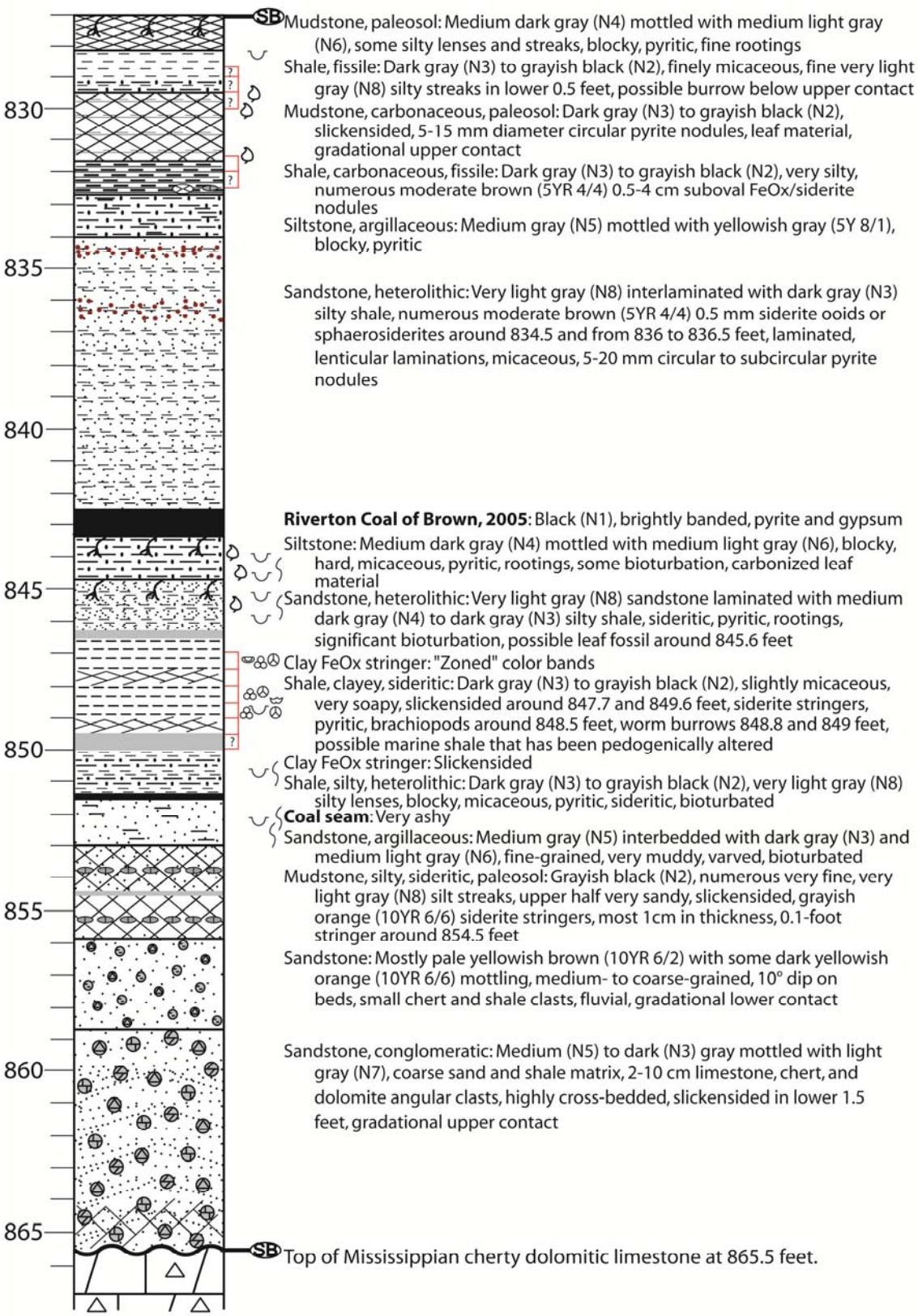


Figure A16. continued.

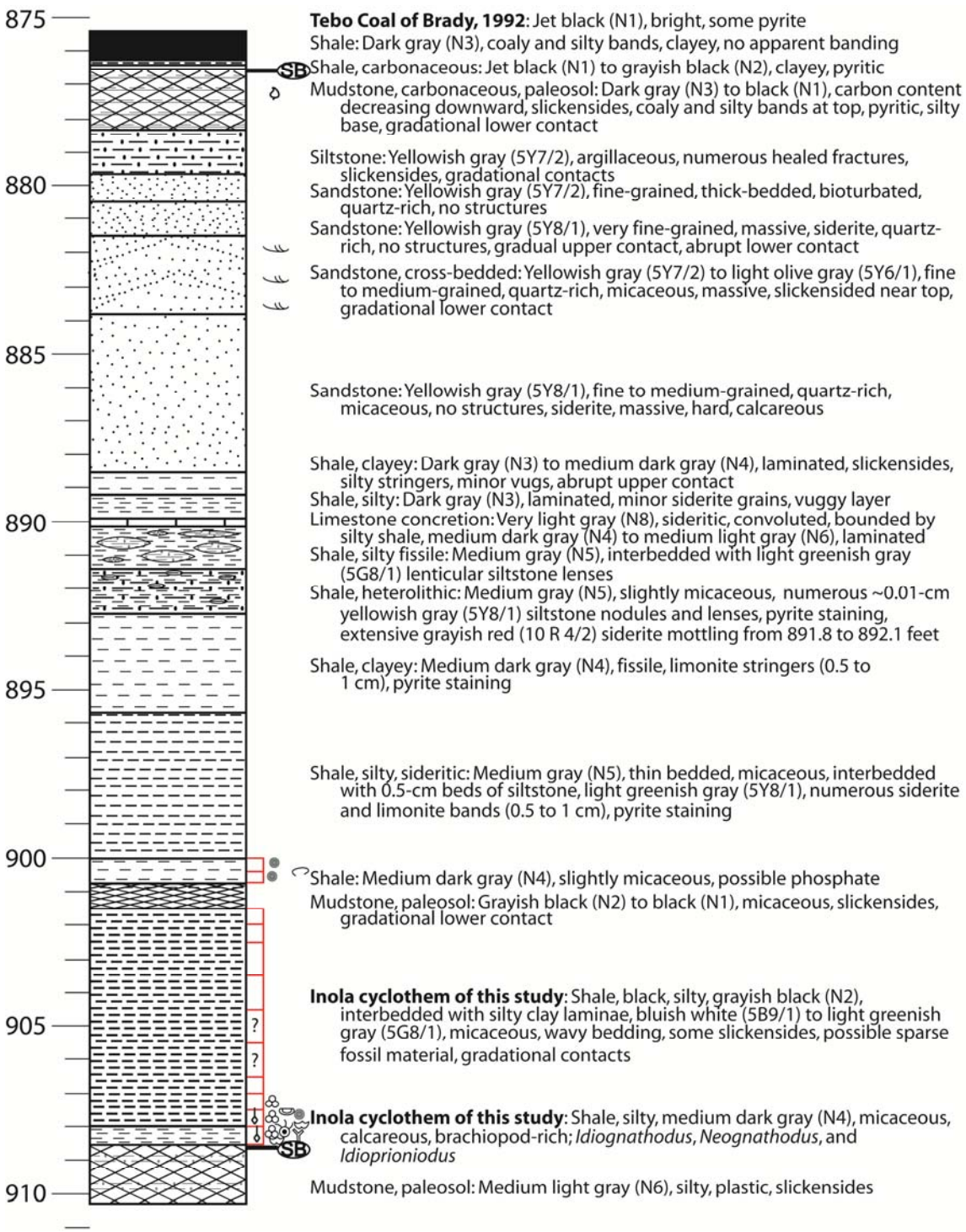


Figure A17. KGS Edmonds 1A core description, Leavenworth Co., KS, previously described by L. Brady (1992).

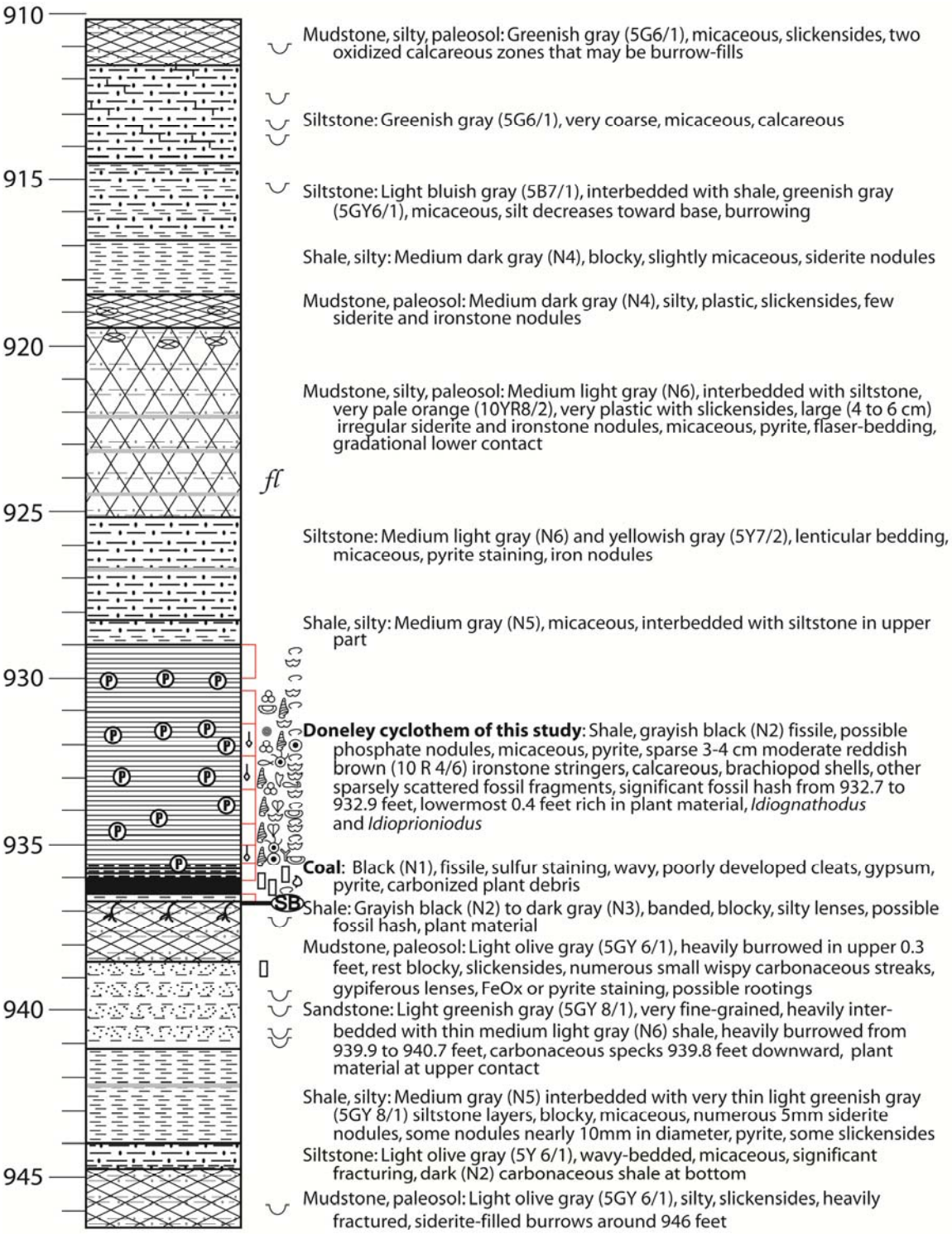


Figure A17. continued.

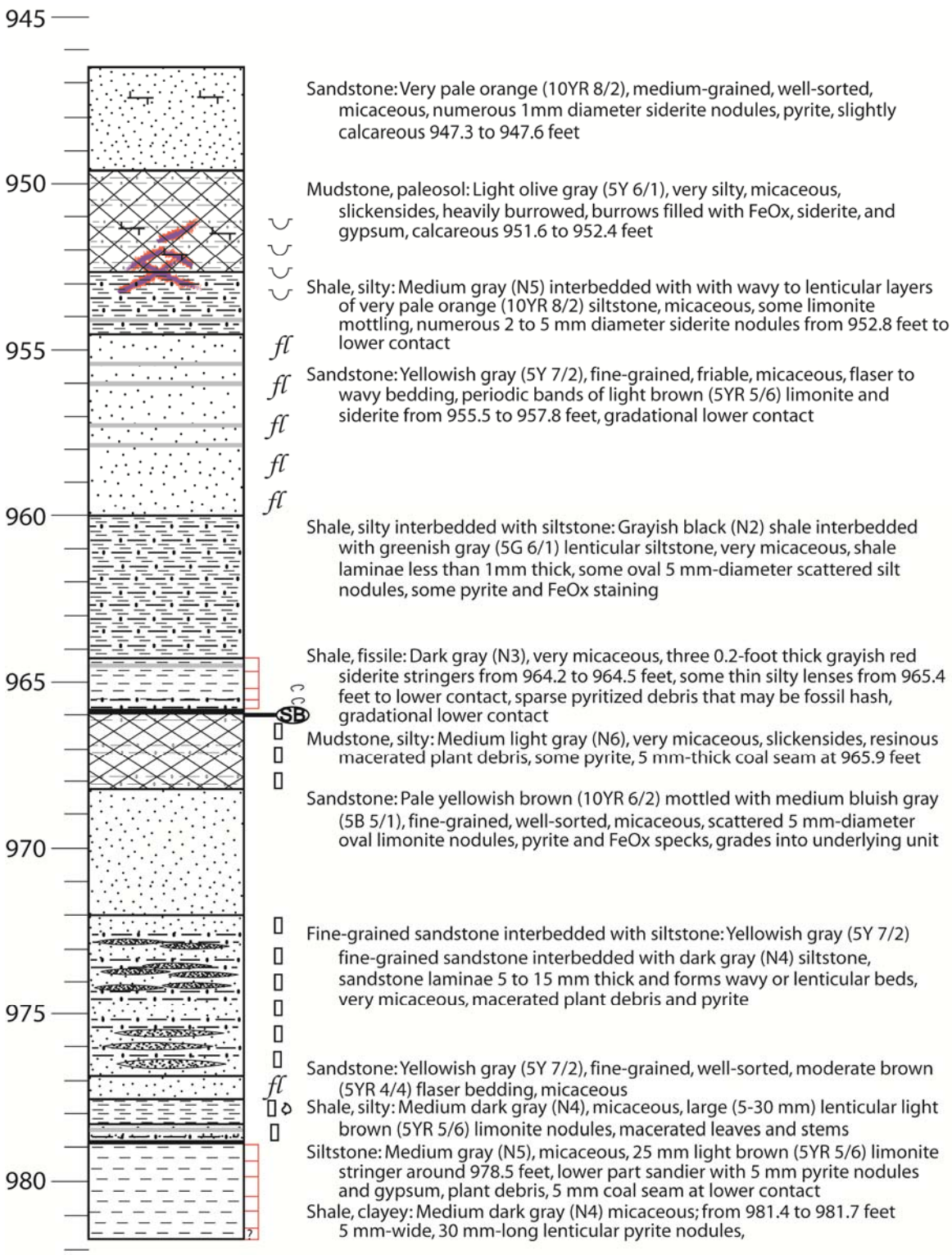
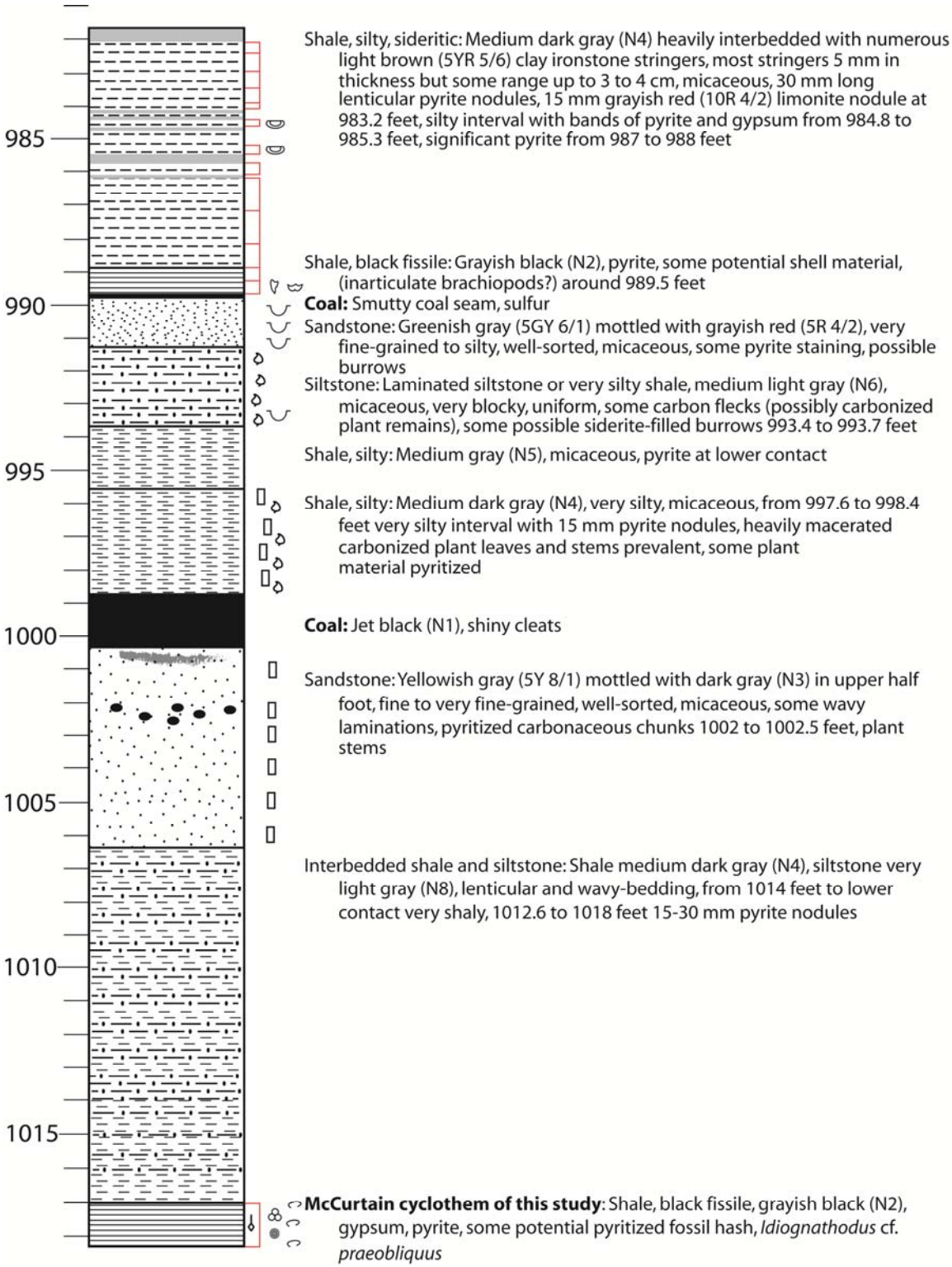


Figure A17. continued.



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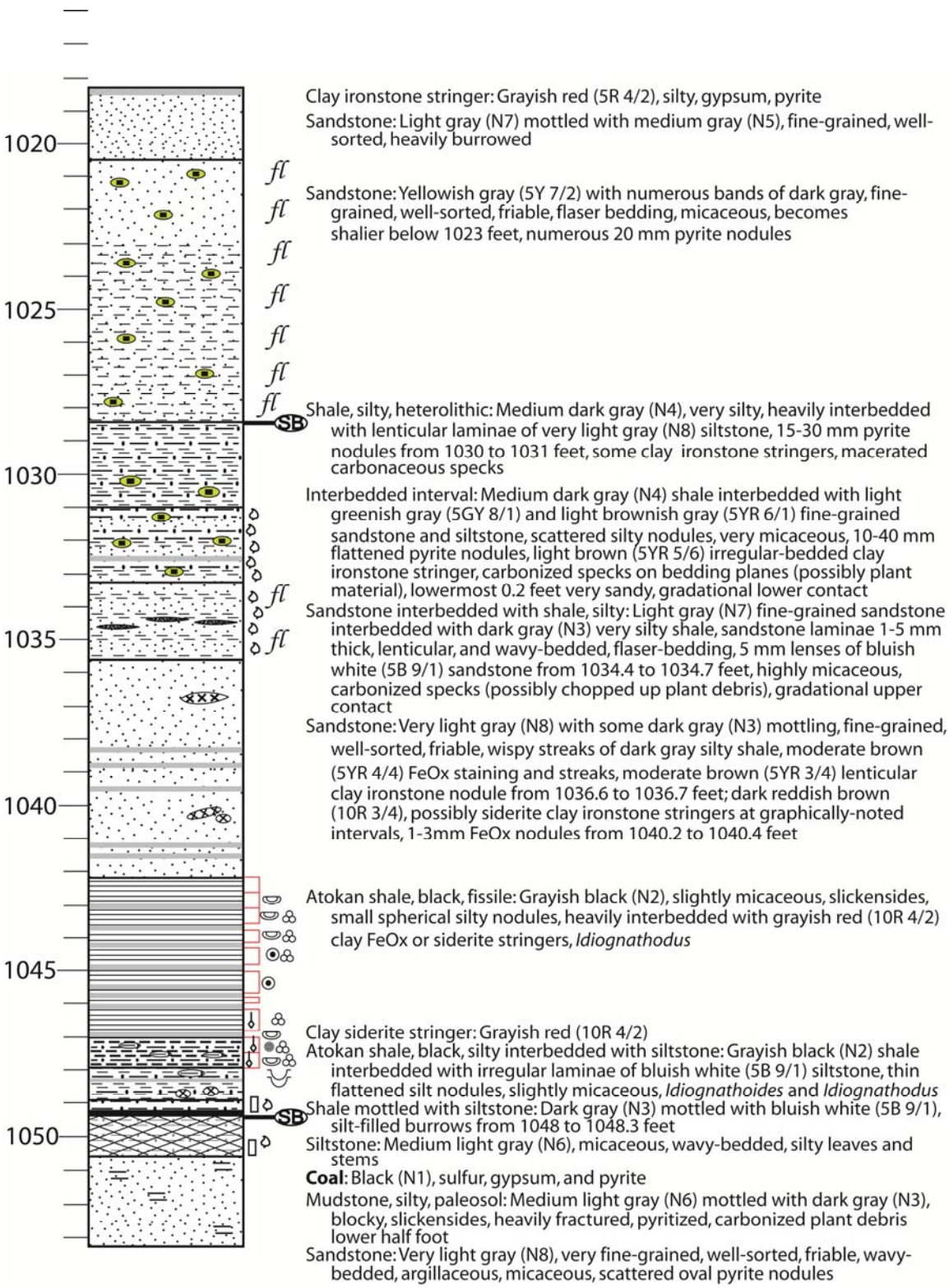

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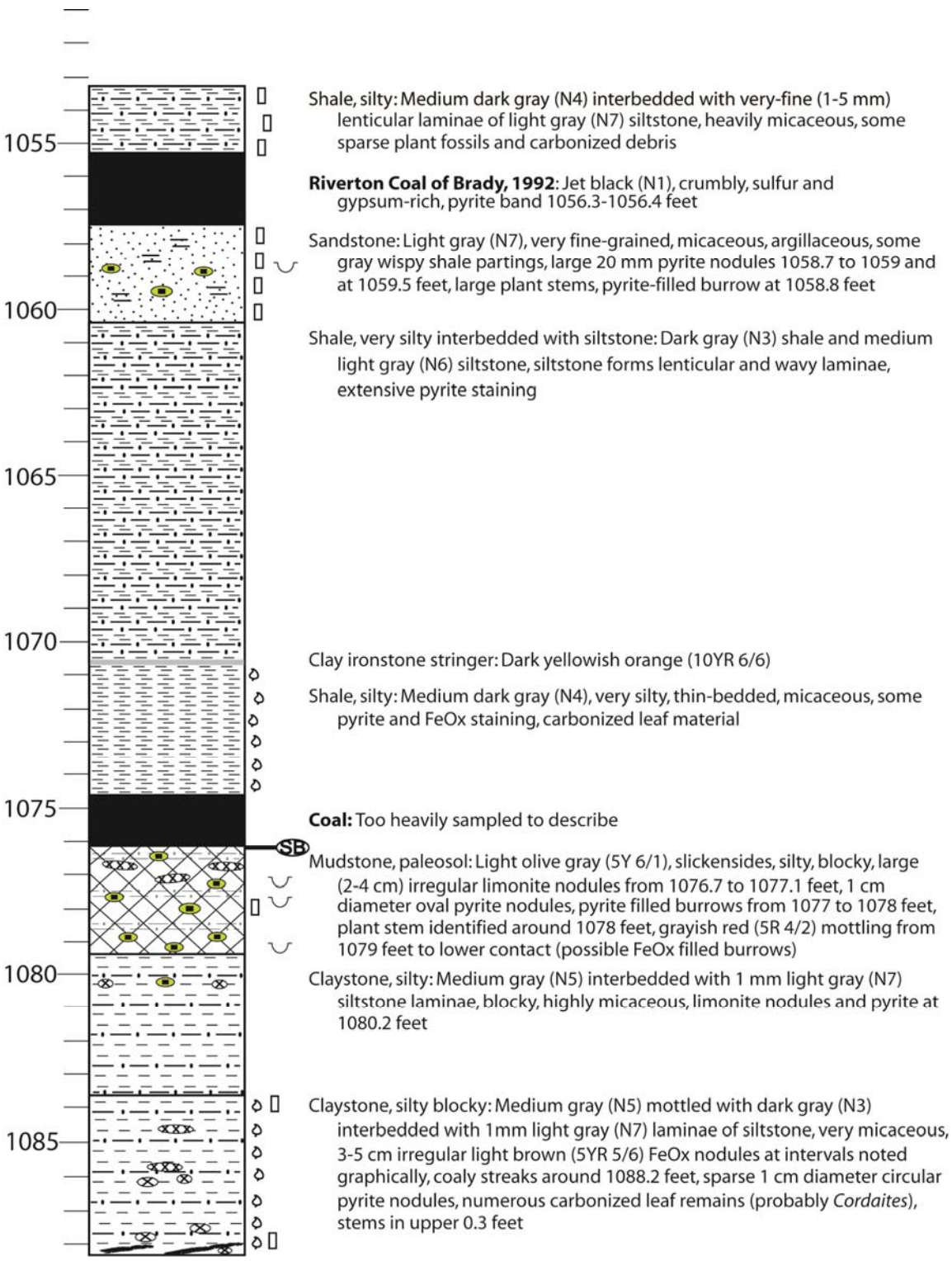

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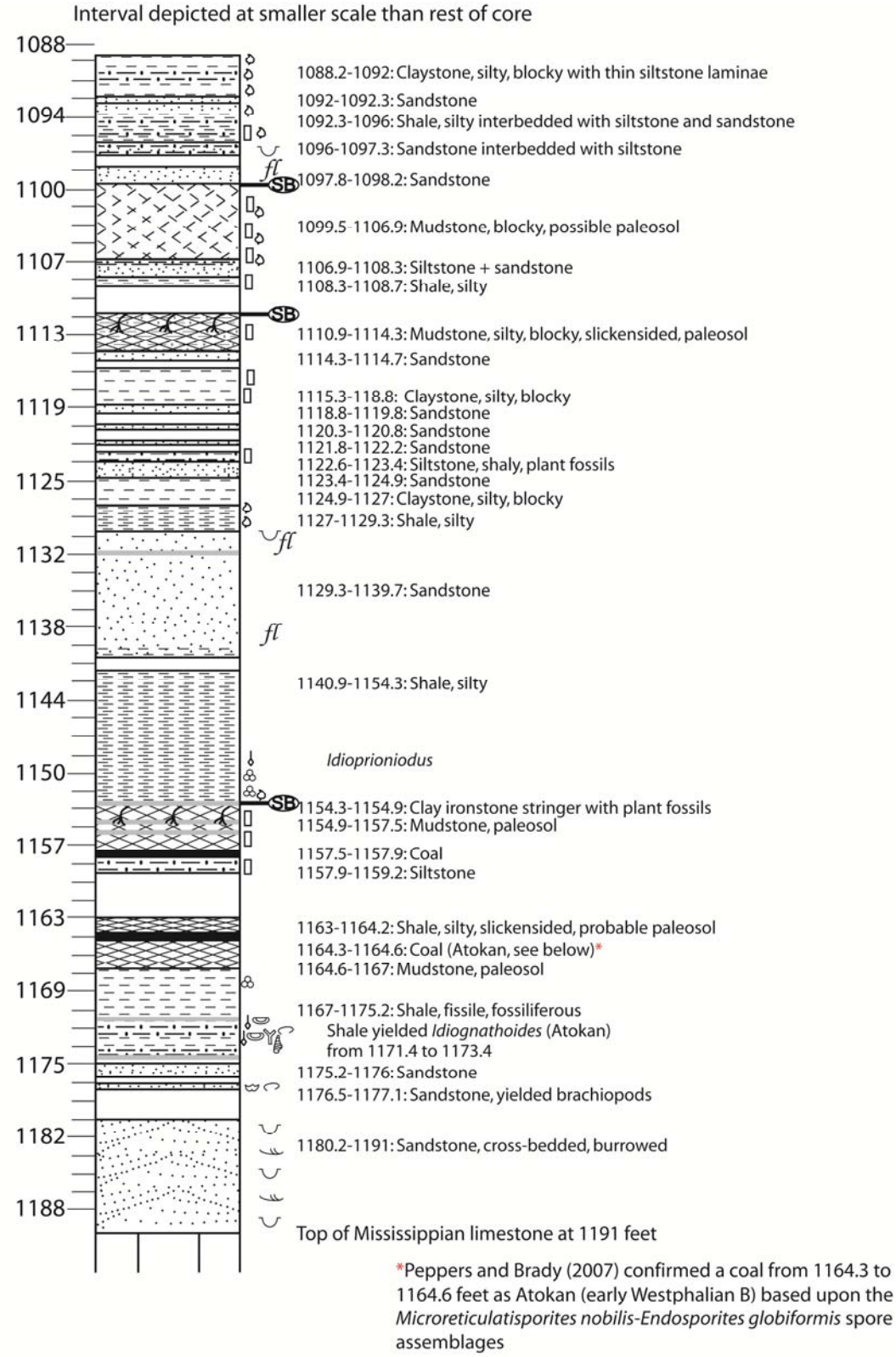

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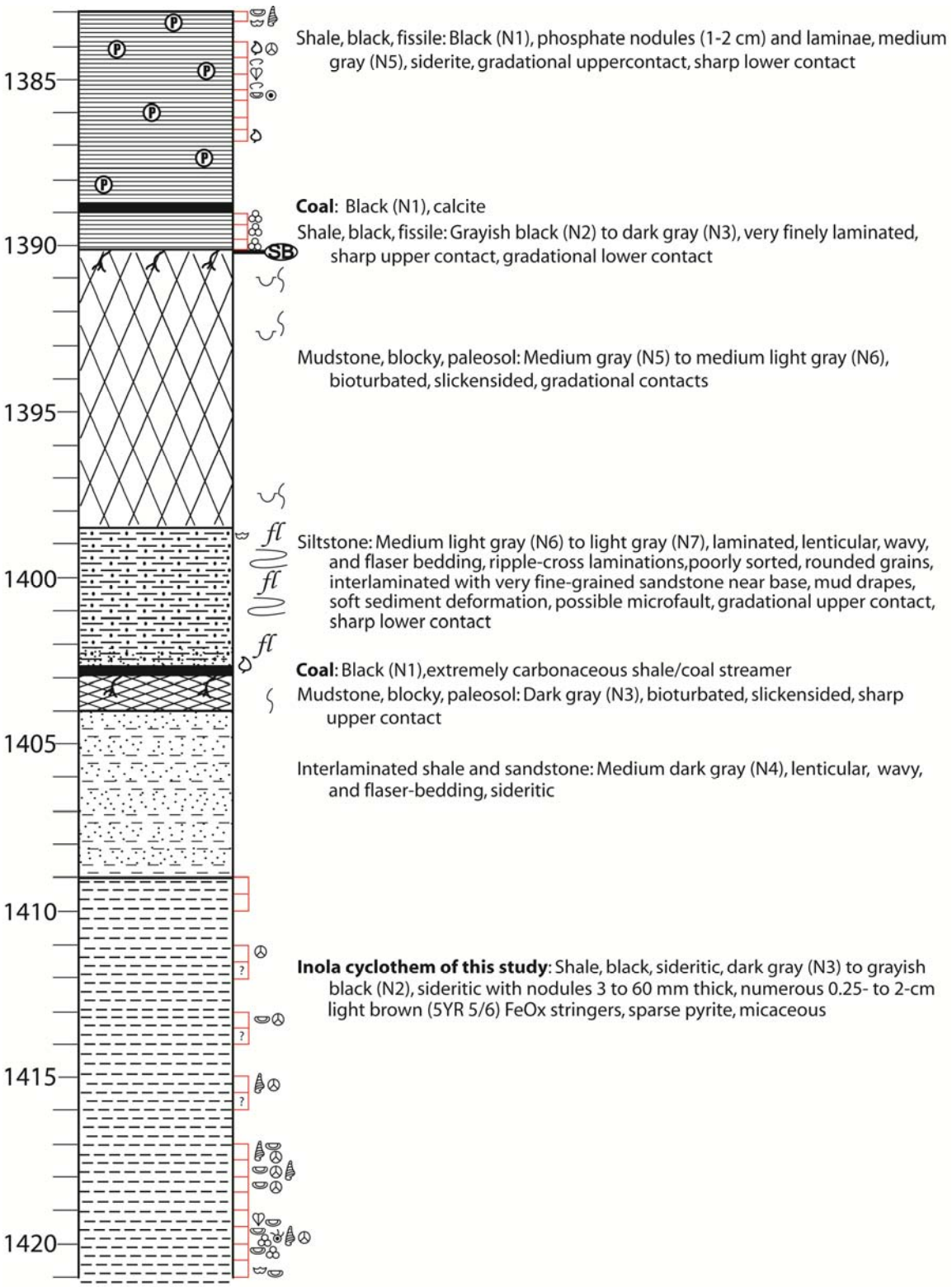
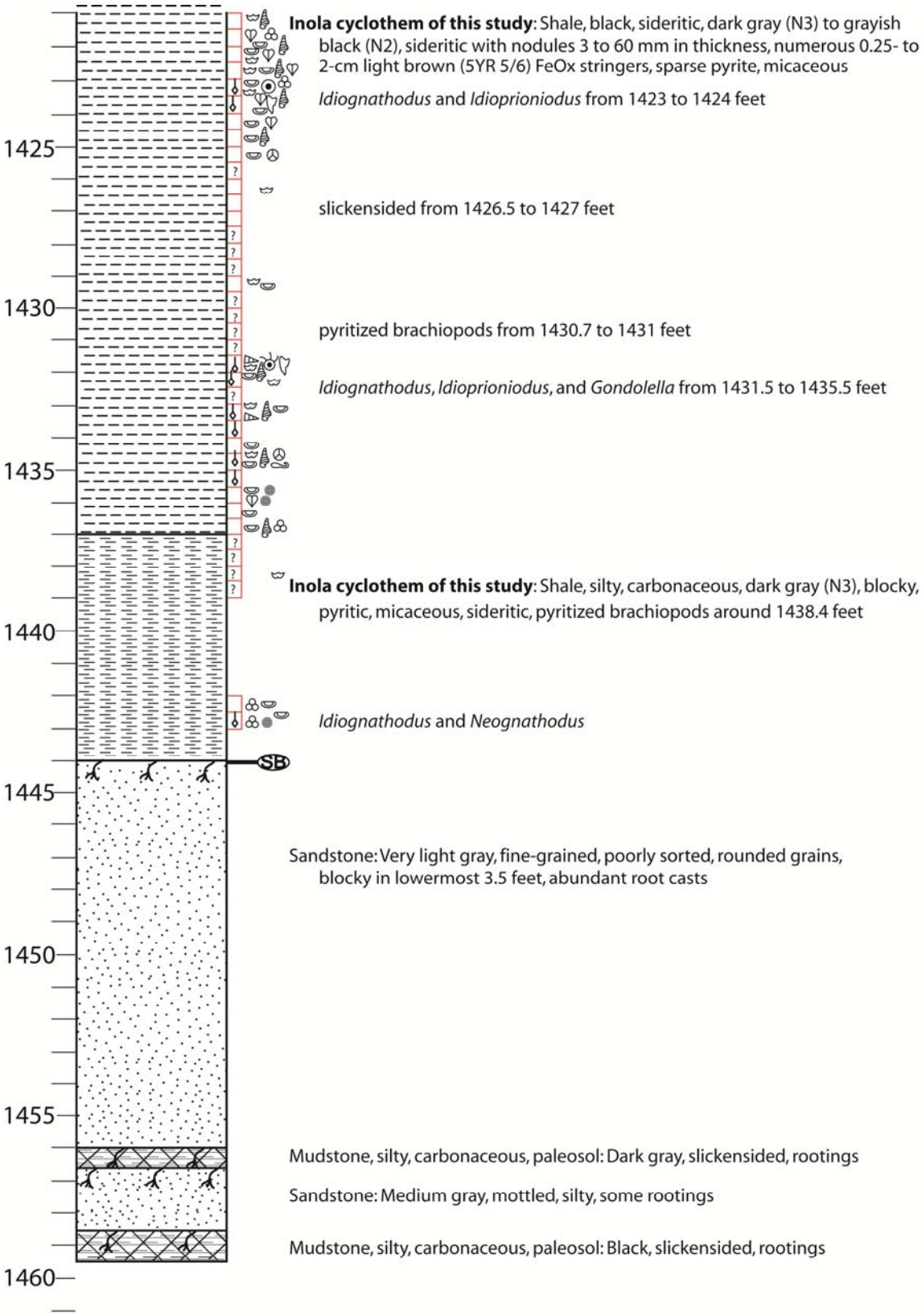


Figure A18. KGS Hopp #1-16 core description, Doniphan Co., KS, previously described by W.M. Brown (2005).



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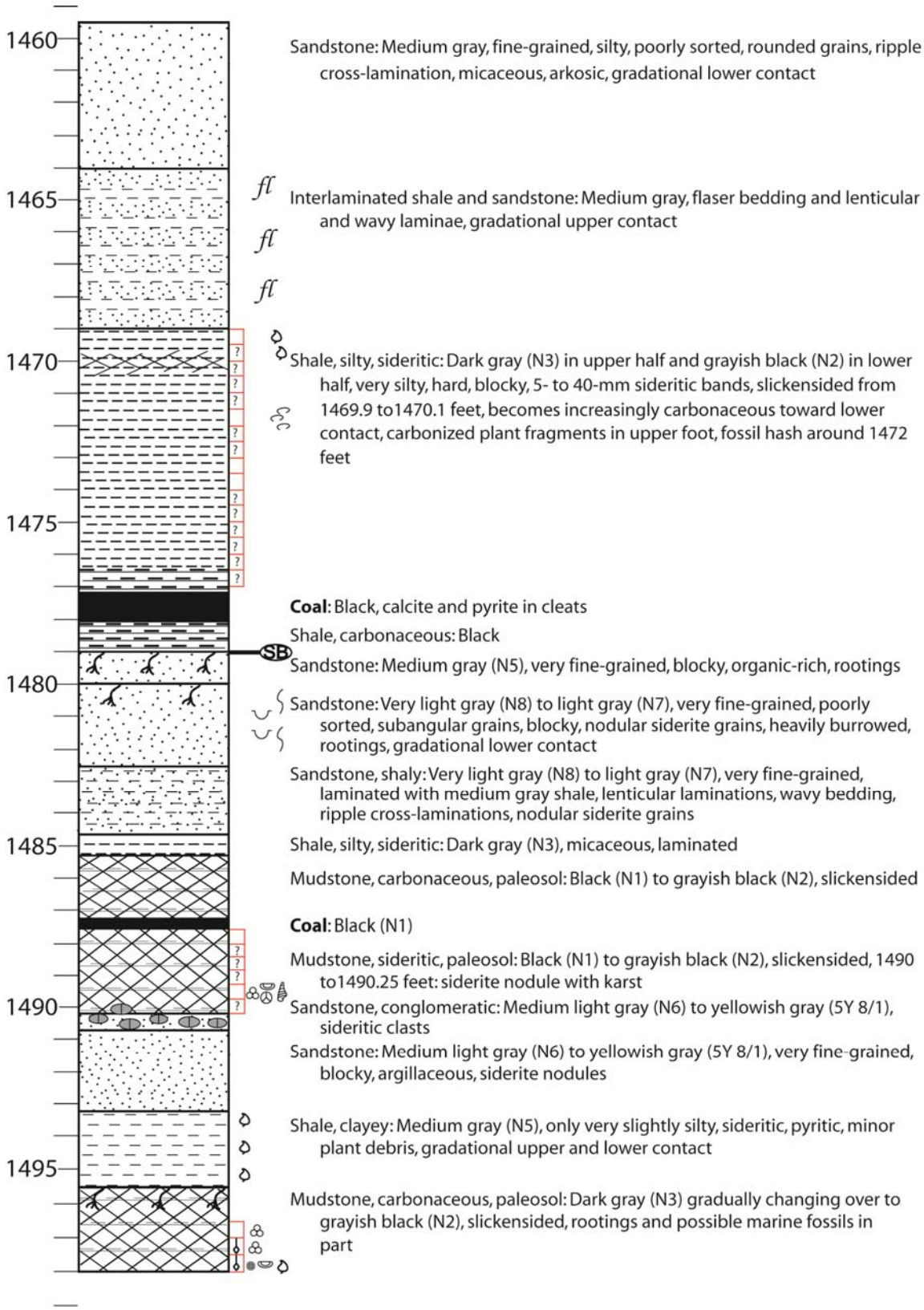

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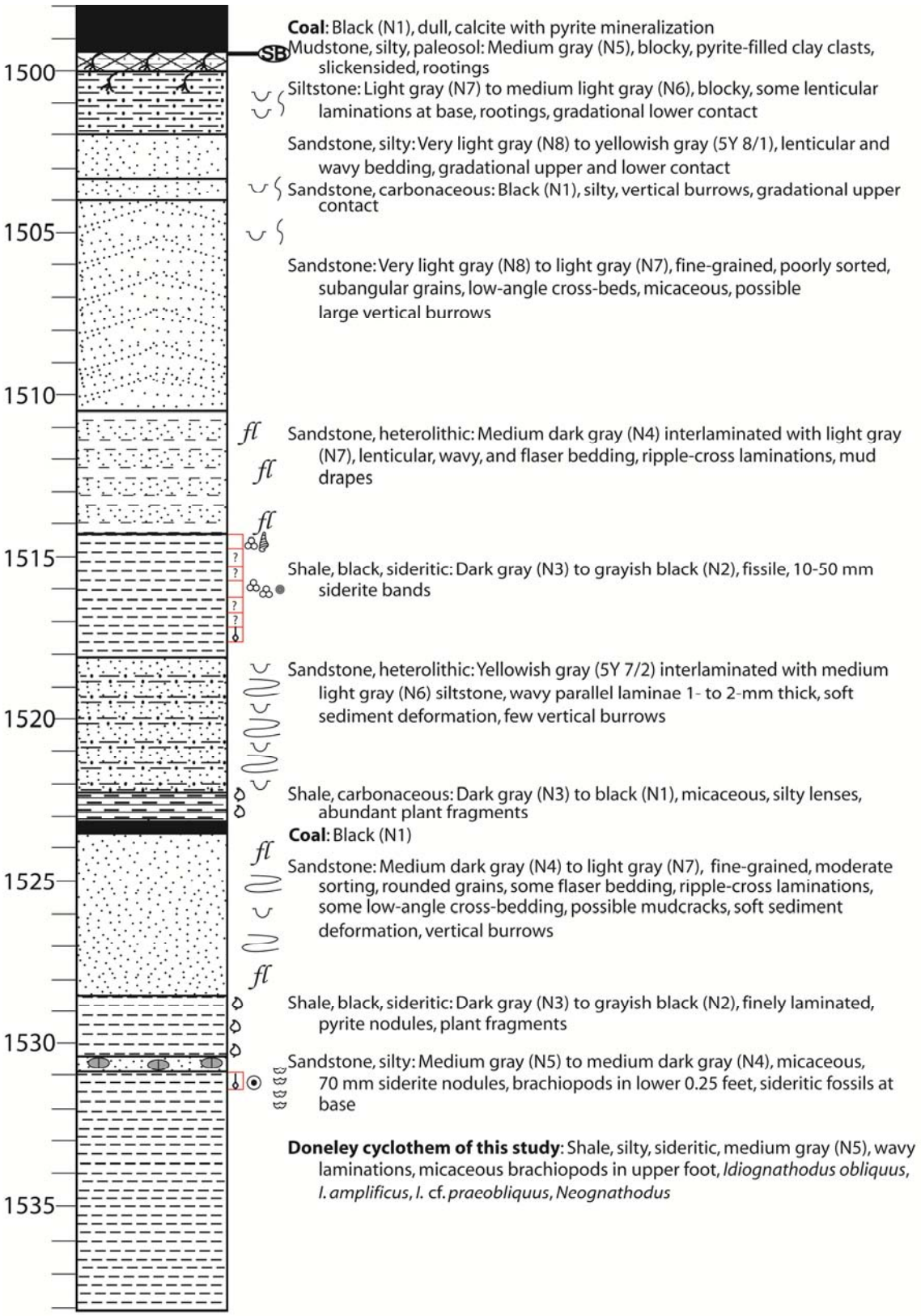

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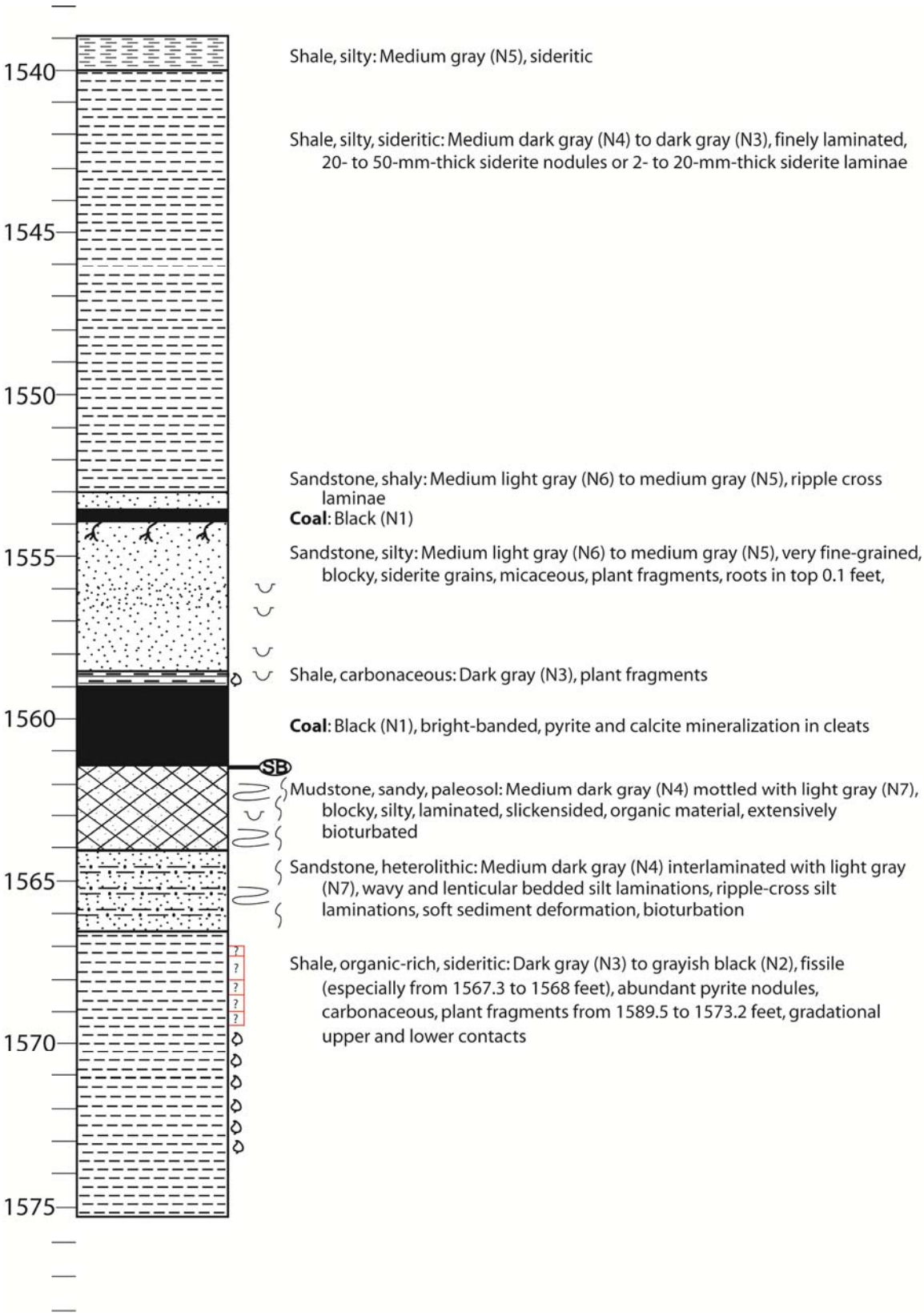

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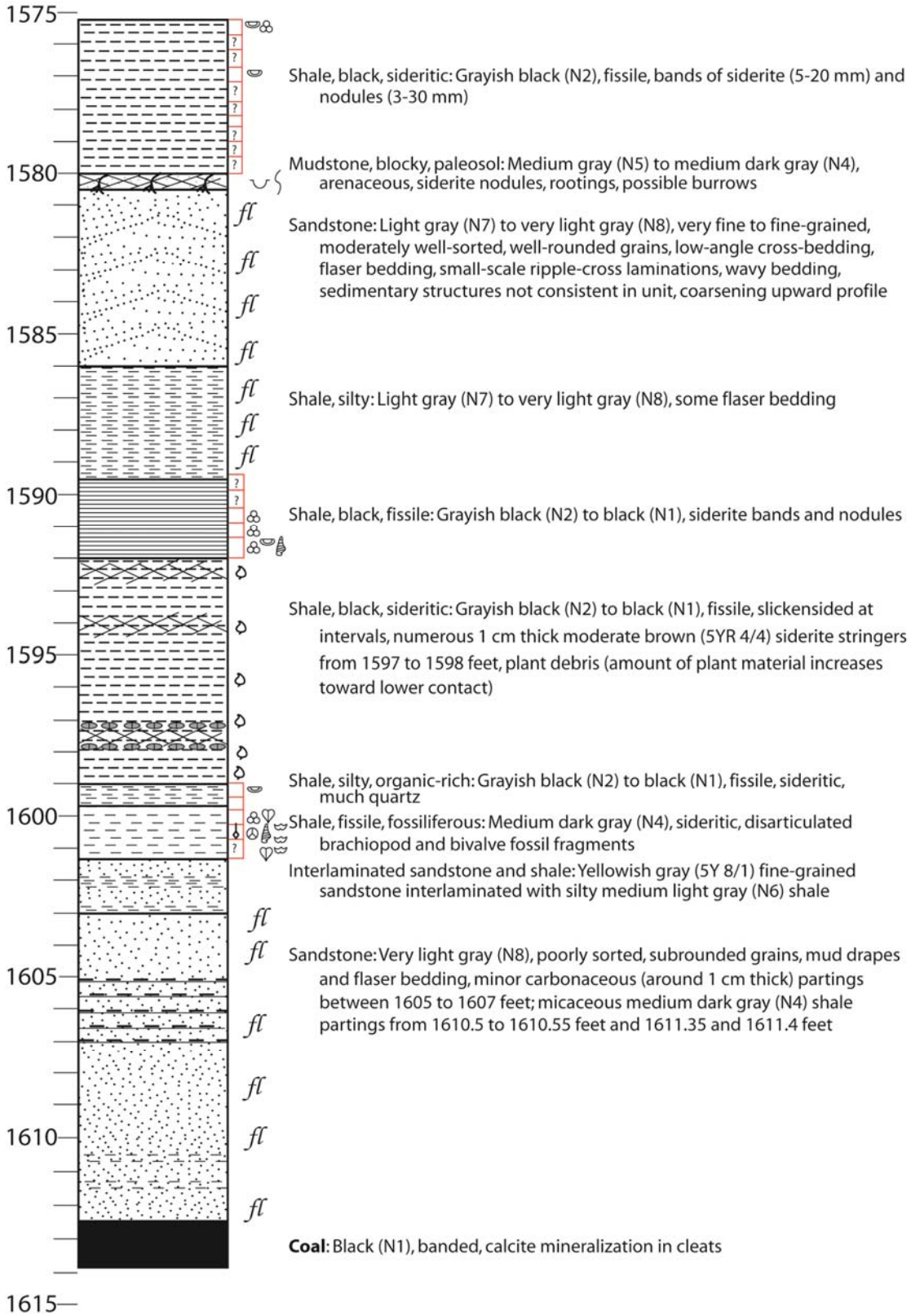

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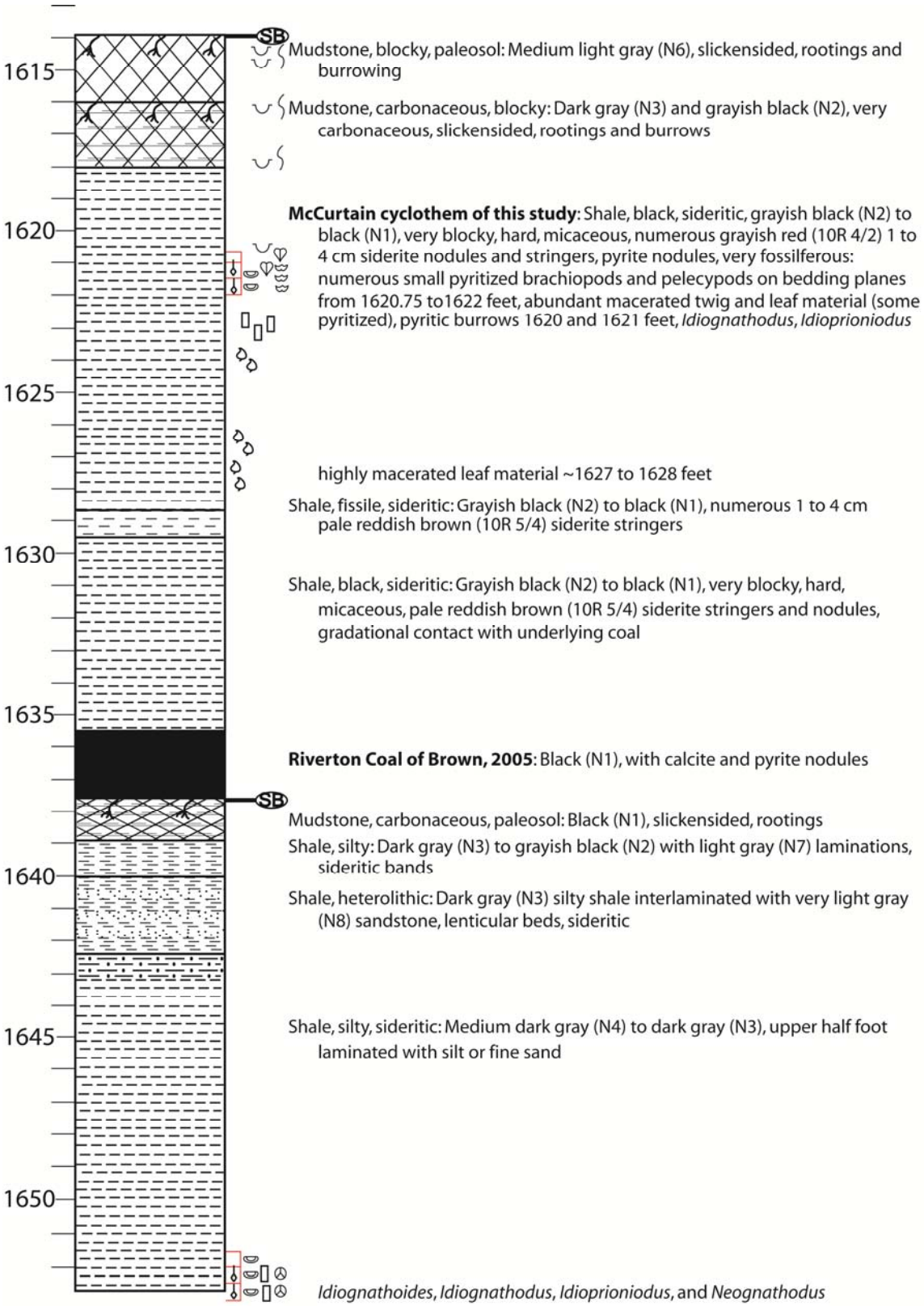

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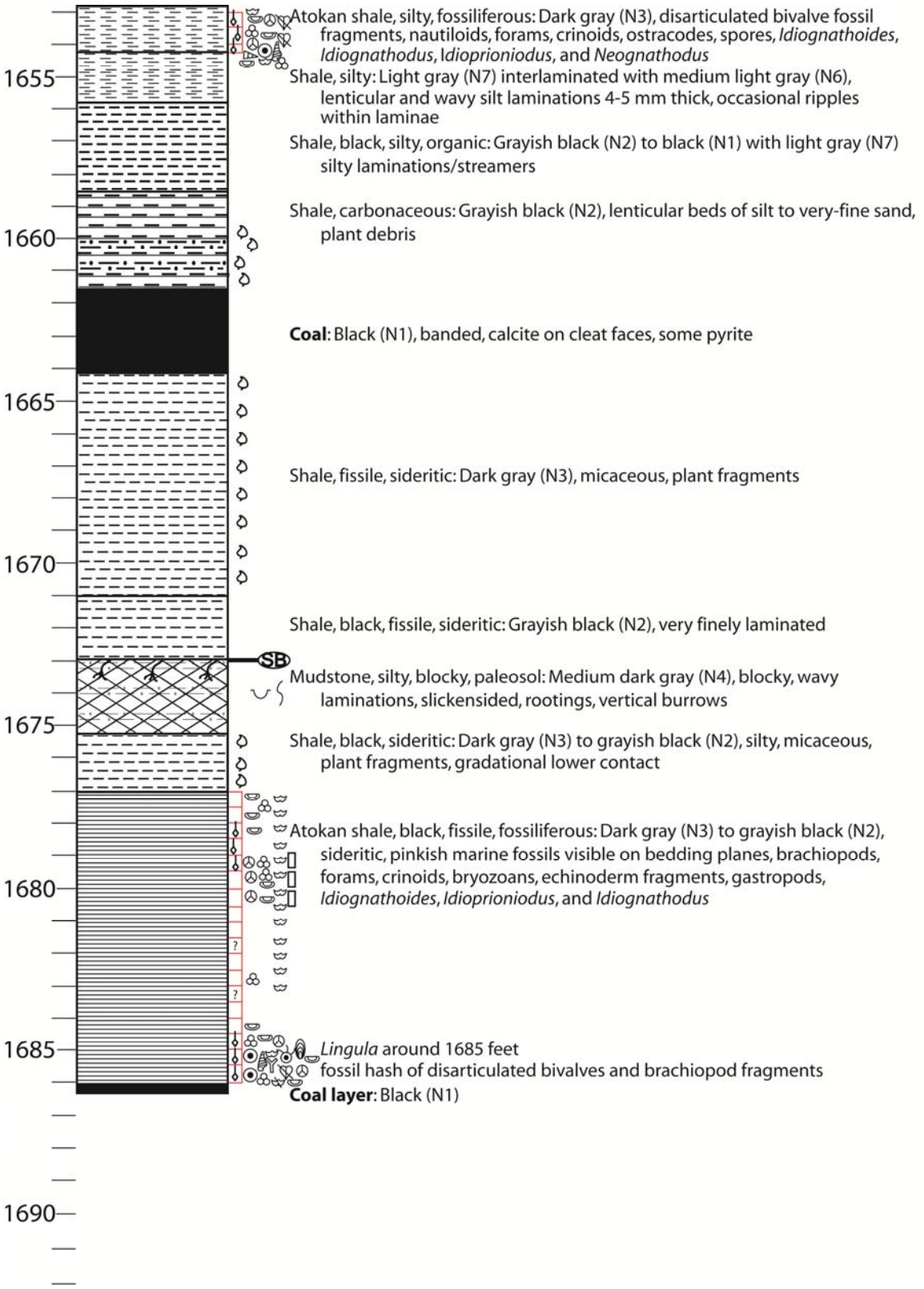

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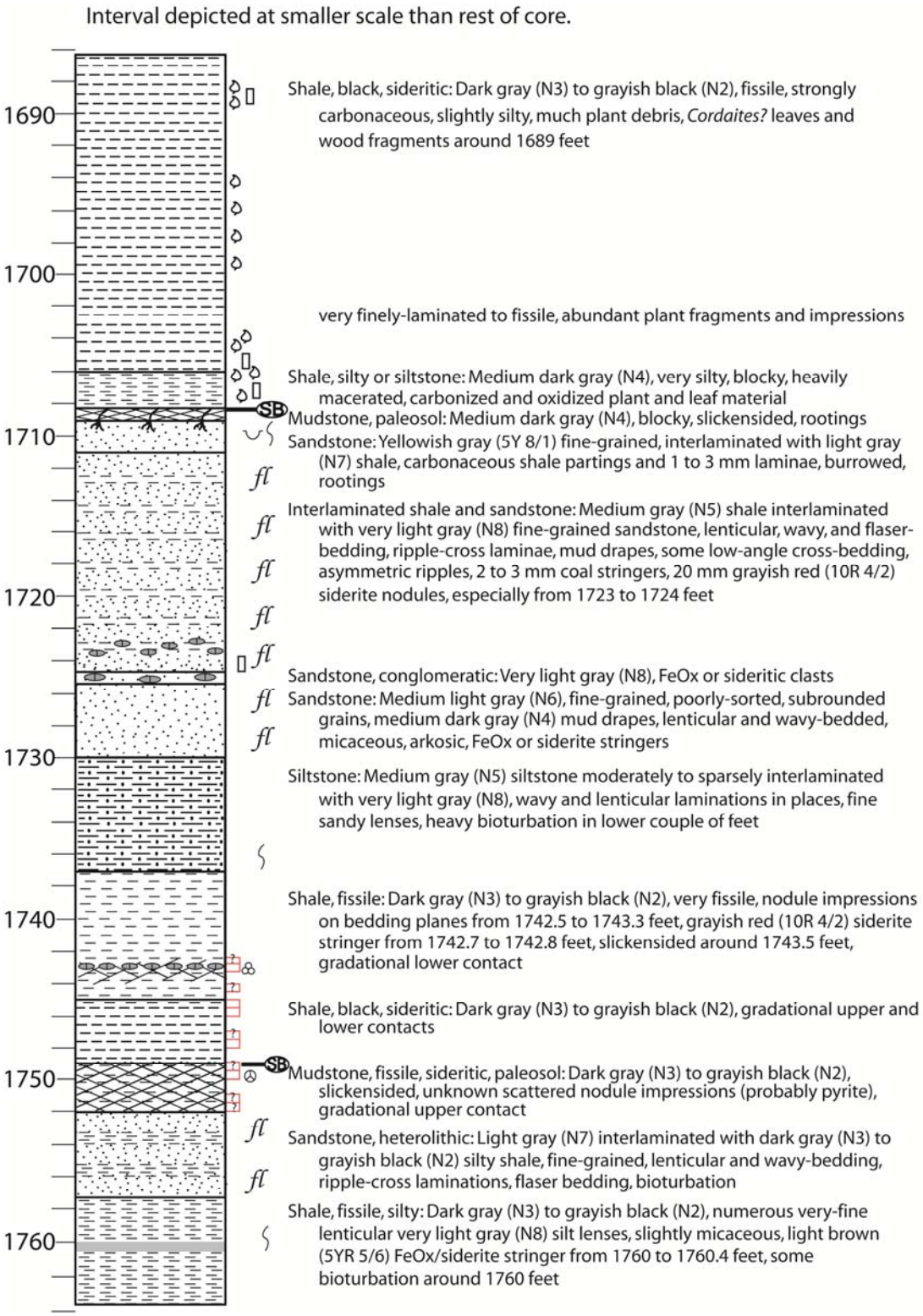

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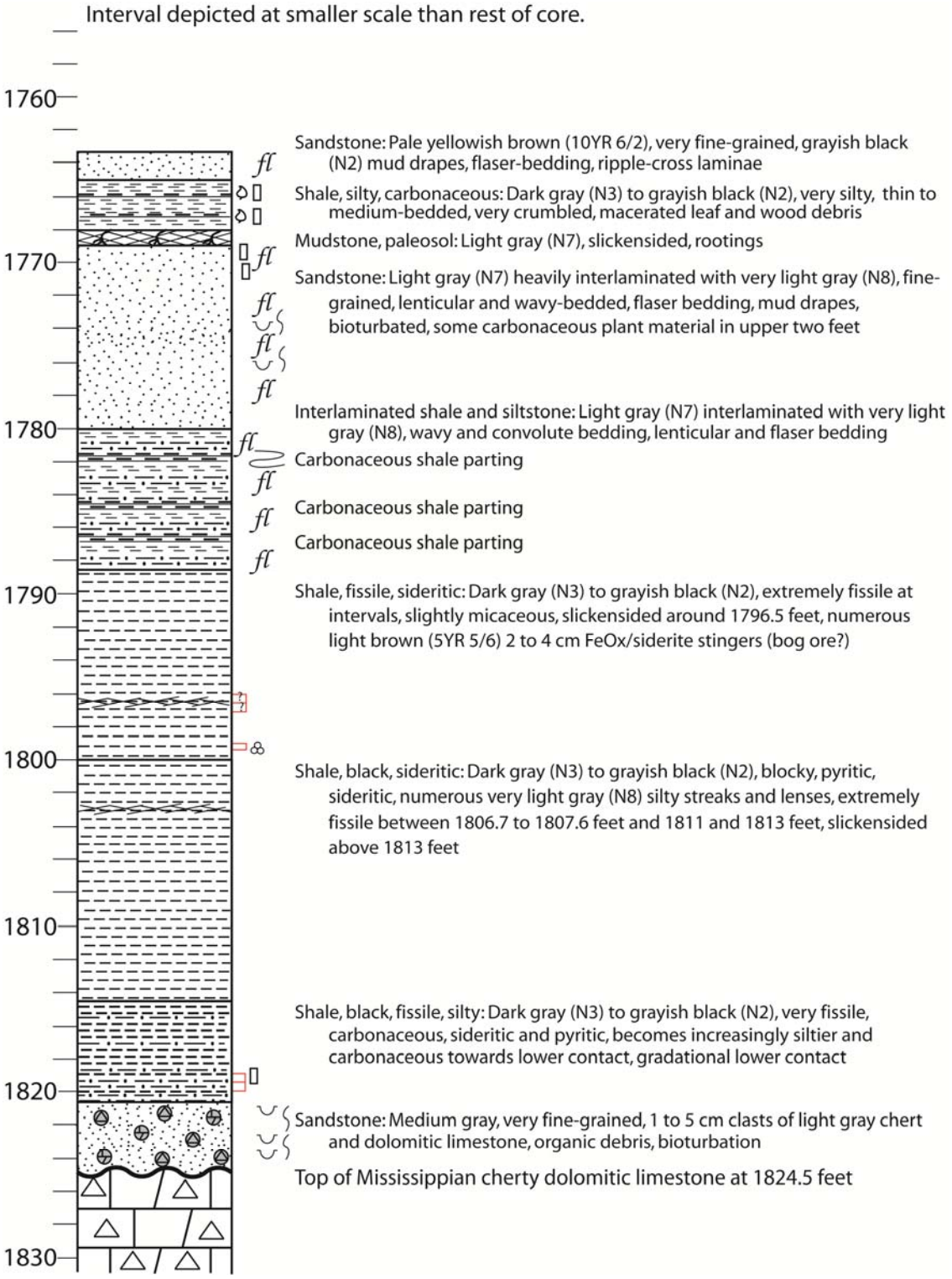

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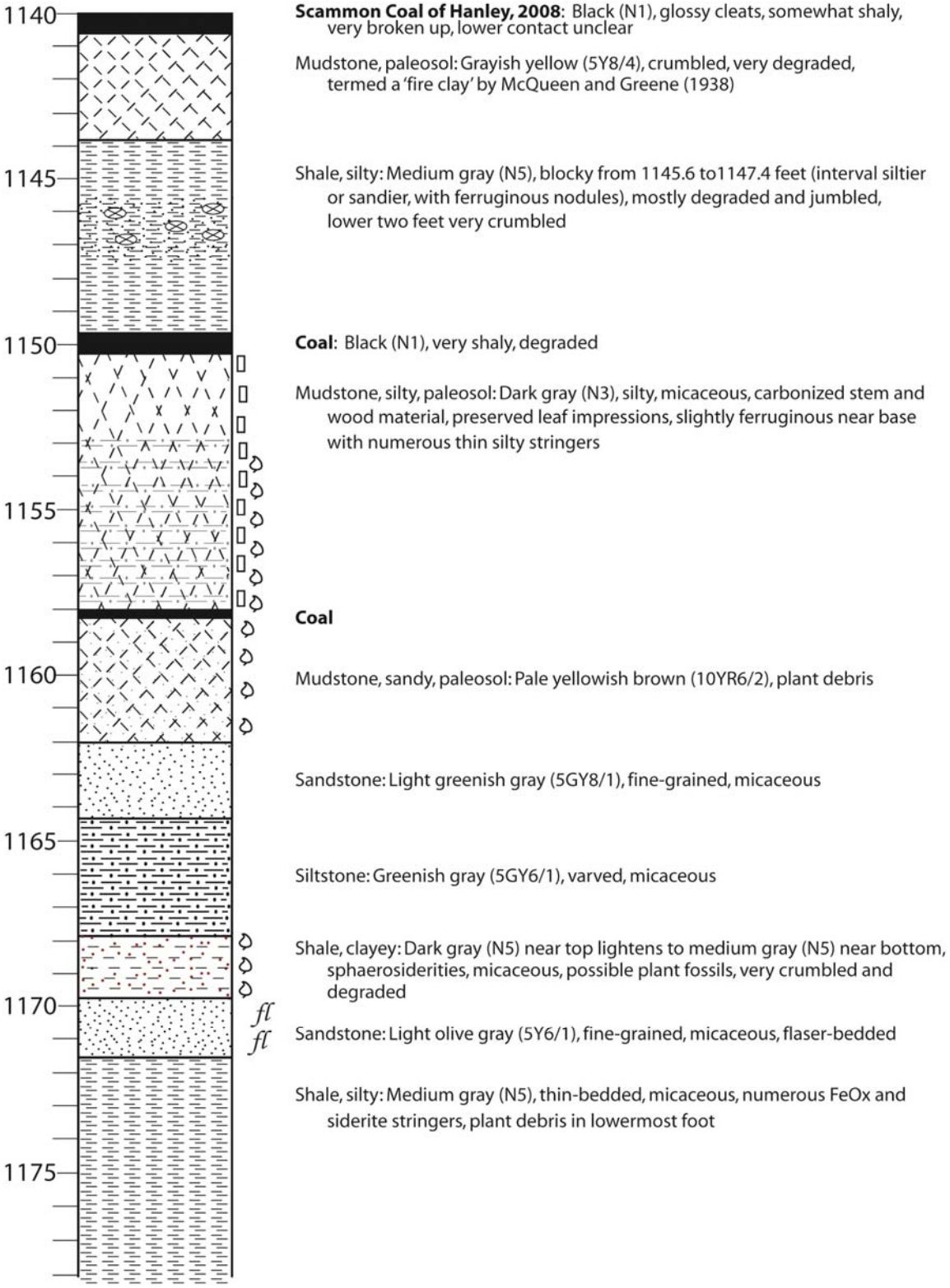
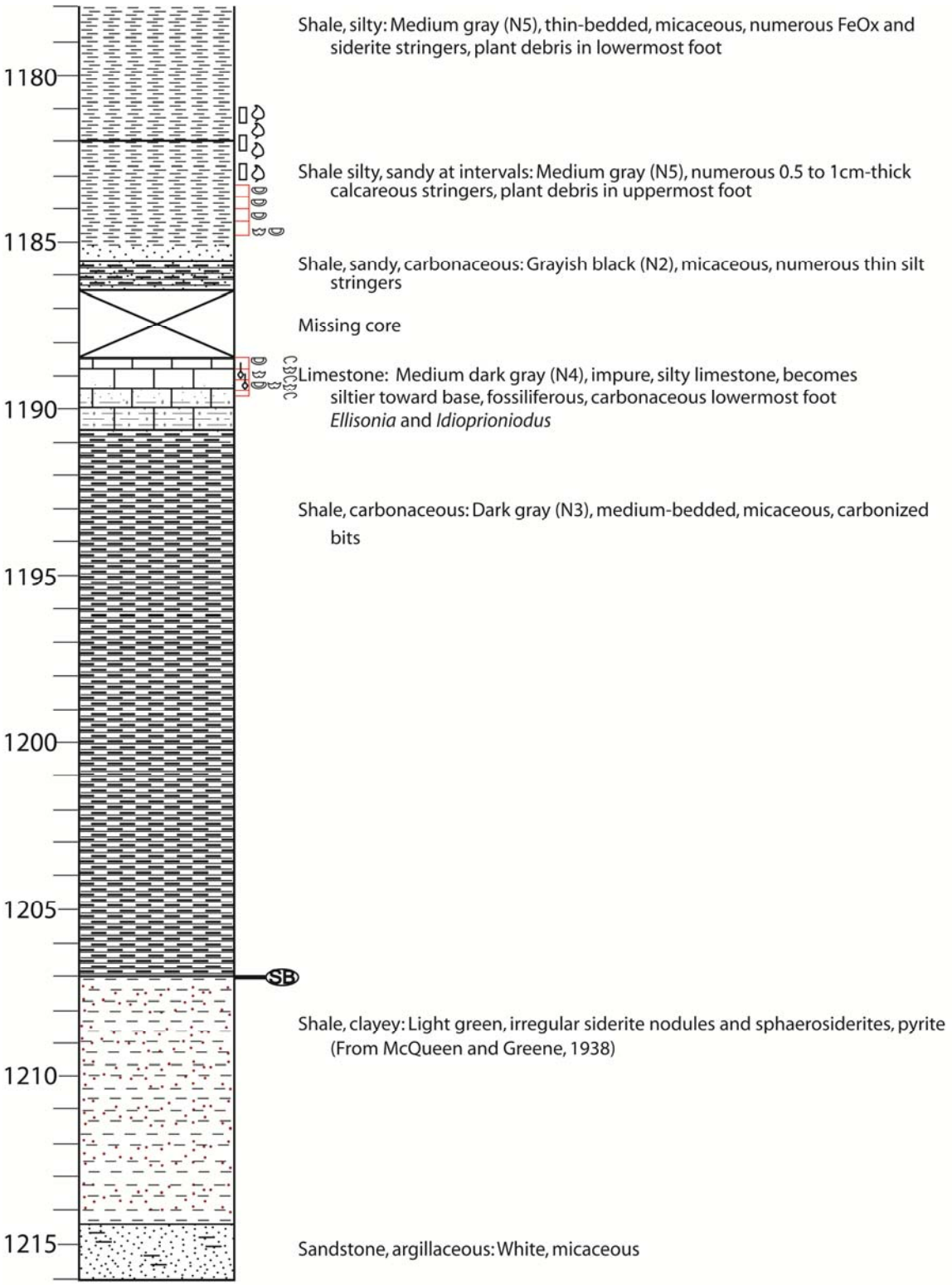


Figure A19. MGS FCC Davis #1 (Forest City) core description, Holt Co., MO.



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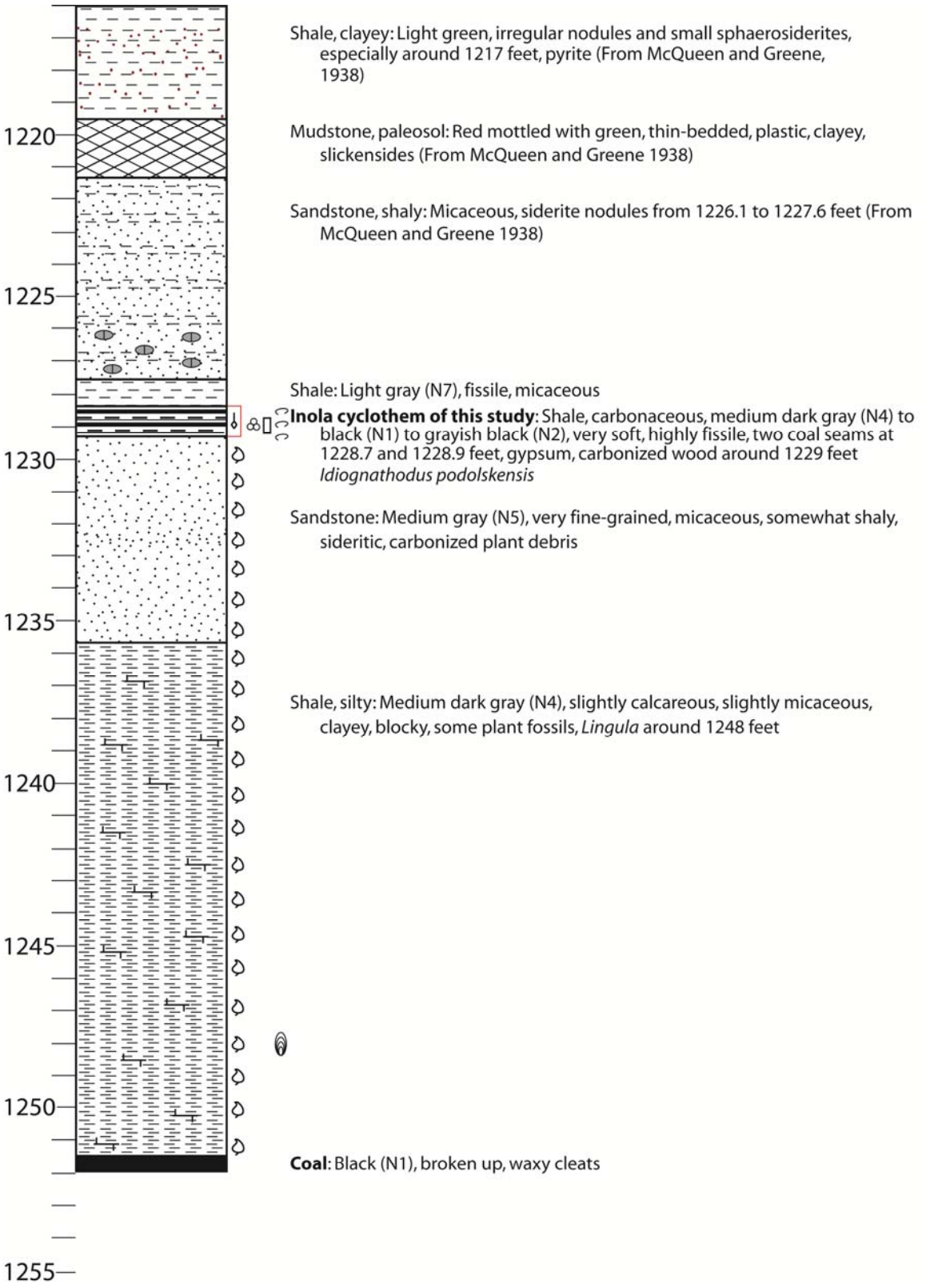

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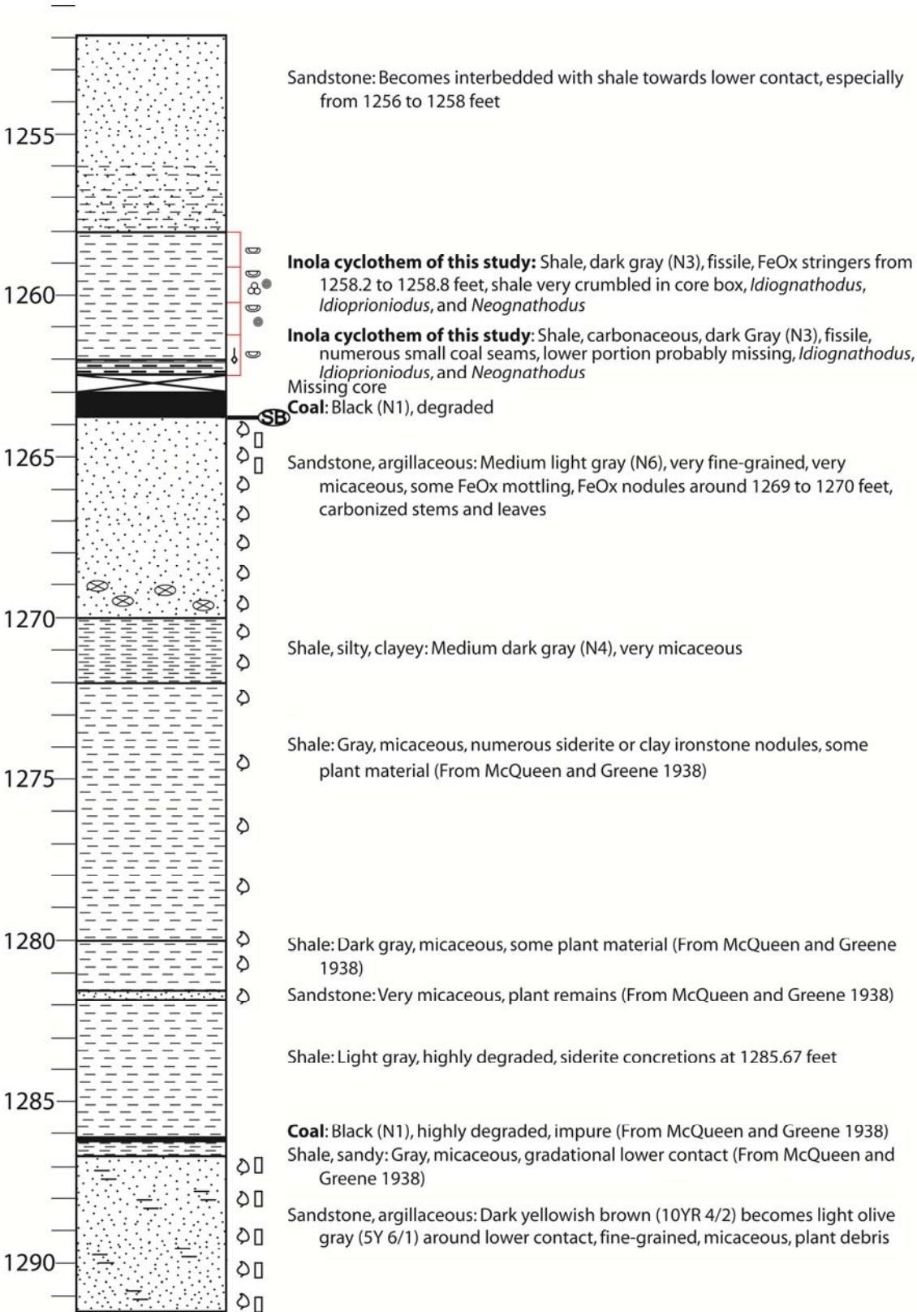

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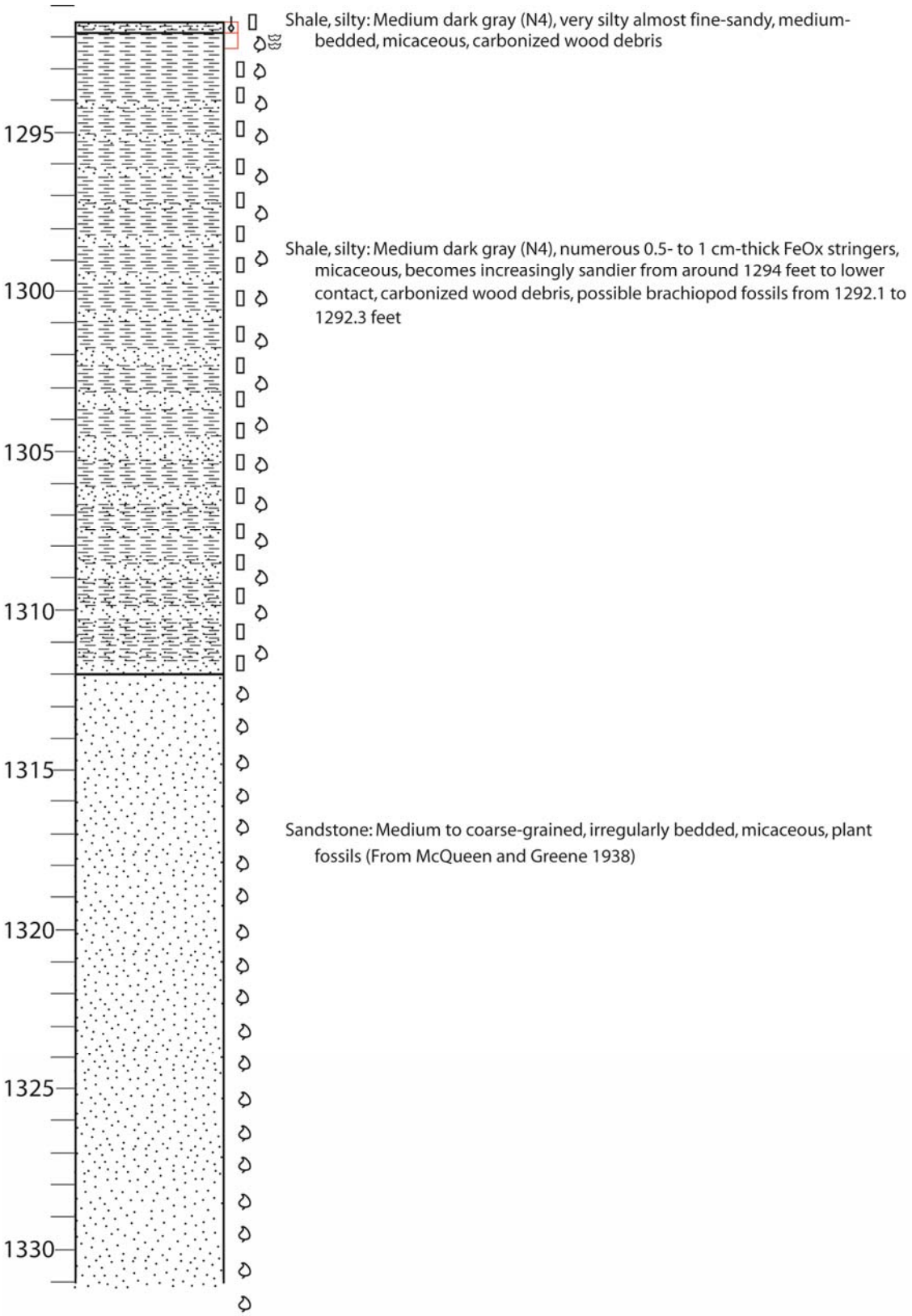

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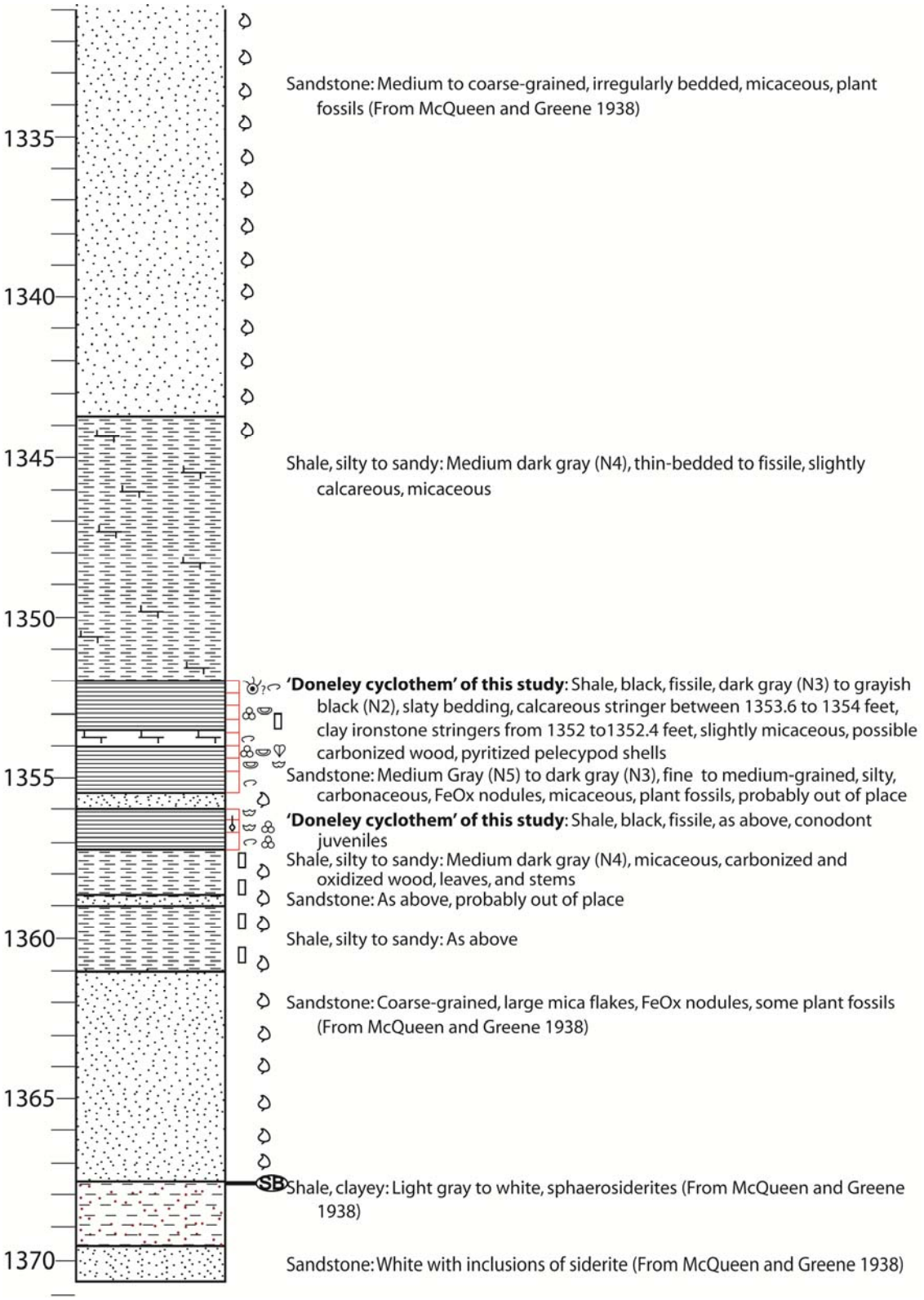

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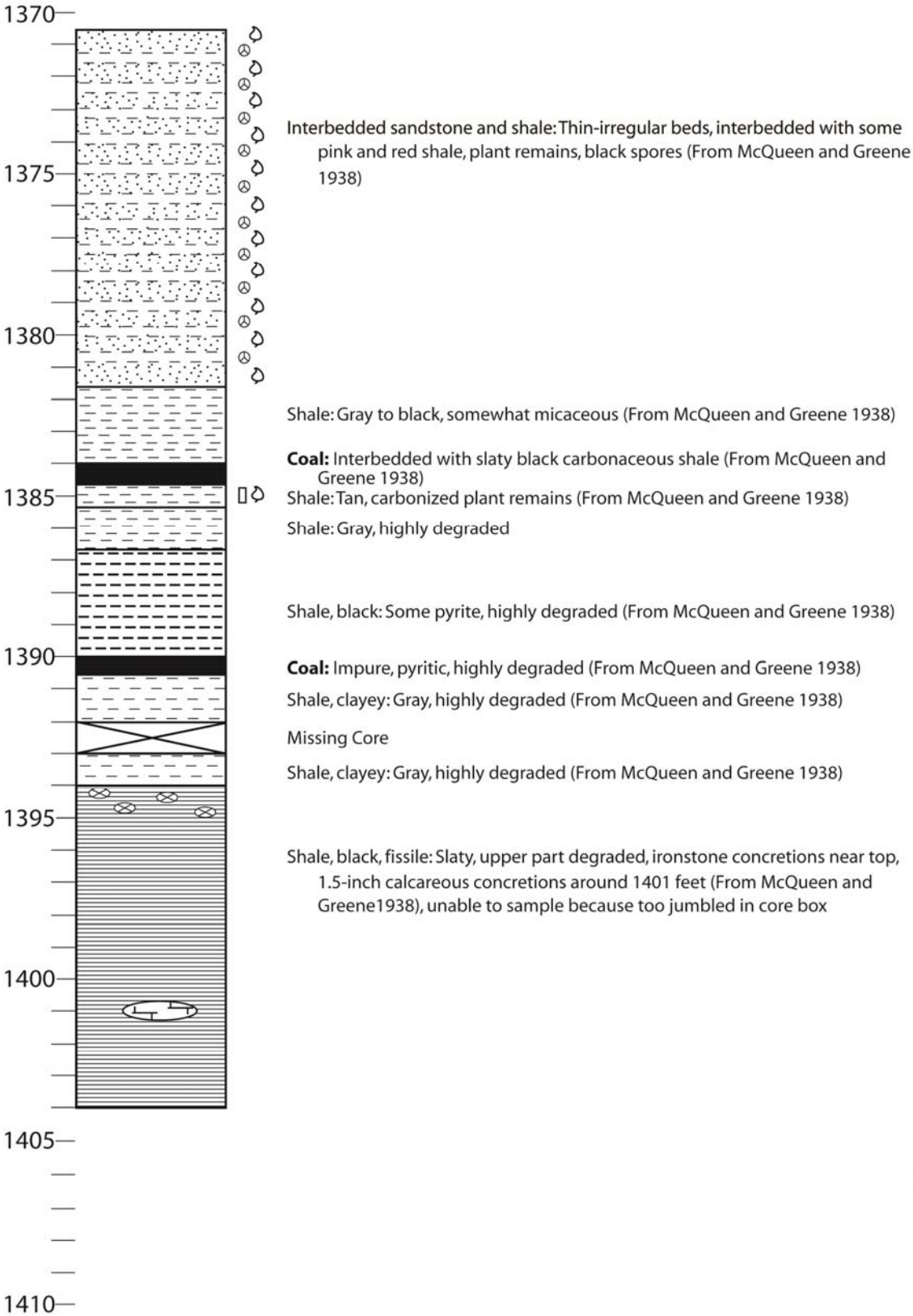

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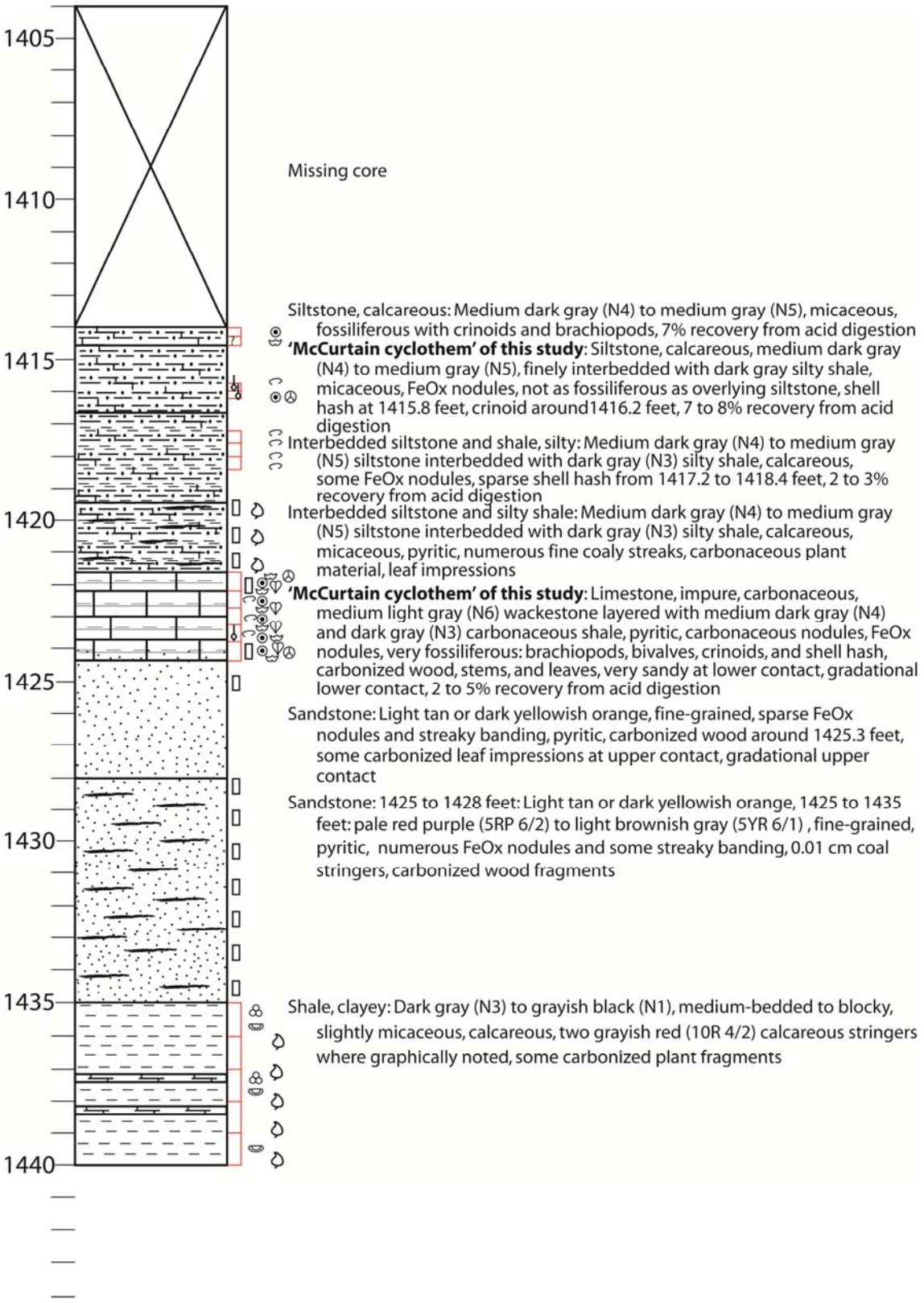


Figure A19. continued.

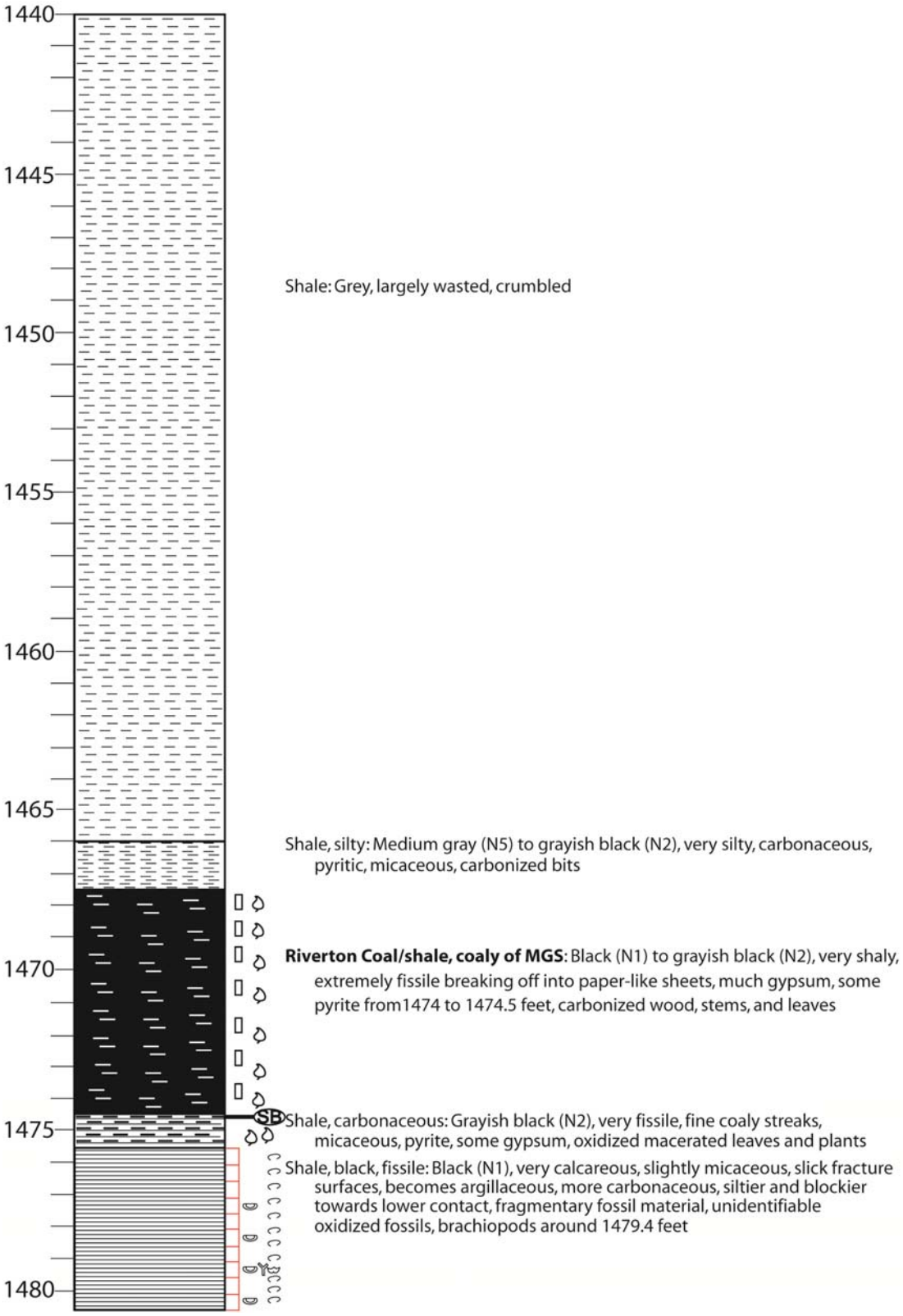
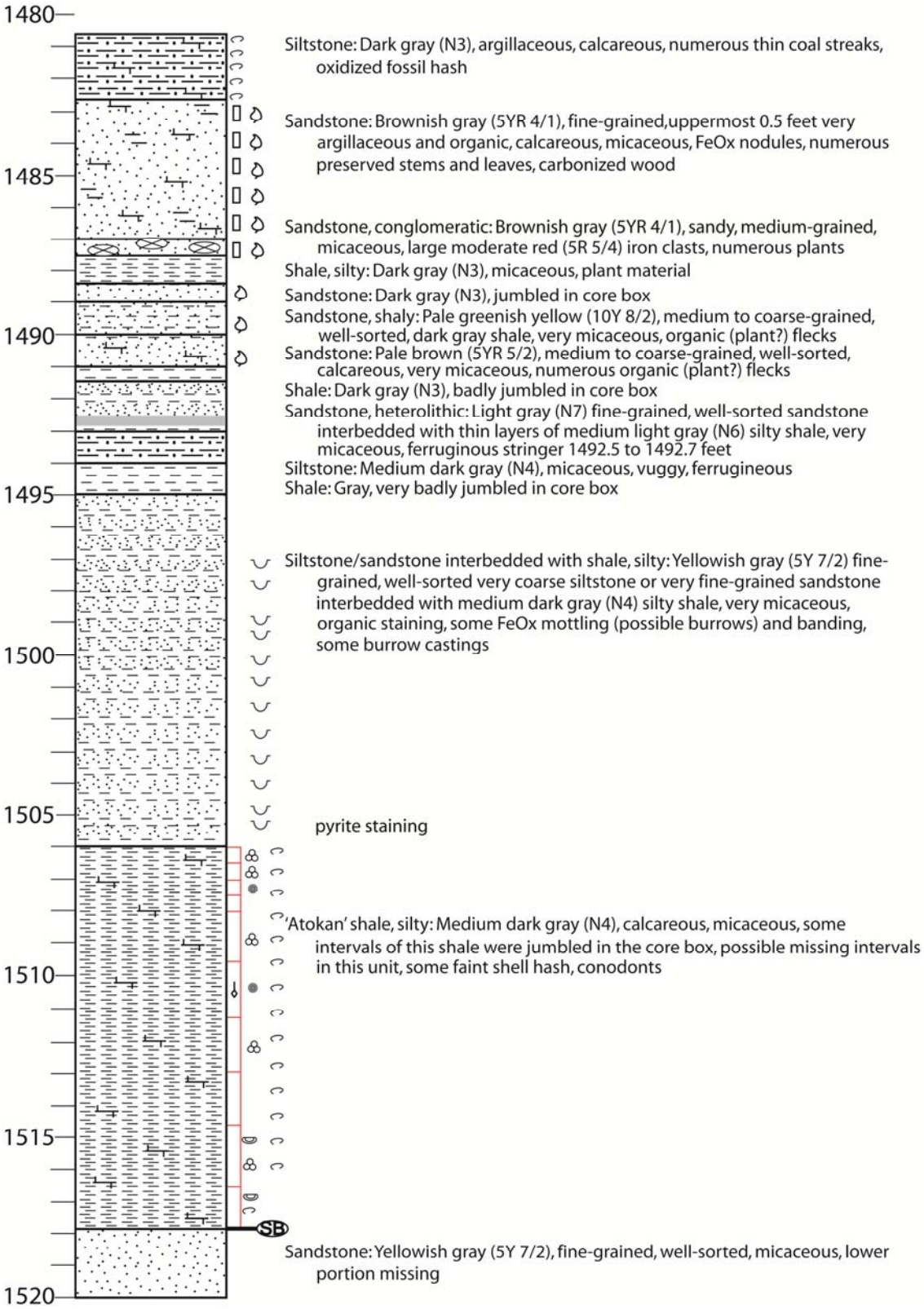


Figure A19. continued.



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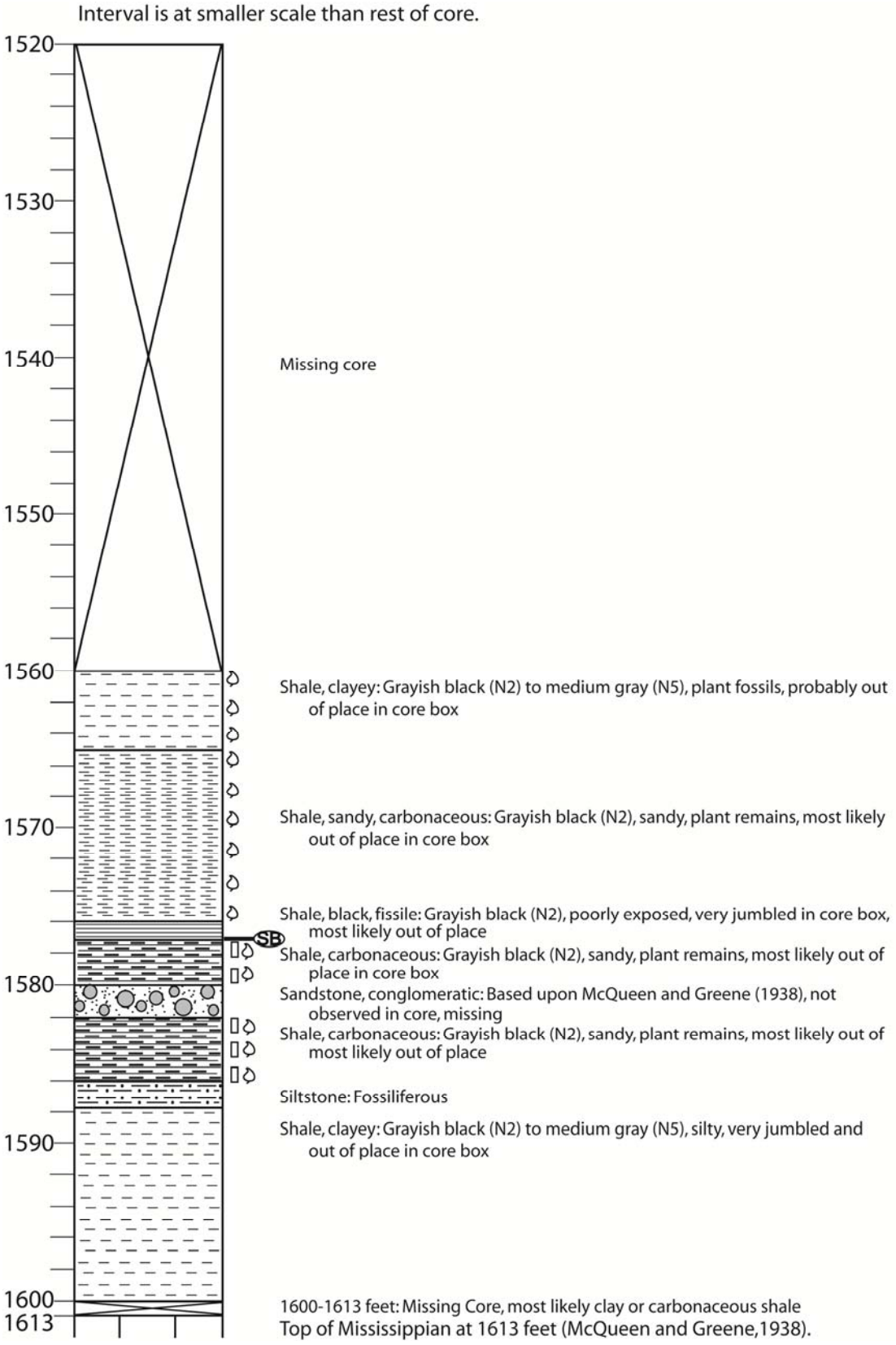

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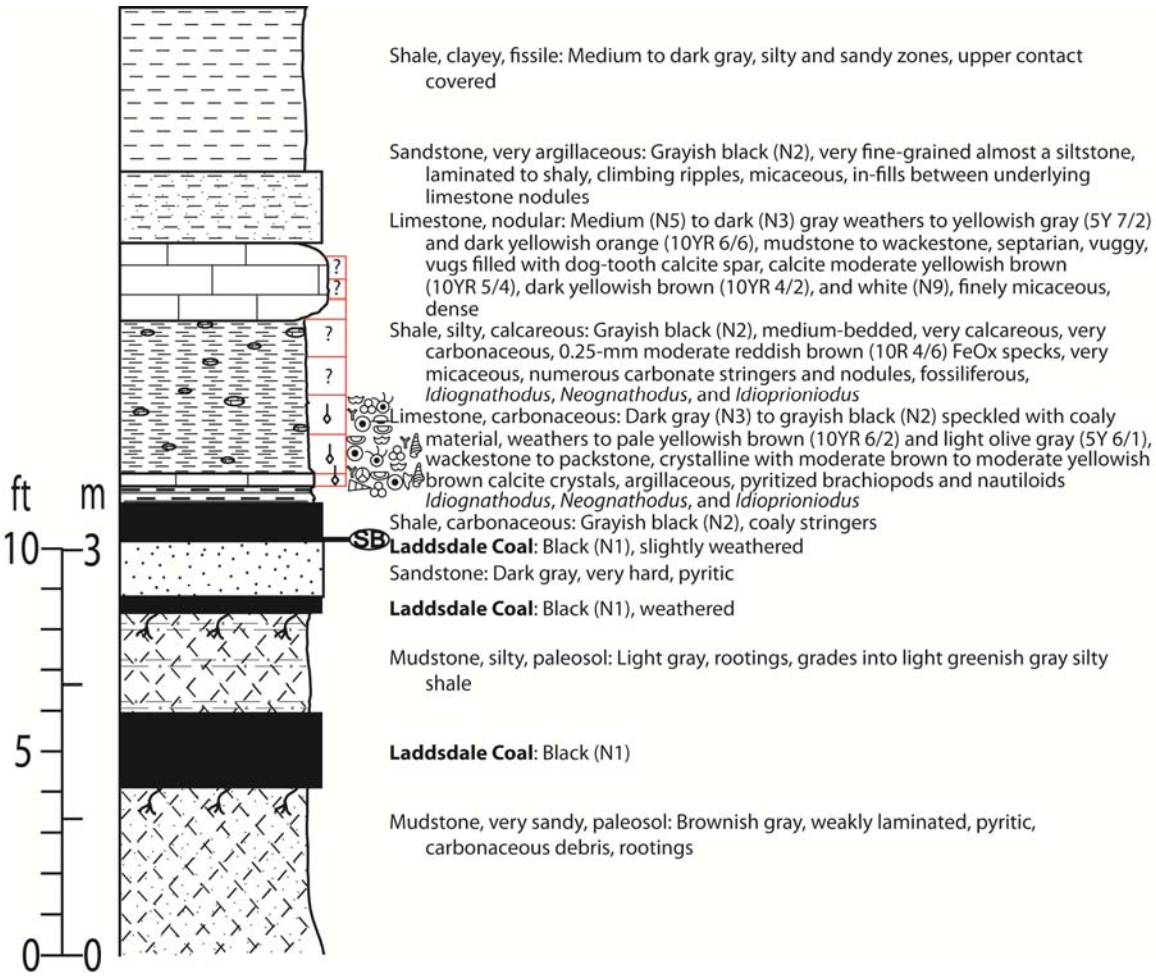


Figure A20. Inola cyclothem, type Laddsdale Coal locality (Ravn and others, 1984), northwest-facing cutbank of Soap Creek, east end of bend in creek, 0.5 miles (0.8 km) west of Salt Creek School, Davis County, IA, Center Sec. 7, T70N, R12W, modified from Ravn et al. (1984), p. 30.

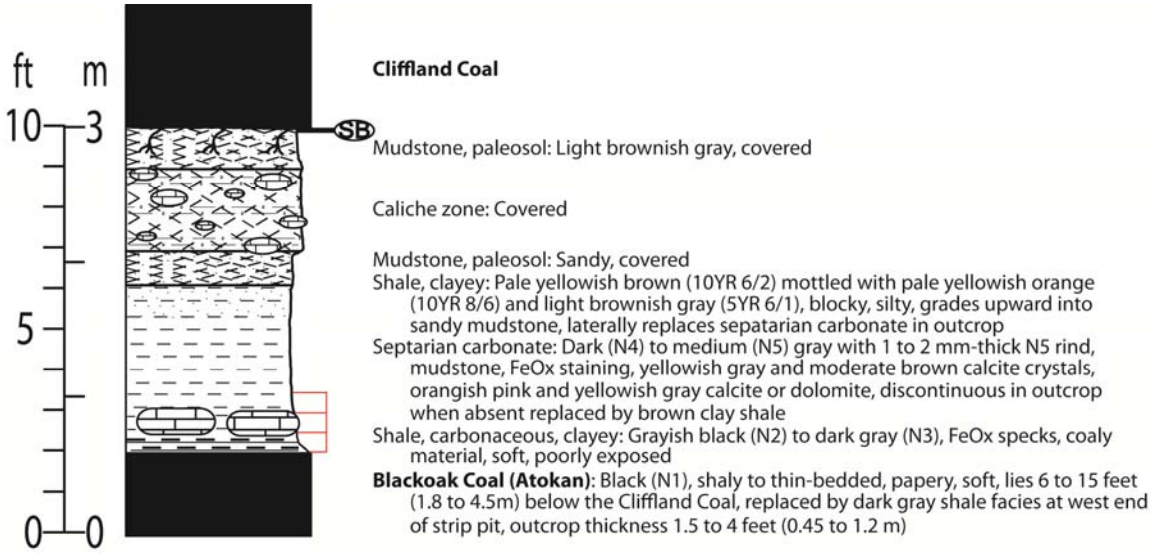


Figure A21. Blackoak Coal and overlying marine units in abandoned strip mine, 0.8 miles (1.3 km) southwest of Lakonta (Truax), Mahaska County, IA, SW-NW Sec. 29, T74N, R16W, measured quarter mile east of Figure A22, modified from Howes et al. (1988), p. 36.

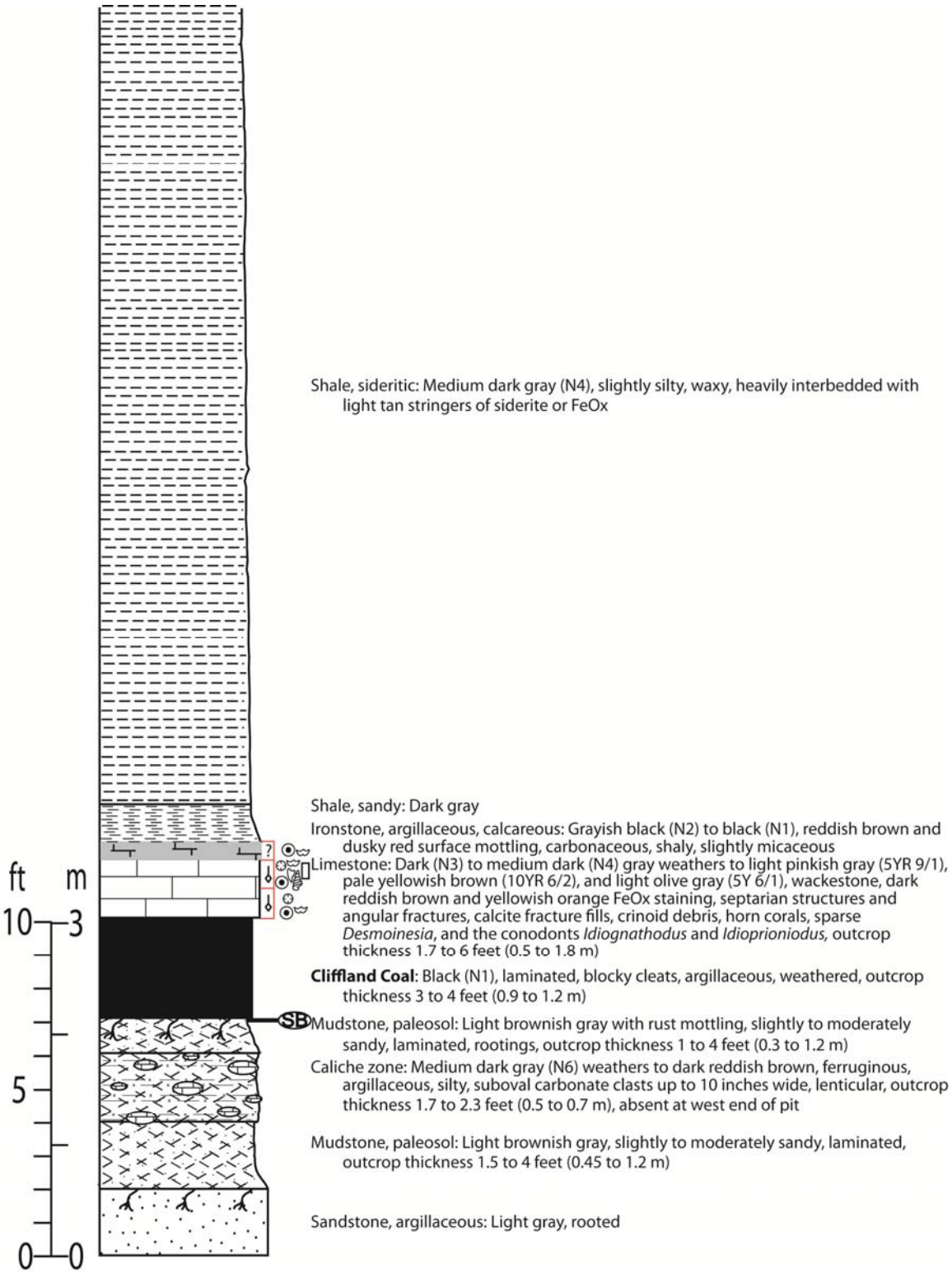


Figure A22. Cliffland Coal and overlying marine units (Doneley cyclothem) at west end of abandoned strip mine, 0.8 miles (1.3 km) southwest of Lakonta (Truax), Mahaska County, IA, SW-NW Sec. 29, T74N, R16W, quarter mile west of Figure A21, modified from Howes et al. (1988), p. 36.

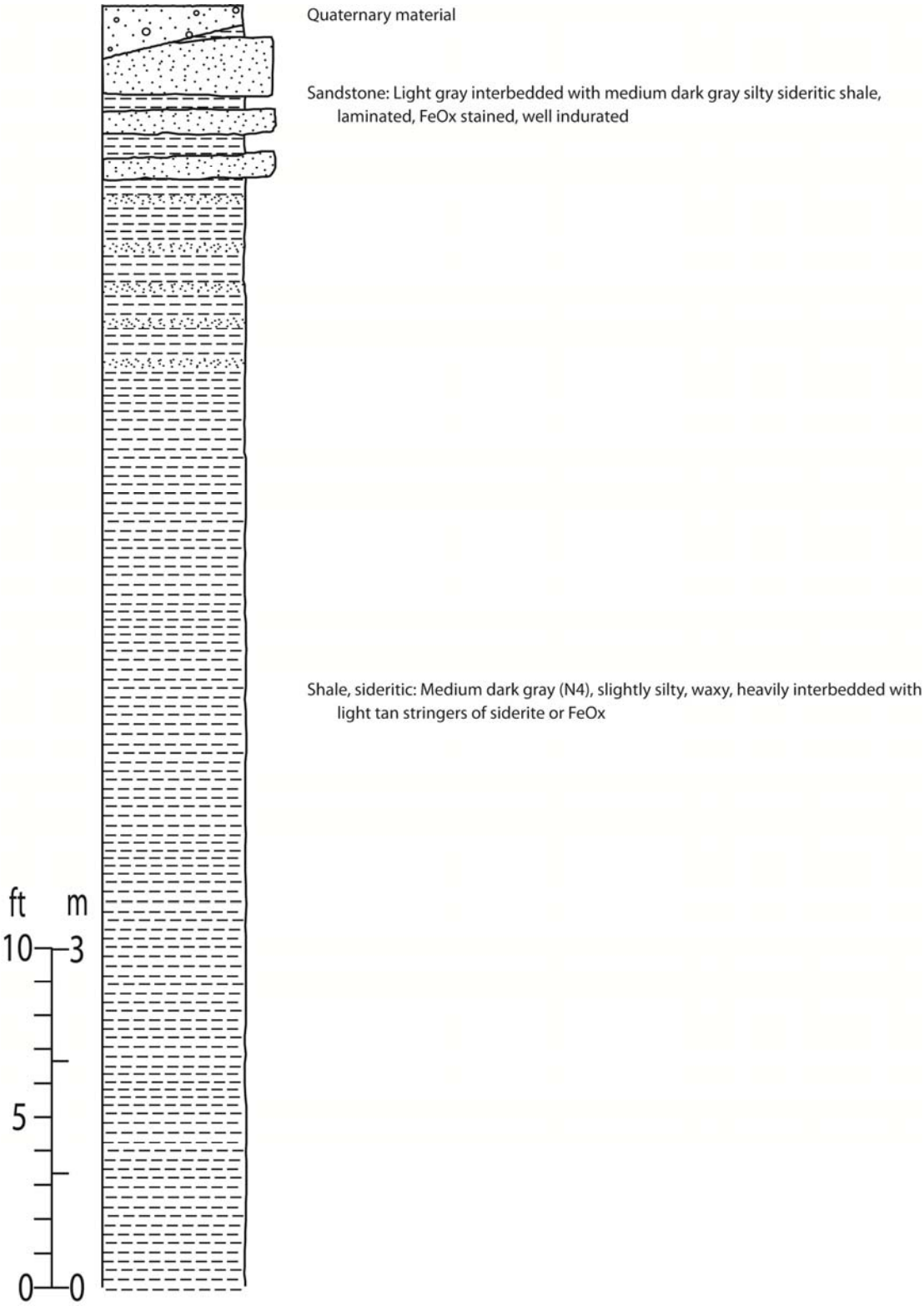


Figure A22. continued.

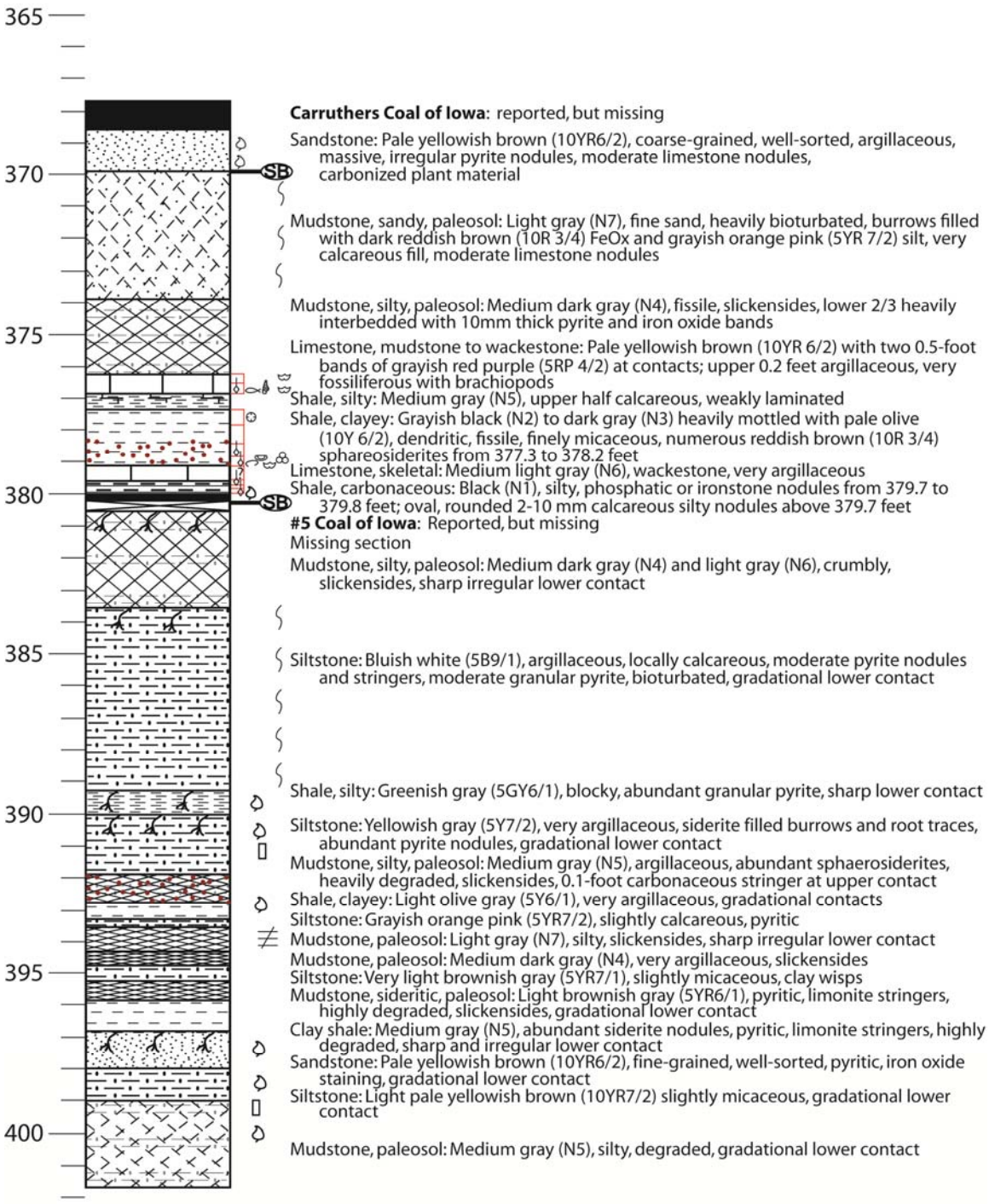


Figure A23. IGS CP-78 coal project core description, Wayne Co., IA, previously described by Paul VanDorpe (modified by author).

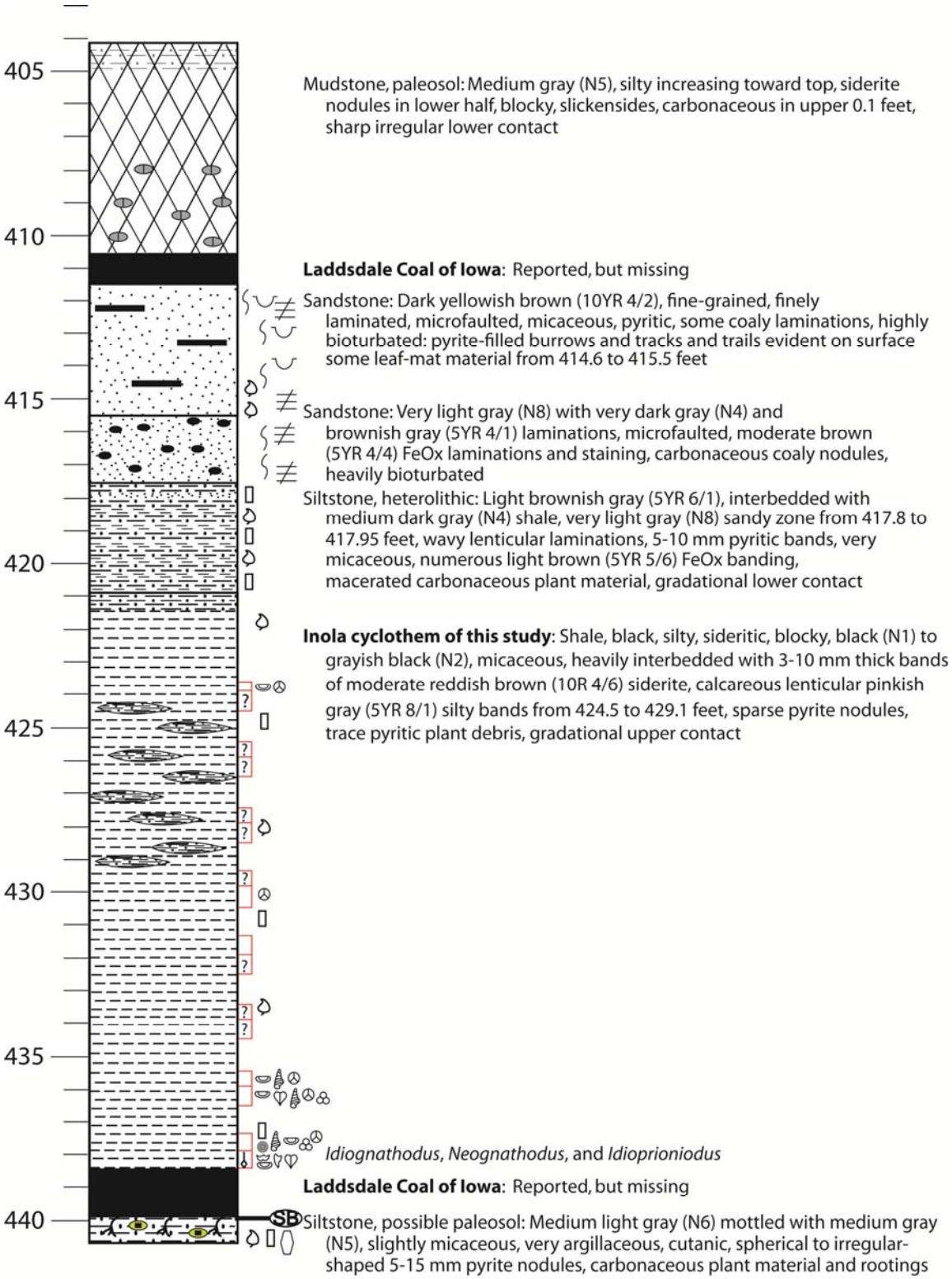


Figure A23. continued.

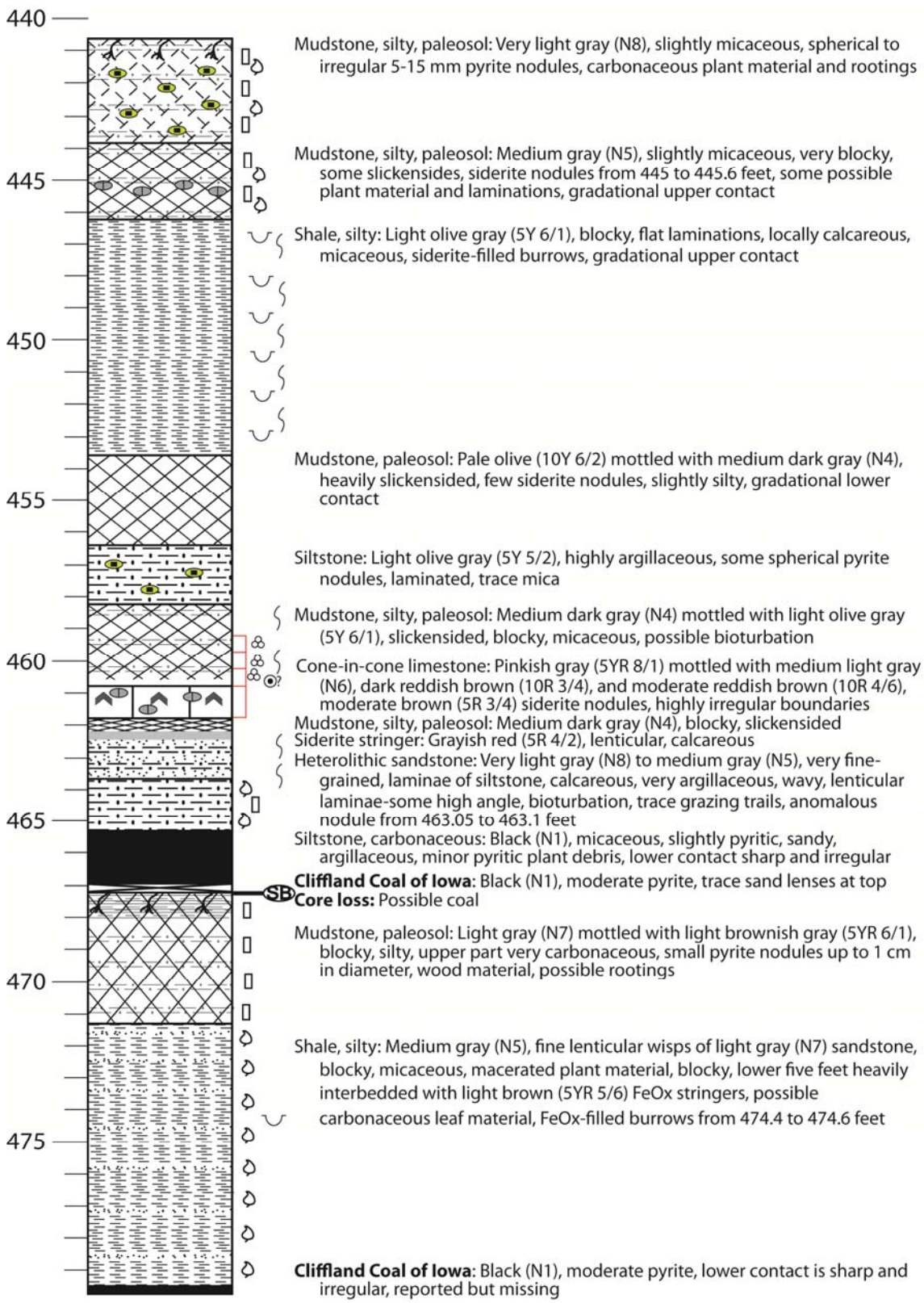


Figure A23. continued.

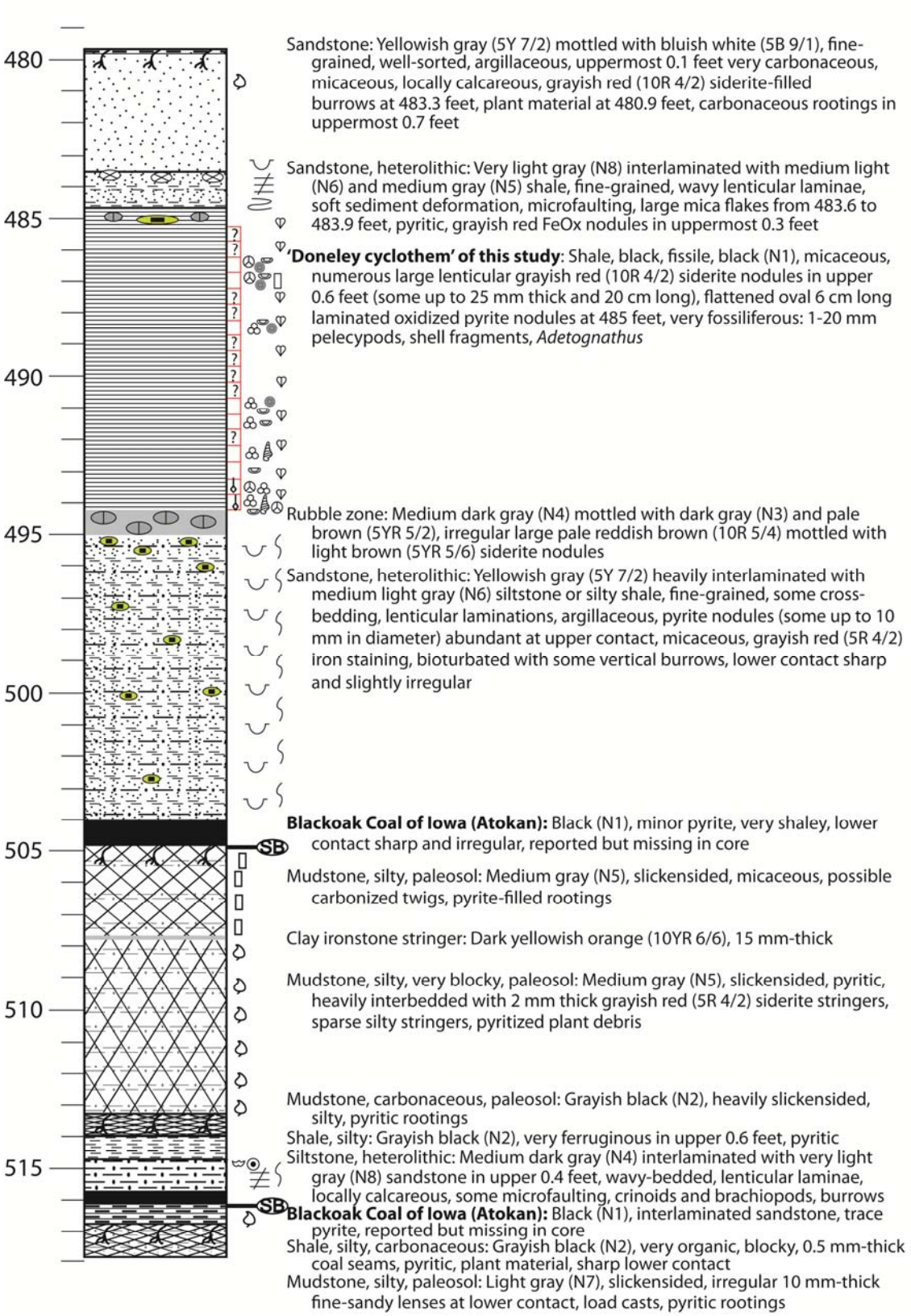


Figure A23. continued.

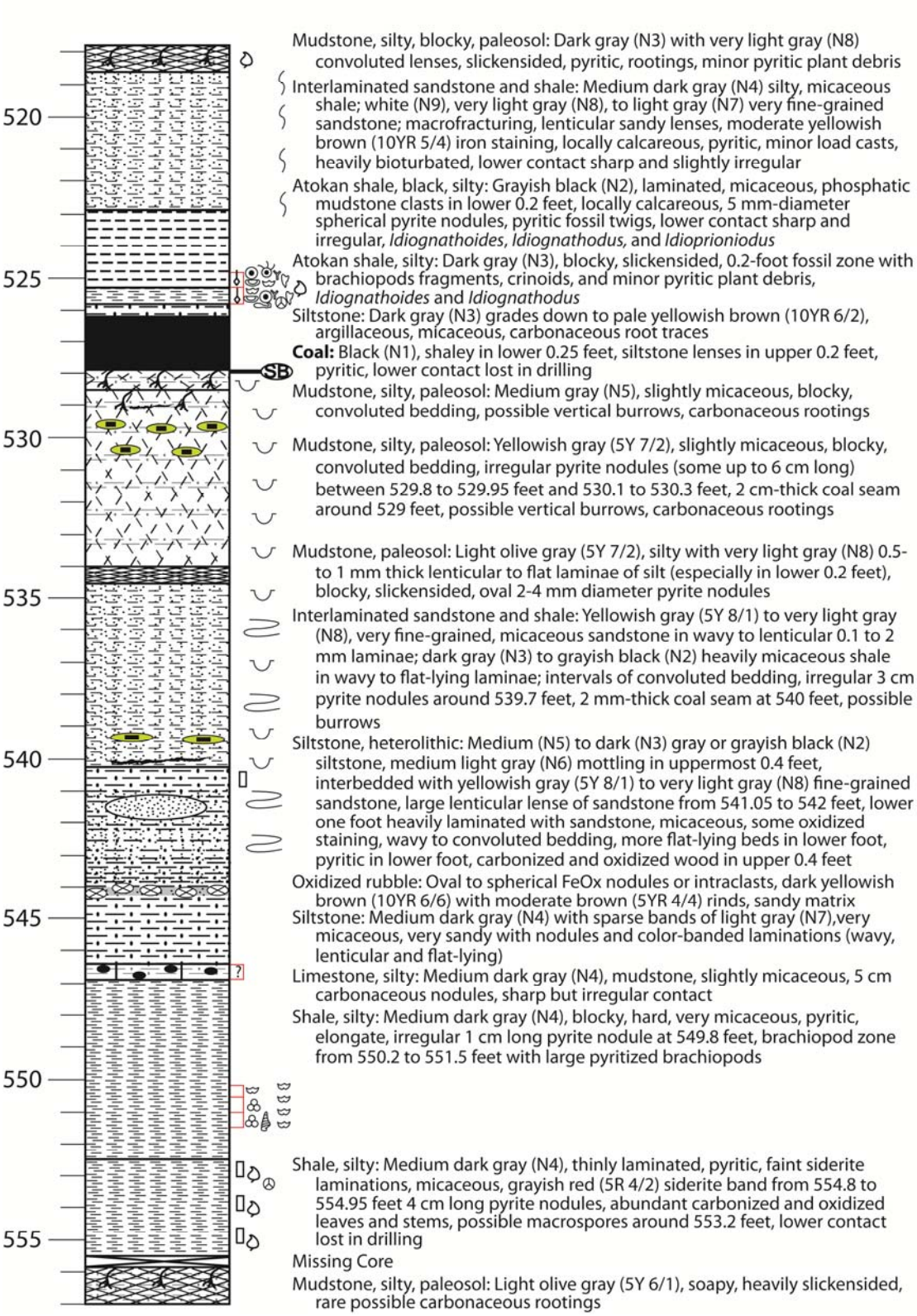


Figure A23. continued.

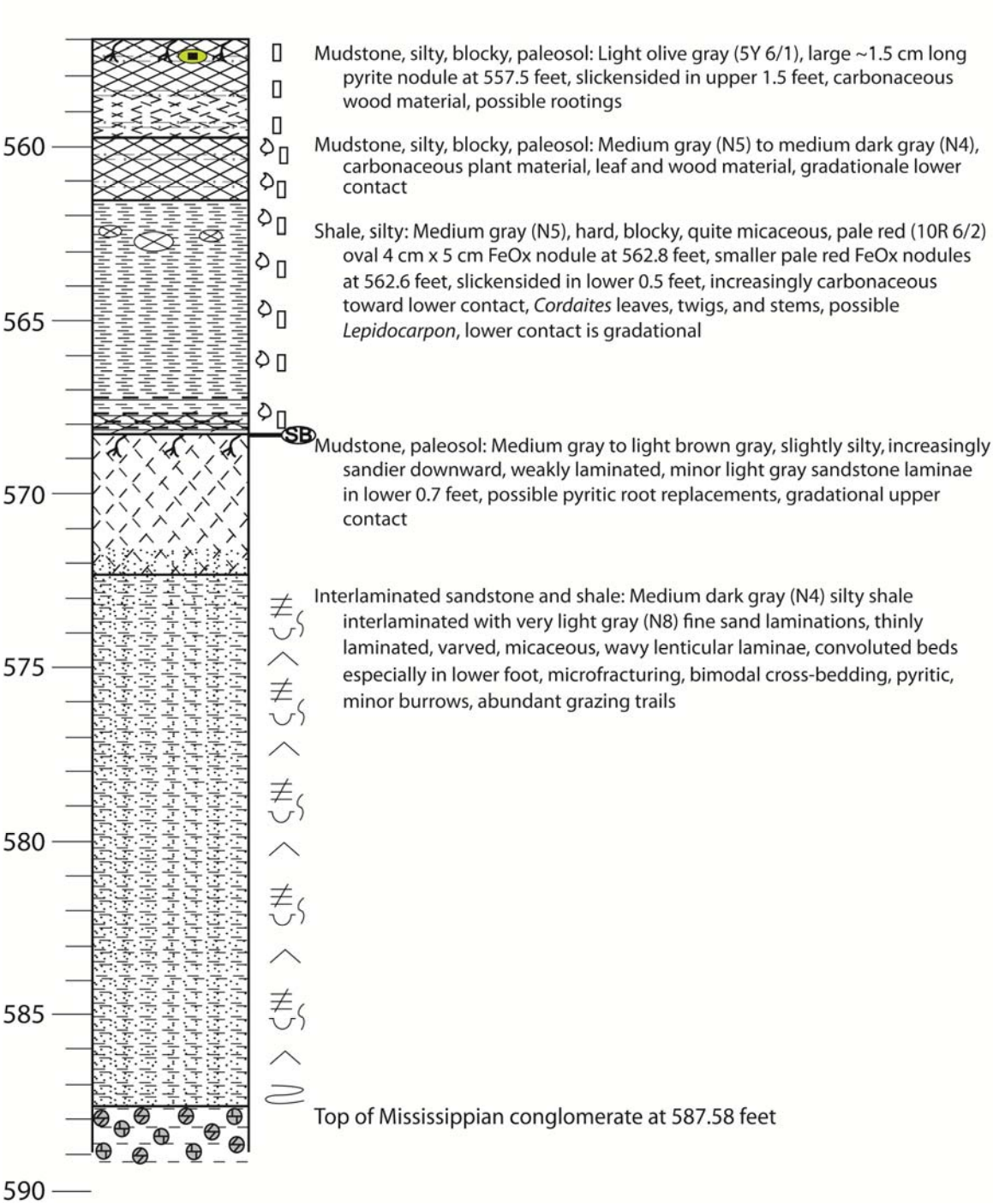


Figure A23. continued.

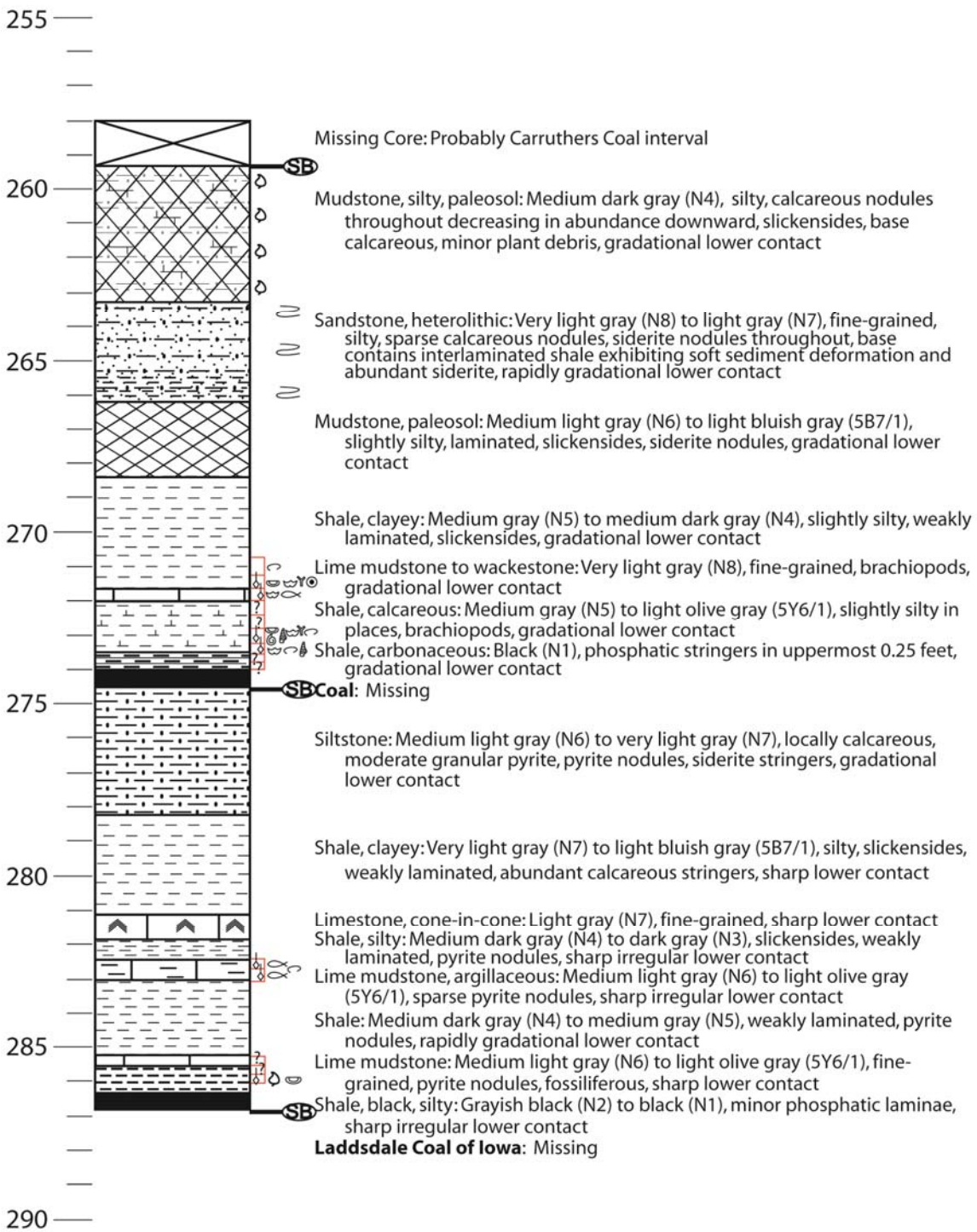


Figure A24. IGS CP-79 coal project core description, Lucas Co., IA, previously described by Paul VanDorpe (1979) (modified by author).

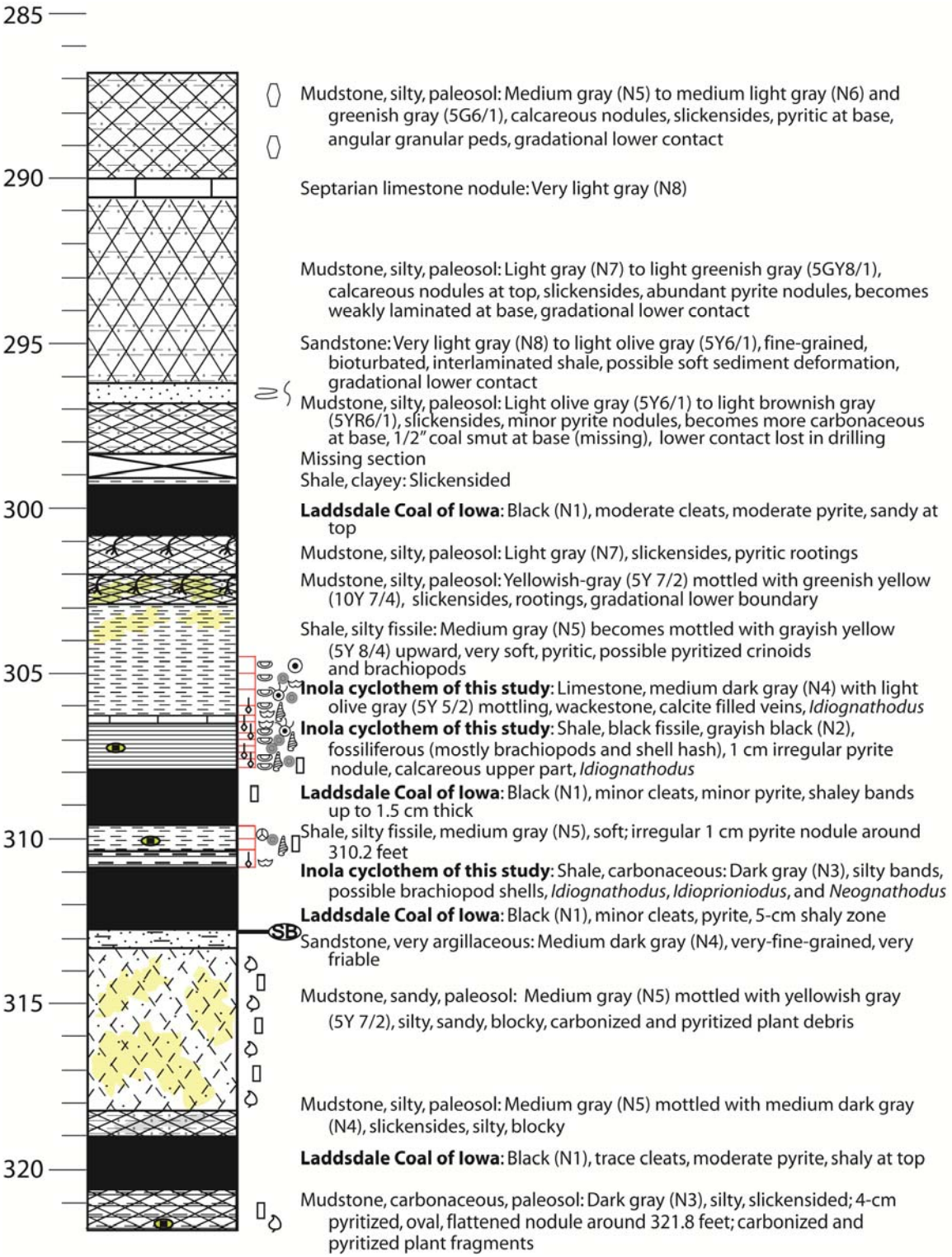


Figure A24. continued.

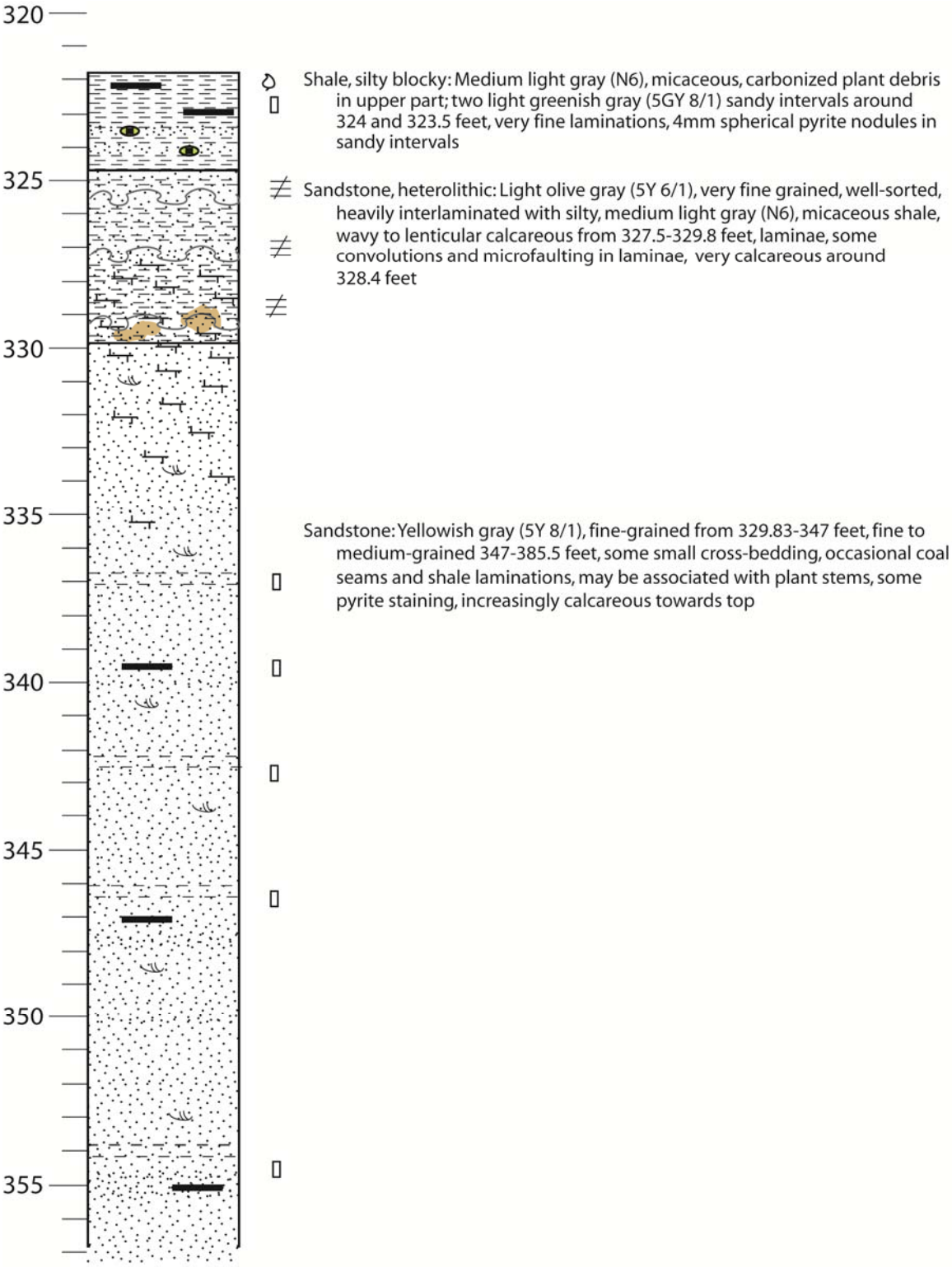


Figure A24. continued.

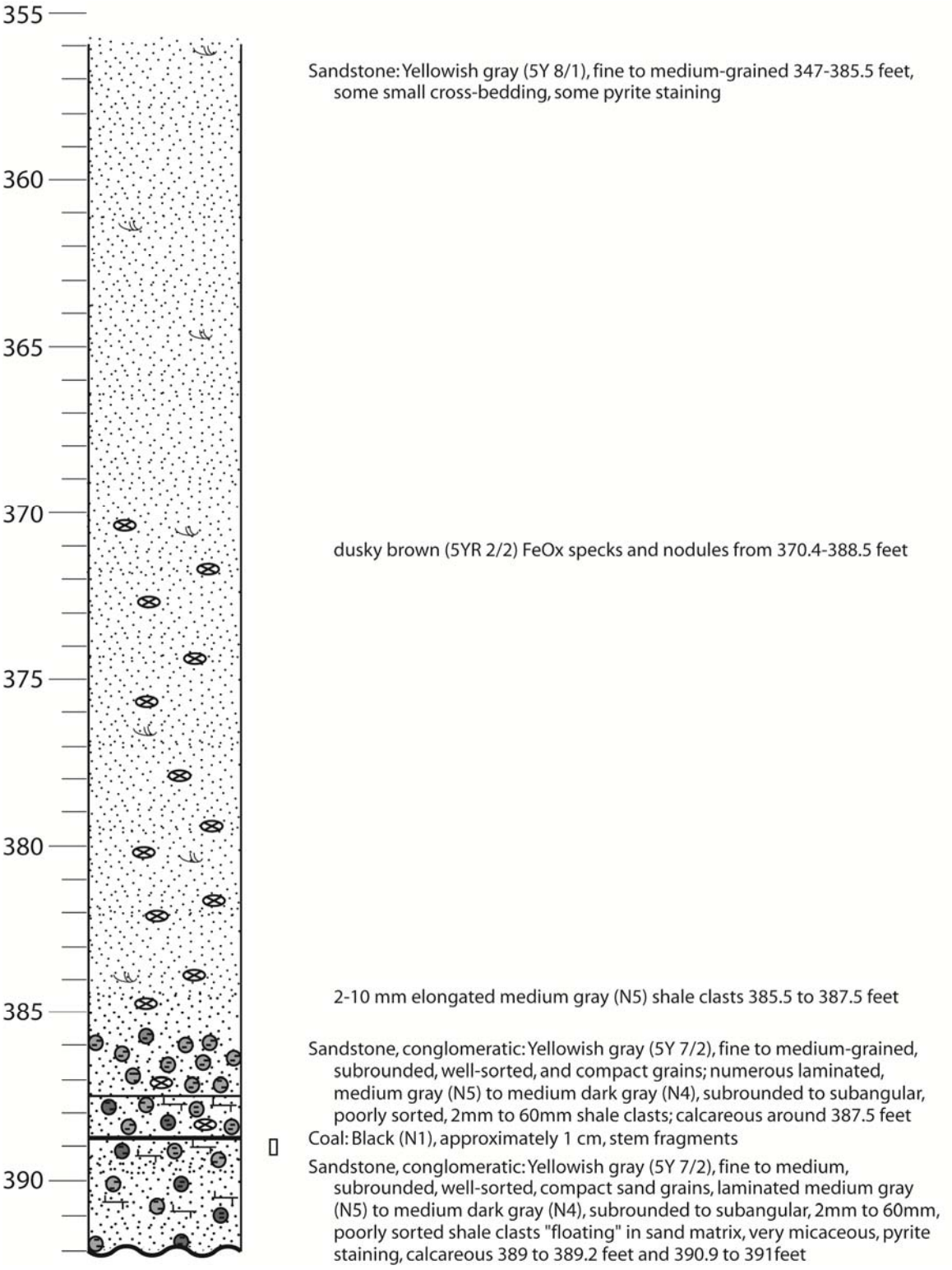


Figure A24. continued.

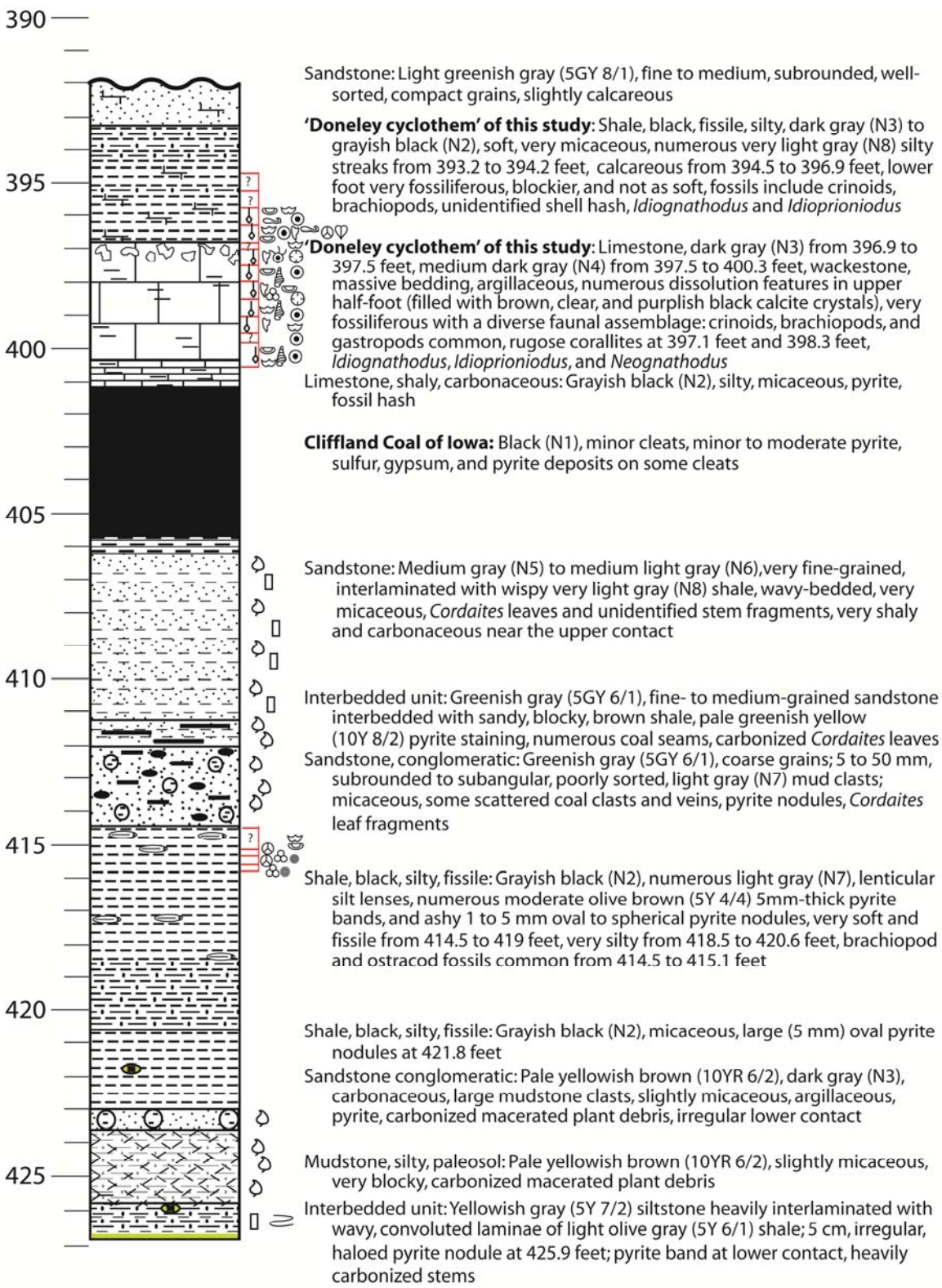


Figure A24. continued.

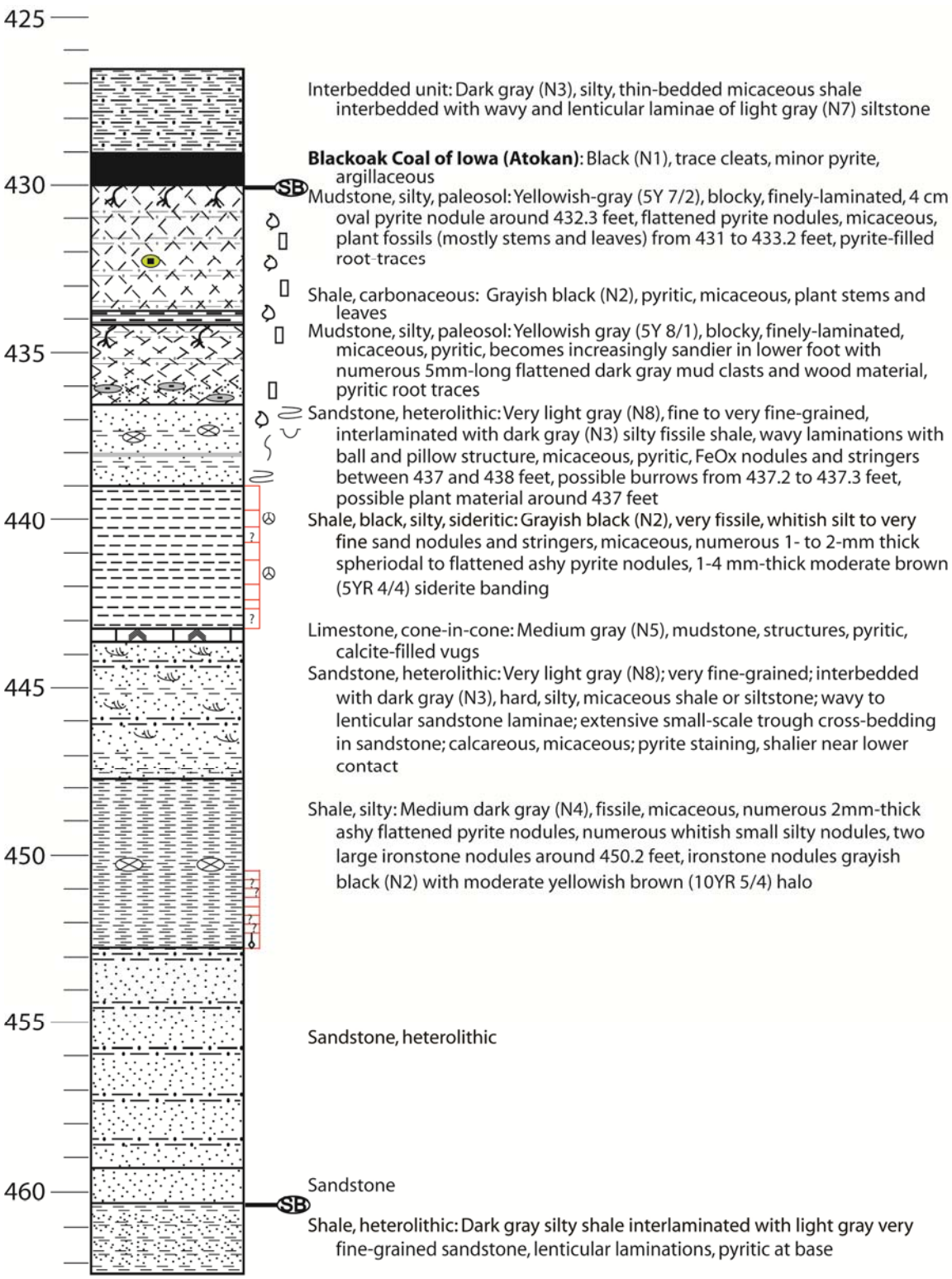


Figure A24. continued.

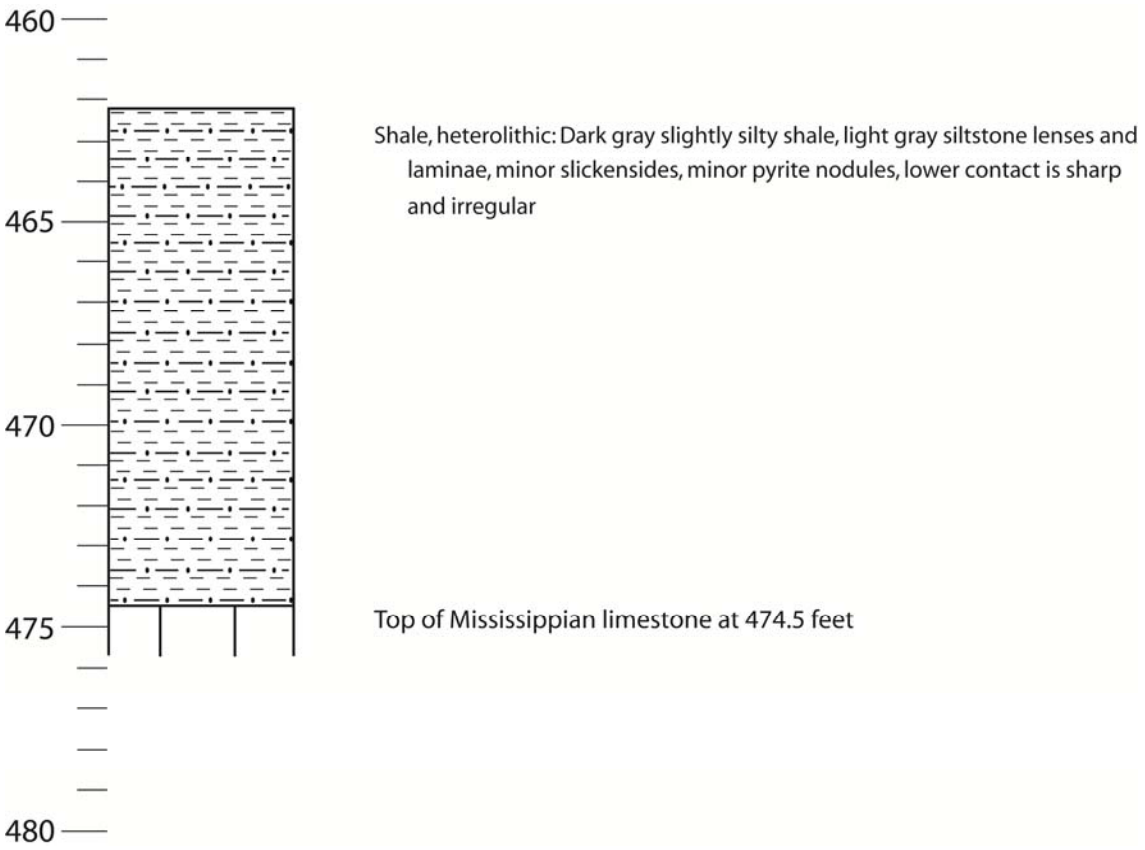


Figure A24. continued.

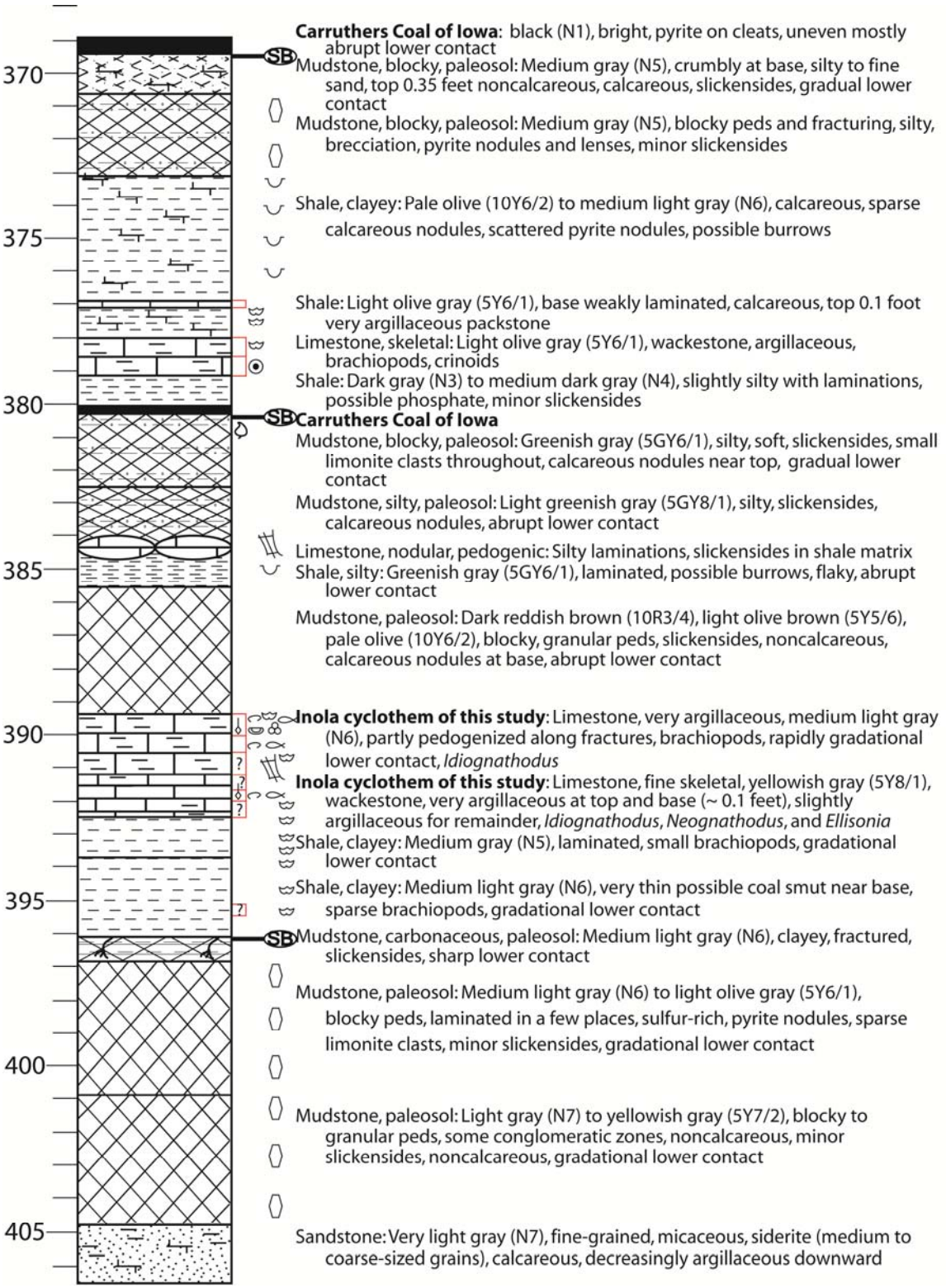
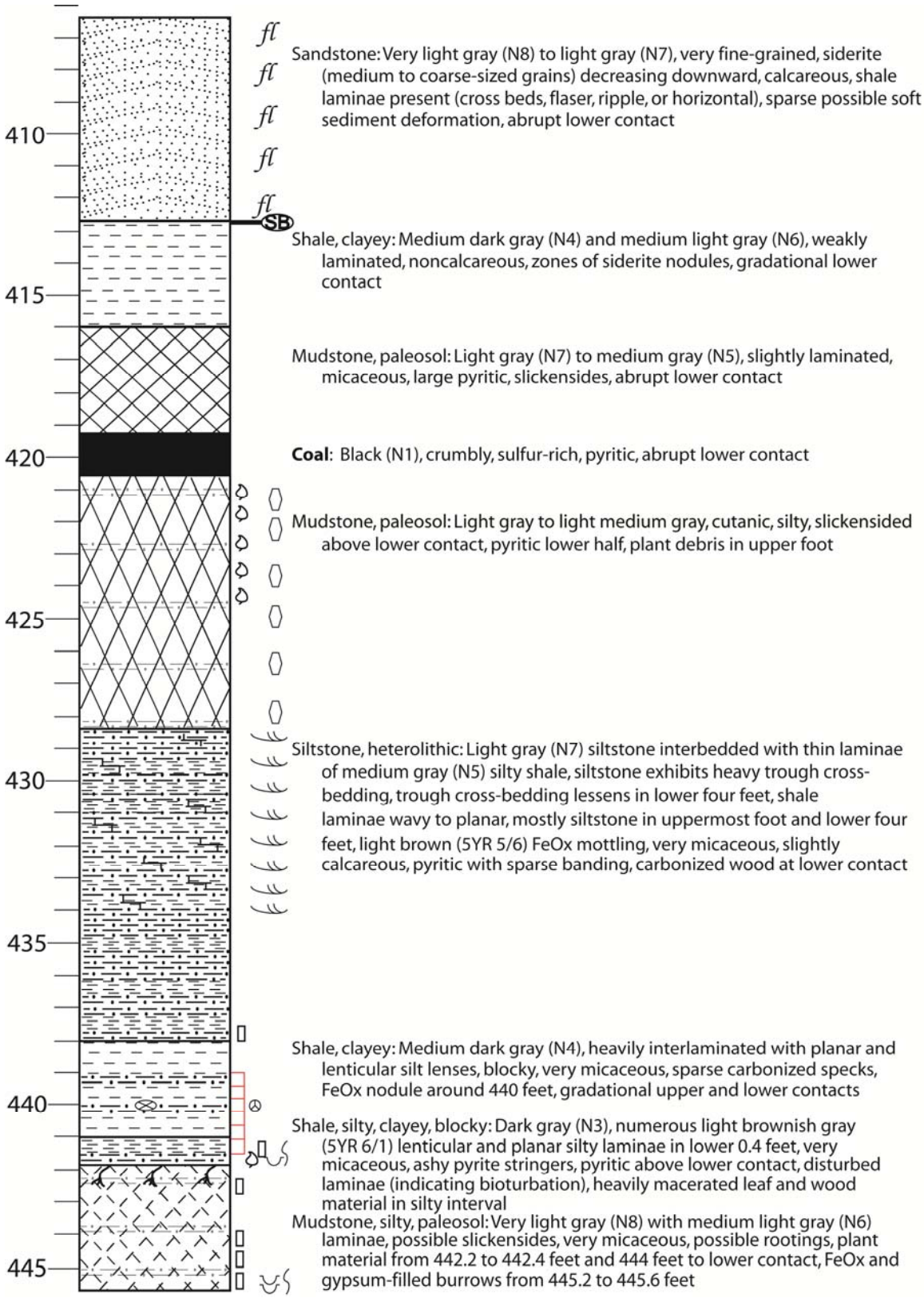


Figure A25. IGS WC-22 (Logan) core description, Harrison Co., IA, previously described by Philip Heckel (43 to 323 feet) and Brian Witzke (323 to 628 feet) (modified by author).



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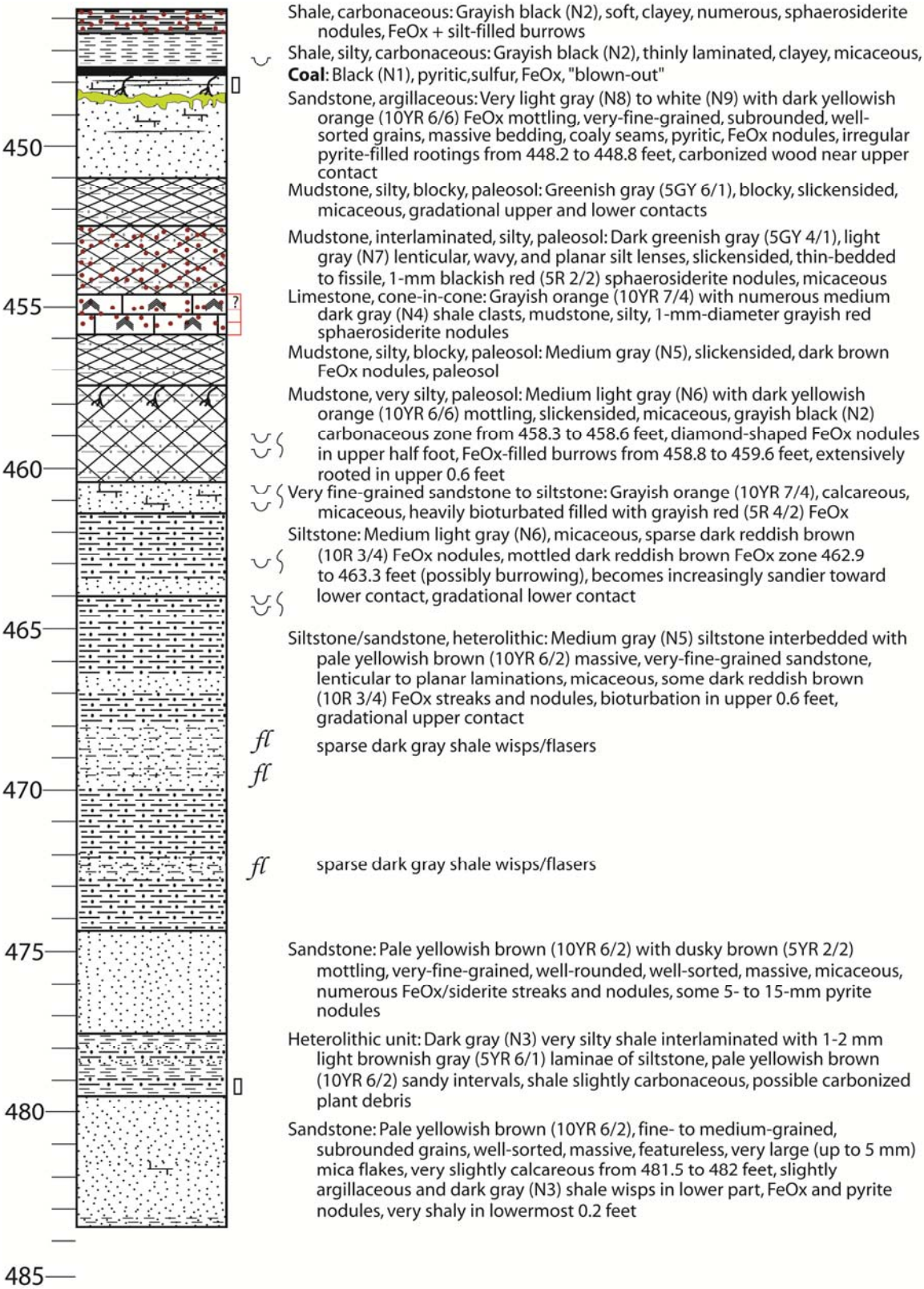

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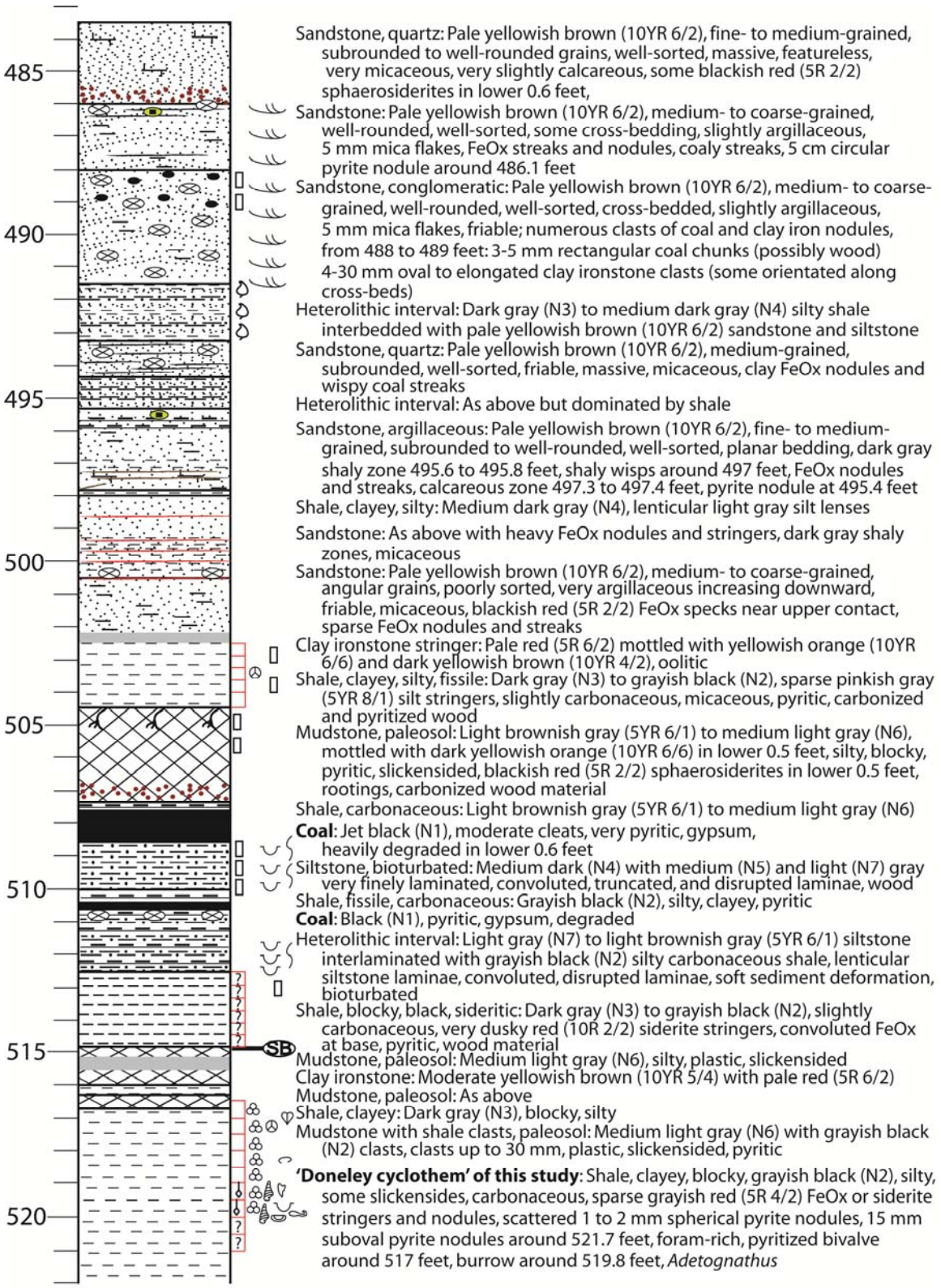

Figure A25. continued.

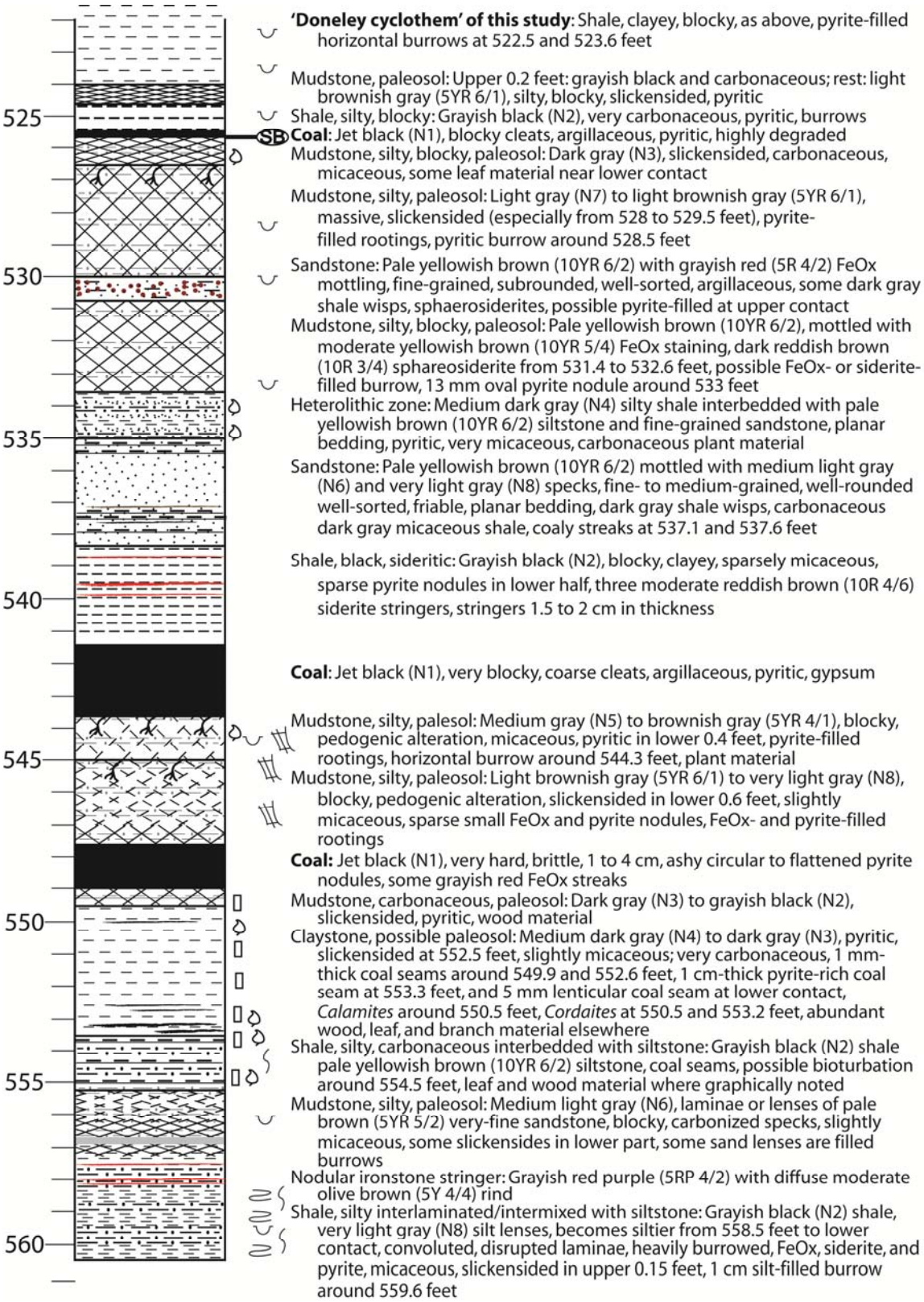

Figure A25. continued.

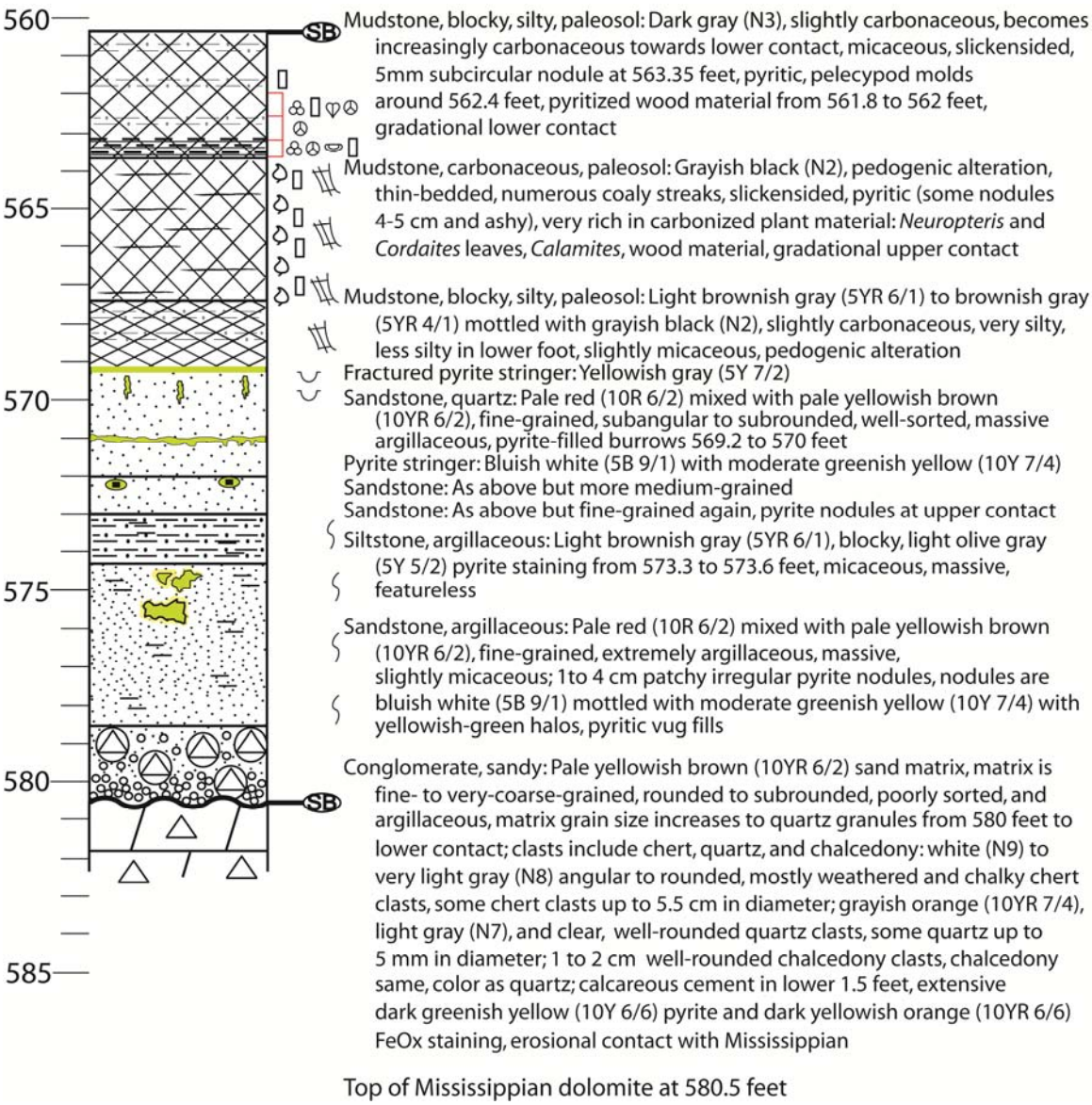

Figure A25. continued.

APPENDIX B

CONODONT INFORMATION

The following tables contain samples that have conodonts. Some conodonts have been identified to genus and species. The first table is the raw conodont data. The second table is abundances normalized to platform elements per kilogram. Only samples from cores or outcrops that had significant or important species of *Idiognathodus* or *Neognathodus* were normalized.

Brushy Creek Tributary (BCT)											
Sample #	Orig.	%	Idiognathodus				Neognathodus		El	Ip	Other
	wt. (g)	picked	amplificus	cf. praeobliquus	juv.	unk.	bothrops	caudatus			
UPRMcCTN Unit #8 (ac)	21	100	17	5	8	1	1	1	15	11	3 lg Pa fragments

Table B1. Conodont abundances of the McCurtain Shale exposure at Brushy Creek Tributary locality, Pittsburg County, Oklahoma.

Brushy Creek Tributary (BCT)									
Sample #	Orig.	%	Idiognathodus				Neognathodus		Ip
	wt. (g)	picked	amplificus	cf. praeobliquus	juv.	unk.	bothrops	caudatus	
UPRMcCTN Unit #8 (ac)	21	100	1619	476	762	95	95	95	1048

Table B2. Conodont abundances of the McCurtain Shale exposure at Brushy Creek Tributary locality, normalized to platform elements per kilogram.

Davis Airfield (SCL-14)									
Sample #	Orig.	%	Idiognathodus				El	Ip	Other
	wt. (g)	picked	amplificus	podol.	obliquus	juv.			
lower contact uppermost shale	500	100	1				1		2 platform fragments, 3 S-elements, 1 ramiform
upper contact uppermst BFS	500	100	2		7	15	11	4	18 platform frags, 67 S-elements, 21 ramiforms
Sam Creek Limestone	805	100		2	1				1 lg Pa fragment, 1 bar

Table B3. Conodont abundances at Davis Airfield section exposure near Muskogee, Muskogee County, Oklahoma, and their corresponding sample numbers.

Davis Airfield (SCL-14)							
Sample #	Orig.	%	Idiognathodus				Ip
	wt. (g)	picked	amplificus	podol.	obliquus	juv.	
lower contact uppermost shale	500	100	2				
upper contact uppermst BFS	500	100	28		97	208	56
Sam Creek Limestone	805	100		3	2		

Table B4. Conodont abundances at Davis Airfield section, normalized to platforms per kilogram.

Wagoner County shale pit (WCSP)										
Sample #	Orig.	%	Idiognathodus				Ad	El	Ip	Other
	wt. (g)	picked	amplificus	podol.	obliquus	juv.				
Sample D: Sam Creek	473	100								6 conodont fragments
D-1: Limestone below Sam Crk	500	7	1	1	5	8	1	10	7	36 lg Pa fragments

Table B5. Conodont abundances at Wagoner County shale pit, Oklahoma, and their corresponding sample numbers (samples not normalized).

Inola Hill																				
Sample #	Orig.	%	Idiognathodus										Neognath.			Ad	El	Ip	G	Other
(footage)	wt. (g)	picked	amplif.	podol.	obliq.	Sp. B	Sp. C	Sp. D	juv.	cf. iowa.	cf. mun.	unk.	asym.	caud.	juv.					
G-2: BFS 17' abv Inola	28	100	58	38	21	6	3	3	120	3	1	8		3		1	16	10		
G-1: BFS lc w/ Inola	500		2						7						1					1 lg Pa frag, 3 S
Hemish Prin. Ref. Sec. 0-0.25' above Inola	850	100	43	25	9				45			11*	10			5	4	1	1	13 Pa frags, * degr. Pa, 3 Hind?
Hemish Prin. Ref. Sec. top Inola	500	100	7	8					6			3*	4			2				*degraded lg Pa
Hemish Prin. Ref. Sec. bottm Inola	500	100							1							1				1 ramiform
Heckel Inola Hill ENCENT Base Black Sh abv Inola LS	800	100	22	8	3				2			4*	3		1	4	2			9 lg Pa frags, *degr. lg Pa

Table B6. Conodont abundances at Inola Hill section near Inola, Rogers County, Oklahoma, and their corresponding sample numbers (*Idiognathodus* species B, *I.* sp. C, *I.* sp. D of Boardman and others, 2004).

Inola Hill																		
Sample #	Orig.	%	Idiognathodus										Neognath.			Ad	Ip	G
(footage)	wt. (g)	picked	amplif.	podol.	obliq.	Sp. B	Sp. C	Sp. D	juv.	cf. iowa.	cf. mun.	unk.	asym.	caud.	juv.			
G-2: BFS 17' abv Inola	28	100	1000	1357	750	214	107	107	4285	107	36	286		107		36	357	
G-1: BFS lc w/ Inola	500		4						15						2			
Hemish Prin. Ref. Sec. 0-0.25' above Inola	850	100	51	29	11				53			13*	12			6	1	1
Hemish Prin. Ref. Sec. top Inola	500	100	15	17					12			6*	8			4		
Hemish Prin. Ref. Sec. bottm Inola	500	100							2							2		
Heckel Inola Hill ENCENT Base Black Sh abv Inola LS	800	100	27	10	4				2			5*	4		1	5		

Table B7. Conodont abundances at Inola Hill section, normalized to platform elements per kilogram (*Idiognathodus* species B, *I.* sp. C, *I.* sp. D of Boardman and others, 2004).

Type Doneley									
Sample #	Orig.	%	Idiognathodus				El	Ip	Other
	wt. (g)	picked	amplificus	obliquus	cf. praeob.	juv.			
clay shale just below FeOx zone	500	100	1	3		1	1	2	2 Pa frags, 2 M-elements, S-elements
dark gray fissile shale above coal	491	100			1	1			1 S-element

Table B8. Conodont abundances at type Doneley section, Craig County, Oklahoma, and their corresponding sample numbers.

Type Doneley							
Sample #	Orig.	%	Idiognathodus				Ip
	wt. (g)	picked	amplificus	obliquus	cf. praeob.	juv.	
clay shale just below FeOx zone	500	100	2	6		2	4
dark gray fissile shale above coal	491	100			2	2	

Table B9. Conodont abundances at type Doneley section, normalized to platform elements per kilogram.

Highway 25 roadcut (H75CC)							
Sample #	Orig.	%	Idiognathodus			El	Other
	wt. (g)	picked	amplificus	obliquus	juv.		
olive fossiliferous shale below Doneley	1000	100	2	1?	4	3	5 Pa frags, 5 ramiforms

Table B10. Conodont abundances at Doneley roadcut on Highway 25, Craig County, Oklahoma.

KGS Cooper CW-1																				
Sample #	Orig.	%	Idiognathodus											Neogn.		Ad	El	Ip	G	Other
(footage)	wt. (g)	picked	amplif.	podol.	obliq.	cf. praeob.	Sp. A	Sp. B	Sp. D	cf. robust.	cf. crass.	unk.	juv.	bothr.	juv.					
575.5-576'	195	100														1				
577-577.5'	163	100	13	6	29		2	1	9	2	7	1	84				63	26	1	
647-647.5'	418	100								2					1	2				
655-655.5'	116	100	1							2										1 Pa frag
655.5-656'	245	100	2																	
656-656.5'	190	100																		1 Pa frag
656.5-657'	166	100											1							2 S-elements
764.8-765'	84	100				3							2	1		2				4 ramiforms, 1 bar
765-765.2'	48	100																		1 Ng tip, 1 partial blade
765.2-765.7'	156	100										2*								*heavily degraded lg Pa
765.7-766.2'	173	100																		fragmentary material
805.9-806.5'	250	100	1			13							18	3 cf.	1		1			10 ramiforms, 17 S

Table B11. Conodont abundances in KGS Cooper CW-1 core, Labette County, Kansas, and their corresponding sampled footages (*Idiognathodus* species A, *I.* sp. B, *I.* sp. D of Boardman and others, 2004).

KGS Cooper CW-1																				
Sample #	Orig.	%	Idiognathodus											Neogn.		Ad	Ip	G	Other
(footage)	wt. (g)	picked	amplif.	podol.	obliq.	cf. praeob.	Sp. A	Sp. B	Sp. D	cf. robust.	cf. crass.	unk.	juv.	bothr.	juv.				
575.5-576'	195	100														6			
577-577.5'	163	100	130	60	290		20	10	90	20	70	10	840				260	10	
647-647.5'	418	100								5					3	5			
655-655.5'	116	100	9							19									
655.5-656'	245	100	9																
656.5-657'	166	100											7						
764.8-765'	84	100				39							26	13		26			
765-765.2'	48	100																	1 Ng tip
805.9-806.5'	250	100	4			53							73	12 cf.	4				

Table B12. Conodont abundances in KGS Cooper CW-1 core, normalized to platforms per kilogram (*Idiognathodus* species A, *I.* sp. B, *I.* sp. D of Boardman and others, 2004).

KGS HCW-1				
Sample # (footage)	Orig. wt. (g)	% picked	El	Other
931-931.05'	30	100	1	
931.05-931.2'	86.7	100		2 lg Pa frags, 6 other frags
1080.3-1080.5'	424	100	1	2 blades

Table B13. Conodont abundances in KGS Hinthorn CW-1 core, Montgomery County, Kansas, and their corresponding sampled footages (samples not normalized).

KGS P&M #7													
Sample #	Orig.	%	Idiognathodus						Neo.	Ad	El	Ip	Other
(footage)	wt. (g)	picked	amplif.	podol.	cf. praeob.	cf. gibb.	juv.	unk.	bothr.				
218.1-218.6'	65	100						1		1			
223.2-223.9'	130	100					1				1		
223.9-224.2'	49	100	30	19			25	4		2	10	7	heavily degraded lg Pa, 4 Ng tips
246.1-246.6'	80	100											1 partial Pa element
246.6-246.85'	65	100		2 juv.?									5 S-elements
246.85-247'	14	100											1 blade fragment
247.3-247.5'	61.5	100						1*					*degraded *Idiognathodus*
389-389.3'	62	100	8		22	1	7	1	5		2		4 lg Pa frag, 8 ram., 8 basal plates, 1 S-ele
389.3-389.6'	59	100			3	3	2						

Table B14. Conodont abundances in KGS P & M #7 core, Cherokee County, Kansas, and their corresponding sampled footages.

KGS P&M #7											
Sample #	Orig.	%	Idiognathodus						Neo.	Ad	Ip
(footage)	wt. (g)	picked	amplif.	podol.	cf. praeob.	cf. gibb.	juv.	unk.	bothr.		
218.1-218.6'	65	100						16		16	
223.2-223.9'	130	100					81				
223.9-224.2'	49	100	769	487			641	103		2	7
246.6-246.85'	65	100		38 juv.?							
389-389.3'	62	100	148		407	19	130	19	93		
389.3-389.6'	59	100			61	61	41				

Table B15. Conodont abundances in KGS P & M #7 core, normalized to platform elements per kilogram.

Type Hackberry Branch												
Sample #	Orig.	%	Idiognathodus					Hnd?	Ad	El	Ip	Other
	wt. (g)	picked	amplif.	podol.	obliquus	juv.	unk.					
unit #8 upper shale 0 to 0.5 feet	1000	100			2	2	1 juv.		1			2 lg Pa frags, 2 S-elements
unit #7 upper ls upper 1/2	500	100		1				2?	1	3	5	2 S-elements
unit #7 upper ls lower 1/2	500	100					1*	2?		4	2	1 lg Pa frag, *degraded lg Pa, 3 S-e, 2 ramiforms
unit #6 middle shale (unac)	1000	100	8	2	1	1				1	4	7 S-elements, 16 ramiforms
unit #6 middle shale (ac)		100		1		1				1		5 ramiforms, 1 S-element

Table B16. Conodont abundances at type Hackberry Branch section, Vernon County, Missouri, and their corresponding sample numbers.

Type Hackberry Branch										
Sample #	Orig.	%	Idiognathodus					Hnd?	Ad	Ip
	wt. (g)	picked	amplif.	podol.	obliquus	juv.	unk.			
unit #8 upper shale 0 to 0.5 feet	1000	100			2	2	1 juv.		1	
unit #7 upper ls upper 1/2	500	100		2				4?	2	11
unit #7 upper ls lower 1/2	500	100						5?		5
unit #6 middle shale (unac)	1000	100	9	2	1	1				4
unit #6 middle shale (ac)	91	100		11		11				

Table B17. Conodont abundances at type Hackberry Branch section, normalized to platform elements per kilogram.

MGS Hess CH-9H														
Sample #	Orig.	%	Idiognathodus						Neognathodus		Ad	El	Ip	Other
(footage)	wt. (g)	picked	amplificus	podol.	obliq.	cf. mun.	juv.	unk.	bothrops	asym.				
427-427.5'	100	100	1	1			2		1					1 lg Pa fragment
439-440'	275	100	32	30	7	2?	15	6	13	2	1	4	1	5 S-elements, 11 ramiforms, degraded lg Pa

Table B18. Conodont abundances in MGS Hess CH-9H core, Bates County, Missouri, and their corresponding sampled footages.

MGS Hess CH-9H												
Sample #	Orig.	%	Idiognathodus						Neognathodus		Ad	Ip
(footage)	wt. (g)	picked	amplificus	podol.	obliq.	cf. mun.	juv.	unk.	bothrops	asym.		
427-427.5'	100	100	11	11			21		11			
439-440'	275	100	139	130	30	9?	65	26	39	9	4	4

Table B19. Conodont abundances in MGS Hess CH-9H core, normalized to elements per kilogram.

KGS Rose Hill #1-6													
Sample #	Orig.	%	Idiognathodus					Neo.	Ad	El	Ip	G	Other
(footage)	wt. (g)	picked	amplificus	podol.	obliquus	juv.	unk.	caudatus					
824.5-825'	227	100								1			
825-825.5'	433	100							1				1 lg frag
828.5-829'	350	100	10	3		4			1	14	12		1 lg Pa frag, 13 other frags
829-829.5'	187	100				1			1		1		1 Ng frag, 5 lg frags
840-840.5'	315	100	48	42	2	85	4	4	5	15	23	1*	*Pb element
871.5-872'	290	100							1				

Table B20. Conodont abundances in KGS Rose Hill #1-6 core Miami County, Kansas, and their corresponding sampled footages.

KGS Rose Hill #1-6												
Sample #	Orig.	%	Idiognathodus					Neo.	Ad	Ip	G	Other
(footage)	wt. (g)	picked	amplificus	podol.	obliquus	juv.	unk.	caudatus				
825-825.5'	433	100							5			
828.5-829'	350	100	30	9		12			3	36		
829-829.5'	187	100				5			5	5		
840-840.5'	315	100	155	135	6	274	13	13	16	74	3*	*Pb element
871.5-872'	290	100							4			

Table B21. Conodont abundances in KGS Rose Hill #1-6 core, normalized to platform elements per kilogram.

KGS Spencer 2-6																
Sample #	Orig.	%	Idiognathodus						Neognathodus			Ad	El	Ip	G	Other
(footage)	wt. (g)	picked	amplificus	podol.	obliquus	cf. robust.	juv.	unk.	cf. asym.	caud.	juv.					
837-837.4'	87	100	2	1	2		5					5	4	3		1 lg Pa frag
837.4-838'	210	100	4				1						5	1		1 lg Pa frag
848.5-848.9'	73	100	6	4	2	2	12	2			2	1	6		1	3 lg Pa frag., 21 frag.
848.9-849' unac	39	100	1				4						2	1		5 lg Pa frag, 2 ramif., 1 S-elem
848.9-849' ac	33	100	4				5					2				2 Pa frag., 5 ram., 1 S, 1 basal
849-849.5' unac	80	100										3				
849-849.5' ac	139	100		1								3				1 blade frag.
879.5-880'	129	100	11				6						1	1		9 frag.
880-880.5'	122	100	3													1 ramiform
880.5-881'	85	100						2*								*degraded frags.
881-881.5'	123	100														1 blade frag.
881.5-882'	104	100			2		1									5 blade frag.
882-882.5'	84	100			1											1 ramiform
882.5-883'	128	100			1 juv.?											2 S-elements
883-883.5'	132	100			1 juv.?		1									1 ramiform, 1 S-element
883.5-884'	153	100	2				2		1					1		num. frag. + elements
884-884.5'	113	100	1							1 juv.		1	1	1		4-5 blades
884.5-885'	127	100	5										1	1		
965.5-966'	95	?														1 fragment

Table B22. Conodont abundances in KGS Spencer #2-6 core, Franklin County, Kansas, and their corresponding sampled footages.

KGS Spencer 2-6														
Sample #	Orig.	%	Idiognathodus						Neognathodus			Ad	Ip	G
(footage)	wt. (g)	picked	amplificus	podol.	obliquus	cf. robust.	juv.	unk.	cf. asym.	caud.	juv.			
837-837.4'	87	100	45	23	45		119					119	68	
837.4-838'	210	100	19				5						5	
848.5-848.9'	73	100	83	56	28	28	167	28			28	14		14
848.9-849' unac	39	100	167				668						167	
848.9-849' ac	33	100	132				165					66		
849-849.5' unac	80	100										273		
849-849.5' ac	139	100		17								52		
879.5-880'	129	100	135				74						12	
880-880.5'	122	100	27											
881.5-882'	104	100			20		10							
882-882.5'	84	100			13									
882.5-883'	128	100			10 juv.?									
883-883.5'	132	100			11 juv.?		11							
883.5-884'	153	100	15				15		7				7	
884-884.5'	113	100	12							12 juv.		12	12	
884.5-885'	127	100	45										9	

Table B23. Conodont abundances in KGS Spencer #2-6 core, normalized to platform elements per kilogram.

KGS Deffenbaugh Quarry #2												
Sample #	Orig.	%	Idiognathodus				Neognath.		Ad	El	Ip	Other
(footage)	wt. (g)	picked	amplif.	podol.	obliquus	juv.	cf. asym.	caud.				
682.5-683'	216	100	1									
685.7-686.1'	142	100	7	1?	1	2			1	1	3	5 lg Pa frag., num. elements
686.3-686.5'	73	100	3		2		2	2		2	3	1 lg Pa frag., 3 ramf., 1 blade, 2 M-e

Table B24. Conodont abundances in KGS Deffenbaugh #2 core, Johnson County, Kansas, and their corresponding sampled footages.

KGS Deffenbaugh Quarry #2										
Sample #	Orig.	%	Idiognathodus				Neognath.		Ad	Ip
(footage)	wt. (g)	picked	amplif.	podol.	obliquus	juv.	cf. asym.	caud.		
682.5-683'	216	100	5							
685.7-686.1'	142	100	49	7?	7	14			7	21
686.3-686.5'	73	100	41		27		27	27		41

Table B25. Conodont abundances in KGS Deffenbaugh #2 core, normalized to platform elements per kilogram.

KGS Edmonds 1A														
Sample #	Orig.	%	Idiognathodus						Neognathodus	Ad	El	Ip	I'des	Other
(footage)	wt. (g)	picked	amplif.	podol.	obliquus	cf. praeob.	juv.	unk.	cf. asymmetricus					
907.5-908'	224	100												1 fragmentary piece
908-908.5'	233	100	41	8	1		40	1	1	5	16	10		6 lg Pa frags, num. elements
931.4-932.4'	312	100								1*				*Ad tip, 3 ramiforms
932.4-933.4'	270	100	3		3		1			1				1 ramiform, 2 S-elements
932.4-933.4' (ls)	81	100									1			3-4 small fragments, 1 ramiform
935-935.6'	328	100	6		1	3	6	1		4	8	8		1 Ng tip, numerous elements
1018-1018.3'	124	100				2								1 ramiform, 1 S-element
1046.2-1047'	186	100					1							juv. could be cf. praeobliq.
1047-1047.5'	169	100					1	1						1 lg Pa frag, 6 S-elements
1047.5-1047.9'	130	100				1							1	
1148-1148.5'	128	100									1	2		1 small fragment observed
1171.4-1172.4'	435							2					1	num. frags and elements
1172.4-1173.4'	330	100						1			2		2	

Table B26. Conodont abundances in KGS Edmonds 1A core, Leavenworth County, Kansas, and their corresponding sampled footages.

KGS Edmonds 1A													
Sample #	Orig.	%	Idiognathodus						Neognathodus	Ad	Ip	I'des	Other
(footage)	wt. (g)	picked	amplif.	podol.	obliquus	cf. praeob.	juv.	unk.	cf. asymmetricus				
908-908.5'	233	100	185	36	5		180	5	5	23	45		
931.4-932.4'	312	100								3*			*Ad tip
932.4-933.4'	270	100	11		11		4			4			
935-935.6'	328	100	21		3	10	21	3		14	27		Ng tip
1018-1018.3'	124	100				17							
1046.2-1047'	186	100					5						juv. could be cf. praeobliq.
1047-1047.5'	169	100					6	6					
1047.5-1047.9'	130	100				8						8	
1148-1148.5'	128	100									17		
1171.4-1172.4'	435							5				2	
1172.4-1173.4'	330	100						3				6	

Table B27. Conodont abundances in KGS Edmonds 1A core, normalized to platform elements per kilogram.

KGS Hopp #1-16																			
Sample #	Orig.	%	Idiognathodus							Neognathodus				Ad	El	Ip	G	I'des	Other
(footage)	wt. (g)	picked	amplif.	podol.	obliq.	cf. praeob.	cf. gibb.	juv.	unk.	bothr.	cf. asym.	caud.	unk.						
1423-1423.5'	229	100																	1 fragment
1423.5-1424'	124	100	2												4	4			3 fragments, 3 ramiforms
1431.5-1432'	289	100	2	2				1						1	4	4	1		2 lg Pa frags, 3 blades
1432-1432.5'	213	100							1										
1432.5-1433'		100																	3 S-elements, 2 ramiforms
1433-1433.5'	273	100	1	1															1 blade fragment
1433.5-1434'	267	100							2*					2					*degraded Pa, 4 S-elements
1434.5-1435'	202	100	1?						1							1			possible *amplificus* (degraded)
1435-1435.5'		100	4	3				1	5			6		8	9	10			poss. *mundulus*, 7 Pa frags
1442.5-1443'	325	100												1					
1497-1497.5'	230	100																	1 small piece lg blade
1497.5-1498'	218	100						1*	1										*poss. juv. *amplificus*
1517.2-1517.7'	165	100							1										
1530.65-1531.05'	193	100	22		4			3	3		1?			1					9 lg Pa frags, 6 Ng tips, 1 S-elem.
1600.3-1600.8'	228	100	2				10	13						4	1				7 lg Pa frags, 1 Ng tip, num. frags
1621-1621.5'	158	100	4			2		4						2	4	1			2 Pa frags, 8 ramiforms, 8 S-elem.
1621.5-1622'	192	100						1											
1652-1652.5'	217	100						2											
1652.5-1653'	181	100																	1 blade fragment
1653-1653.5'	272	100																2	5 S-elements
1653.5-1654'	185	100	3			4					3				1	2		1	2 lg Pa frags, num. elements
1654-1654.35' ac	183	100				10							2		6	5		22	6 lg Pa frags, num. elements
1654-1654.35 unac	200	100																3	2 Pa frags, 4 S-el., 10 ramiforms
1678-1678.5'	138	100						1											1 ramiform
1678.5-1679'	255	100						5	1*									1	*unk. genus, 5 S, 12 ramiforms
1679-1679.5'	299	100						5											numerous frags and elements
1684.5-1685'	197	100							2										1 lg Pa frag, 3 ramiforms
1685-1685.5 ac	42	100				4		8		2								22	numerous frags and elements
1685-1685.5 unac	336	100				3			2									2	1 lg Pa frag, 1 S-element
1685.5-1686.1'	281	100				22		17								1		5	2 Pa frags, 7 ramiforms, 2 frags

Table B28. Conodont abundances in KGS Hopp #1-16 core, Doniphan County, Kansas, and their corresponding sampled footages.

KGS Hopp #1-16																		
Sample #	Orig.	%	Idiognathodus							Neognathodus				Ad	Ip	G	I'des	Other
(footage)	wt. (g)	picked	amplif.	podol.	obliq.	cf. praeob.	cf. gibb.	juv.	unk.	bothr.	cf. asym.	caud.	unk.					
1423.5-1424'	124	100	16												32			
1431.5-1432'	289	100	8	8				4						4	16	4		
1432-1432.5'	213	100							5									
1433-1433.5'	273	100	4	4														
1433.5-1434'	267	100							9*					9				
1434.5-1435'	202	100	5?						5						5			possible *amplificus* (degraded)
1435-1435.5'		100	20	15				5	25			30		40	150			poss. m*undulus*
1442.5-1443'	325	100												3				
1497.5-1498'	218	100						5*	5									*poss. juv. a*mplificus*
1517.2-1517.7'	165	100							6									
1530.65-1531.05'	193	100	710		129			97	97		32?			32				
1600.3-1600.8'	228	100	9				47	60						19				
1621-1621.5'	158	100	26			13		20						13	7			
1621.5-1622'	192	100						5										
1652-1652.5'	217	100						10										
1653-1653.5'	272	100															11	
1653.5-1654'	185	100	41			55					41				27		14	
1654-1654.35' ac	183	100				55							11		27		120	
1654-1654.35 unac	200	100															176	
1678-1678.5'	138	100						10										
1678.5-1679'	255	100						43	9*								9	*unk. genus
1679-1679.5'	299	100						19										
1684.5-1685'	197	100							11									
1685-1685.5 ac	42	100				173		348		87							956	
1685-1685.5 unac	336	100				10			7								7	
1685.5-1686.1'	281	100				80		62							4		18	

Table B29. Conodont abundances in KGS Hopp #1-16 core, normalized to platform elements per kilogram.

MGS FCC-Davis #1												
Sample #	Orig.	%	Idiognathodus				Neognathodus		Ad	El	Ip	Other
(footage)	wt. (g)	picked	amplif.	podol.	juv.	unk.	bothr.	asym.				
1188.8-1189.1'	114	100								1	2	5 ramiforms
1189.1-1189.4'	87	100										2 fragments
1228.42-1229.45'	82	100		1								
1261.3-1262.4'	119	100	2		13	1*	1	6	1	3	7	9 S, 8 ram., 2 lg Pa frags, *degr. lg Pa
1291.67-1291.83'	81	100										1 piece
1356.4-1356.8'	71.5	100			1							
1415.8-1416'	69	100										1 S-element
1416-1416.2'	77	100										1 M-element
1423.2-1423.7'	157	100										1 blade fragment
1509.6-1511.3'	181	100										fragmentary

Table B30. Conodont abundances in MGS Davis “Forest City” core, Holt County, Missouri, and their corresponding sampled footages.

MGS FCC-Davis #1										
Sample #	Orig.	%	Idiognathodus				Neognathodus		Ad	Ip
(footage)	wt. (g)	picked	amplif.	podol.	juv.	unk.	bothr.	asym.		
1188.8-1189.1'	114	100								49
1228.42-1229.45'	82	100		13						
1261.3-1262.4'	119	100	18		114	9	9	53	9	61
1356.4-1356.8'	71.5	100			14					

Table B31. Conodont abundances in MGS Davis “Forest City” core, normalized to platform elements per kilogram.

Type Laddsdale																
Sample #	Orig.	%	Idiognathodus					Neognathodus				Ad	Hnd?	El	Ip	Other
	wt. (g)	picked	amplif.	podol.	obliq.	juv.	unk.	bothr.	asym.	juv.	caud.					
TL3: 12-24"	450	100	2			1				1			1	1	3	2 ramiforms, 8 S-elements
TL2: 0-12" acidized	68	100	8	6	8	31	4			3	20	3	7	23	6	29 lg Pa frags, 20 Ng frags, 27 ram.
TL2: 0-12" unac	450	100		1	1?	4							1	3		1 lg Pa frags, 3 ram., 4 S-elements
TL1: 0.8' carb. ls	500	100	15	5	3	7	5	1	3		4		3	1	1	23 lg Pa frags, 16 Ng frags, 15 ram.

Table B32. Conodont abundances at type Laddsdale section, Davis County, Iowa, and their corresponding sample numbers.

Type Laddsdale														
Sample #	Orig.	%	Idiognathodus					Neognathodus				Ad	Hnd?	Ip
	wt. (g)	picked	amplif.	podol.	obliq.	juv.	unk.	bothr.	asym.	juv.	caud.			
TL3: 12-24"	450	100	5			2				2			2	7
TL2: 0-12" acidized	68	100	145	109	145	564	73			55	364	55	127	109
TL2: 0-12" unac	450	100		3	3?	10							3	
TL1: 0.8' carb. ls	500	100	30	10	6	14	10	2	6		8		6	2

Table B33. Conodont abundances at type Laddsdale section, normalized to platform elements per kilogram.

Lakonta strip pit										
Sample #	Orig.	%	Idiognathodus				Ad	El	Ip	Other
	wt. (g)	picked	amplificus	Sp. B	obliquus	juv.				
BC5: 20" Is above Cliffland 7-14"	250	100	1					1		5 Ig Pa fragments, 1 ramiform, 5 fragments
BC4: 20" Is above Cliffland 0-7"	500	100	17	7	1 4 degr.	2	2	8	13	66 Ig Pa fragments, 5 Ng fragments, 13 Ng tips, 13 phosphatic fragments (possibly con.), num. frags and elem.

Table B34. Conodont abundances at Lakonta strip pit section, Mahaska County, Iowa, and their corresponding sample numbers (*Idiognathodus* species B of Boardman and others, 2004).

Lakonta strip pit									
Sample #	Orig.	%	Idiognathodus				Ad	Ip	Other
	wt. (g)	picked	amplificus	Sp. B	obliquus	juv.			
BC5: 20" Is above Cliffland 7-14"	250	100	4						
BC4: 20" Is above Cliffland 0-7"	500	100	34	14	2 8 degr.	4	4	26	phosphatic fragments (possibly con.)

Table B35. Conodont abundances at Lakonta strip pit section, normalized to platform elements per kilogram (*Idiognathodus* species B of Boardman and others, 2004).

IGS CP-78													
Sample #	Orig.	%	Idiognathodus					Neo.	Ad	El	Ip	I'des	Other
(footage)	wt. (g)	picked	amplificus	podol.	cf. gibbus	juv.	unk.	cf. asym.					
437.9-438.5'	252	100	1	1				2	1	4	1		1 Ng frag, 1 unk- ele.
493.3-493.8'	190	100							2				1 ramiform, 1 S-element
493.8-494.3'	201	100							1				
524.8-525.25'	127	100				5	6			2	5	25	1 I'des frag, 5 Ig Pa frags
525.25-525.7'	137	100			1	1	4			1		12	2 Ig Pa frag, 7 ramiforms

Table B36. Conodont abundances in IGS CP-78 core, Wayne County, Iowa, and their corresponding sampled footages.

IGS CP-78												
Sample #	Orig.	%	Idiognathodus					Neo.	Ad	Ip	I'des	Other
(footage)	wt. (g)	picked	amplificus	podol.	cf. gibbus	juv.	unk.	cf. asym.				
437.9-438.5'	252	100	4	4				8	4	4		1 Ng frag
493.3-493.8'	190	100							11			
493.8-494.3'	201	100							5			
524.8-525.25'	127	100				40	49			40	202	1 I'des frag
525.25-525.7'	137	100			8	8	31				94	

Table B37. Conodont abundances in IGS CP-78 core, normalized to platform elements per kilogram.

IGS CP-79																						
Sample #	Orig.	%	Idiognathodus											Neognathodus				Ad	El	Ip	G	Other
(footage)	wt. (g)	picked	amplif.	podol.	obliq.	cf. praeob.	Sp. B	cf. mun.	cf. robust.	cf. crass.	cf. iowa	juv.	unk.	cf. asym.	caud.	aff. asym.	juv.					
271.2-271.6'		100							3													3 basal plates, 5 S-elements
272.4-272.8'		100	1					4	12							3						1 lg Pa frag, 2 lg frags
272.8-273.2'		100	3						8				1			3						5 lg frags, 1 rm., 3 S, 2 bas.
273.2-273.6'		100							20	5	4	7							3	7		4 lg frags
273.6-273.8'		100							5	6	5	17	5									3 lg Pa frags
273.8-274'		100							3	2		1							23	13		2 lg Pa frags
285.5-285.8'		100							12	15	4	44	3			3			17	18	25	18 lg Pa frags
285.8-286.1'		100	2	7					4	1	6	9	1						15	5	51	7 lg Pa frags
305.5-306'	422	100																				2 frag. S- or M-elements
306-306.3'	324	100	2	1	2							1	1					7	5			3 Id Pa frags, 9 S-el., 2 ram.
306.5-306.8'	138.5	100	1	2																		1 S-elem., 2 frags, 7 ram.
306.8-307'	159	100		2																		5 S-elements, 1 ramiform
307.4-307.6'	106	100																1				
307.6-307.91'	220	100																3	2			3 S-elements
310.4-310.91'	218	100	10	8	5				1			25	5				1	2	5	1		4 Pa frags
395.8-396.3' unac	371	50	2																	1		1 S-element, 1 ramiform
395.8-396.3' ac	47	100	7	2	3		1					15	2					1	7	9		3 Ng frags, 6 lg Pa frags
396.3-396.8'	139	100	8	3	5		4					13	1		9		7	1	8	7		1 Ng frag
397-397.5'	227	100	3																	2		frag. Ides?, 1 lg Pa frag.
397.5-398'	321	100	2									1			1					1		6 lg Pa frags, 8 frags
398-398.5'	402	100	2		1							3			6			1	7	4		8 lg Pa frags
398.5-399'	399	100	1		2	2						9		2					4	10		11 lg Pa frags
399-399.5'	311	100	1			2							1	1					2	4		2 lg Pa frags, 5 ramiforms
399.75-400.5 unac	366	100	1			1						6		7					11	5		3 lg Pa frags
452.25-452.8'	183	100																				1 blade fragment

Table B38. Conodont abundances in IGS CP-79 core, Lucas County, Iowa, and their corresponding sampled footages (*Idiognathodus* species B of Boardman and others, 2004).

IGS CP-79																
Sample #	Orig.	%	Idiognathodus								Neognathodus			Ad	Ip	Other
(footage)	wt. (g)	picked	amplif.	podol.	obliq.	cf. praeob.	Sp. B	cf. robust.	juv.	unk.	cf. asym.	caud.	juv.			
306-306.3'	324	100	6	3	6				3	3				22		
306.5-306.8'	138.5	100	7	15												
306.8-307'	159	100		13												
307.4-307.6'	106	100												9		
307.6-307.91'	220	100												14		
310.4-310.91'	218	100	93	74	46			9	231	19			9	19	9	
395.8-396.3' unac	371	50	16												8	
395.8-396.3' ac	47	100	291	83	125		42		625	83				42	375	
396.3-396.8'	139	100	66	25	41		33		107	8			58	8	58	
397-397.5'	227	100	13												9	frag. I'des?
397.5-398'	321	100	7						3			3			3	
398-398.5'	402	100	5		3				8			15		3	10	
398.5-399'	399	100	3		5	5			23		5				26	
399-399.5'	311	100	3			7				3	3				14	
399.75-400.5 unac	366	100	4			4			22		25				18	

Table B39. Conodont abundances in IGS CP-79 core, normalized to platform elements per kilogram (*Idiognathodus* species B of Boardman and others, 2004).

IGS WC-22									
Sample #	Orig.	%	Idiognathodus			Neognath.	Ad	El	Other
(footage)	wt. (g)	picked	amplificus	podolskensis	unknown	unknown			
389.4-390'	187	100			1*				*degraded Ig Pa
391.75-392'	105	100	1?	1		1		2	
519-519.5'	160	100					1		1 M-element
519.5-520'	188	100	1						

Table B40. Conodont abundances in IGS WC-22 “Logan” core, Harrison County, Iowa, and their corresponding sampled footages.

IGS WC-22						
Sample #	Orig.	%	Idiognathodus		Neognath.	Ad
(footage)	wt. (g)	picked	amplificus	podolskensis	unknown	
391.75-392'	105	100	10?	10	19	
519-519.5'	160	100				6
519.5-520'	188	100	5			

Table B41. Conodont abundances in IGS WC-22 “Logan” core, normalized to platform elements per kilogram.

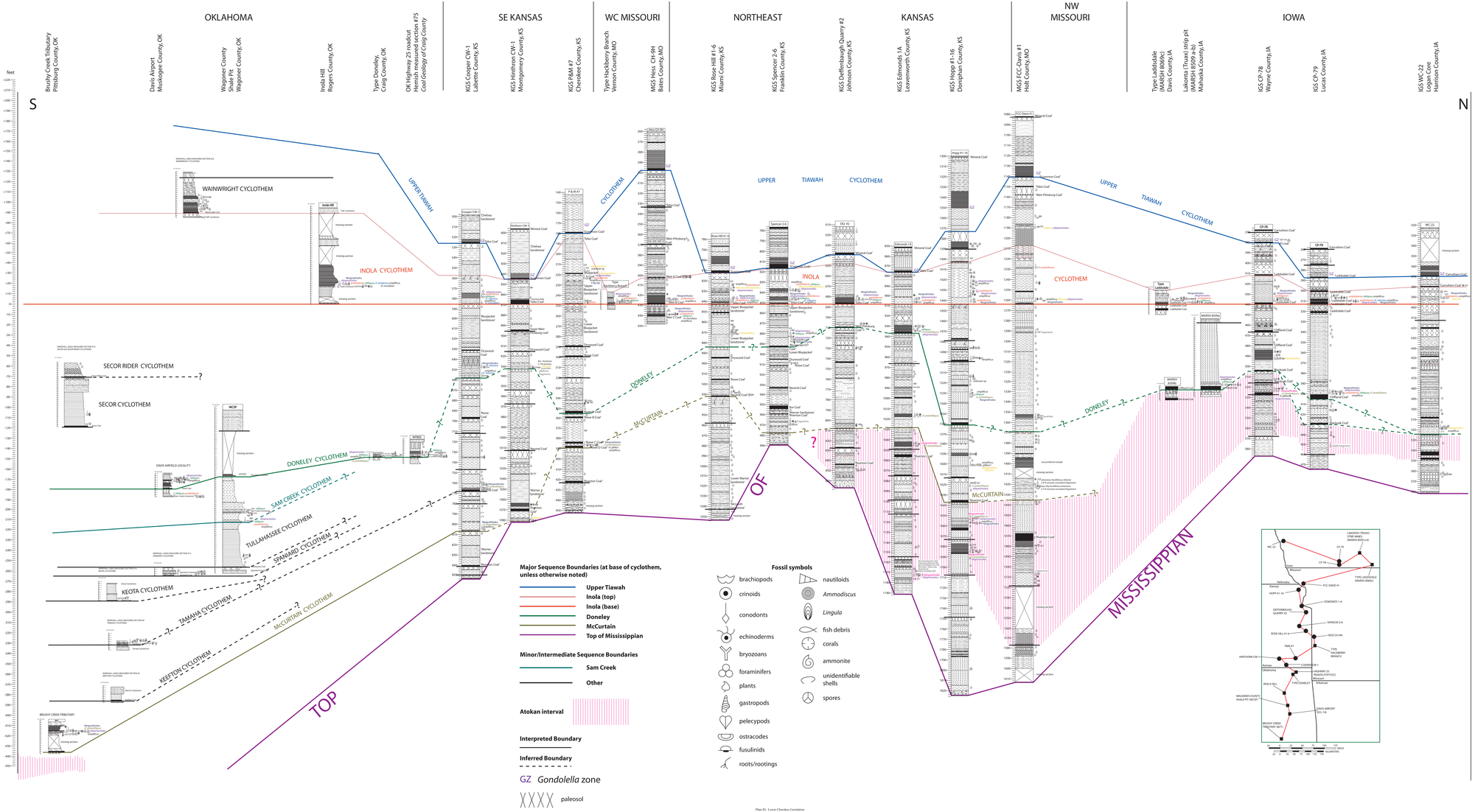

Plate B1. Lower Cherokee Correlation