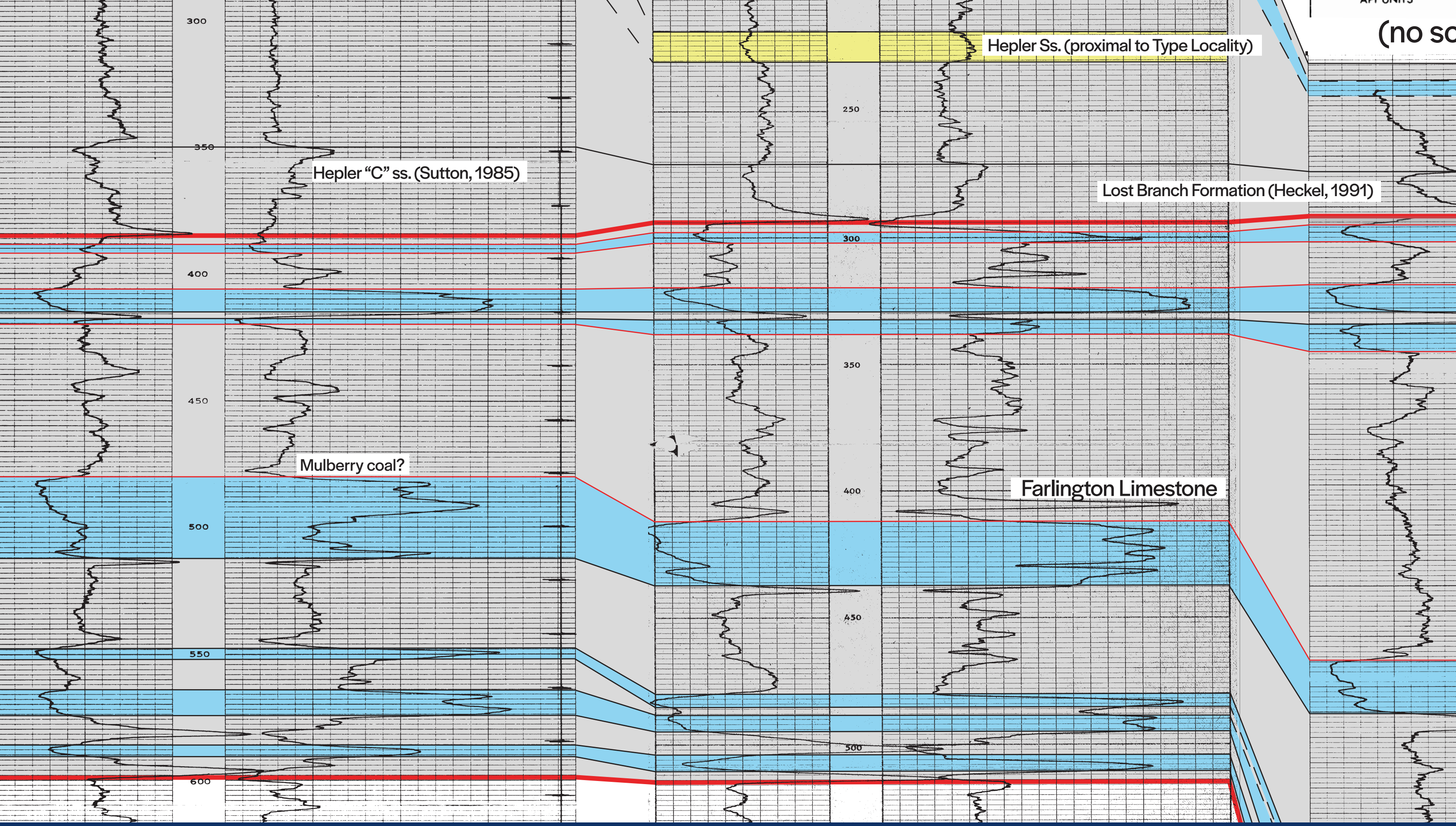

Kansas Geological Survey Bulletin 265

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KU KANSAS GEOLOGICAL SURVEY
The University of Kansas

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Figures

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Key Words
Cherokee Group
Marmaton Group
Pleasanton Group
Petrophysics
Forest City Basin
Cherokee Basin

ABSTRACT

Pennsylvanian (Upper Carboniferous) strata in eastern Kansas have been investigated for more than 120 years. We have determined, however, that discrepancies arising from emphases on either outcrop observations or subsurface data, as well as the loss of some key outcrops since their first descriptions, created major problems in prior stratigraphic interpretations. One particularly problematic stratigraphic interval contains the boundaries between units in the Marmaton (Desmoinesian) and Pleasanton (Missourian) groups, which encompasses the global Moscovian-Kasimovian stage boundary. We use 246 petrophysical well logs, especially gamma ray and neutron logs, to provide greater stratigraphic control among 22 previously described type outcrops, neostratotypes, and principal reference localities. Nine new stratigraphic cross sections resulting from our analysis of these data permit innovative interpretations of ancient facies belts as well as a reassessment of the geometry and structural history of the Cherokee–Forest City Basin. We make three recommendations regarding group boundaries on the basis of our analysis: 1) The boundary between the Cherokee and Marmaton groups should be placed at the base of the Excello Shale, thereby including the unit within the Marmaton Group. An unnamed limestone underlying the Excello Shale and observed in some areas should ideally be included within the Marmaton, but this unit will require further study. 2) The boundary between the Marmaton and Pleasanton groups should be placed at the base of the Nuyaka Creek Shale Member, as opposed to the standing placement at the base of the Hepler Sandstone. 3) The boundary between the Pleasanton and Kansas City groups should be maintained at the base of the Critzer Limestone Member of the Hertha Limestone. Additionally, we advocate the following changes to stratigraphic nomenclature in Kansas: 1) the Fort Scott Limestone should be revised to include the Excello Shale; 2) members of the Lenapah Limestone (the Idenbro Limestone Member, Perry Farm Shale Member, and Norfleet Limestone Member) should be abandoned because of prior miscorrelations; 3) the stratigraphic interval between the Lenapah Limestone and the Nuyaka Creek Shale Member correlates to either the Holdenville Shale or Memorial Shale—therefore, we leave this interval unnamed; and 4) with our proposal to place the lower boundary of the Pleasanton Group at the base of the Nuyaka Creek Shale Member, the lower boundary of the Lost Branch Formation should likewise be moved to that same level. The stratigraphic contexts of the Seminole, Tacket, and Shale Hill formations remain to be clarified by future work.

INTRODUCTION

The long history of stratigraphic studies in Kansas has produced a voluminous literature that has resulted in complexity and confusion in terms of stratigraphic nomenclature and correlation. This is no less true in Middle Pennsylvanian (Upper Carboniferous) strata in eastern Kansas, where regional variability in the use, definition, and stratigraphic position of many units has frequently changed through time and historical interpretations drawn from those units have not kept pace with subsequent revisions (see Oborny et al., 2022a). The loss of some key outcrops since their initial descriptions or studies that emphasized outcrop observation to the exclusion of subsurface data, or vice versa, created major problems in prior stratigraphic interpretations. This contribution seeks to reconcile known recent and historical stratigraphic discrepancies with new observations based on subsurface correlation of petrophysical well log data to important type, neostratotype, and principal localities for Pennsylvanian lithostratigraphic units in eastern Kansas.

GEOLOGICAL BACKGROUND

Geological Setting

Upper Desmoinesian and Lower Missourian (Pennsylvanian, Upper Carboniferous) strata analyzed in this study were deposited in an epicontinental sea that covered much of the North American Midcontinent (fig. 1). Prior to deposition of the mid-Desmoinesian, there existed two separate Pennsylvanian-aged basins: the Cherokee Basin to the south and the Forest City Basin in the north, separated by the Bourbon arch (Lee, 1943). The Forest City Basin was filled by mid-Desmoinesian time and hitherto considered the "Northern Midcontinent Shelf" component of the Cherokee Basin, with strata generally thickening southward from southwestern

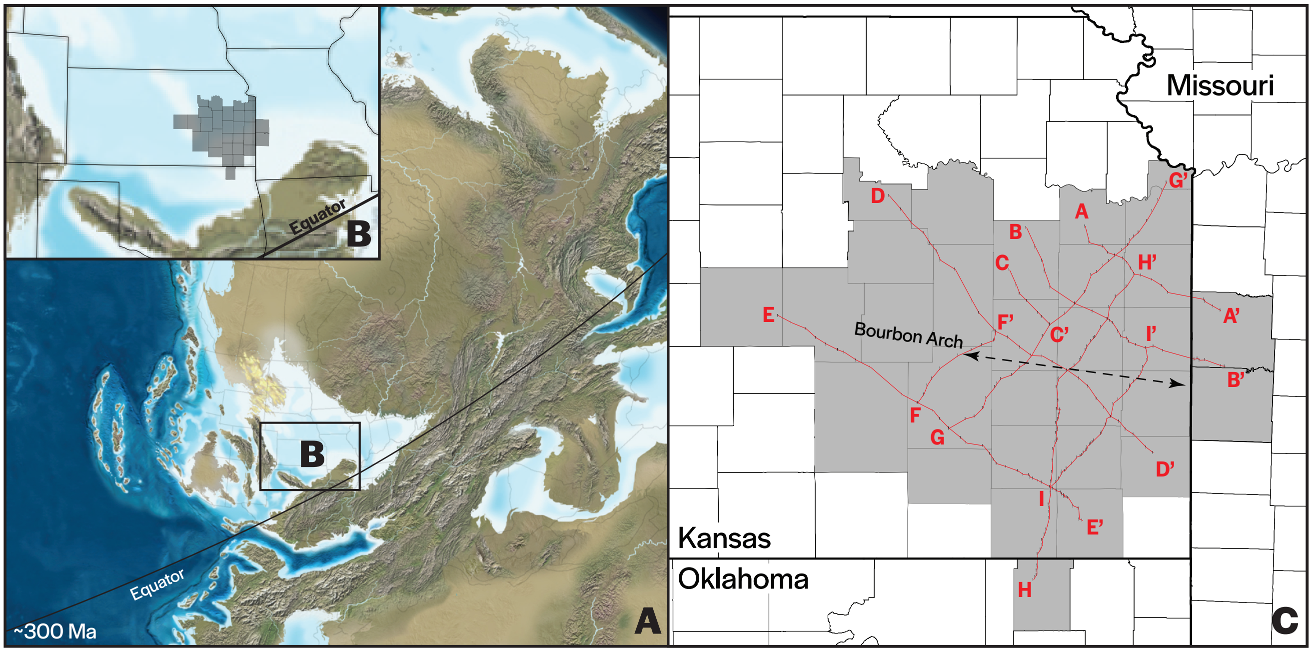

Figure 1. A) Laurentian paleogeographic reconstruction (300 Ma) from Blakey (2013). Paleo-equator is from Heckel (2013). **B)** Focus area of study (i.e., 30 counties) overlying state boundaries. **C)** Thirty-county focus area with cross sections A through I. Black dots represent locations of petrophysical well logs used in this study. West-to-east dashed line with arrows represents general trend of the Bourbon arch as reported by Lee (1943).

Iowa to northeastern Oklahoma (e.g., Joeckel et al., 2007; Heckel, 2013, 2023). Oborny and Hasiuk (2022), however, determined that the entire Pennsylvanian succession thickened southeastward toward the Ozark Plateau in Missouri. Thus, Oborny and Hasiuk (2022) refer to a combined Cherokee–Forest City Basin (CFCB). The combined basin's erosional margin is closely mirrored by the present-day Pennsylvanian outcrop belt, which encompasses northeastern Oklahoma, eastern Kansas, western Missouri, southeastern Nebraska, southwestern Iowa, and several Indian Nations. Two North American stages bear names from this outcrop belt, Desmoinesian for the Des Moines River in Iowa and Missourian for the Missouri River north of Kansas City. These intervals are roughly equivalent to the global Kasimovian and Moscovian stages, respectively, which are recognized by the International Commission on Stratigraphy (fig. 2; Cohen et al., [2013] 2023).

Nomenclatural History and Boundary Definitions

A long history of study by many authors has resulted in confusing and sometimes contradictory statements about Pennsylvanian stratigraphic nomenclature in Kansas (e.g., Drake, 1897; Adams, 1903; Schrader, 1908; Ohern, 1910; Moore, 1932, 1936; Wilmarth, 1936; Jewett, 1941, 1945; Moore, 1948; Moore et al., 1951; Condra and Reed, 1959; Hatcher, 1961; Zeller, 1968; Heckel, 1992; Watney and Heckel, 1994; Fay, 1997; Baars and Maples, 1998; Heckel and Watney, 2002; Gentile and Thompson, 2004; Bridges et al., 2019; and Oborny et al., 2022a). A detailed analysis of all facets in this rich and complex history is beyond the scope of this study. We therefore limit our discussion to nomenclatural history and boundaries of the Marmaton and Pleasanton groups.

Heckel (1992), Watney and Heckel (1994), and Heckel and Watney (2002) proposed nomenclatural revisions in Kansas for the upper Cherokee through Douglas groups to reconcile longstanding stratigraphic and nomenclatural issues. These studies proposed revisions to group and subgroup boundaries between and within the Cherokee, Marmaton, Pleasanton, and lower Kansas City groups; they also redefined the nomenclature of the Pleasanton Group. The Desmoinesian-Missourian stage boundary—historically established at the base of a unit termed the Hepler Sandstone and coinciding with the boundary between the Marmaton and Pleasanton groups (Jewett, 1940; Moore et al., 1951)—was also moved higher to the base of a unit termed the Exline Limestone (Heckel and Watney, 2002; Heckel et al., 2002). At present, the nomenclatural schemes proposed by Heckel (1992), Watney and Heckel (1994), and Heckel and Watney (2002), apart from that applying to the Zarah Subgroup (Oborny et al., 2022b), have not formally been adopted for use in Kansas by the Kansas Geological Survey (KGS) Stratigraphic Nomenclature Committee. Nevertheless, the recommendations of Heckel and Watney (2002) are now recognized, with some modification, by the geological surveys of Iowa and Missouri (Pope, 2012; Bridges and Mulvany, 2019; Bridges et al., 2019). Furthermore, in the absence of a more recent review than that of Condra and Reed (1959), the Conservation and Survey Division in Nebraska has adopted Pennsylvanian stratigraphic revisions from neighboring states, particularly those of Watney and Heckel (1994), Pope (2012), and Heckel and Watney (2002) (R. M. Joeckel, personal communication, April 2023).

This bulletin may in places use both a lithologic term and a rank term when discussing certain units, such as "Fort Scott Limestone

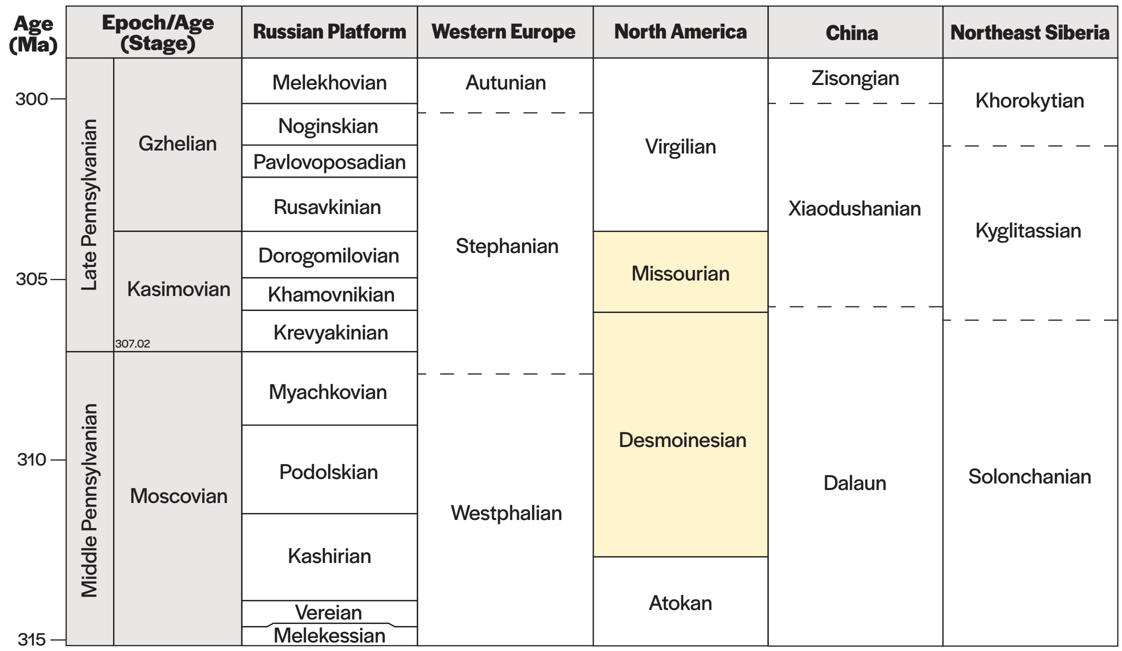

Figure 2. Correlation chart showing relationship between North American stages of strata in this study and international stages (from Oborny and Hasiuk, 2022; after "Carboniferous Regional Subdivisions" chart, fig. 23.5, in Aretz et al., 2021).

Formation" and "Fort Scott Limestone." We do so because state surveys use similar nomenclatural schemes while recognizing some stratigraphic units at different ranks, typically formation instead of member or vice versa, and because lithic or hierarchal designations are used in some instances. A good example is the contrast between the Marmaton succession in Bridges and Mulvany (2019) and Bridges et al. (2019) and that in Zeller (1968) and Pope (2012), which is outlined in some detail below. Names that include both a lithologic term and a stratigraphic rank are generally not favored by the International Stratigraphic Guide (Chapter 5.F; Salvador, 1994), although the North American Stratigraphic Code describes such usage for members (Article 30c; North American Commission on Stratigraphic Nomenclature, 2021).

Definition of the Marmaton Group and its lower boundary

The stratigraphic name "Marmaton" was first used by Keyes (1897) in defining a shale formation between the Oswego and Pawnee limestones along Marmaton Creek where it traverses the Kansas-Missouri state line in eastern Bourbon County, Kansas. This unit is now recognized as the Labette Shale in the lower Marmaton Group (fig. 3). Haworth (1898) later redefined the upper and lower boundaries of the group (at that time ranked as a formation) in Kansas, including within it all strata from the basal contact of the Oswego Limestone through the top of an interval he termed the "Pleasanton shales." The name "Oswego"—applied to the lowest limestone interval of the Marmaton—was already in use in New York State to define a Silurian unit (Adams, 1903, p. 30) and was retired in favor of the Fort Scott Limestone. Moore (1932) restricted the Marmaton's upper stratigraphic range and elevated it to group rank—establishing the upper boundary at a regional disconformity beneath an interval of unnamed shales and sandstones. A prominent yet laterally discontinuous sandstone overlying this disconformity, named the Hepler Sandstone, would later be used in defining the current boundary between the Marmaton and Pleasanton groups in Kansas (Jewett, 1940; Moore et al., 1951, and forthcoming discussion). The formal upper and lower boundary definitions have remained essentially the same for nearly 90 years, even though its internal subdivisions and nomenclature have changed (fig. 3).

The Fort Scott Limestone Formation, the base of which defines the boundary between the Cherokee and Marmaton groups in Kansas, was first described by Bennett (1896, p. 88–91) for exposures near Fort Scott, Bourbon County, Kansas. Jewett (1941, p. 303) established a formal type locality at a now-overgrown quarry about 1 mile (1.6 km) north of the town (37.859584°, -94.699822°). Several constituent members were originally defined in Missouri, and the regional internal subdivision of the unit varies across state lines. In particular, the Fort Scott Limestone is a formation in Kansas but it has been elevated to a subgroup in Missouri, where it contains four formations (Bridges and Mulvany, 2019; Bridges et al., 2019). We refer the reader to the historical reviews of the Fort Scott Limestone by Jewett (1941) and Gentile and Thompson (2004, p. B-135-190) for details. In Kansas, the Blackjack Creek Limestone Member, considered to be a formation in Missouri, comprises the basal member of the Fort Scott Limestone. Cline (1941, p. 36) defined the Blackjack Creek for an exposure studied by Hinds (1912, p. 220) in northeastern Johnson County, Missouri, about 90 miles (about 145 km) northeast of the type section of the Fort Scott Limestone. Hinds and Greene (1915) correlated the Blackjack Creek southwest of its type locality to the lower carbonate at the type section of the Fort Scott Limestone in Kansas, an interpretation also adopted by Jewett (1941). Gentile and Thompson (2004) established a neostratotype

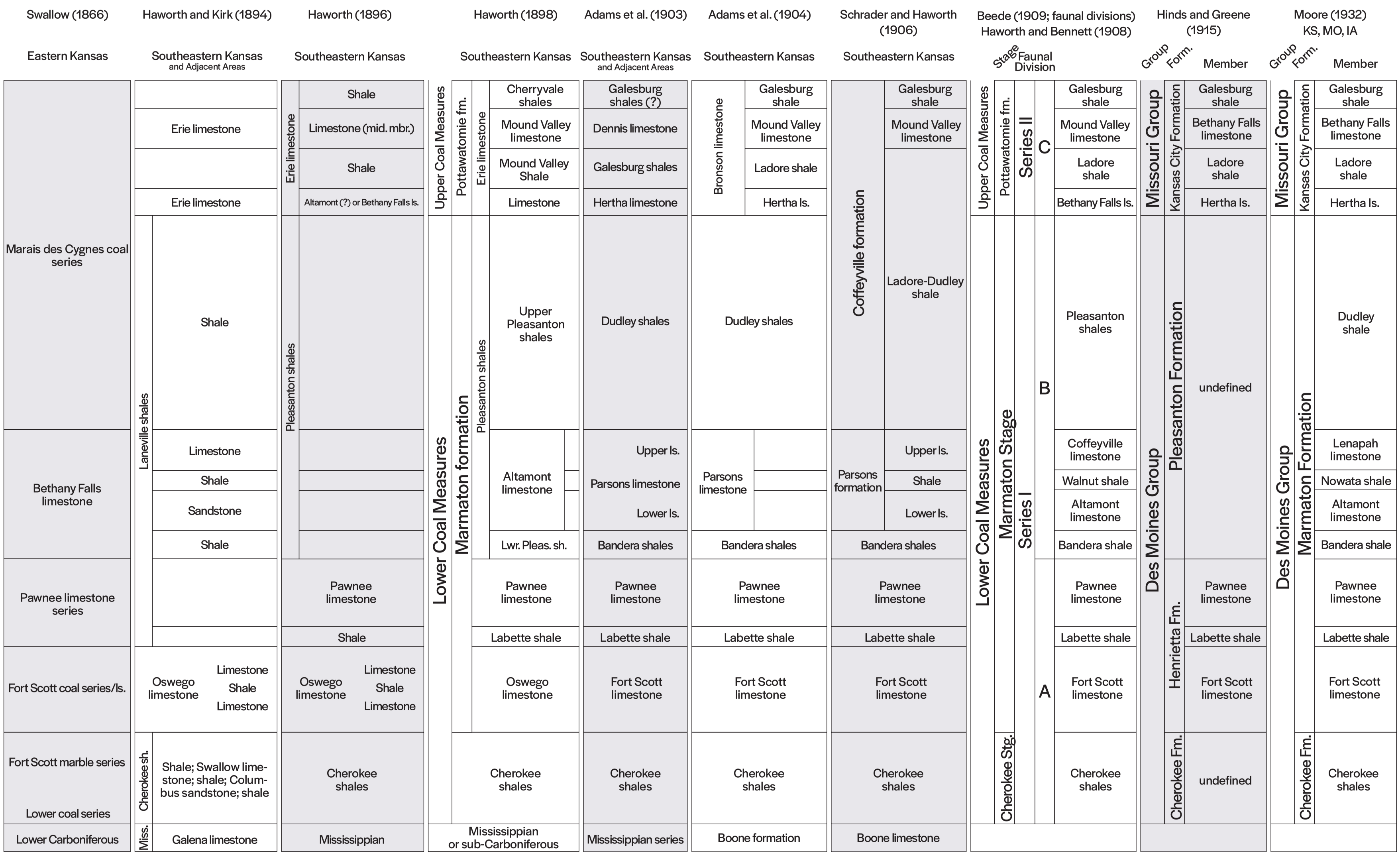

Figure 3. Nomenclatural history of upper Desmoinesian through lower Missourian (Pennsylvanian) strata in Kansas (modified from Oborny et al., 2022a). See Oborny et al. (2022a) for further information regarding prior works and unit abbreviations listed within the figure.

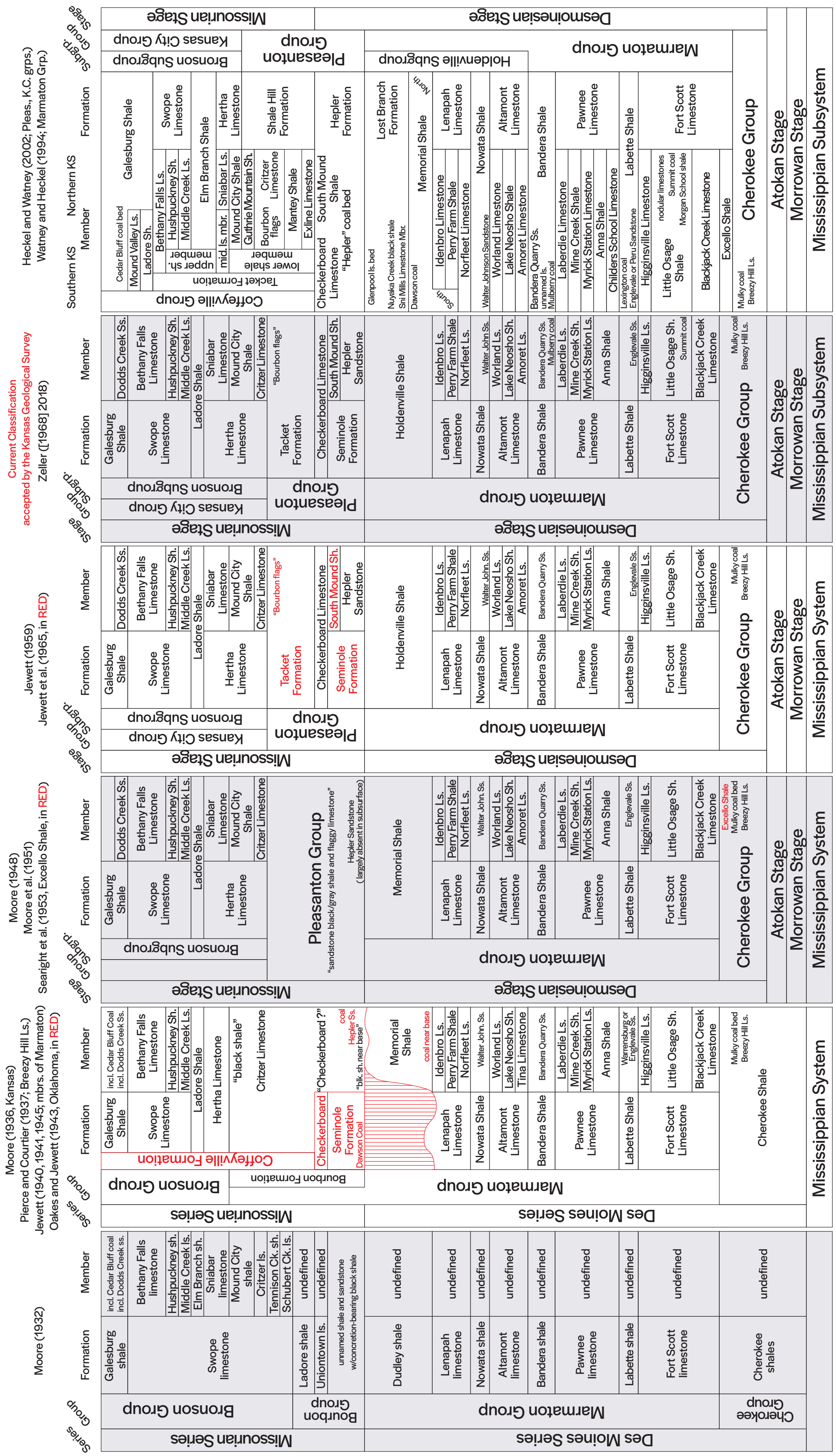

Figure 3 (continued).

section for the Blackjack Creek about 78 miles (about 126 km) northeast of the Fort Scott Limestone type section (38.792443°, -93.890134°).

Watney and Heckel (1994) proposed moving the boundary between the Cherokee and Marmaton groups in Kansas from the base of the Blackjack Creek to a lower stratigraphic position coincident with the base of the underlying Excello Shale. This placement has been formally adopted in Missouri (Gentile and Thompson, 2004, p. B-136; Bridges et al., 2019). Iowa and, informally, Nebraska recognize the Excello Shale as a part of the Marmaton Group, although the basal boundary of the Marmaton Group is at the base of an unnamed limestone that underlies the Excello Shale (Ravn et al., 1984; Pope, 2012). Although the Excello Shale is formally or informally included in the Marmaton Group in Iowa, Missouri, and Nebraska, it is recognized as the upper member of the Cherokee Group in Oklahoma (formally; see Hemish, 2002) and Kansas (informally). The original type section for the Excello Shale was in a former coal strip pit (Searight, 1955, p. 35; Gentile and Thompson, 2004) in northeastern Missouri, about 171 miles (about 275 km) northeast of the Fort Scott Limestone type section (39.633688°, -92.518709°). Gentile and Thompson (2004) proposed a neostratotype section approximately 65 miles (about 105 km) northeast of the Fort Scott Limestone type section (38.563083°, -93.913994°).

Definition of the Pleasanton Group and its lower and upper boundaries

The name "Pleasanton" was first applied by Haworth (1895) to a thick succession of shale near the town of Pleasanton in Linn County, Kansas. The name was used for the interval between the presently recognized Pawnee Limestone (middle Marmaton Group) and the overlying then so-called "Erie limestone" (fig. 3). Haworth (1896) correlated the basal beds of the Erie limestone to a limestone, presently recognized as the Altamont Limestone, near Altamont, Kansas, 75 miles (about 121 km) to the southwest. Haworth (1898) later realized that this correlation was erroneous by determining that the limestone unit near Altamont thinned northward and that shales underlying and overlying this limestone coalesced to form the thick succession of Pleasanton shale near Pleasanton, Kansas. In effect, Haworth (1898) defined the entire shale interval, encompassing the Altamont Limestone, as the Pleasanton shales. Haworth (1898, p. 40) also subdivided the Pleasanton shales into two intervals, a lower one between the Pawnee and the Altamont and an upper one between the Altamont and the Erie. Adams (1903) later applied the name "Hertha" to the basal bed of the Erie Limestone (the modern Sniabar Limestone Member) and provided a revised nomenclatural hierarchy for the Pleasanton interval in southern Kansas (Adams, 1903, p. 32–35). This revision replaced the lower and upper Pleasanton shales designation in that region with the "Bandera" and "Dudley" shales, respectively, separated by a "Parsons limestone." The Parsons limestone is equivalent to the modern Altamont through Lenapah. The salient implication of this revision is that the lower Pleasanton shales of earlier studies was effectively removed from future definitions of the Pleasanton Shale. Investigations over the subsequent 45 years applied either the name "Dudley" in southeastern Kansas (Adams, 1903) or Pleasanton in northeastern Kansas for shales immediately below Haworth's (1895) Erie limestone. The term Bourbon was also applied to the interval in conjunction with Nebraska (Moore, 1948; Condra and Reed, 1959). In 1947, Moore proposed that the use and definition of the term Pleasanton become regionally standardized. Though the rank and definition of the Pleasanton varies regionally, it is presently recognized by the geological surveys of Iowa (Pope, 2012), Kansas (Zeller, 1968), Nebraska (informally; R. M. Joeckel, personal communication, April 2023), and Missouri (Bridges and Mulvany, 2019; Bridges et al., 2019).

The boundary between the Marmaton and Pleasanton groups is currently established in Kansas at the base of the Seminole Formation (fig. 3). The term Seminole was first applied by Taff (1901) to a sandy conglomeratic unit in southeastern Seminole County, Oklahoma (34.996169°, -96.480933°). Branson (1957) raised it to the rank of formation and included within it all strata from the base of the conglomerate through the basal contact of an overlying Checkerboard Limestone; the Checkerboard type section is located in Okmulgee County, Oklahoma (Gould, 1925, p. 72; 35.766227°, -96.126322°). Moore (1936, p. 74) previously provided a tentative correlation of the Checkerboard Limestone northward into Kansas to within the "Bourbon Formation" (within the present Pleasanton Group) at a stratigraphic position below a limestone termed the Critzer Limestone. A more detailed assessment by Oakes and Jewett (1943) also came to this conclusion, and Jewett et al. (1965) formalized the usage of Seminole and Checkerboard formations within the Pleasanton Group of Kansas. Jewett et al. (1965) used the basal contact of the Hepler Sandstone in defining the base of the Seminole Formation (i.e., base of the Pleasanton Group) and adopted nomenclature first used by Emery (1962, p. 11) to define the overlying shale division, between the Hepler Sandstone and Checkerboard Limestone, as the South Mound Shale Member (i.e., type section; 37.442209°, -95.206321°; located in Neosho County, Kansas). Jewett et al. (1965) also noted that the South Mound Shale Member could be identified only where the Checkerboard Limestone was present and established a neostratotype section for the unit approximately 20 miles southwest of the unit's original type section (37.193348°, -95.410139° in Labette County, Kansas). This unit was later given a principal reference section by Heckel (1991, p. 44–45, Outcrop 18) adjacent to the original type section of Emery (1962).

Jewett (1940) established the type section of the Hepler Sandstone at an exposure approximately 1.5 miles (2.4 km) north of the town of Hepler in Bourbon County, Kansas (37.696456°, -94.969919°). This exposure is about 204 miles (about 328 km) northeast of the type section of the Seminole Formation in Oklahoma. Though the rank and definition of a Hepler lithostratigraphic unit has changed several times (e.g., Jewett, 1940; Moore et al., 1951; Jewett, 1959; Jewett et al., 1965; Zeller, 1968; Heckel and Watney, 2002), the use of the unit's basal contact to define the boundary between the Marmaton and Pleasanton groups in Kansas has generally persisted. The name Hepler, however, has been applied to numerous lenticular sandstones at various stratigraphic positions near the unit's type locality in Bourbon County, Kansas (Sutton, 1985; Bennison, 1985, p. 231; Heckel, 1991). Therefore, Heckel and Watney (2002) redefined the Hepler Sandstone as the Hepler Formation, which included all those separate lenticular sandstones. Those authors also retained a basal contact that corresponds to the boundary between the Marmaton and Pleasanton groups. Heckel and Watney (2002) determined that the Checkerboard Limestone of Oklahoma was laterally discontinuous into Kansas (cf. Jewett et al., 1965), thereby redefining the Checkerboard Limestone as a member within their new Hepler Formation. These proposed revisions, with some modification to rank and lithic designation, are now recognized in Iowa (Pope, 2012), Nebraska (informally; R. M. Joeckel, personal communication, April 2023), and Missouri (Bridges and Mulvany, 2019; Bridges et al., 2019). The proposed revisions by Heckel and Watney (2002) to this boundary have not formally been adopted for use in Kansas by the Kansas Geological Survey (KGS) Stratigraphic Nomenclature Committee.

The boundary between the Pleasanton and Kansas City groups in Kansas is currently established at the contact between the Tacket Formation and overlying Critzer Limestone Member of the Hertha Limestone Formation (fig. 3). Jewett et al. (1965) assigned the name Tacket to all strata between the Checkerboard Limestone and Critzer Limestone Member and established a type section for the unit in Labette County, Kansas (37.259632°, -95.34904°). Jewett (1932) applied the name "Critzer" to a limestone within the shale that Moore (1936) called the Bourbon Formation. Moore later proposed that the term Bourbon should instead be replaced with Pleasanton and that the interval's upper boundary should be established at the base of the Critzer (Moore, 1948). With this revision, the Critzer and overlying Mound City Shale Member of Jewett (1932) were included as members of the newly defined Hertha Limestone in the Kansas City Group, resulting in the present nomenclatural hierarchy for this interval (Zeller, 1968). The type section of the Critzer Limestone Member, and the group boundary position, is located near Critzer, Linn County, Kansas, (38.138822°, -94.915329°).

From the 1960s into the 1990s, the Pleasanton Group in Kansas and correlative strata in Missouri underwent extensive litho- and biostratigraphic evaluation (e.g., Hatcher, 1961; Emery, 1962; Jewett et al., 1965; Howe, 1982; Underwood, 1984; Sutton, 1985; Pavlicek, 1986; and Heckel, 1992). The findings from several of these works were foundational to the proposed and widely accepted nomenclatural revisions to the Pleasanton Group by Heckel and Watney (2002). Investigations of the Pleasanton Group in Livingston County, Missouri, (Howe, 1982) and in Linn and Bourbon counties, Kansas, (Jewett et al., 1965; Underwood, 1984) and of the Tacket Formation (Pavlicek, 1986; Heckel, 1992) in Kansas and Oklahoma are particularly important. In Missouri, Howe (1982) subdivided the Pleasanton Group into three formations—the Seminole, Lee Summit, and Shale Hill—which he correlated to the Seminole, Checkerboard, and Tacket formations in Kansas (fig. 4). Pavlicek (1986) determined that the upper black shale in the Tacket Formation of southern Kansas (i.e., the uppermost formation of the Pleasanton Group; Zeller, 1968) contained conodont fauna indicative of the Hushpuckney Shale Member of the Swope Limestone of the Kansas City Group in northeastern Kansas. Heckel (1992) agreed with the biostratigraphic interpretations of Pavlicek (1986) and concluded that the continued application of the name "Tacket" to the upper part of the Pleasanton Group was problematic, as it encompassed multiple formations above and below the Pleasanton–Kansas City group boundary of Zeller (1968). Therefore, Heckel (1992) and Heckel and Watney (2002) proposed that the Shale Hill Formation of Howe (1982) be adopted—and the original definition revised to include the Lee Summit Formation of Howe (1982)—in place of the Tacket Formation in areas north of the type area for the Tacket Formation in Labette County, southeastern Kansas (fig. 4). Additionally, Heckel (1992) and Heckel and Watney (2002) proposed a new internal hierarchy of members within the Shale Hill Formation and moved the Pleasanton–Kansas City group boundary up to the base of the Mound City Shale Member.

The type section of the Shale Hill Formation is in Livingston County, Missouri (stratigraphic section 25, p. 84, in Howe, 1982; 39.749896°, -93.634723°). Here, Howe (1982) noted a "thin streak" of coal overlying 1–2 feet (0.3–0.6 m) of clay or underclay between the Critzer and Mound City members of the Hertha Limestone. This coal streak and underclay would later provide support for the conclusion that the Critzer be included as a member in the upper Pleasanton Group shale rather than the overlying Hertha Limestone. If the Critzer is a transgressive component of the Hertha cyclothem, then coal and underclay cannot exist between the Critzer and the black fissile facies of the Mound City (P. H. Heckel, personal communication, August 2021; Heckel, 2013, therein fig. 7 cycle 12). Neither Heckel (1992) nor Heckel and Watney (2002) addressed this sequence stratigraphic implication, however. Instead, these authors noted that the "Bourbon flags," an enigmatic informal unit observed in Bourbon and Linn counties, Kansas (see evaluations of flags by Jewett et al., 1965, and Underwood, 1984), were likely a basinward facies of the Critzer and that a southeastward thickening shale that Heckel (1992) and Heckel and Watney (2002) termed the Guthrie Mountain Shale existed between the Bourbon flags and the black fissile facies of the Mound City in eastern Kansas. Heckel (1992) and Heckel and Watney (2002) noted a lithological similarity between the Guthrie Mountain Shale and shales of the Pleasanton Group elsewhere. Therefore, Heckel (1992) and Heckel and Watney (2002) concluded that the Critzer should not be a part of the Kansas City Group and established the boundary between the Pleasanton and Kansas City groups at the top of the newly defined Guthrie Mountain Shale Member (i.e., base of black fissile Mound City Shale Member). The type section of the Guthrie Mountain Member of the Shale Hill Formation is 1.5 miles southwest of Guthrie Mountain in Bourbon County, Kansas, about 140 miles (about 225 km) southwest of the Shale Hill type section in Livingston County, Missouri (37.979405°, -94.915452°). Additionally, for later discussion, Heckel (1992, p. 33) stated that the two best reference sections for the Bourbon flags are the spillway of Hidden Valley Lake (Bourbon County, Kansas, 38.024527°, -94.958271°) and in the lower part of the composite principal reference section of the Shale Hill Formation in Linn County, Kansas, along U.S. Highway 69 (38.116251°, -94.71348°).

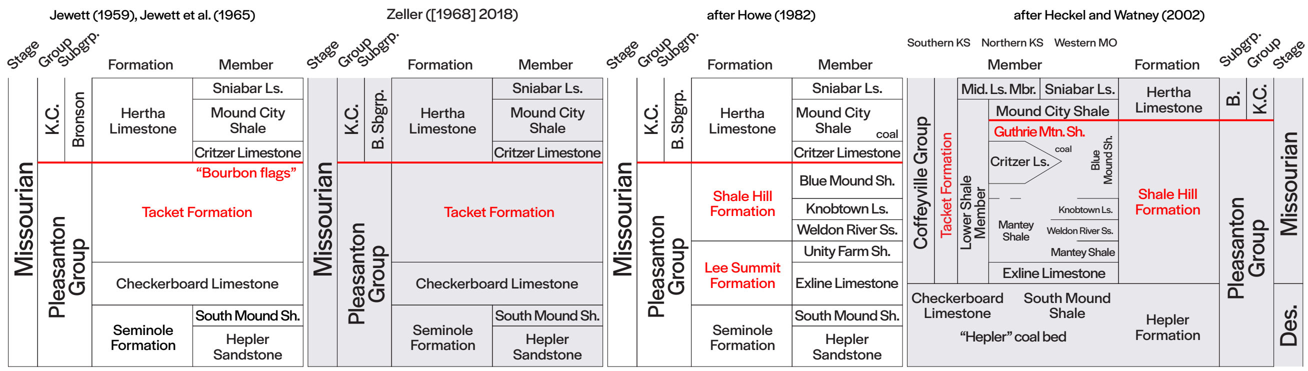

Figure 4. Select nomenclatural changes to the Pleasanton Group in Kansas and Missouri between 1959 and 2002. The Checkerboard Limestone of Kansas was considered by Howe (1982) to be correlative to the Exline Limestone in Missouri. Heckel (1992) and Heckel and Watney (2002) later concluded that the Checkerboard Limestone thinned northward from its type location in Oklahoma to within the upper part of the South Mound Shale Member. Therefore, based on Heckel and Watney (2002), the Checkerboard Limestone could not be correlative to the Exline Limestone in Missouri, and we illustrate the Checkerboard Limestone at a position below the Exline Limestone in the Heckel and Watney (2002) column. The Bourbon flags were considered by Heckel (1992) and Heckel and Watney (2002) to represent a basinward facies of the Critzer Limestone. The assigned position of the Bourbon flags in this figure does not take into account the conclusions of Howe (1982, p. 21) who speculated, while expressing uncertainty, that the Bourbon flags in Kansas could be correlative to the Unity Farm Shale Member in Missouri. Heckel (1992) later expanded the definition of the Unity Farm Shale Member to include all strata between the Exline and Critzer members (i.e., encompassing the Knobtown Limestone and Weldon River Sandstone members). Heckel and Watney (2002, p. 11) also define the Unity Farm in this way. However, fig. 2 therein illustrates the Critzer pinching out within the upper part of the Blue Mound Shale Member in Missouri, suggesting that the shale immediately below the Critzer—which Heckel (1992) included within the Unity Farm Shale Member—was later removed from the Unity Farm and included within the lower part of the Blue Mound. We illustrate the interpretations of Heckel and Watney (2002, fig. 2), which also illustrates the Weldon River and Knobtown members of Howe (1982) being absent in Kansas. Units discussed in text and boundary between the Pleasanton and Kansas City groups are in red. Abbreviations: B. Sbgrp. = Bronson Subgroup, Des. = Desmoinesian, K.C. = Kansas City, Ls. = Limestone, Mid. Ls. Mbr. = Middle Limestone Member, Sh. = Shale, Subgrp. = Subgroup, Ss. = Sandstone, and Mtn. = Mountain

METHODS

This study focuses on the Marmaton and Pleasanton groups of the upper Desmoinesian through lower Missourian stages, but we include correlations in the upper Missourian and lower Virgilian stages in our data. Detailed outcrop-to-subsurface stratigraphic analyses of the upper Desmoinesian through mid-Virgilian stages were accomplished through the integration of 243 petrophysical well logs and 24 drillers' logs to construct well-log cross sections that span 30 adjoining counties in Kansas, Missouri, and Oklahoma (Supplemental File 1: Well Locations; table 1).

Data from numerous additional petrophysical and drillers' logs were also used to evaluate important type sections (Supplemental File 2: Type Section Evaluations; table 2). We sought to maintain less than 6 miles (10 km) between wells where practicable. In areas with complex structural or stratigraphic architecture, we used log data at intervals of 1 mi (1.6 km) or less to capture details. Petrophysical data were mostly gamma-ray and bulk density or neutron logs. We employed drillers' logs where available or as needed to identify lithofacies and lithologic variability. Subsurface data were collected from official online sources (KGS, 2021; MDNR, 2021; OCC, 2021) and complemented by data from other investigations that made various petrophysical, core data, and lithostratigraphic interpretations (e.g., Underwood, 1984; Knight, 1985; Sutton, 1985; Killen, 1986; Staton, 1987; Heckel, 1991; Hemish, 2002; Brown, 2003; Lange, 2003; Johnson, 2004; Newell and Bailey, 2012; Newell and Stalder, 2014; Oborny et al., 2017). Nine cross sections (A through I; Supplemental File 4) were constructed in a grid to verify the circular correlation of stratigraphic units (fig. 1c). Five northwest–southeast cross sections (A–E) parallel known faults or tectonic zones such as the Bolivar-Mansfield and Fall River tectonic zones (Berendsen and Blair, 1986, 1991; Baars and Watney, 1991; Blair et al., 1992; Mcbee, 2003; Cox, 2009). Four additional cross sections (F–I) trend southwest–northeast, or perpendicular to the same tectonic zones. Units within our cross sections are colored on the basis of the dominant lithology. We strove to distinguish between shale- (gray) and carbonate- (blue) dominated intervals. Nevertheless, the sheer size of the study area precludes accounting for all variability in lithofacies within particular units. Thus, some shales within carbonate-dominated intervals and some carbonates within shale-dominated units are not distinguished. Moreover, some formations are colored on the basis of their lithological designation at the formational level. For example, some limestone formations of the Marmaton Group are colored blue even though they contain thin internal shales (e.g., the Lake Neosho Shale

Table 1. Statistical information for cross sections A through I (Supplemental File 4).

Cross Section	# of Logs	Start County	End County	Stratigraphic Interval
A	16	Douglas	Bates (Missouri)	Upper Cherokee through basal Lansing groups
B	24	Osage	Bates (Missouri)	Upper Cherokee through basal Shawnee groups
C	7	Osage	Coffey	Upper Cherokee through middle Shawnee groups
D	27	Geary	Crawford	Upper Cherokee through Shawnee groups
E	42	McPherson	Labette	Upper Cherokee through Shawnee groups
F	10	Greenwood	Coffey	Upper Cherokee through Shawnee groups
G	32	Greenwood	Wyandotte	Upper Cherokee through middle Shawnee groups
H	48	Nowata (Oklahoma)	Miami	Upper Cherokee through basal Lansing groups
I	37	Wilson	Linn	Upper Cherokee through Shawnee groups
	243	Total Logs		

Member of the Altamont Limestone). The datum used in all cross sections is the top of the Hushpuckney Shale Member because of the ease with which it can be correlated by its prominent gamma-ray signature in petrophysical logs. We also used the descriptive term "carbonate" when discussing intervals that are typically described as limestones due to our inability to rule out local dolomitization (e.g., Railsback, 1984, 1993). Some dolomitization appears to have occurred where post-depositional fluid migration altered original lithologies along known tectonic zones.

For upper Desmoinesian through mid-Virgilian units, more than 160 type, principal reference, and neostratotype sections are contained within an area spanning 452 miles (727 km) from Seminole County, Oklahoma, to Appanoose County, Iowa. Many of these sections, 91 in total, are within one township of our cross sections (Supplemental File 3). Given that the objective of the present study was to assess group and subgroup boundaries, we developed subsurface correlations that traversed type localities for lithostratigraphic units that define group boundaries or to include type, principal reference, and neostratotype sections proximal to our cross sections. Several type localities for group-level boundary-defining units are in parts of Oklahoma (e.g., Memorial Shale Formation, Holdenville Shale, Seminole Formation, Nuyaka Creek Shale Member), northeastern Missouri (e.g., Excello Shale Member), Nebraska (e.g., South Bend Limestone Member), and Iowa (e.g., Exline Limestone Member) well beyond range of the present study. Accordingly, we use type or principal reference sections located in Kansas to define these historical boundaries (table 2; e.g., Hepler Sandstone Member, Critzer Limestone Member, Bonner Springs Shale Member, etc.). We also provide outcrop-to-subsurface analyses of several type sections and type petrophysical logs (table 2). We have converted all Public Land Survey System (PLSS) information published in prior works to GPS coordinates using the Kansas Geological Survey's LEOWEB app, although we concede that these coordinates are only approximations.

The present investigation ties in to the detailed study of Oborny et al. (2017) and previously established subsurface nomenclature and subgroup boundary designations for the Kansas City and Lansing groups in northeastern Kansas. Similarly, correlations into southeastern Kansas and northeastern Oklahoma permit the assignment of Marmaton Group strata within our cross sections. Several type sections for individual units in the Marmaton Group lie within a few miles of the southern termini of our cross sections E and H. Our preliminary assessment of these type sections (Supplemental File 2), as well as our comparison of these new data to similar subsurface studies in that area, further support the assignment of these units in the Marmaton Group (e.g., Hemish, 2002; Johnson, 2004).

Several revisions of the Pennsylvanian succession in Kansas have been proposed since 1968 (e.g., Heckel, 1992; Watney and Heckel, 1994; and Heckel and Watney, 2002) and although many are in use by the geologic community, they have not all been adopted in Kansas. Therefore, to frame our discussion of new subsurface data, we combined the nomenclatural schemes of Watney and Heckel (1994), Heckel and Watney (2002), and Oborny et al. (2017) in our cross sections (Supplemental File 4). We indicate where there are discrepancies in the stratigraphic positions of historical units and the correlations of those units to their type localities, and we propose modifications accordingly.

RESULTS

Depositional Architecture

Unit correlations in petrophysical logs indicate that the total upper Desmoinesian through mid-Virgilian succession (about 10 Myr; Aretz et al., 2021; fig. 2), observed in cross sections A–I, thickens

Table 2. Reference lithological sections included in petrophysical cross sections (A–I) or within detailed evaluations illustrated in Supplemental File 2 (designated as S2 in table).

Cross Section/ Supplemental	Reference	Section Type
ALL Cross Sections	Heckel and Watney (2002)	Generalized Section
A	Newell (1935)	Type Block Limestone Member
B	Heckel and Watney (2002)	Type Mantey Shale Member
B	Heckel and Watney (2002)	Principal Reference Shale Hill Formation
D	French and Watney (1993)	Generalized Section
D	Heckel and Watney (2002)	Neostratotype and Principal Reference of Hepler Formation
E	Jewett (1941, 1945)	Type Idenbro Limestone Member
E	Heckel (1988)	Type Dennis Limestone
E	Heckel and Watney (2002)	Neostratotype Tacket Formation
E	Jewett (1941)	Type Altamont Limestone
G	Heckel and Watney (2002)	Principal Reference Zarah Subgroup
H	Heckel and Watney (2002)	Type Cherryvale Formation
I	Jewett (1932)	Type Critzer Limestone Member
S2	Jewett (1941)	Type Altamont Limestone
S2	Jewett (1941)	Type Bandera Shale
S2	Jewett (1941, 1945)	Type Idenbro Limestone Member
S2	Greenberg (1986)	Alternative Type Idenbro Limestone Member
S2	Jewett (1941)	Type Labette Shale
S2	Ohern (1910); Jewett (1941)	Type Lenapah Limestone
S2	Heckel (1991)	Type Lost Branch Formation
S2	Jewett (1941)	Type Norfleet Limestone Member
S2	Jewett (1941)	Type Perry Farm Shale Member

toward a basin depocenter in southwestern Missouri or northwestern Arkansas (Supplemental File 4). Cross sections B, D, and E all show similar architecture and a general east-to-southeast thickening of strata. A west-side-up syndepositional fault occurs at the northwest end of cross sections D and E. This fault truncates strata that are pre- to late-Cherokee Group in age, indicating post-Mississippian and pre-Marmaton fault activation. In cross sections B, D, and E, the internal architecture of the Pleasanton and Kansas City groups is complex. This architecture is associated with a syndepositional, southwest–northeast striking anticline in eastern Kansas. Stratigraphic architecture is markedly simpler, however, in the northwest–southeast trending cross section A. Bedding in this cross section is relatively uniform and thickens into Missouri. Therefore, the fault and the anticline affecting deposition of strata in cross sections B, D, and E did not influence the deposition of strata in cross section A. This observation suggests that both structures terminate between cross sections A and B, potentially in the Bolivar-Mansfield Tectonic Zone (McBee, 2003; Cox, 2009) at the Marais des Cygnes River in northeastern Linn County, Kansas. We also observe that lithofacies belts trend southwest–northeast, parallel to these structures.

Southwest–northeast trending cross sections F, G, H, and I all exhibit similar stratigraphic architecture and a gradual southward thickening of the upper Desmoinesian through middle Virgilian succession. This thickening is subtle, however, in comparison with the east-southeast thickening observed throughout the study area. The depositional architecture of cross sections F–I contains evidence for northwest–southeast trending fault zones (e.g., cross section F), where architectural changes occur throughout the entire Paleozoic stratigraphic succession at individual points between petrophysical logs in the correlations. We have definitively identified some of these fault zones and postulate others within these cross sections where we observe stratigraphic juxtaposition, terminations, or both (Supplemental File 4). With these northwest–southeast trending fault zones, we observed a faulted zone between cross sections D and E that—based on architectural comparisons of these two sections and analyses of available data—appears to show more than 50 miles (80.5 km) of dextral juxtaposition.

Group and Subgroup Boundary Designations

Three upper Desmoinesian through lower Missourian stages group boundaries are recognized in Kansas (Zeller, 1968). Heckel (1992), Watney and Heckel (1994), and Heckel and Watney (2002) have proposed various modifications to these group boundaries. Our results indicate that 1) the Pleasanton–Kansas City group boundary, as originally defined by Moore (1948) and Moore et al. (1951) and adopted by Zeller (1968), should be maintained and 2) the lower and upper boundaries of the Marmaton Group should be revised according to the North American Stratigraphic Code (North American Commission on Stratigraphic Nomenclature, 2021, Articles 19a, 23d, and 23e). Below, we discuss our findings, as well as the implications for revision or maintenance of these boundaries, in ascending stratigraphic order.

1. Boundary between the Cherokee and Marmaton groups (revised)

The boundary between the Cherokee and Marmaton groups in Kansas is currently the base of the Blackjack Creek Limestone Member of the Fort Scott Limestone (Zeller, 1968; fig. 5). The type localities for the Blackjack Creek and Fort Scott, which overlie the group boundary, as well as that of the underlying Excello Shale, are located beyond reach of the present study in easternmost Kansas or in Missouri. Previous investigations within our study area, however, identified either the Fort Scott Limestone or underlying Excello Shale in the subsurface (Killen, 1986; Staton, 1987; Northcutt, 1997; Hemish, 2002; Newell and Bailey, 2012; Newell and Stalder, 2014). We provide type-to-subsurface correlations for several units in the Marmaton Group to provide robust stratigraphic control of the Fort Scott Limestone and Excello Shale (Supplemental File 2; e.g., type Labette and Bandera Shale formations). The Fort Scott Limestone directly overlies the Excello Shale across our study area. The black fissile facies of the Excello Shale produces a prominent peak on gamma-ray logs and, in southeastern Kansas, directly overlies a limestone unit that appears to be genetically related (Supplemental File 4, cross sections D–E and H–I). The base of this limestone marks the transition from an underlying thick succession of interbedded shales and sands into an overlying interval that is punctuated by the thick limestones of the Marmaton Group. The limestone unit, however, was not observed in northern and western parts of the study area. Therefore, the Excello Shale is in direct contact with the underlying thick succession of predominantly interbedded shales and sands of the Cherokee Group in these areas.

2. Boundary between the Marmaton and Pleasanton groups (revised)

The boundary between the Marmaton and Pleasanton groups in Kansas is currently the base of the Hepler Sandstone Member of the Seminole Formation (Zeller, 1968; fig. 5). This boundary was considered to be a regional disconformity. We include the type section of the Hepler established by Jewett (1940) as well as the neostratotype and principal reference sections of Heckel (1992) and Heckel and Watney (2002, p. 8–9) in cross section D (Supplemental File 4). We also include areas where the term "Hepler" was applied to numerous lenticular sands at various stratigraphic positions (Bennison, 1985; Sutton, 1985). Cross section D shows that the Hepler is not laterally correlative west of its type locality and that there is not a regional disconformity at its base. The Hepler type section likely correlates to the "Knobtown Sandstone horizon" of Sutton (1985, p. 19). Moreover, the Hepler "C," which was considered by Sutton (1985) to be representative of the "true" Hepler, is actually below the Hepler type section (fig. 6). The data presented here, however, indicate a regional disconformity underlies a black fissile shale previously identified in petrophysical logs and outcrop as the Nuyaka Creek Shale Member (Sutton, 1985, p. 19; Heckel, 1991, p. 20; Hemish, 2002). This shale maintains a prominent peak in gamma-ray logs throughout the study area and underlies the Hepler "C" interval in northeastern Kansas. Within petrophysical logs, the Hepler "C" is identifiable regionally as the first progradational package (Emery and Myers, 1996) above the prominent gamma-ray signature of the Nuyaka Creek. Sutton (1985) documented the Hepler "C" in petrophysical logs and in outcrop at the town of Trading Post in Linn County, Kansas, where the Nuyaka Creek is also exposed at times of low water level in the northern bank of the Marais des Cygnes River, immediately west of the U.S. Highway 69 overpass. Additionally, these data indicate that the Hepler "C" is correlative to the relatively thin progradational interval containing the Glenpool at its top, as it is defined at the Lost Branch Formation type section in Labette County, Kansas (fig. 6, Supplemental File 2, and all cross sections; also see Heckel, 1991). The regional disconformity observed by the current study at the base of the Nuyaka Creek in addition to the base of the Hepler Formation as defined by Heckel and Watney (2002; i.e., base of Hepler "C") are both exposed along Pumpkin Creek between the type sections of the Lost Branch Formation and South Mound Shale Member (0.75 miles [1.2 km] apart; Jewett et al., 1965; Heckel, 1991). However, these data indicate that the basal contact of the Hepler "C" was likely deposited prior to deposition of the Glenpool limestone bed—the Glenpool identified as being silty-to-sandy by Heckel (1991)—at the type section of the Lost Branch Formation.

Our assessment of the boundary between the Marmaton and Pleasanton groups, as defined by Jewett (1940) and Zeller (1968), indicates that the group boundary should be moved to a lower stratigraphic position, coincident with the base of the black Nuyaka Creek Shale Member. Our analysis of this group boundary identified several significant miscorrelations between type sections for lithostratigraphic units established by Jewett (1941) in the upper part of the Marmaton Group. Some of these type sections either correlate to each other or are at the wrong stratigraphic position, whether above or below the Nuyaka Creek, in Zeller (1968), Heckel and Watney (2002), Bridges and Mulvany (2019), and Bridges et al. (2019). Furthermore, limestones and shales immediately below the basal Nuyaka Creek disconformity may not correlate to any known type sections (cross section G).

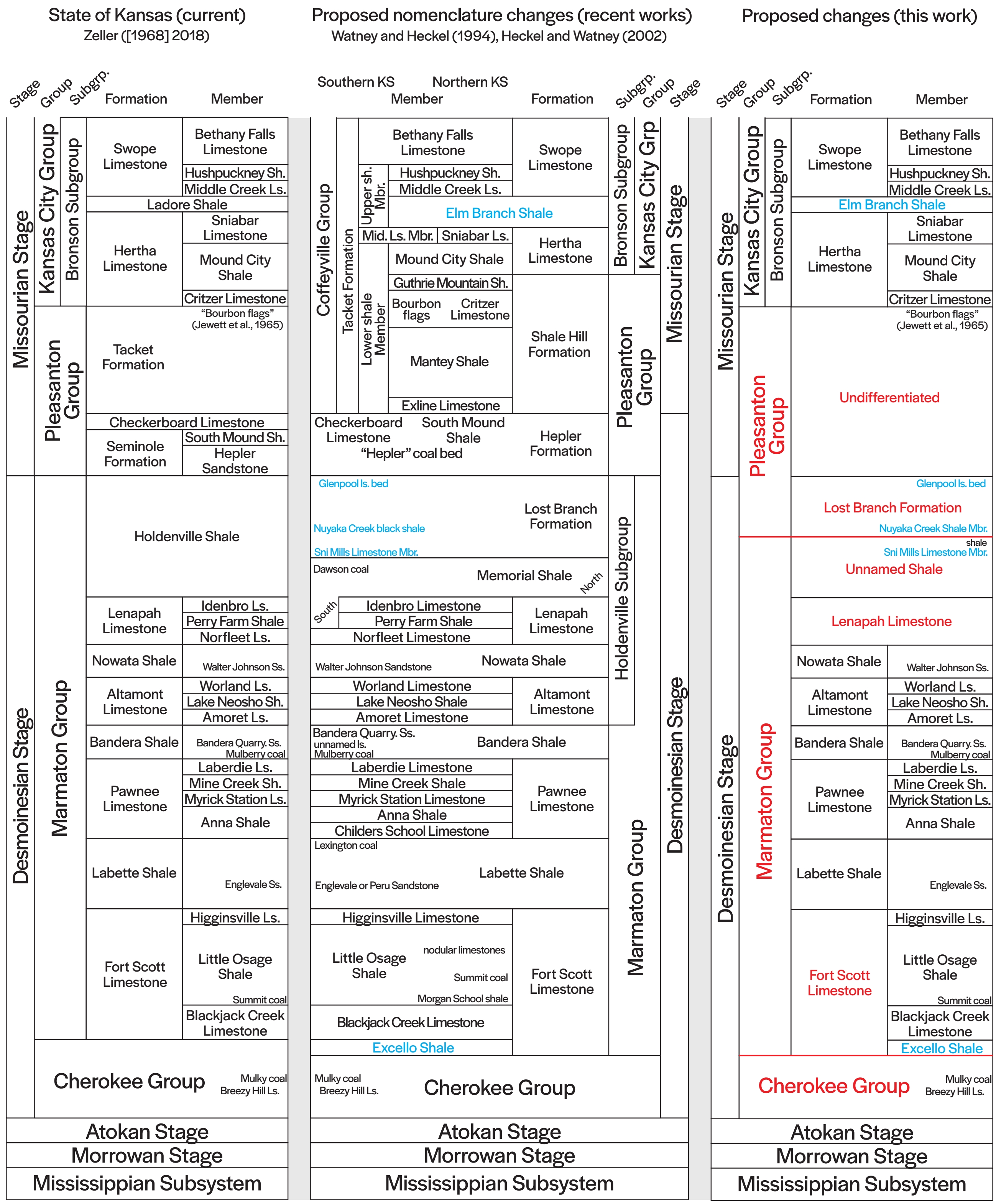

Figure 5. Left column: Current nomenclatural framework for Pennsylvanian units in Kansas (Zeller, [1968] 2018). Center column: Composite nomenclatural framework for Pennsylvanian units based on recent works (Heckel, 1994; Heckel and Watney, 2002). Right column: Proposed changes to group boundaries and stratigraphic nomenclature (changes highlighted in red). Blue text represents our endorsement of nomenclature proposed prior to this work that were adopted for use by Watney and Heckel (1994) and Heckel and Watney (2002). Abbreviations: Subgrp. = Subgroup, Sh. = Shale, Ls. = Limestone, Ss. = Sandstone, Mbr. = Member, and Mid. = Middle.

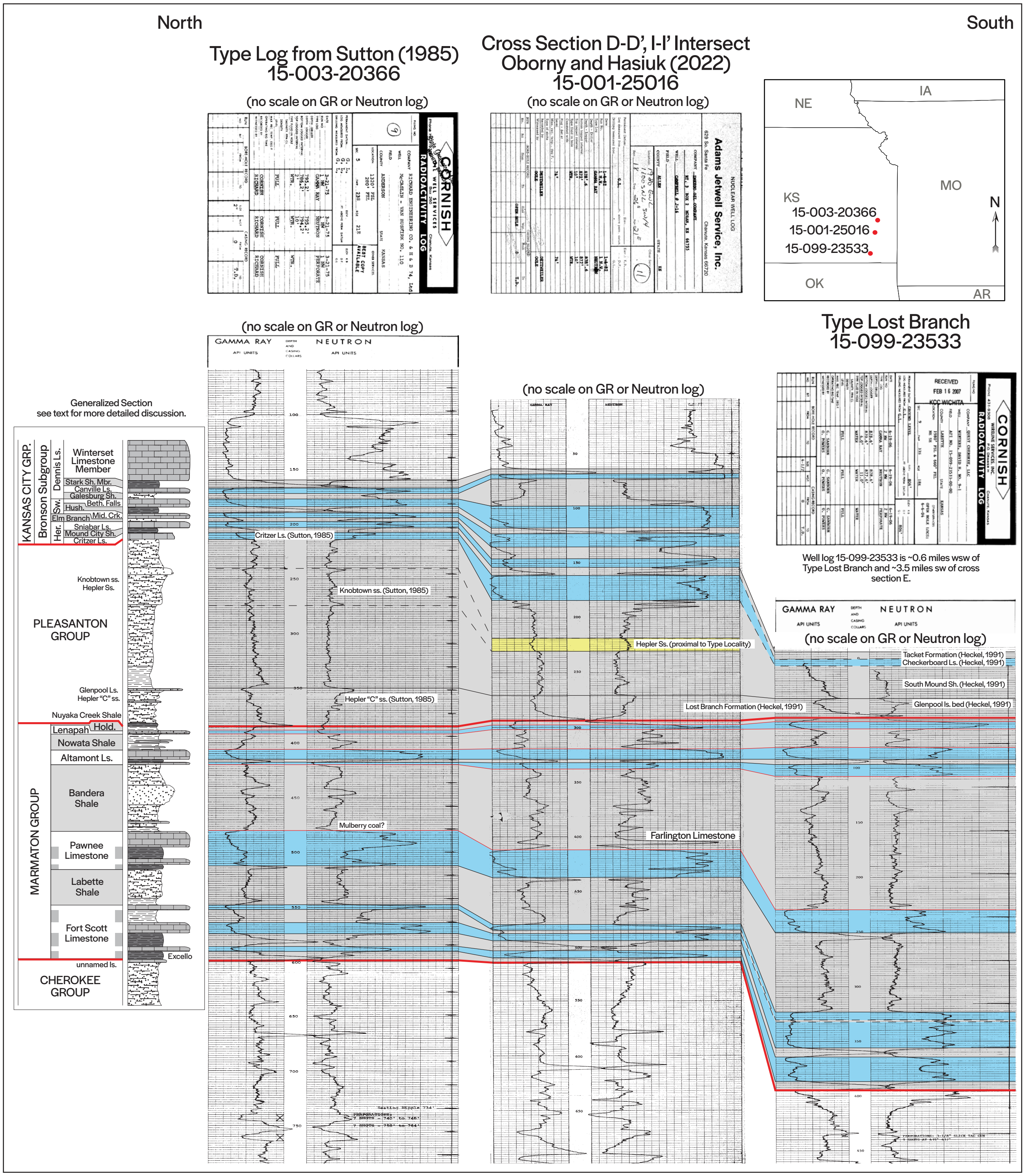

Figure 6. Petrophysical analyses of the Hepler lithostratigraphic unit as defined by various authors. Note: For simplicity we do not highlight the Ladore Shale and Mound Valley Limestone in well log API 15-001-25016. For further details about these units, refer to cross sections D and I. The current authors retain some uncertainty regarding the historical identification of the Checkerboard Limestone at the Lost Branch Formation type section. Abbreviations: GR = Gamma Ray, GRP. = Group, Mbr. = Member, Ls. = Limestone, Sh. = Shale, Ss. = Sandstone, Sw. = Swope, Hush. = Hushpuckney, Mid. = Middle, Crk. = Creek, Beth. = Bethany, Her. = Hertha, Hold. = Holdenville,

3. Boundary between the Pleasanton and Kansas City groups (maintained)

The boundary between the Pleasanton and Kansas City groups is currently established in Kansas at the base of the Critzer Limestone Member (Zeller, 1968; fig. 5). Boundary revisions proposed by Heckel (1992) and Heckel and Watney (2002) place the boundary at the base of the overlying Mound City Shale Member and include significant revisions to the interval (figs. 4 and 5). To assess these revisions, we include the U.S. Highway 69 composite section from Linn County, Kansas, emphasized by Heckel (1992) and Heckel and Watney (2002), in our cross section B (Supplemental File 4). Cross section B also includes the principal reference section of the Shale Hill Formation and the type section of the Mantey Shale Member. Cross section I traverses within 2 miles (3.2 km) of the type location of the Critzer as established by Jewett (1932). We also revisited the type section outcrop as well as several documented exposures nearby and assessed the original field notes of Jewett. Cross section I also traverses the study area of Underwood (1984), who evaluated the Bourbon flags in Bourbon and Linn counties, Kansas. Underwood (1984) and Heckel (1992) considered the Bourbon flags to be the basinward facies of the Critzer. We include petrophysical log data from about 0.7 miles (about 1.3 km) east-northeast and about 1.5 miles (about 2.4 km) south of the Hidden Valley spillway in cross section I (APIs 15-011-23790 and 15-011-23626, respectively). Heckel (1992, p. 33) considered this spillway and the U.S. Highway 69 composite section to be the two best reference sections for the Bourbon flags. In addition, we provide new evaluation of the type exposure of the Guthrie Mountain Shale that Heckel (1992) and Heckel and Watney (2002) used to justify, in part, proposed revisions to the boundary between the Pleasanton and Kansas City groups. Lastly, we assess a new and more complete exposure of this interval located about 1.7 miles (about 2.7 km) east of the Guthrie Mountain type section in Bourbon County, Kansas. This interval encompasses 10 ft (3 m) of shale preceding the black fissile Mound City through Hushpuckney members of the Bronson Subgroup (Supplemental File 5).

Regionally, we observe a limestone or silty limestone underlying the Mound City Shale Member. This limestone marks the transition from the thick shale succession of the Pleasanton Group into the thick carbonate-dominated strata of the Kansas City Group (see fig. 6 and cross section I in Supplemental File 4). Although our subsurface correlations only come within 2 miles (about 3.2 km) of the Critzer type exposure, the limestone observed in our correlations is at a correlative stratigraphic position. Also, the Critzer is observed at several other outcrops in that area.

In cross section I, the Critzer correlates to a stratigraphic position above the Bourbon flags at the spillway of Hidden Valley Lake. The Bourbon flags unit is best identified in cross section I, where it occurs immediately below the Critzer (between 86 and 108 ft [26 and 33 m] in well API 15-011-21849 and between 82 and 129 ft [25 and 39 m] in well API 15-011-23626). The Bourbon flags are evident along a southwest–northeast trend from southern Linn County into northern Bourbon County (cf. Underwood, 1984) parallel to or along depositional strike of the anticline we have identified. Additionally, our new data indicate that the Bourbon flags are shale dominated southeastward, perpendicular to stratigraphic and structural strike, and stratigraphically stand apart from the Critzer as one traverses about 5.6 miles (about 9 km) southeast from the Hidden Valley spillway to the new exposure evaluated east of the Guthrie Mountain Shale type section. Therefore, the Bourbon flags unit correlates to the middle part of what our regional correlations identify as the Pleasanton Group (Supplemental File 5). This position approximately correlates to the cone-in-cone limestone observed by Heckel and Watney (2002, their fig. 12) at the type exposure of the Guthrie Mountain Shale.

Our detailed outcrop and regional subsurface petrophysical analyses of the Guthrie Mountain Shale type section and of the new more complete exposure of the interval (Supplemental File 5) indicate that the Critzer is laterally discontinuous in some areas. The discontinuous nature of the Critzer is frequently observed in our cross sections, though when present, always immediately precedes the Mound City Shale Member. On the east side of the Guthrie Mountain type section, we observe a blocky calcareous siltstone-to-silty limestone bed between the silty Guthrie Mountain and black fissile Mound City. Although lithologically different, we tentatively correlate this bed with the Critzer based on stratigraphic position. We did not, however, observe a blocky calcareous siltstone-to-silty limestone bed at the base of the black fissile Mound City within the new more complete exposure of the interval east of the Guthrie Mountain Shale type section (Supplemental File 5). Instead, a predominantly non-arenaceous gray shale occurs at the base of our measured section and grades upward into the black fissile facies of that unit. A concretionary-to-nodular limestone is evident within the black fissile facies of the Mound City, similar to that documented at the Guthrie Mountain type section (Heckel, 1992; Heckel and Watney, 2002). We also observe within cross sections B, D, E, and I that the Sniabar Limestone Member—and locally the underlying Mound City and overlying Elm Branch—thickens toward the southeast, perpendicular to stratigraphic and structural strike (fig. 7; also see Supplemental File 5). Also, a shale-to-sand-dominated interval is present in the middle part of the Sniabar, with the unit's lower limestone thinning and becoming absent in some areas. This expanded Sniabar can be observed at the newly described exposure east of the Guthrie Mountain type section (Supplemental File 5). The middle Sniabar shale-to-sand interval encompasses a majority of the Mound City identified by prior studies at 1) the principal reference section of the Hepler Formation (see cross section D), 2) the type section of the Guthrie Mountain Shale (see Supplemental File 5), and 3) the principal reference section of the Shale Hill Formation (see cross section B and figs. 4, 8, and 12 in Heckel and Watney, 2002). The intervals assigned to the Guthrie Mountain Shale at the Shale Hill and Hepler Formation principal and neostratotype sections, respectively, do not appear correlative to the type exposure of the Guthrie Mountain. Instead, they are at a higher stratigraphic position overlying the Critzer and represent a gray shale facies of a thickened Mound City that precedes deposition of the black fissile facies of that unit (fig. 7 and cross sections B and D).

Several drillers' logs within 1 mile (1.6 km) of the principal reference section of the Shale Hill Formation and type section of the Mantey Shale Member at the U.S. Highway 69 locality (see cross section B) suggest that the mid-Marmaton Altamont Limestone is about 25 ft (about 7.6 m) below the surface of the highway. This observation places the overlying limestone—identified there as the Bourbon flags facies of the Critzer by Heckel (1992) and Heckel and Watney (2002)—at a stratigraphic position equivalent to the Lenapah Limestone of the upper Marmaton Group. However, based on our observations, including 1) that the gray shale identified as the Guthrie Mountain by Heckel (1992) and Heckel and Watney (2002) at the principal reference section of the Shale Hill Formation instead represents the gray shale facies of the Mound City observed in other sections and 2) that the Bourbon flags and Critzer are non-correlative in nature, the limestone identified as the Bourbon flags along U.S. Highway 69 could be the Critzer based on stratigraphic position when working down section. Combined, all observations complicate the use of the U.S. Highway 69 locality in redefining the boundary between the Pleasanton and Kansas City groups in Kansas. We also note that there appears to be a change in regional structural kinematics along the Bolivar-Mansfield Tectonic Zone, which trends through northeastern Linn County, Kansas, proximal to this U.S. Highway 69 composite section. Overall, this section requires further analysis. Given the complicated nature of our observations pertaining to this group boundary, we summarize as follows:

1. The Bourbon flags appear to thin into the middle part of the Pleasanton Group shale.
2. The Critzer Limestone Member can be correlated throughout much of Bourbon and Linn counties at a stratigraphic position above the Bourbon flags.
3. The Mound City and Sniabar members and the Elm Branch Shale all thicken to the southeast, perpendicular to the southwest–northeast trending structural high.
4. A majority of the Mound City Shale Member, as previously defined by Heckel (1992) and Heckel and Watney (2002) at the neostratotype section of the Hepler Formation and the principal reference section of the Shale Hill Formation, is instead an expanded Sniabar Limestone Member where the unit is dominated by a shale-to-sand facies in its middle part. The lower Sniabar is thin or absent in some areas.
5. A limestone, which may at times be characterized as a blocky calcareous siltstone-to-silty limestone, is observed in northwestern Bourbon County and is directly overlain by the Mound City Shale Member. This limestone can be correlated throughout our petrophysical data, though it appears to be laterally discontinuous in some areas. At the type section of the Guthrie Mountain Shale, the unit is present at a stratigraphic position above the Guthrie Mountain.
6. The Guthrie Mountain Shale type section does not appear correlative to the Guthrie Mountain Shale as it is defined at

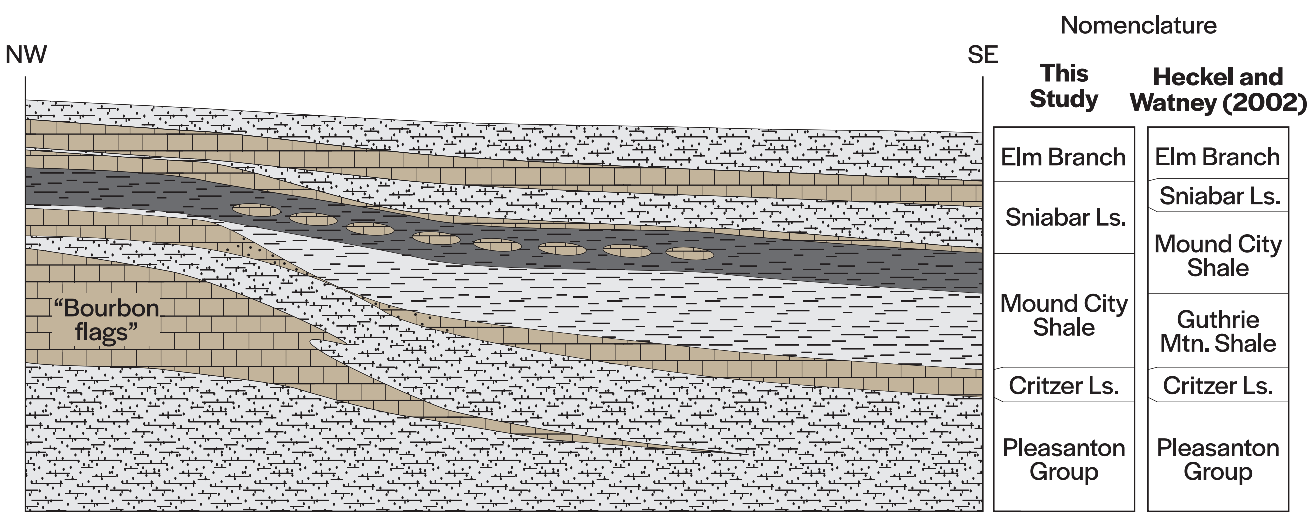

Figure 7. Diagram showing generalized depositional trend during upper Pleasanton and lower Kansas City group time based on observations at the Guthrie Mountain Shale type section, a more complete section about 1.7 miles (about 2.7 km) to the east, and cross sections D and E in Supplemental File 4. We observe a southwest–northeast trending structural high at the time of deposition that is prominent in Bourbon and Linn counties, Kansas, where several historically important outcrops exist. This structure is accompanied by thickening of several units toward the east-southeast. These new observations affect the nomenclature assigned by Heckel (1991, 1992) and Heckel and Watney (2002) at several type, principal, and neostratotype sections. These include the Guthrie Mountain Shale type section, principal reference section of the Shale Hill Formation/type section of the Mantey Shale Member, and neostratotype section of the Hepler Formation. Further evaluation of the composite principal reference section of the Shale Hill Formation/type section of the Mantey Shale Member will be required due to new uncertainties in historical unit identifications at that section that result from our analyses of historical drillers' log data. However, we find the Guthrie Mountain type section does not correlate to the Guthrie Mountain of other sections. Abbreviations: Ls. = Limestone, Mtn. = Mountain.

the neostratotype section of the Hepler Formation and the principal reference section of the Shale Hill Formation.

7. The Guthrie Mountain Shale, as previously defined at the neostratotype section of the Hepler Formation, is representative of an expanded Mound City Shale Member. Similarly, this appears to be the case at the principal reference section of the Shale Hill Formation, though additional data will be needed to resolve the stratigraphic and structural complexities in that area.

DISCUSSION

Depositional Architecture

Our detailed outcrop-to-subsurface correlations provide a new interpretation of facies belts, basin geometry, and structural history for this area of the Midcontinent during the upper Desmoinesian and Missourian stages. The generally accepted interpretation for this region is that the Pennsylvanian-aged Forest City and Cherokee basins were separated by a west–east or northwest–southeast anticline, termed the Bourbon arch (first defined by Lee, 1943), that was most prominent during Morrowan through lower Desmoinesian time (i.e., Cherokee Group), immediately prior to deposition of our studied interval. By mid-Desmoinesian (i.e., mid- to upper-Cherokee Group), the Forest City Basin was filled with sediment and considered a northern extension of the Cherokee Basin (Lee, 1943). Later works refer to this northern extension as the "Northern Midcontinent Shelf" (Joeckel et al., 2007) and identify southward thickening of strata toward a depocenter in Oklahoma during at least the upper Desmoinesian and lower Missourian stages (Heckel and Watney, 2002; Heckel, 2013, 2023). The inferred west-east trending margin of this depocenter, or basin, was established at or immediately north of the Kansas-Oklahoma state line during deposition of the Marmaton Group and was loosely coincident with the Bourbon arch during deposition of the Pleasanton and lower Kansas City groups. Our current findings support, in part, the observations of Heckel (2013, 2023) and the long history of works by that author that units generally thicken and transition to deeper facies southward. However, the data in our study suggest that facies belts strike southwest–northeast, paralleling syndepositional structures in the region that were later offset by northwest–southeast trending dextral transpressional shear zones. This observation is most evident when comparing the very similar depositional architectures of cross sections D and E that appear to have more than 50 miles (about 80 km) of dextral juxtaposition between them (see fig. 8). However, some historical works identified linear continuous structures (i.e., the Nemaha Ridge/anticline and Humboldt Fault) trending from southeastern Nebraska into north-central Oklahoma that were considered to be pre- or syndepositional to the studied interval (e.g., Merriam, 1963; Yarger, 1982). These prior interpretations conflict with our data due to cross-cutting relationships of the shear zone in question and those of the Humboldt Fault Zone and associated structures. Though not explicitly discussed in detail, Baars and Watney (1991) and Baars (1995) both identify similar displacement within basement rocks roughly along the same trend identified in this study. Though further investigation is needed, data from studies of 1) the upper Mississippian unconformity, 2) the Viola Limestone, Simpson Group, and Chattanooga Shale in central Kansas (Berendsen and Blair, 1986), and 3) the Precambrian basement in southeastern Kansas (Berendsen and Blair, 1991) provide further support for the presence of significant and measurable dextral juxtaposition along a northwest–southeast trending shear zone in the region. Additionally, the most recent gravity and magnetic data reported for Kansas by Kruger (1996) show the Midcontinent rift system terminating at the fault zone in question (fig. 8, panel D). Berendsen and Blair (1986) also argued that the Humboldt Fault Zone is composed of a series of individual anastomosing fault blocks that step down to the east rather than being one continuous fault. Though we see an east-side-down orientation of the southwest–northeast trending fault observed in cross sections D and E, we interpret this fault as a backthrust resulting from the structural salient of the Midcontinent rift system during formation of the Arkoma Basin to the southeast. This interpretation is supported by the complex architecture associated with a southwest–northeast trending anticline in eastern Kansas that indicates lithospheric shortening in that area, and we suggest this is representative of the Arkoma foreland basin forebulge. Finally, such an interpretation would bring the basins and arches of eastern Kansas and the Arkoma Basin into alignment with modern foreland basin tectonic theory (e.g., DeCelles and Giles, 1996).

Group and Subgroup Boundaries

1. Discussion of boundary between the Cherokee and Marmaton groups (revised)

Our regional observations support the conclusions of Watney and Heckel (1994) that the Excello Shale should be regarded as a member of the Fort Scott Limestone in Kansas (fig. 5). Therefore, our new data support a revision of the boundary between the Cherokee and Marmaton groups to a position coincident with at least the basal contact of the Excello Shale. The Excello Shale is a black and fissile shale and has a high gamma-ray response. Such black shales have been attributed to both highstand (e.g., Heckel, 1994, 2013) and transgressive (e.g., Wignall and Maynard, 1993) systems tracts; evidence for both models exist within the CFCB's Pennsylvanian succession. If the Excello Shale corresponds to a highstand systems tract (cf. Heckel, 1994, 2013), then a lithostratigraphically mappable limestone unit that would serve as the basal member of the Marmaton Group should be present in the region. Such a limestone has been observed in southeastern Kansas and northern Oklahoma in our correlations (see cross sections D, E, H, and I). Prior petrophysical studies in Oklahoma (Northcutt, 1997; Hemish, 1986, 2002) and Kansas (Knight, 1985) have identified this limestone as the Breezy Hill Limestone Member; however, the use of the term Breezy Hill for this limestone is problematic for the following reasons. The Breezy Hill was defined by Pierce and Courtier (1937) at a hill located southwest of Mulberry in Crawford County, Kansas, named Breezy Hill (37.548217°, -94.628831°; see Moore, 1937a, stop 2 on p. 29; type location also reported at the southern part of Breezy Hill in section 10–11 by Gentile and Thompson, 2004, see p. A-131–134). At that section, the Breezy Hill is separated from the overlying Excello by a 0.9–1.1 ft (about 0.3 m) thick coal termed the Mulky coal bed. Because coals are characteristic of lowstand systems tracts, the Breezy Hill cannot be

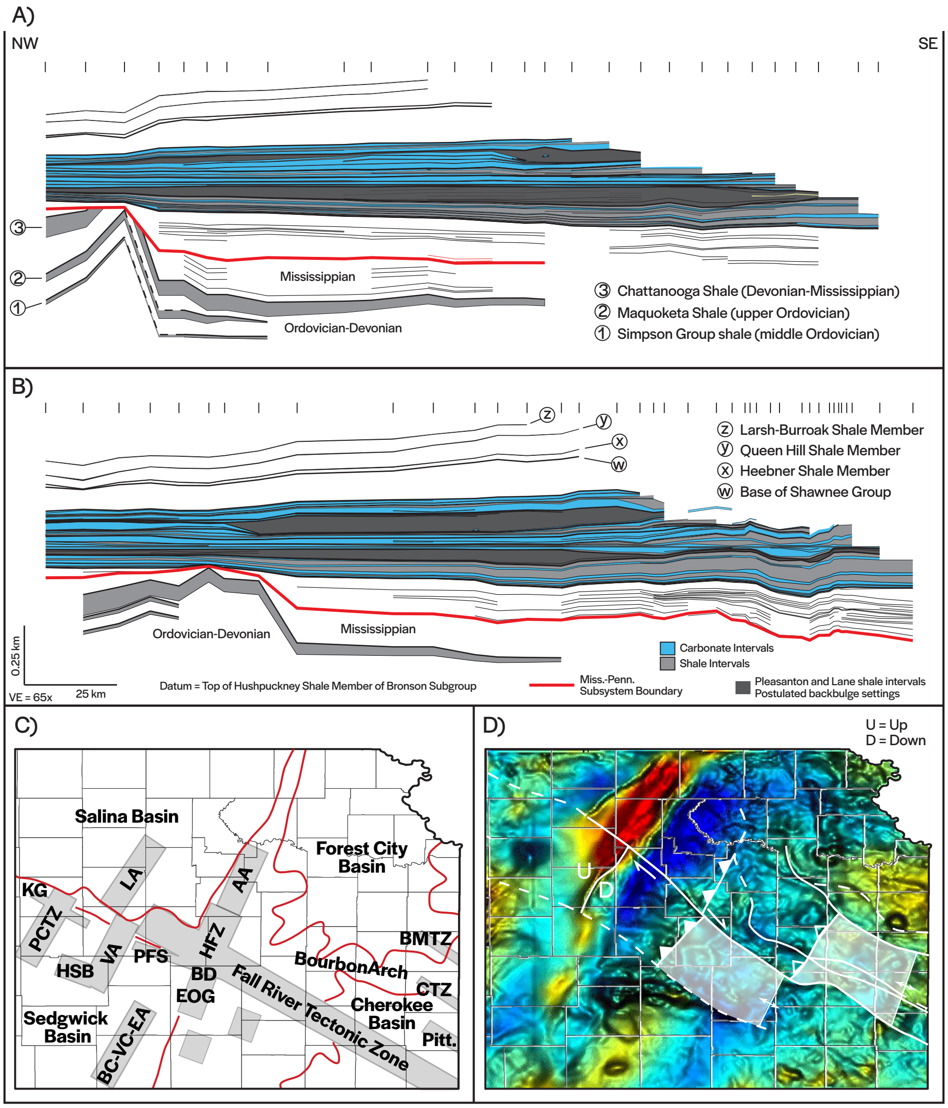

Figure 8. Preliminary regional structural analyses. **A)** Cross section D with accurately scaled distance between well locations. **B)** Cross section E with accurately scaled distance between well locations. Note the dark gray coloration assigned to the Pleasanton Group (as the interval is defined herein) and Lane Shale of the Zarah Subgroup within panels A and B. Abbreviations: Miss-Penn. = Mississippian-Pennsylvanian. **C)** Eastern Kansas with known structural elements (gray polygons) that are Permian or older and structural provinces (red outlines). The Bourbon arch and Forest City and Cherokee basins are illustrated as originally mapped by Lee (1943). Though numerous studies have referred to the Bourbon arch, none have improved upon this 1943 study and as such the Bourbon arch remains to this day under-evaluated and vague. Baars and Watney (1991) later defined the Bourbon Arch Complex, a northwest–southeast trending region extending from the Fall River Tectonic Zone (FRTZ) to just north of the Bolivar-Mansfield Tectonic Zone (BMTZ). The Salina Basin is illustrated as mapped by Newell (1987). The Sedgwick Basin is compiled from Merriam (1963) and Carr et al. (1995). Abbreviations and source of information in chronological order: Fath (1921; EOG: Eldorado oil and gas field [“domes”]), Pierce and Courtier (1937; Pitt.: Pittsburg anticline), Merriam (1963; BC-VC-EA: Bluff City–Valley Center–Elbing anticline, BD: Burns Dome), Berendsen and Blair (1986; FRTZ, HFZ: Humboldt Fault Zone, KG: Kanopolis Graben, LA: Lindsborg anticline, PCTZ: Peace Creek Tectonic Zone, PFS: Peabody Fault System [“low graben”], VA: Voshell anticline), Berendsen and Blair (1991; BMTZ, CTZ: Chesapeake Tectonic Zone, FRTZ), Watney et al. (2003; HSB: Hutchinson Salt Basin), Gerhard (2004; AA: Alma Anticline). **D)** Anticlinal structures, faults (white lines), and slip directions interpreted from subsurface correlations in cross sections A through I. Slip direction along the Lindsborg anticline is from Berendsen and Blair (1986; i.e., bounded by east-side-down displacement). The eastern-most thrust (hollow arrows) requires further evaluation as we do not have sufficient data at depth, apart from the stratigraphic architecture within correlations, to demonstrate right-lateral juxtaposition of the west-side-up fault visible in panel B. Transparent white polygons represent postulated backbulge settings associated with the Arkoma Foreland Basin system. Underlying colored map represents combined gravity and magnetic data from Kruger (1996).

representative of the transgressive systems tract that preceded Excello deposition at this locality. The Breezy Hill type locality is relatively close to the current study area, 13.5 miles (about 22 km) east of cross section D. Based on the laterally continuous nature of all strata in our correlations, we would expect to find some evidence of the Mulky coal bed in petrophysical logs and drillers' logs data underlying the Excello Shale. However, we find no evidence for this association in our correlations. We suggest that the Breezy Hill at its type section is an altogether different limestone unit, at a lower stratigraphic position within the upper part of the Cherokee Group, and therefore stands apart from the Excello Shale. Furthermore, according to R. S. Sawin (personal communication, September 2022), coauthor of the Crawford County Geological Map (West et al., 2008), no readily mappable limestone was observed immediately preceding the Excello Shale within Crawford County. Our interpretation also raises uncertainty regarding the stratigraphic assignment of the Breezy Hill in petrophysical logs by Knight (1985), Northcutt (1997), and Hemish (2002). For these reasons, we leave the limestone, which appears to underly the Excello Shale in several of our correlations, unnamed. We also note that when this limestone is present, it should ideally be included as the basal member of the Marmaton Group. This practice is conducted in Iowa (Pope, 2012) and Nebraska (informally; R. M. Joeckel, personal communication, April 2023); however, such a recommendation here will require further investigation.

2. Discussion of boundary between the Marmaton and Pleasanton groups (revised)

Our analysis of the boundary between the Marmaton and Pleasanton groups identified numerous discrepancies in the historical lithostratigraphic correlations of this interval. Most notable are miscorrelations between unit type sections and inaccurate assignment of units to certain stratigraphic positions. These miscorrelations require additional revisions at the formation and member level. Also, there are several limestones and shales within the interval that, at present, we are unable to reliably assign any known nomenclature. For this discussion, we refer the reader to fig. 3, drawing attention to the varying stratigraphic positions of the coal and black shale units of the Memorial Shale.

Lenapah Limestone and members (**revised**)

Cross section H passes within about 1.6 miles (about 2.5 km) of the Lenapah Limestone type section (36.887793°, -95.629234°) in Nowata County, Oklahoma. Related petrophysical data exist from a well about 0.25 miles (0.07 km) north of the type section (i.e., OCC, 2021; well: Krenz #30-1, API# 35-105-29821; Supplemental File 2, Type Lenapah Limestone). Based on stratigraphic position, the Lenapah Limestone at the type section appears to be represented by the carbonate unit overlying the Nowata Shale. Our correlations, however, indicate that most of the lower 15 ft (about 4.5 m) of limestone at the type section represents a discontinuous and localized carbonate facies within the upper part of the underlying Nowata. Moore (1937b, p. 55) had previously included this lower 15 ft (4.5 m) of limestone within the Lenapah Limestone; however, Jewett (1941, p. 337) later speculated that it could instead represent the Perry Farm Shale Member. Despite this historical uncertainty, Moore (1937b) and Jewett (1941) both considered the upper 6 ft (1.8 m) of limestone (i.e., bed 3) at the Lenapah type section to be the Idenbro Limestone Member. However, our assessment of the type sections for all three members of the Lenapah Limestone (the Norfleet, Perry Farm, and Idenbro) indicates that these limestones are at higher stratigraphic positions relative to the Lenapah Limestone type section in Oklahoma and therefore are not correlative.

In our analyses of the Norfleet Limestone Member, we correlate to within 2 miles (3.2 km) of the type locality via cross section E. A petrophysical log and accompanying driller's log data are available for a well about 0.15 miles (0.24 km) north of the unit's type exposure (37.211274°, -95.289982°) in Labette County, Kansas (Supplemental File 2, Type Norfleet Limestone). Our analyses suggest that the black platy shale observed by Jewett (1941) in the base of the Norfleet is correlative to the Nuyaka Creek Shale Member. No other limestone that could represent the Lenapah Limestone or its members occurs between what we identify as the Nuyaka Creek and the underlying Altamont Limestone. This observation is evident throughout many of our cross sections (e.g., cross sections D, G, H, and I). These findings are problematic in that, regionally, the Nuyaka Creek is identified above the Lenapah Limestone (e.g., Sutton, 1985; Heckel, 1991; Hemish, 2002).

In our analysis of the Perry Farm Shale Member, we assessed petrophysical logs and accompanying drillers' logs from an area about 0.15 miles (0.24 km) north of the type exposure (37.279488°, -95.365073°) in Labette County, Kansas (Supplemental File 2). Jewett (1941) identified both the Norfleet and Perry Farm at this location. Here, too, we observed a black shale at the base of the Norfleet at the position of the Nuyaka Creek. We conclude that the Norfleet and the Perry Farm type sections correlate to each other but are stratigraphically higher than the Nuyaka Creek and also above the Lenapah Limestone. The thin limestone overlying the Perry Farm at both the Norfleet and Perry Farm type sections is at a similar stratigraphic position to the unit Heckel (1991) called the Glenpool limestone bed at the type locality of the Lost Branch Formation (37.188687°, -95.418355°). This locality is between the Norfleet and Perry Farm type locations, but the Glenpool type section is far to the south in Tulsa County, Oklahoma (Bennison, 1984; 35.944211°, -96.011738°). Our interpretations are supported by the identification of the Nuyaka Creek in the lower part of the Lost Branch type section (Heckel, 1991), about 11.5 ft (3.5 m) below the Glenpool and by new petrophysical log analyses at the Lost Branch type section (Supplemental File 2, Type Lost Branch).

Our analysis of the Idenbro Limestone Member type section and inclusion of this section within cross section E demonstrate that the Idenbro type section, as was defined by Jewett (1941, 1945; 37.28467°, -95.406977°) in Labette County, Kansas, is at a stratigraphic position about 110 ft (33.5 m) above the Hushpuckney Shale Member of the Swope Limestone. We maintain that the type section location reported in Jewett (1941, 1945) is inaccurate. In KGS files pertaining to Labette County, Kansas, there are no descriptions of rock exposures in sec. 2, T. 32 S., R. 18 E., as documented by Jewett (1941, 1945). Jewett indeed may have described rock exposures in this section, because exposures have been reported at this location by P. H. Heckel (personal communication, March 2021). Nevertheless, a 1939 description by Jewett of an exposure located 6 miles (1.8 km) to the east of the Idenbro type section is nearly identical to the type section descriptions reported in Jewett (1941, 1945) (Supplemental File 2, Alternate Type Idenbro Limestone Member, Jewett description). Furthermore, Bennison's (1998) geological map for Labette County, Kansas, depicts the outcrop attributed to the Idenbro type section by Jewett (1941, 1945) as the Mound Valley Limestone. The type section of the Mound Valley Limestone is located 4 miles (1.2 km) to the south of this outcrop (Heckel and Watney, 2002; 37.226524°, -95.414829°). Finally, Greenberg (1986) used the rock exposure described by Jewett in 1939 as the type locality of the Idenbro, which is compatible with the geological map of Labette County (Bennison, 1998). In the following discussion, we refer to the Idenbro locality in sec. 2, T. 32 S., R. 19 E. as the alternative type section of the Idenbro (37.283361°, -95.301806°).

In our analysis of the alternative type section of the Idenbro, we assessed a petrophysical log (about 1 mile [1.6 km] west) and accompanying driller's log (about 0.2 miles [0.3 km] northeast) in Labette County, Kansas (Supplemental File 2, Alternate Type Idenbro Limestone Member). We determined that the Idenbro at this location correlates to bed 3 at the Lenapah Limestone type section and can be traced throughout our cross sections. However, the nodular limy Perry Farm Shale Member reported at the alternative type Idenbro location is at the same stratigraphic position as the upper Nowata Shale in proximal subsurface data. These observations agree with Jewett (1941) in that the lower 15 ft (4.6 m) of flaggy limestones, or what we identify as a localized carbonate unit within the Nowata Shale, at the Lenapah Limestone type section is correlative to the nodular limy shale reported as the Perry Farm at the alternative type section of the Idenbro. Comparison of these data to regional cross sections indicate that the Nuyaka Creek would overlie the Idenbro at its alternative type locality.

Given our observations on the Norfleet, Perry Farm, Idenbro, and Lenapah type sections, we conclude that the Lenapah Limestone consists of a single unit (fig. 5; herein restricting the unit's original definition to bed 3 at its type location) and that bed 3 at the Lenapah Limestone type section correlates to the alternative type section of the Idenbro.

Jewett (1941, p. 337) speculated that the lower 15 ft (4.6 m) of nodular limestone and shale at the Lenapah Limestone type section correlated northward to the Perry Farm Shale Member due to a notable abundance of *Marginifera* brachiopods immediately below the Idenbro at both the Lenapah and Idenbro type locations (our alternative type Idenbro). Thus, there is a strong similarity between these sections. Given that the term Lenapah (Ohern, 1910) holds seniority over the Idenbro (Jewett, 1941), we identify this limestone throughout our study as the Lenapah Limestone Formation without subdividing members. Such a distinction is used in Iowa (Pope, 2012), Missouri (Bridges et al., 2019; Bridges and Mulvany, 2019), Nebraska (informally; R. M. Joeckel, personal communication, April 2023), and Oklahoma (Fay, 1997; T. M. Stanley, personal communication, November 2021), where the Lenapah Limestone is representative of a single limestone, namely the Norfleet Limestone Member in Iowa, Missouri, and Nebraska and the Eleventh Street Limestone Member in Oklahoma.

Basal disconformities of the Nuyaka Creek Shale and Hepler Sandstone members

To identify the Nuyaka Creek Shale Member in our cross sections, we tie directly into areas where this unit has previously been identified in petrophysical logs and in outcrop (i.e., Sutton, 1985, p. 19; Heckel, 1991, p. 20; Heckel and Watney, 2002; Hemish, 2002). The Nuyaka Creek was originally defined as a bed by Dott and Bennison (1981) at an exposure along Nuyaka Creek in Okfuskee County, Oklahoma (35.475003°, -96.264746°). This type exposure is about 45 miles (about 72 km) southwest of Tulsa, Oklahoma, outside of our current study area, and therefore we cannot verify the unit's correlation from its type exposure to prior studies. We do not question the identification of this unit by prior authors given that the Nuyaka Creek can be readily correlated in outcrop by its distinct black and fissile lithology and through subsurface petrophysical logs via the unit's prominent gamma-ray signature, which is similar to a number of under- and overlying black shales—such as the Excello, Anna, Lake Neosho, Hushpuckney, and Stark—in the Marmaton and Kansas City groups.

The Nuyaka Creek maintains its prominent gamma-ray signature in all of our cross sections, and it is the first fissile black shale above the Lenapah Limestone (our definition). The basal contact of the Nuyaka Creek appears to be disconformable throughout our study area. In southern and east-central Kansas (Labette County, Lost Branch type section; and Linn County, at Trading Post), the shale immediately overlies a coal, clay, or both, suggesting that the disconformable contact relates to subaerial exposure prior to shale deposition. We also observe the Nuyaka Creek in direct contact with the Nowata Shale in several locations (e.g., cross sections D, G–I) or, as is the restricted case in the Kansas City metropolitan area, additional limestone and shale units between the Lenapah and basal contact of the Nuyaka Creek (unnamed interval in cross section G). Overall, these observations support the conclusion that the basal contact of the Nuyaka Creek is representative of a disconformable surface. Our correlations document that this surface represents both missing underlying strata in numerous locations but also *additional* underlying strata in other locations.

Prior to the establishment of the "Hepler" lithostratigraphic unit by Jewett (1940), Moore (1932, 1936) identified the sandstone unit's basal contact as a regional disconformity. This disconformity was used by Moore (1948) and Moore et al. (1951) in defining the boundary between the Marmaton and Pleasanton groups. In some cases, the Hepler Sandstone is reported to rest upon the mid-Marmaton Bandera Shale. Nevertheless, this unit could not be identified in the subsurface a short distance west of its outcropping locality by Moore et al. (1951, p. 91), and sandstones are not always present at the basal disconformity (Moore, 1936, p. 72–74). We have correlated through cross section D to the type section of the Hepler Sandstone established by Jewett (1940), as well as the neostratotype and principal reference sections of Heckel (1992) and Heckel and Watney (2002, p. 8–9). We observe the unit thinning or interfingering with arenaceous shale about 12 miles (about 19 km) west-northwest of its type exposure. This finding agrees with the observations of Moore et al. (1951) that the Hepler Sandstone does not extend for any meaningful distance into the subsurface. We therefore conclude that the base of the Hepler Sandstone does not represent a regional unconformity, and we propose moving the boundary between the Marmaton and Pleasanton groups to the base of the Nuyaka Creek (fig. 5). We further propose that the Nuyaka Creek should be formalized as the lowest stratigraphic member in the Pleasanton Group. The Seminole and Tacket formations of Zeller (1968) and the Shale Hill Formation of Watney and Heckel (2002) will require further investigation and we leave the interval undifferentiated in our fig. 5.

Unnamed limestones and shales (upper Lenapah Limestone through basal Nuyaka Creek Shale Member)

The shale immediately overlying the Lenapah Limestone and underlying the Nuyaka Creek Shale Member—which includes a limestone bed in the Kansas City metropolitan area—has previously been designated by various authors as either the Holdenville Shale or Memorial Shale. Type sections for these two units are located in Oklahoma outside of our study area; however, the most recent works by Watney and Heckel (1994) and Heckel and Watney (2002) used Memorial Shale in defining the interval immediately overlying the Lenapah Limestone. These authors established the upper contact of the Memorial Shale at the base of a unit termed the Sni Mills Limestone Member and assigned the limestone to a stratigraphic position between a unit termed the Dawson coal bed and the Nuyaka Creek (fig. 5). Greene in Moore et al. (1936, p. 18, bed 5 fig. 8 therein) named the Sni Mills in Jackson County, Missouri (see Howe, 1953, p. 21; 38.943373°, -94.127455°). Howe (1953) considered the unit correlative to the Idenbro Limestone Member of the Lenapah Limestone. Howe (1953, p. 13), working in Missouri, also described a dark, fissile, phosphatic shale within the lower part of the Holdenville Formation (Holdenville Shale in Kansas) (i.e., at a stratigraphic position immediately overlying the Sni Mills). Heckel (1991) later identified this fissile shale as the Nuyaka Creek black shale bed and determined the Sni Mills was at a stratigraphic position above the Idenbro Limestone Member. Heckel (1991, p. 37, outcrop 8) also provided a principal reference section for the Sni Mills a few miles to the south of its original type section at 38.913309°, -94.140137°. As with the Holdenville and Memorial type sections, the type and principal sections of the Sni Mills lie outside of our study area, about 36 miles (about 58 km) due east of our northernmost data in cross section A. We do not, however, have reason to disagree with the identification of the Nuyaka Creek overlying the Sni Mills, and we therefore tentatively identify the additional limestone, observed between the Lenapah and basal disconformity of the Nuyaka Creek at the north end of cross section G, as the Sni Mills Limestone Member. Based on this conclusion, the shale between the Lenapah and Sni Mills would be the Memorial Shale as defined by Watney and Heckel (1994) and Heckel and Watney (2002). This assignment leaves no clear nomenclatural definition for the shale between the Sni Mills and basal disconformity of the Nuyaka Creek. Alternatively, the Holdenville Shale, as documented at the Nuyaka Creek type section in Oklahoma (Dott and Bennison, 1981), appears to encompass our unnamed shale interval as well as strata overlying the newly observed basal disconformity of the Nuyaka Creek in Kansas. Hemish (2002, fig. 20) also used this interpretation in the southern part of his study in northeastern Oklahoma. Therefore, based on works to the south of our study area, the strata between the Lenapah Limestone and basal disconformity of the Nuyaka Creek in Kansas would correlate to units within the Holdenville interval (upper contact of Holdenville coincides with base of Seminole Formation).

Given these observations, the assignment of both Holdenville Shale and Memorial Shale to the unnamed interval appears to be appropriate. However, at least as is the case in Kansas, it is parsimonious to restrict the upper boundary of the interval to coincide with the disconformity at the base of the Nuyaka Creek. In the case of the Memorial Shale, the unit's upper boundary definition would need to be moved to a higher stratigraphic position to include the shale between the Sni Mills and the Nuyaka Creek. In the case of the Holdenville Shale, the unit's upper boundary definition would need to be restricted and placed at a lower stratigraphic position. In either case, we propose the Nuyaka Creek and overlying strata be included within the Pleasanton Group. At this time, we leave the interval between the Lenapah and Nuyaka Creek unnamed (fig. 5), though based on seniority, the term Holdenville (Taff, 1901) should be applied to the interval. We do note, however, that the Memorial Shale (Dott, 1941) type section is more proximal to Kansas and the necessary revision to the unit's upper boundary definition is less severe than those necessary in bringing the Holdenville Shale into alignment with our new data.

3. Discussion of boundary between the Pleasanton and Kansas City groups (maintained)

This boundary is closely associated with complex stratigraphic architecture that appears in several of our datasets (cross sections B, D, and E). We interpret the development of a southwest–northeast trending anticline in easternmost Kansas during the deposition of this interval, which appears to terminate at the Bolivar-Mansfield Tectonic Zone in northeastern Linn County, Kansas. This interpretation is drawn from the relatively uniform thickening of strata into Missouri (cross section A), which is most notable in the Pleasanton Group. This anticline resulted in moderate-to-significant thickening of some strata in the upper Marmaton and lower Kansas City groups and thinning of others, such as the Pleasanton shales, which possibly indicates syndepositional migration of the anticline. We hypothesize that this migration is responsible for some of the complexities identified in our data, including 1) the deposition of the Bourbon flags of the Critzer Limestone Member (Underwood, 1984; Heckel, 1992), 2) the poorly documented shale-to-sand interval that arises within the middle part of the Sniabar Limestone Member, 3) the gray shale facies of the Mound City Shale Member, and 4) the lithological variability of the Critzer Limestone Member (i.e., calcareous siltstone to silty limestone to limestone) as well as the unit's historically documented laterally discontinuous nature, which also can be observed in our cross sections. We conclude that the complex stratigraphy along this structure strongly influenced the historic development of numerous nomenclatural schemes and stratigraphic interpretations over the last century. We identify several problems in the internal subdivisions of the Pleasanton Group (e.g., the Guthrie Mountain, Bourbon flags, Mantey Shale, and Exline Limestone members of the Shale Hill Formation) as proposed by Heckel (1992) and Heckel and Watney (2002). Therefore, we cannot recommend that the complex nomenclatural revisions proposed by these authors for the Pleasanton and Kansas City group boundary be adopted in full. Nevertheless, our new data are robust enough to support the classification currently used by the KGS in defining this stage boundary (Zeller, 1968). At present, we do not differentiate any units above the Lost Branch Formation for our newly defined Pleasanton Group (fig. 5).

SUMMARY AND CONCLUSIONS

This bulletin highlights longstanding issues in Kansas stratigraphy, addressing some of them and specifying needs for future work. Our approach of employing detailed subsurface correlation of petrophysical well-log data to important type, neostratotype, and principal localities proves highly instructive and can be implemented in future studies. Detailed outcrop-to-subsurface correlations provide new interpretations for facies belts, basin geometry, and structural history during the upper Desmoinesian and Missourian stages.

In assessing three upper Desmoinesian through lower Missourian stages group boundary definitions currently recognized in Kansas (Zeller, 1968), in addition to recent proposed modifications made to these boundaries by other authors, we recommend the following changes:

1. The boundary between the Cherokee and Marmaton groups should be placed at the base of the Excello Shale Member. An unnamed limestone underlying the Excello Shale in some areas should ideally be included within the Marmaton Group, but this limestone will require further investigation.
2. The boundary between the Marmaton and Pleasanton groups should be placed at the base of the Nuyaka Creek Shale Member.
3. The boundary between the Pleasanton and Kansas City groups should be maintained at the base of the Critzer Limestone Member of the Hertha Limestone.

We also recommend the following salient changes in stratigraphic nomenclature in Kansas:

1. The Fort Scott Limestone (Zeller, 1968) should be revised to include at least the Excello Shale (cf. Watney and Heckel, 1994).
2. Members of the Lenapah Limestone (the Idenbro, Perry Farm, and Norfleet) should be abandoned based on miscorrelation.
3. The interval between the Lenapah Limestone and the Nuyaka Creek Shale Member corresponds to either the Holdenville Shale (Zeller, 1968) or Memorial Shale (Watney and Heckel, 1994). This interval should be formally named in the future after additional investigation.
4. With our proposal to place the boundary between the Marmaton and Pleasanton groups at the base of the Nuyaka Creek Shale Member, the lower boundary of the Lost Branch Formation of Watney and Heckel (1994) should likewise be placed at the base of the Nuyaka Creek Shale Member. We leave the Seminole Formation of Zeller (1968) undifferentiated, noting the interval requires further investigation.

Several issues remain to be resolved regarding the internal subdivisions of the Pleasanton Group. This is the case for both the current classification scheme in Kansas (Zeller, 1968) and recent proposed nomenclatural changes (i.e., Heckel and Watney, 2002). In this paper, we identify multiple problems with the use of the name "Tacket Formation" as well as the definition of the constituent members of the Shale Hill Formation of Heckel and Watney (2002). Additional work will be needed to resolve these matters as well.

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