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Control of Middle Pennsylvanian (Desmoinesian) Depositional Patterns by Minor Movements along Lineaments in Northeast Missouri

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ABSTRACT

Thin Middle Pennsylvanian (Desmoinesian) cyclic strata, include underclays, coals, black phosphatic shales, limestones, sandy mudstones, and sandstones crop out in much of northeastern Missouri. These strata were deposited disconformably on a platform underlain by Middle Mississippian limestones that connected the Forest City Basin to the northwest with the Illinois Basin to the east. The platform is broken into a series of rigid crustal blocks by northwest and northeast trending lineaments that are interpreted as basement fault zones that are related to late Precambrian-early Cambrian rifting of the Rodinia supercontinent.

The strata thicken and thin abruptly in a number of paleolows (depositional centers) and paleohighs (areas of thinning) that are unrelated to regional patterns. Six depositional models: irregularities on the pre-Pennsylvanian erosion surface, onlap and convergence, offlap and erosion, differential compaction, folding during deposition, and fault block tectonics, are possible causes of the thickness anomalies. Comparisons of thickness values, isopach maps and trend surface maps of individual stratigraphic units reveal that fault block tectonics is the most likely model. Thus, minor uplift, depression, or tilting of adjacent crustal blocks was the primary cause of the abrupt thickness changes.

INTRODUCTION

The area of study in northeastern Missouri is underlain by Middle Pennsylvanian (Desmoinesian) strata of the Cherokee and Marmaton Groups (figures 1 and 2) that consist of widespread, thin units of marine transgressive and regressive cyclic sequences (Searight 1959). The principal rock types include underclays, coals, phosphatic shales, calcareous shales, and limestones (calcilutites). Sandstones and sandy shales are confined to the Lagonda and Fort Scott Formations (figure 2). Individual facies were deposited in environments in which energy levels varied greatly as follows: 1) very low - underclays, coals and black phosphatic shales; 2) low - limestones and calcareous shales; and 3) moderate to high - sandstones and sandy mudstones. Individual members range in thickness from one to two centimeters to approximately 10 meters. Contacts between facies are sharp except for the sandstones and sandy mudstones which grade into one another. The area of study is relatively small, approximately 23,300 km^2. Thus, marine transgressions and regressions must have been rapid enough that the surfaces on which the coals, black phosphatic shales, and limestones are essentially synchronous.

The pre-Pennsylvanian surface represents a long period of weathering, erosion, and development of karst features on Middle Mississippian (Osagean) limestones. The oldest Pennsylvanian rocks are chert pebble conglomerates that were derived from reworked Mississippian residuum that filled stream channels and sinks on the pre-Pennsylvanian erosional surface. The Cheltenham Clay overlies the chert pebble conglomerates and essentially filled in the remaining paleotopographic features on the pre-Pennsylvanian surface. All post-Cheltenham strata were deposited as conformable succession. Searight (1959) indicated that a number of the lithologies from the interval between the Cheltenham Clay and the underclay of the Croweburg Coal in southwestern Missouri are absent in northeastern Missouri. During this part of Pennsylvanian time, northeastern Missouri was sufficiently elevated so that the Tebo Coal and its underclay, and the Tiawah Limestone were deposited in several scattered depositional centers. The missing cycles are represented by moderate thickening of the underclays of the Tebo, Croweburg, Bevier-Wheeler, and Mulky Coals. Regionally, the Pennsylvanian section has been deeply eroded. It has been completely removed in many modern stream valleys. Where preserved, the combined thickness of post-Cheltenham strata ranges from 2 to 40 m.

TECTONIC SETTING

The major tectonic features in Missouri are the Ozark Uplift, the Mississippi Embayment, and the Forest City Basin (figure 3). Searight and Searight (1961) divided the northern and western flanks of the Ozark Uplift into structural segments based on the age of the youngest strata preserved at the surface. From southwest to northeast these are: 1) Tri-State Plateau, 2) West-Central Salient, 3) East-Central Recess, and 4) Lincoln Fold. In the East-Central Recess (the area of study), strata younger than the Mulky Coal overlap older Pennsylvanian units southeastward onto the Ozark Uplift and northeastward on to the flank of the Lincoln Fold. On both the West-Central Salient and Lincoln Fold the youngest indurated rocks preserved are pre-Pennsylvanian in age. Pennsylvanian strata do not pinch out on these bordering structural features and therefore, must have originally covered the entire northern flank of the Ozark Uplift. During Desmoinesian time, the East-Central Recess was a gradually subsiding platform that connected the Forest City Basin with the Illinois Basin through the St. Louis Depression.

Kisvarysani and Kisvarysani (1976) identified a number of lineaments in Missouri based on interpretation of Land Sat 11 imagery. Several of these lineaments cross the East-Central Recess in northwest and northeast trends (figure 4). The distribution of Desmoinesian strata (figure 1) has a striking affinity with these lineaments. A major lineament forms the southwestern boundary of the East-Central Recess. The Lincoln Fold is in part faulted and may also be a lineament that was not apparent on the Land Sat 11 images. In addition, the outcrop patterns in figure 1 strongly suggest that there are several additional lineaments in the area.

Clendenin and others (1989) interpret the structural framework of southeastern Missouri as a late Proterozoic-early Cambrian system of northwest-striking transfer faults and northeast-striking extensional faults that developed during the rifting of the Rodinia supercontinent. Through time, rigid crustal blocks separated by these fault systems were structurally elevated and depressed (figure 5). They concluded that during Late Cambrian time the faults were reactivated and extended northwestward across the mid-continent region producing a series of major lineaments. Gibbons (1974) indicated that uplift and tilting of blocks bounded by basement faults was the major tectonic mechanism of deformation in the Ozark region throughout the Paleozoic Era. Clendenin and others (1989) are in agreement with Gibbons and identify several specific episodes of activity on the fault system. One of the most important of these episodes of activity was related to the Ouachita Orogeny during Late Mississippian through Late Pennsylvanian time. The deposition of the rocks addressed during this study occurred during this time.

Projection of the major transfer faults of Clendenin and others (1989) from southeastern Missouri into northern Missouri coincides closely with several of the northwest trending lineaments recognized by Kisvarysani and Kisvarysani (1976) and appear to be extensions of them (figure 5). It is likely that the northeast trending lineaments in northern Missouri are extensions of these faults. The deposition of Cherokee and Marmaton strata were substantially influenced by the elevation, depression, or tilting of these rigid, fault-bounded crustal blocks.

Superimposed on the fault block framework of northeastern Missouri are a number of broad anticlines and synclines with northwest and northeast trends (figure 4). These structures range in length from 10 to 60 kilometers and have closures of between 10 to 30 meters. Dips on the flanks are generally less than 10 degrees although dips as high as 35 degrees occur locally. These folds have been noted by several previous workers: Winslow (1891), Gordon (1893), Hinds (1912), Hinds and Greene (1915), Marbut (1898), Markham (1919), Groskopf , and others. (1939), Barrett (1940), Branson (1944), Griggs (1940), Allen (1941), McQueen (1943), Unklesbay (1952, 1956), Searight (1959), and McCracken (1971). The trends of these folds are parallel to the principal lineaments and most occur along or near them. These structures are interpreted to be drape folds over the boundaries of adjacent crustal blocks. All Desmoinesian rocks are folded, indicating that at least the final episode of folding was post- Desmoinesian in timing.

THICKNESS ANALYSIS OF LITHOLOGIC UNITS

Seventeen individual lithologic units underlie much of the study area (figure 2). These, from the base upward are: 1) Tiawah Limestone, 2) underclay of the Croweburg Coal, 3) Croweburg Coal, 4) Mecca Quarry Shale, 5) Ardmore Limestone (several limetones interbedded with calcareous shales), 6) underclay, 7) Wheeler and Bevier Coals, 8) Lagonda Formation (sandstone and sandy mudstones), 9) underclay, 10) Mulky Coal, 11) Excello Shale, 12) Blackjack Creek Limestone, 13) underclay of the Summit Coal, 14) Summit Coal, 15) unnamed black phosphatic shale, 16) Houx Limestone, and 17) Higginsvitle Limestone. In addition the underclay and Tebo Coal underlie the Tiawah Limestone in a few scattered depositional centers. Thicknesses of stratigraphic units used in the data base for this study were obtained from outcrops, coal mine records, coal test borings, and the following published sources: Winslow (1891), Hinds (1912), Hinds and Greene (1915), McQueen (1943), Unklesbay (1952 and 1956), and Searight (1959). A total of 69 localities with reliable thickness data were identified (figure 6).

During this study we investigated the variations in thickness of all 17 lithologic units. We found that although the number of localities in which individual units occur vary greatly, the general patterns of thickening and thinning were similar for each stratigraphic unit. However, data on strata below the underclay of the Croweburg Coal and above the Blackjack Creek Limestone were so limited that only general thickness trends could be established. The cycle that includes the strata between the base of the Lagonda Formation and the top of the Blackjack Creek Limestone contains all of the facies present within the study area and has the largest data base. Therefore, we have selected this interval for discussion. The data base is included as table 1.

Thickness Patterns

The cycle selected for discussion is composed of the following lithologic units in ascending order: 8) Lagonda Formation, 9) underclay, 10) Mulky Coal, 11) Excello Shale, and 12) Blackjack Creek Limestone. As stated above, except for the sandstones and sandy mudstones in the Lagonda Formation all lilithologic units are thin and were deposited in low energy environments. Under these conditions each facies should be a thin sheet with very gradual regional changes in thickness. In northern Missouri, however, this is not the case, rather thickness changes are abrupt and increase or decrease from three to five times locally. The lithologic characteristics and thickness patterns of the strata are presented as table 2.

We located paleolows (depositional centers) and paleohighs (areas of thinning) on isopach maps (figure 7), trend surface maps (figures 8 and 9). Comparison of the locations of paleolows and paleohighs on the isopach maps (figure 7) shows that each lithologic unit thickens in paleolows and thins in paleohighs locally, but these localities generally do not persist throughout the cycle.

The most striking thickness anomaly occurs along a northeast-southwest trend from southeastern Monroe County through central Callaway and Audrain Counties to Ralls County (figure 7). The relationship between each lithologic unit and this trend is as follows: 8) Lagonda Fm. - thickens to the southwest; 9) underclay - slight thickening to the southwest; 10) Mulky Coal - thickens to the northeast; 11) Excello Shale - thickens to the northeast; and 12) Blackjack Creek Limestone - generally thick but thinner to the northeast. This trend is along and near a major northeast-southwest lineament.

Localities used in the data base in the trend surface analysis were established by placing a square grid over the study area with the northwest corner as the generator of the X,Y coordinates. Thicknesses in centimeters of each lithologic unit were digitized for each locality. Polynomial and planar quadratic surfaces were calculated from the data base following the discussions of Krumbein and Graybill (1965) and Davis (1986). Residual values of 90%, 95%, and 97.5% were calculated for each locality and used for comparison. Analysis of these values for each confidence level indicated that the 97.5% level was the most discriminating and therefore, only these values are used here. Values greater than (+), within (0), and less than (-) the calculated values are shown on figures 8 and 9. These values were plotted on maps (figures 8 and 9) to determine the locations of paleolows and paleohighs. The maps indicate multiple paleolows and paleohighs in the same general areas indicated on the isopach maps.

DISCUSSION

Sonnenberg and Weimer (1981) modeled five mechanisms as causes of thickness anomalies in large bundles of stratigraphic units in the northern part of the Denver Basin. These are as follows: 1) onlap; 2) convergence; 3) offlap and erosion; 4) compaction; and 5) faulting. They concluded that recurrent movement on basement faults was the primary influence on thickness patterns in this area. We tested each of these models to determine whether similar mechanisms could have influenced the depositional patterns of the thin Pennsylvanian strata in northeastern Missouri. Because of the tectonic framework of the study area, we combined 1) onlap and 2) convergence and considered two additional models: 6) paleogeography of the pre-Pennsylvanian surface and 7) uplift and subsidence related to folding during deposition. Each of these models is considered in the following discussion.

Model 1. Thickness Anomalies Related to Paleotopography of the Pre-Pennsylvanian Erosion Surface.

As discussed above the earliest Pennsylvanian sediments, chert pebble conglomerates and the Cheltenham Clay, were deposited on a Pre-Pennsylvanian surface where they filled valleys and sinks producing a surface of low relief. The first Desmoinesian deposits are clays deposited in a very low energy environment. The isopach map (figure 10) shows that there is no general pattern of thickening and thinning consistent with predepositional topography.

Model 2. Thickness Anomalies Related to Onlap and Convergence

Sonnenberg and Weimer (1981) state that onlap results from marine transgression so that conformable sedimentary units progressively pinch out on the margins of basins or on structures within a basin. They further state that convergence is the gradual thinning of a stratigraphic unit locally which may result in pinch out without marine transgression. Sedimentary units from the top of the Cheltenham Clay through the Lagonda Formation (figure 2) thin and pinch out from southwest to northeast. Although all of the succeeding strata are conformable this pattern of thinning does not persist. Instead, the strata in the interval from the base of the underclay of the Mulky Coal through the Blackjack Creek Limestone progressively onlap the Cheltenham Clay, but do not thin and pinch out. This indicates that the depositional surface on the top of the Cheltenham Clay had a gradual downward slope from northeast to southwest. This surface was gradually leveled by deposition of the underlying strata so that the underclay of the Mulky Coal covered all of northeastern Missouri. All of the Pennsylvanian strata were deposited in marine transgressive-regressive cycles and none of them thin gradually and pinch out within the North-Central Recess during periods of marine still-stand. The scattered locations of paleolows and paleohighs in these units therefore cannot be related to onlap or convergence.

Model 3. Thickness Anomalies Related to Offlap and Erosion
Offlap and erosion result from marine regressions so that in conformable sedimentary units each successively younger unit exposes a portion of the immediately older unit. Erosion commonly truncates all of the units within a conformable sequence (Sonnenberg and Weimer 1981). The lithologic units from the base of the Lagonda Formation through the Blackjack Creek Limestone are conformable. There is no evidence of offlap and only minor erosion during deposition of these units. This is true of the remainder of the strata as well (Searight 1959).

Model 4. Thickness Anomalies Related to Compaction
Compaction is the thinning of sediments due to the weight of overburden. The compactibility of sediments is a function of grain size, grain shape, mineral composition of grains, and the quantity of interstitial water present during deposition. Thus, sediments of the same depositional thickness that differ in some or all of these characteristics will have greatly different thicknesses after compaction (Sonnenberg and Weimer 1981). The underclay, Mulky Coal, and Excello Shale are the most compactible lithologies in the succession. The Blackjack Creek Limestone, deposited as a lime mud is dominantly a calcilutite recrystallized to a very fine crystalline limestone. Extreme compaction of this generally thin lime mudstone should have produced complete recrystalliztion with at least moderate crystal sizes. In addition, large fossils are moderately flattened, but small forms are undeformed. Therefore the compaction of the Blackjack Creek is considered to be moderate. In the Lagonda Formation, the sandstones are the least compactible lithologies in the succession while the sandy mudstones are moderately compactible. If thickening and thinning of these sedimentary units is related to differential compaction, the thickest deposits of limestone and sandstone should occur in localities in which highly compactible units are thinnest. Reference to figures 7, 8, 9, and 10 show that this is not the case. Therefore, differential compaction cannot be considered an important mechanism in the location of paleolows and paleohighs.

Model 5. Thickness Anomalies Related to Folding During Deposition
Folding during sedimentation produces paleolows in synclinal troughs and paleohighs on anticlinal axis. If the anticlines and synclines in the study area were active during Desmoinesian time sedimentary units should thicken in the synclines and thin over the anticlines. A comparison of the locations of the folds (figure 4) with the isopach maps (figure 7) and trend surface maps (figures 8 and 9) shows that this is not the case. Some of the structures occur on the margins of thickness anomalies while others are located well away from anomalies. In addition thickness anomalies cover areas generally much broader than the structures. Thus, this model does not adequately account for the patterns of sedimentation.

Model 6. Thickness Anomalies Related to Fault Block Tectonics
Sonnenberg and Weimer (1981) define fault block tectonics as the geometric and mechanical style of deformation in which basement blocks behave in rigid fashion. They consider basement as "rocks that are mechanically homogeneous and isotropic and behave in a brittle manner "When under stress these basement rocks yield to brittle deformation that results in rigid blocks of varying size and shape bounded by faults or shear zones. As stated previously in this discussion lineaments in northeastern Missouri are considered to be basement faults related to continental rifting. Stress, which caused

local uplift, depression, and rotation of the rigid blocks, was transmitted to this area during the Ouachita Orogeny to the south. A comparison of the isopach maps of the Blackjack Creek Limestone (figures 7A and B) shows a strong correlation between thickness anomalies and the positions of the lineaments. The remaining isopach maps (figures 7C-F) and the trend surface maps (figures 8 and 9) indicate similar patterns. It is also apparent that movements along certain lineaments were more instrumental in the localization of paleohighs and paleolows than were movements along the remainder. Of particular note is the northeast trending lineament that extends from central Callaway County into southeastern Monroe County that coincides with the thickness anomalies in this area. Because the sedimentary units deposited are extremely thin, the vertical or rotational displacements of block margins were very small during deposition of individual facies.

Thickness anomalies in the five units, Lagonda Formation through the Blackjack Creek Limestone, are closely related to the positions of major northwest and northeast trending lineaments. This relationship is supported by both isopach and trend surface maps. The lineaments are interpreted as a fault system formed by the rifting of Rodinia Supercontinent in the late Precambrian that created a collage of rigid crustal blocks in northeastern Missouri. These blocks were displaced in small increments by block fault tectonics several times during the Paleozoic. During Desmoinesian time at least some of these crustal blocks were raised, depressed, and rotated relative to one another in response to the stress generated by the Ouachita Orogeny. Very small displacements along block margins produced small paleolows and paleohighs that caused thickening and thinning of the various lithologic units. Although a single cycle has been considered in this discussion similar facies in the other Desmoinesian cycles have similar thickness patterns.

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Figure 1. Location map of the study area showing the distribution of Desmoinesian strata.

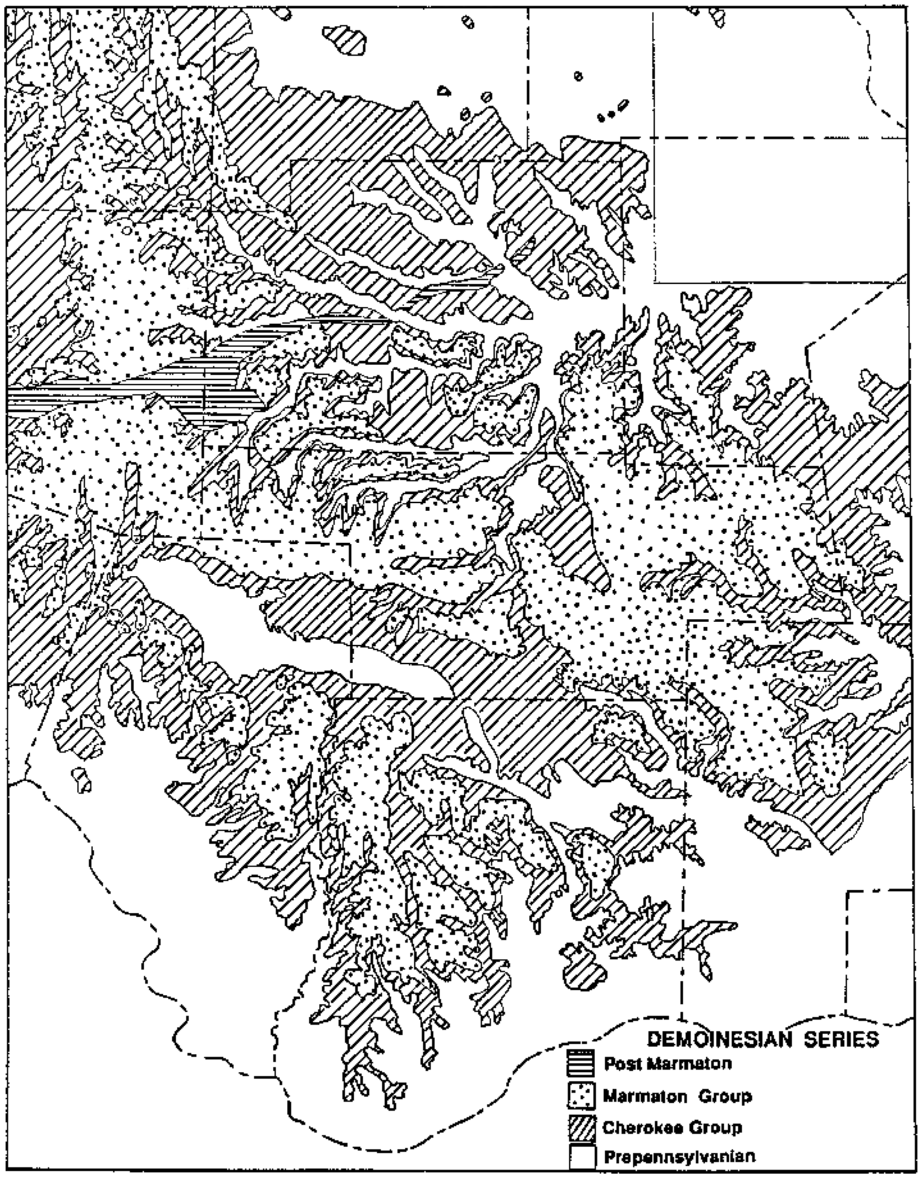


Figure 2. Generalized stratigraphic column of Desmoinesian strata exposed in the study area.

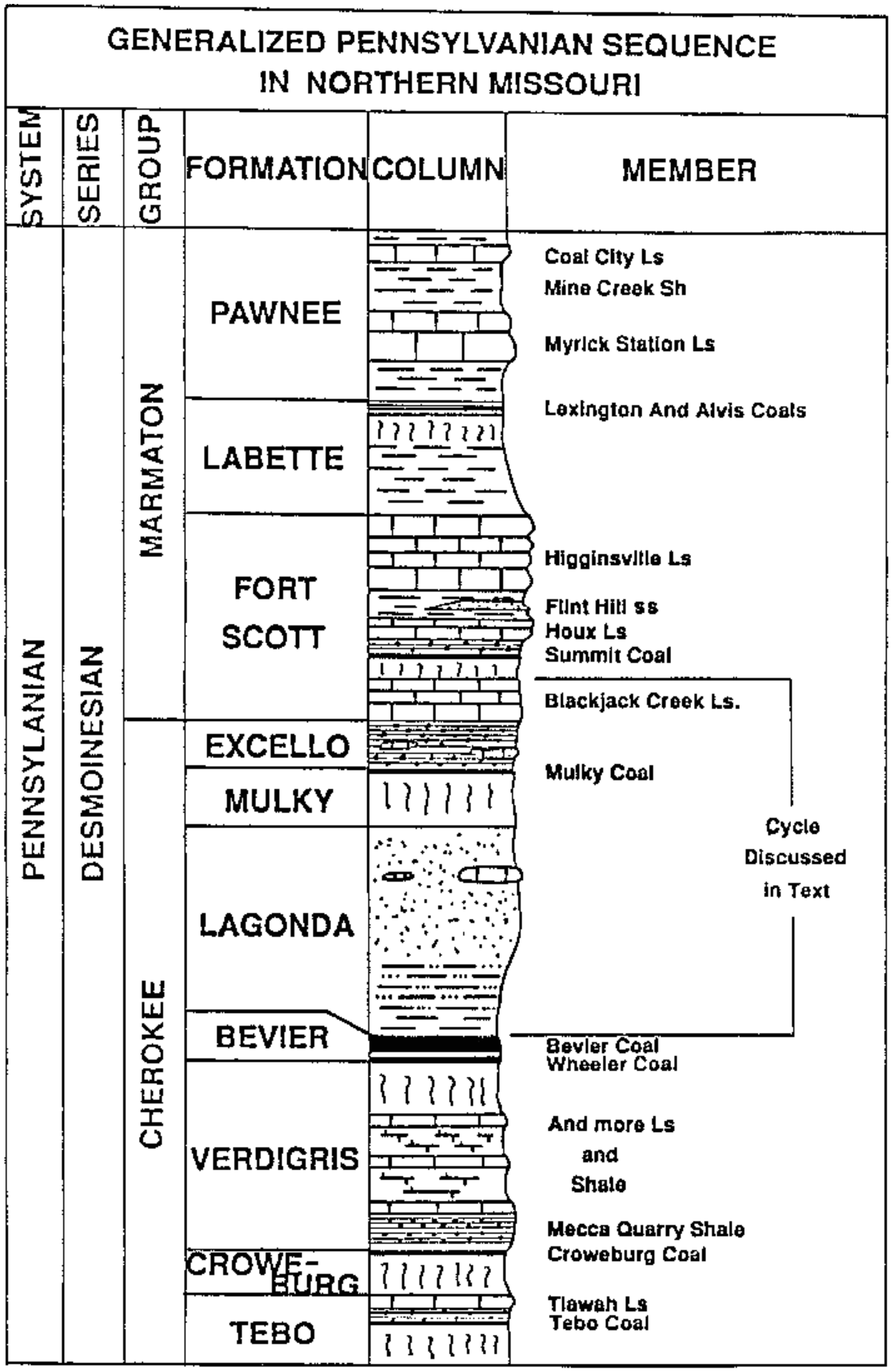


Figure 3. Principal structural features in Missouri (modified from Searight and Searight, 1961).

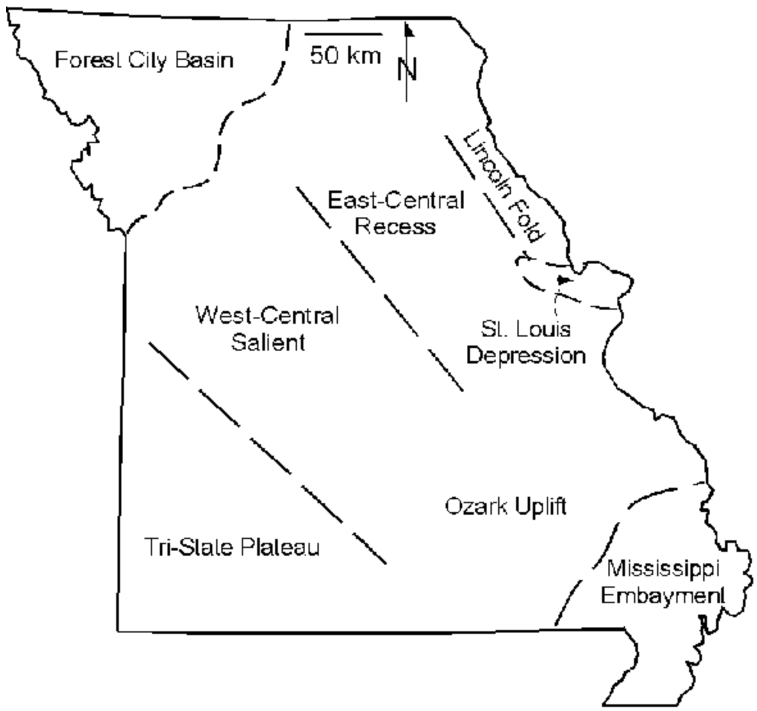


Figure 4. Principal folds and lineaments in northeastern Missouri (modified from Kisvarysani and Kisvarysani, 1976 and Searight, 1959).

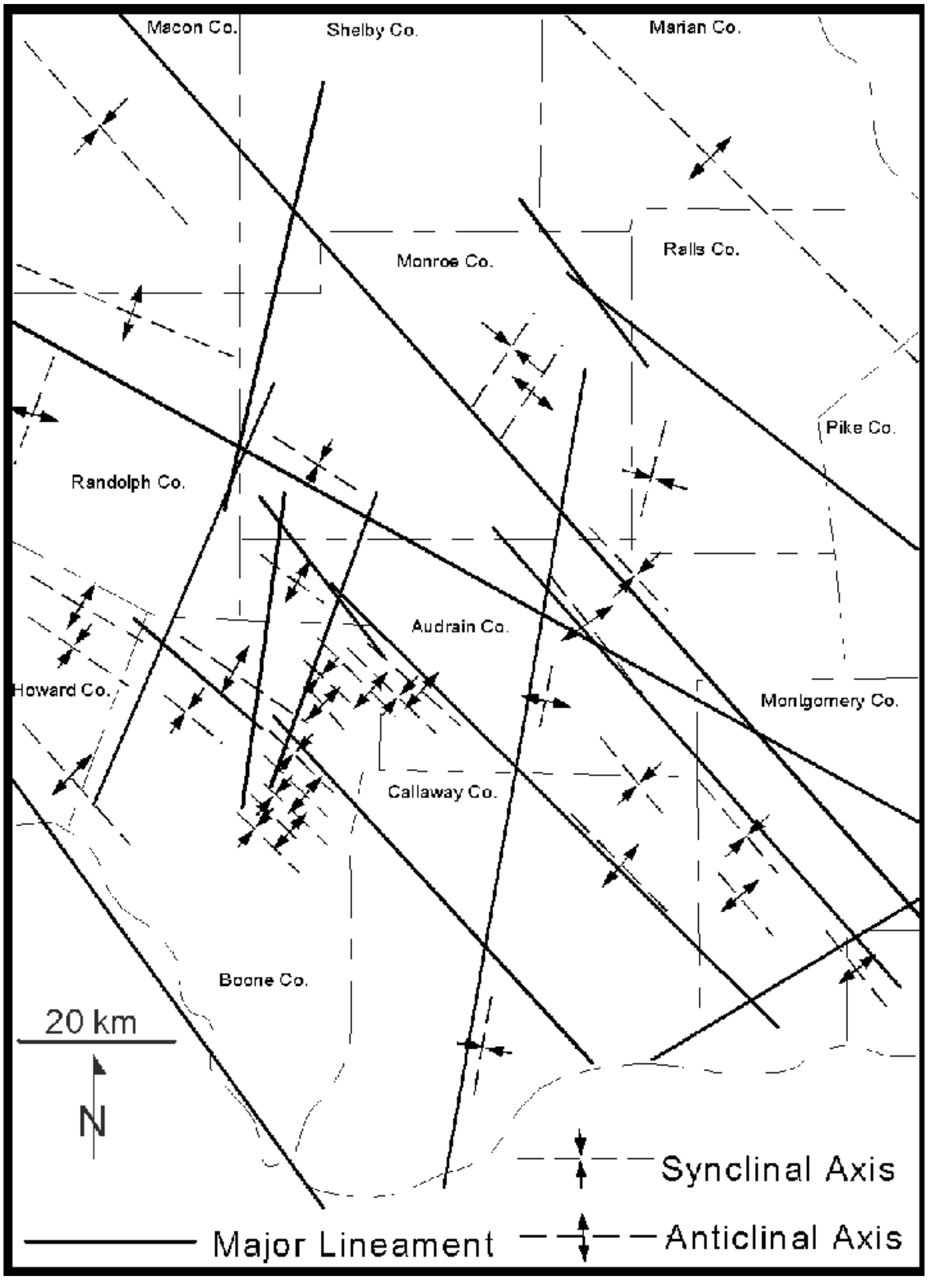


Figure 5. Relationship between principal lineaments in northeastern Missouri to major fault zones in southeastern Missouri (modified from Kisvarysani and Kisvarysani, 1976 and Clendenon and others, 1989). A -- Cap Au Gres Fault; B -- Ste. Genevieve Fault; C -- Sims Mountain Fault; D -- Black Fault; E -- Ellington Fault; F -- Shannon Fault.

Figure 6. Location map of measured sections of Desmoinesian strata.

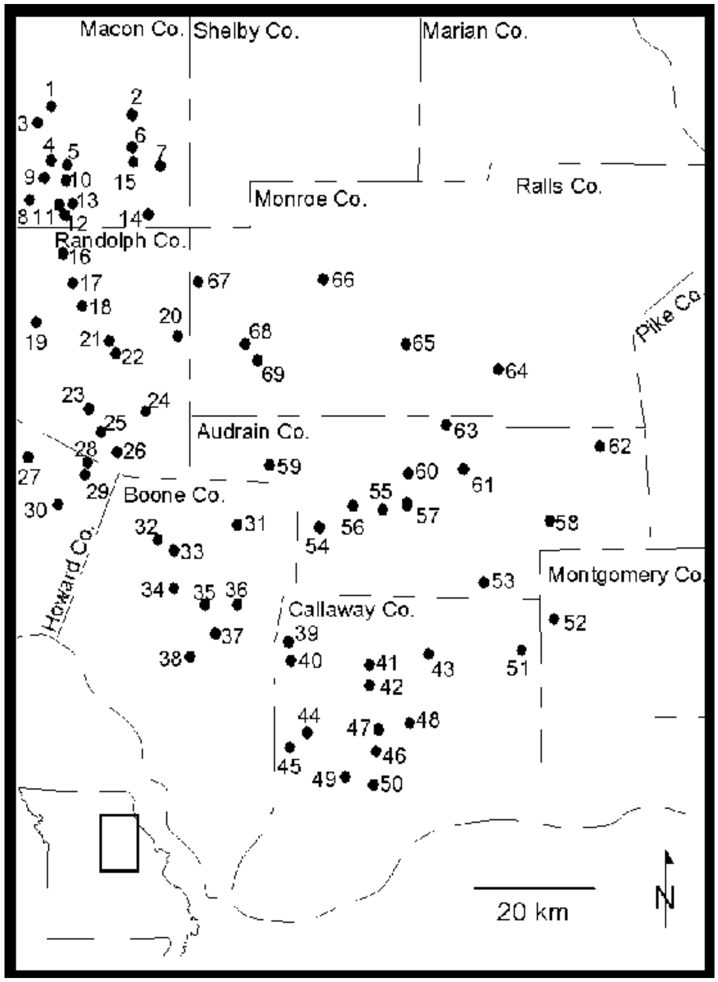


Figure 7. Isopach maps of lithologic units in the Lagonda-Blackjack Creek cycle superimposed on the principal lineaments that occur within the study area. A) Blackjack Creek Limestone (isopachs only). B) Blackjack Creek limestone (with lineaments), C) Excello Shale, D) Mulky Coal, E) Underclay of Mulky Coal, F) Lagonda Formation.

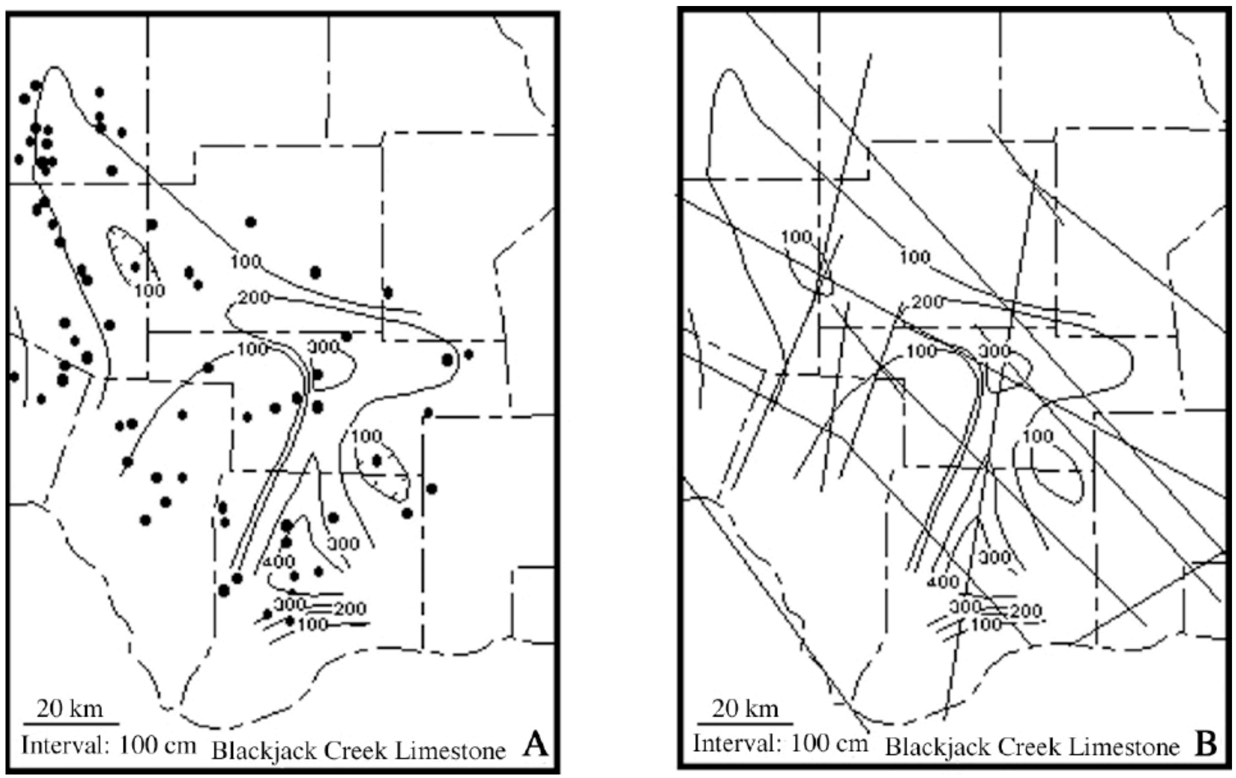
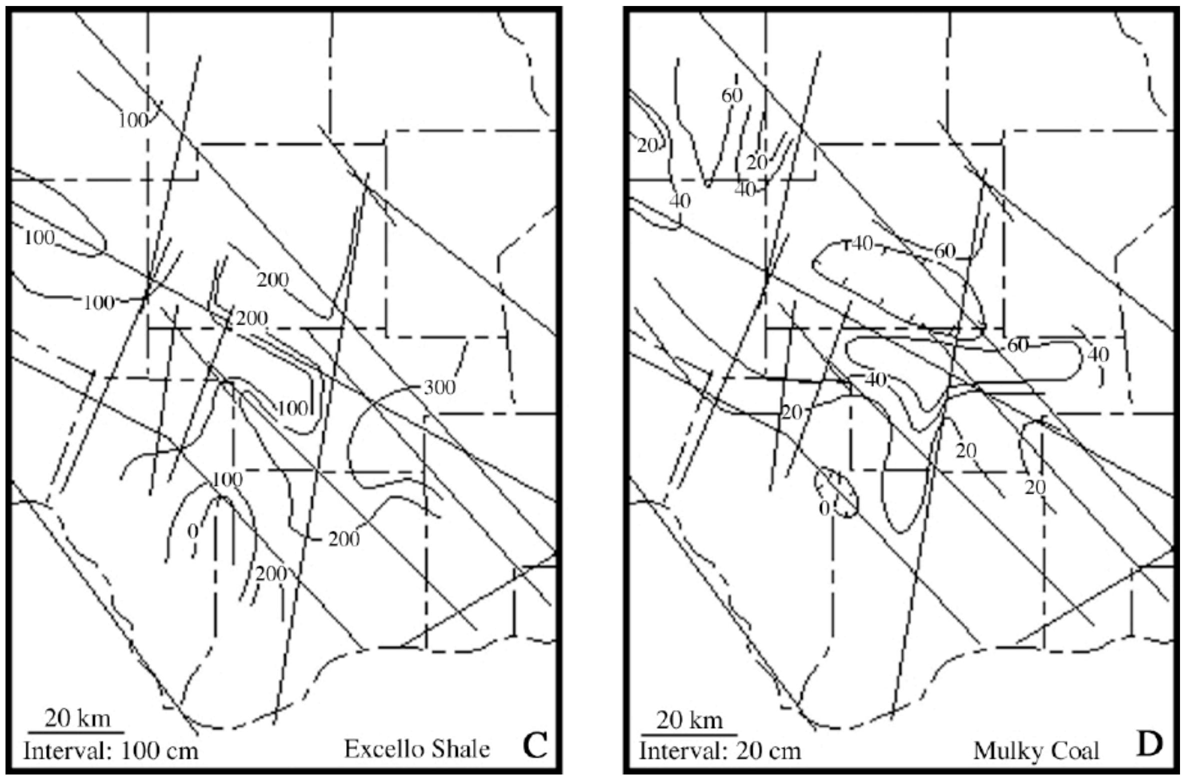


Figure 7. continued.



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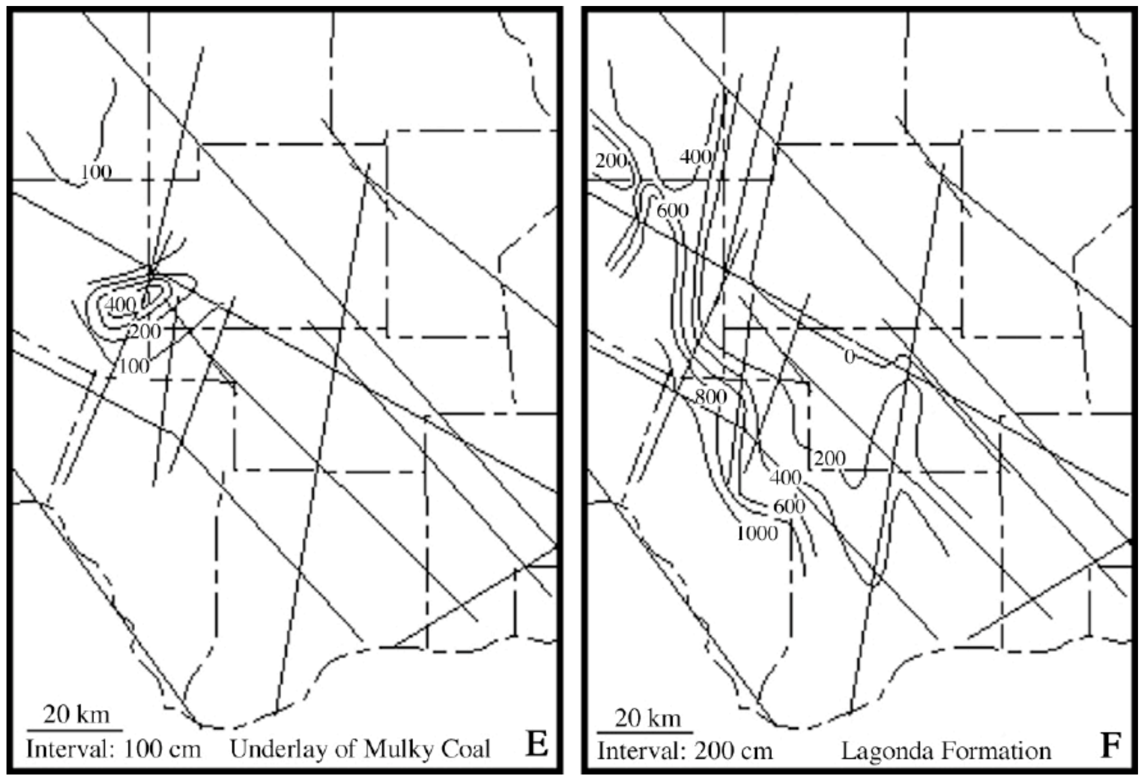

Figure 8. Trend surface maps based on a quadratic polynomial surface superimposed on lineaments. A) Blackjack Creek Limestone, B) Excello Shale, C) Mulky Coal, D) Underclay of Mulky Coal, E) Lagonda Formation.

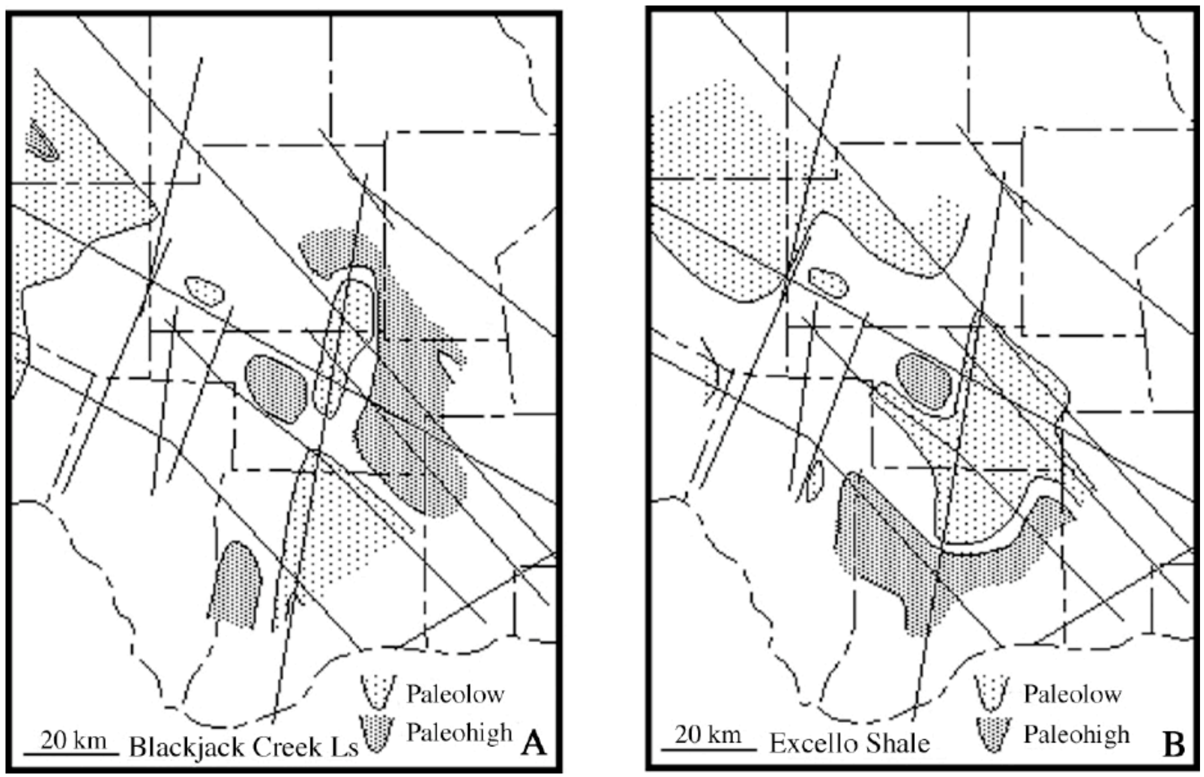

Figure 8. continued.

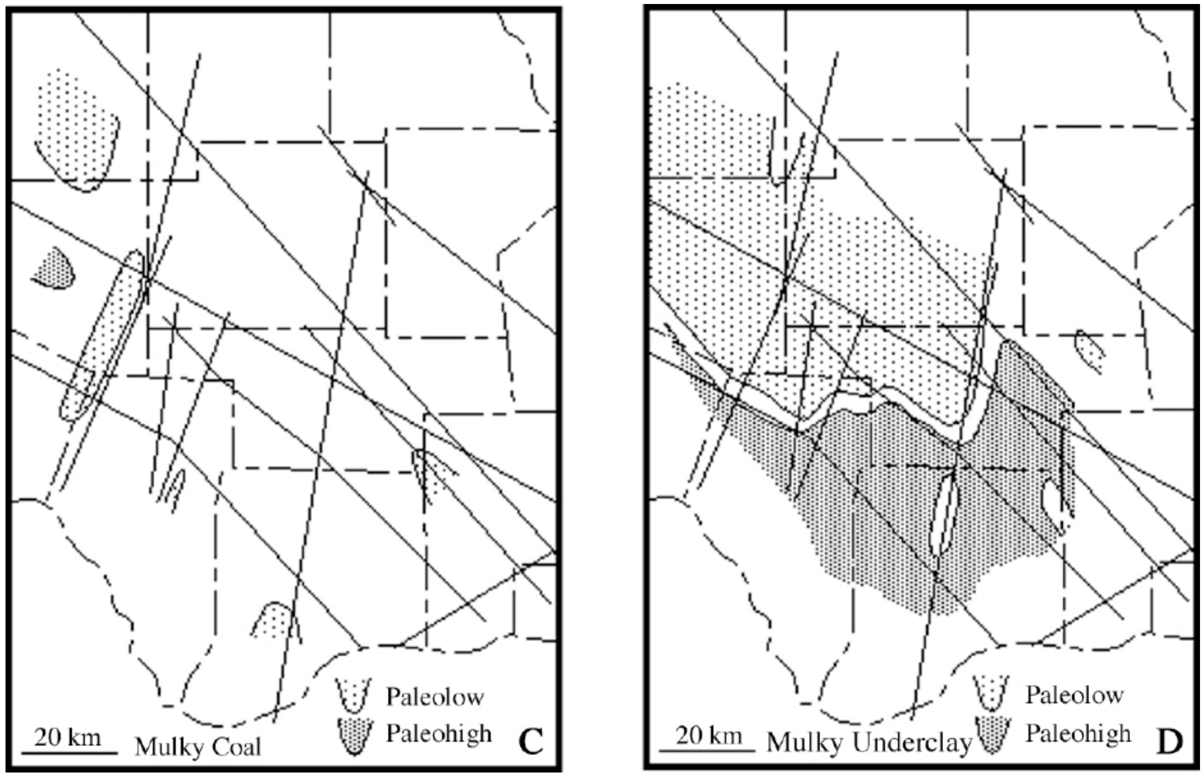

Figure 8. continued.

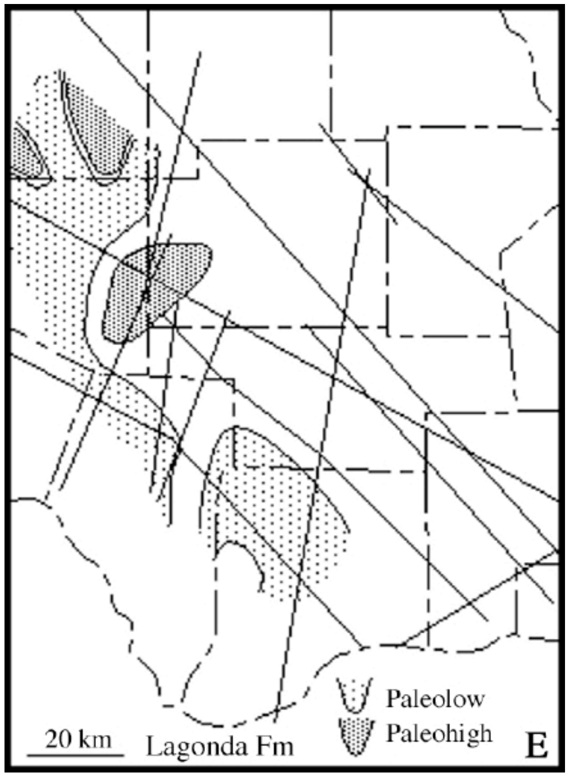

Figure 9. Trend surface maps based on a quadratic planar surface superimposed on lineaments. A) Blackjack Creek Limestone, B) Excello Shale, C) Mulky Coal, D) Underclay of Mulky Coal, E) Lagonda Formation.

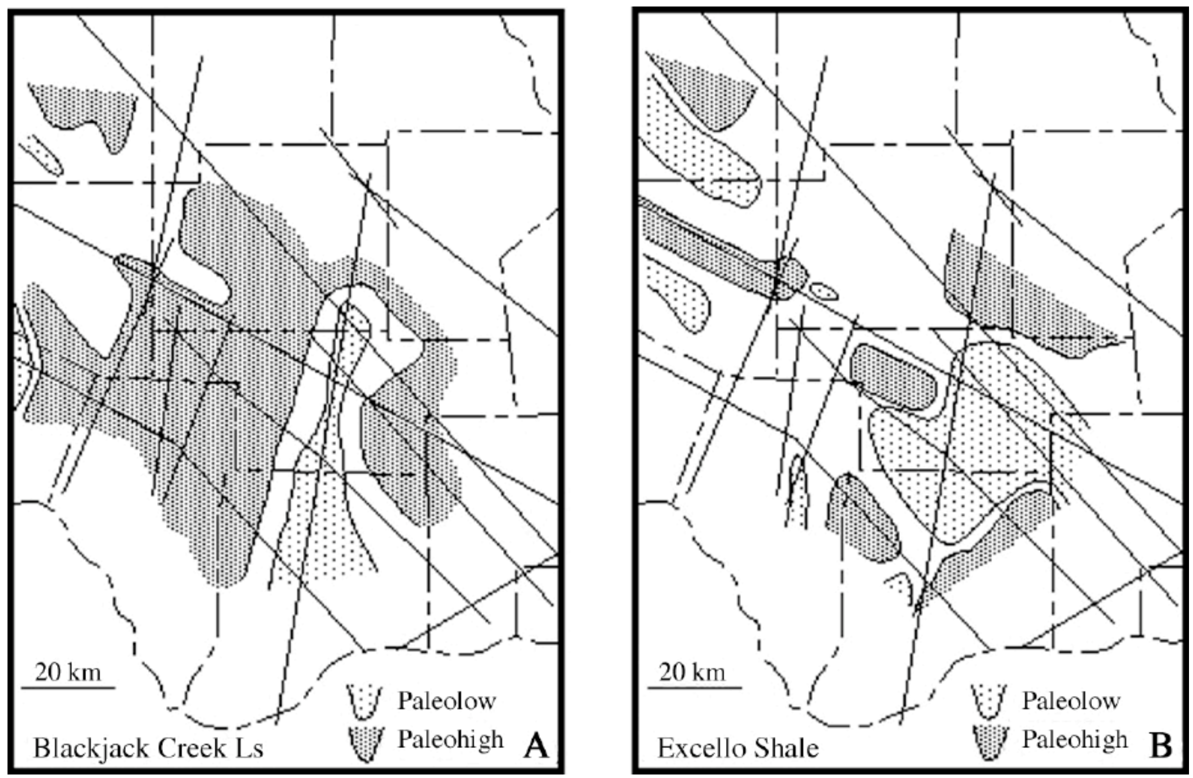

Figure 9. continued.

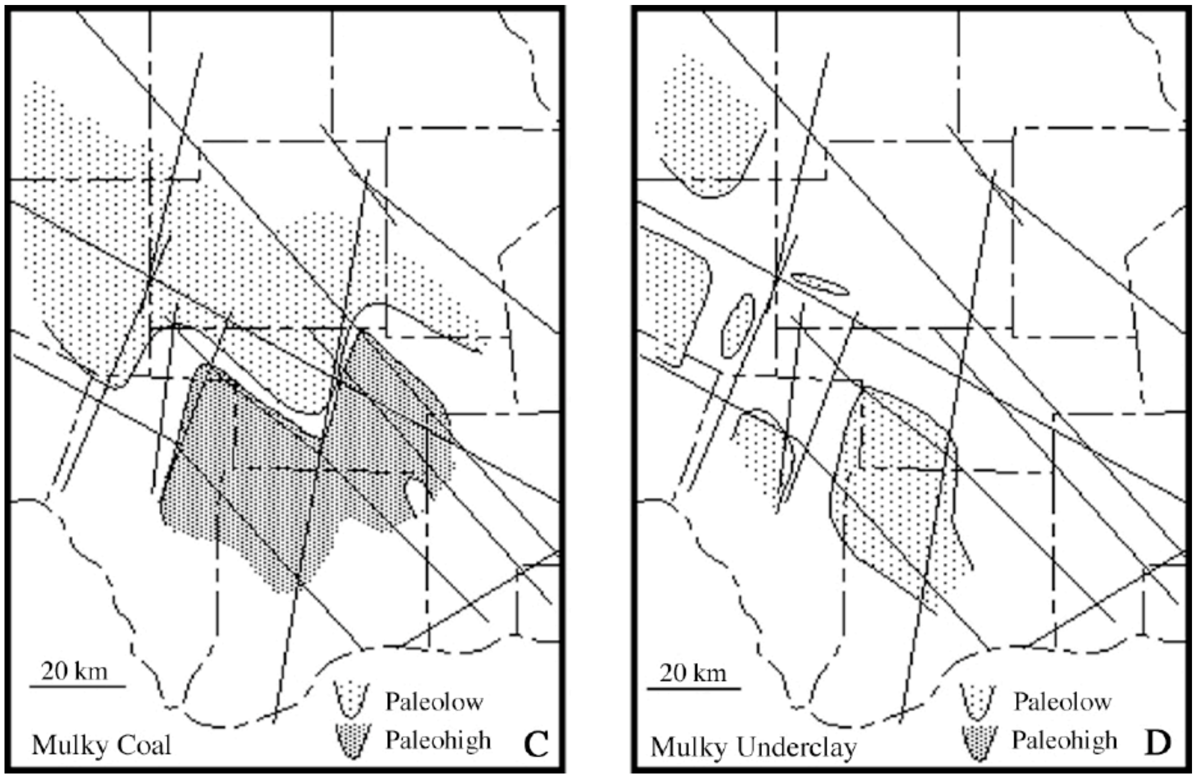

Figure 9. continue

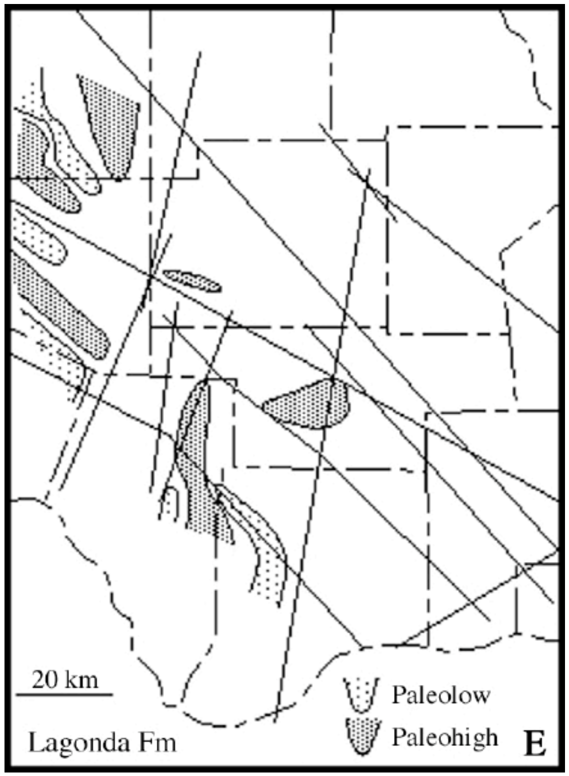

Figure 10. Isopach map of the interval from the base of the underclay of the Croweburg coal through the Ardmore limestone.

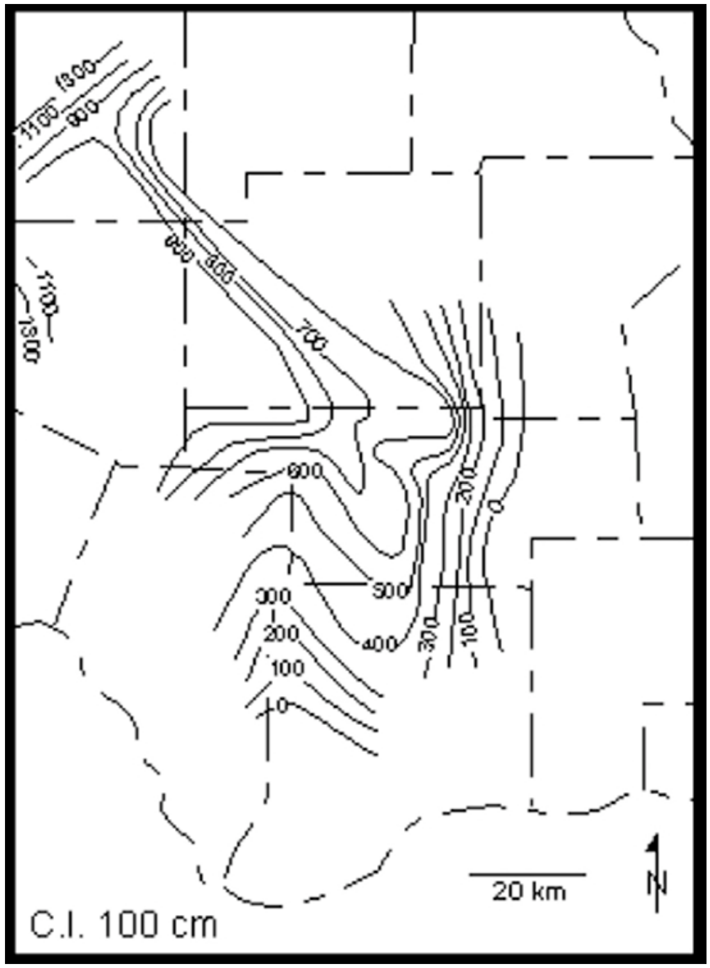

Figure 11. Comparison of thickness anomalies of the highly compactible underclay of the Mulky Coal, Mulky Coal, and Excello Shale with the less compactible Blackjack Creek Limestone.

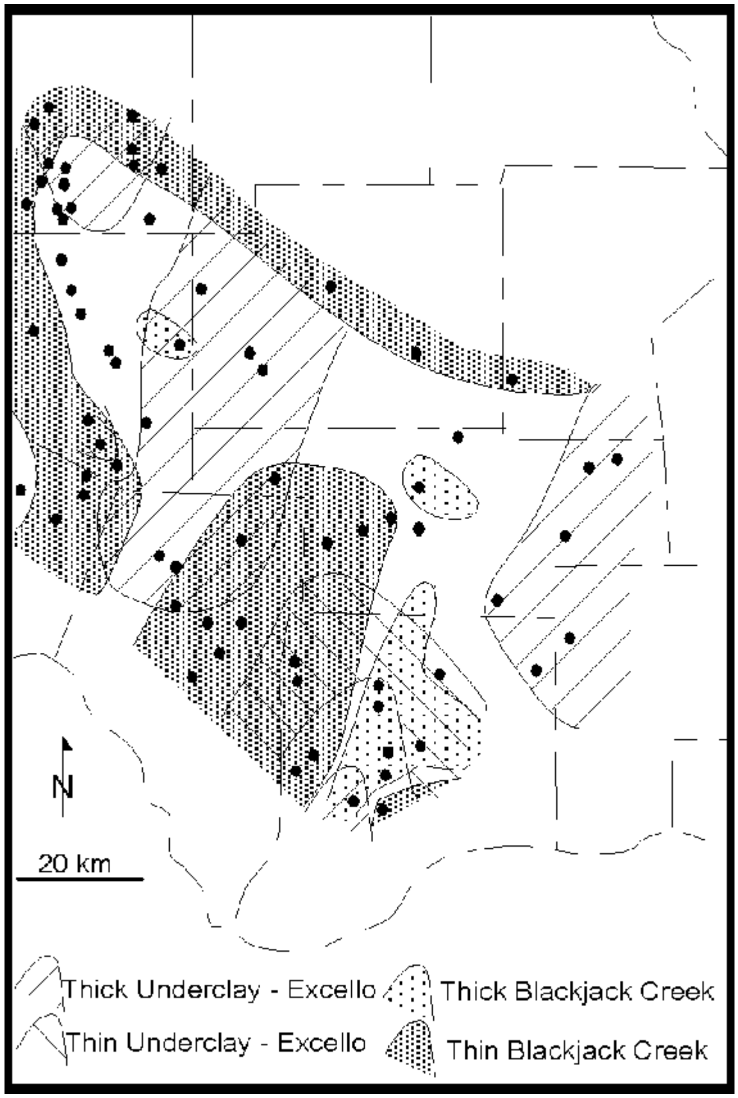

Table 1. Data Table for the Lagonda-Blackjack Creek Section. Index to numbers of stratigraphic units: 8 = Lagonda Formation, 9 = Underclay of the Mulky Coal, 10 = Mulky Coal, 11 = Excello Shale, 12 = Blackjack Creek Limestone. PO = Polynomial quadratic trend surface, PL = Planar trend surface, + = greater than predicted value, 0 = within predicted value, - = less than predicted value. * = Data from Searight, 1959; # = data from Hinds, 1912.

Locality	Stratigraphic Unit	Thickness (cm)	PO	PL
1* SW1/4 SE1/4 sec. 18, T57N, R14W,	12	91.4	+	-
Macon County, MO	11	121.9	0	-
	10	45.7	+	+
	9	167.6	+	+
	8	411.5	+	0
2* SE1/4 SW1/4 sec. 18, T57N, R13W,	12	53.3	0	-
Macon County, MO	11	55.9	+	-
3# NW1/4 sec. 27, T57N, R15W,	12	91.4	+	-
Macon County, MO	11	152.4	+	0
	10	45.7	+	+
	9	------	ND	ND
	8	594.4	+	+
4* SE1/4 NE1/4 sec. 12, T56N, R15W,	12	91.4	+	-
Macon County, MO	11	162.6	+	+
	10	40.6	+	+
	9	106.7	+	+
	8	525.8	+	+
5# NW1/4 SW1/4 sec. 8, T56N, R14W,	12	106.7	+	-
Macon County, MO	11	121.9	+	-
	10	61.0	+	+
	9	------	ND	ND
	8	335.3	0	-
6# NW1/4 SE1/4 sec. 31, T57N, R13W,	10	66.0	+	+
Macon County, MO	9	152.4	+	+
	8	61.0	-	-
7* SW1/4 SE1/4 sec. 9, T56N, R13W,	12	71.0	0	-
Macon County, MO	11	111.8	+	-
	10	27.9	0	-
	9	55.9	0	-
	8	73.7	-	-
8* E1/2 SE1/4 sec. 13, T56N, R15W,	12	50.8	0	-
Macon County, MO	11	157.5	+	0
	10	15.1	0	-
	9	71.1	+	-
	8	320.0	0	-
9# NW1/4 SW1/4 sec. 17, T56N, R14W,	10	55.9	+	+
Macon County, MO	9	------	ND	ND
	8	579.0	+	+
10* NE1/4 NW1/4 sec. 30, T56N, R14W,	12	91.4	+	-
Macon County, MO	11	160.0	+	+
	10	50.8	+	+
	9	139.7	+	+
	8	411.5	+	0
11* NW1/4 NE1/4 sec. 18, T56N, R14W,	12	106.7	+	-
Macon County, MO	11	139.7	+	0
	10	55.9	+	+
	9	101.6	+	0
	8	807.7	+	+
12* sec. 29, T56N, R14W,	12	170.2	+	+
Macon County, MO	11	167.6	+	+

Table 1. continued.

Locality	Stratigraphic Unit	Thickness (cm)	PO	PL
13# NE1/4 NW1/4 sec. 29, T56N, R13W,	12	124.5	0	0
Macon County, MO	11	188.0	+	+
	10	38.1	+	+
	9	53.3	0	-
	8	152.4	0	-
14# SE1/4 NW1/4 sec. 18, T56N, R13W,	12	91.4	0	-
Macon County, MO	11	172.7	+	+
	10	45.7	+	+
	9	91.4	0	0
	8	157.5	0	-
15# SW1/4 SE1/4 sec. 15, T56N, R13W,	12	94.0	0	-
Macon County, MO	10	7.6	0	-
	8	459.1	0	+
16# sec. 5, T55N, R14W,	12	121.9	+	0
Randolph County, MO	11	61	+	-
	10	38.1	+	+
	9	30.5	0	-
	8	243.8	0	-
17# sec. 36, T55N, R16W,	12	91.5	0	-
Randolph County, MO	11	45.7	0	-
	8	975.4	+	+
18* sec. 15, T54N, R15W,	8	1353.1	0	-
Randolph County, MO				
19* SE1/4 NE1/4 sec. 8, T54N, R14W,	12	137.2	+	0
Randolph County, MO	11	139.7	+	0
20* sec. 36, T54N, R15W,	12	61.0	0	-
Randolph County, MO	11	121.9	+	-
	10	45.7	+	+
	9	61.0	0	-
21* SE1/4 SW1/4 sec. 27, T54N, R14W,	12	137.2	+	0
Randolph County, MO	11	152.4	+	0
	10	45.7	+	+
	9	15.2	0	-
	8	609.6	+	+
22* SW1/4 SE1/4 sec. 27, T54N, R14W,	12	116.8	0	0
Randolph County, MO				
23* NW1/4 SE1/4 sec. 29, T53N, R14W,	12	61.0	0	-
Randolph County, MO				
24* SW1/4 NE1/4 sec. 31, T53N, R13W,	12	106.7	0	-
Randolph County, MO	11	61.0	0	-
	10	45.7	+	+
	9	457.2	+	+
	8	129.5	0	-
25# SW1/4 SW1/4 sec. 16, T52N, R14W,	12	61.0	0	-
Randolph County, MO	11	30.5	0	-
	10	30.5	0	-
	9	30.5	0	0
	8	812.8	+	+
26# NW1/4 NE1/4 sec. 35, T52N, R14W,	12	61.0	0	-
Randolph County, MO	11	30.5	0	-
	10	30.5	0	-
	9	------	ND	ND
	8	843.3	+	+
27# sec. 25, T52N, R15W,	12	152.4	0	+
Howard County, MO				
28# sec. 10, T51N, R14W,	12	76.2	0	-
Howard County, MO				

Table 1. continued.

Locality	Stratigraphic Unit	Thickness (cm)	PO	PL
29* SE1/4 NW1/4 sec. 10, T51N, R14W, Howard County, MO	12	76.2	0	-
	11	15.2	0	-
	10	2.5	0	-
	9	101.6	0	0
	8	1112.5	+	+
30# NE1/4 NW1/4 sec. 17, T51N, R14W, Howard County, MO	12	50.8	0	-
31* SW1/4 sec. 36, T51N, R12W, Boone County, MO	8	457.2	0	-
32* SW1/4 SW1/4 sec. 11, T50N, R13W, Boone County, MO	12	106.7	0	-
	11	66.0	0	-
	10	0.6	0	-
	9	61.0	0	+
33* SE1/4 NW1/4 sec. 13, T50N, R13W, Boone County, MO	12	50.8	0	-
34* SE1/4 NE1/4 sec. 1, T49N, R13W, Boone County, MO	8	726.4	0	+
35# NE1/4 NW1/4 sec. 8, T49N, R12W, Boone County, MO	12	76.2	0	-
	11	198.1	0	+
	8	548.6	0	+
36# sec. 19, T49N, R12W, Boone County, MO	12	61.0	0	-
37* NW1/4 NE1/4 sec. 27, T49N, R12W, Boone County, MO	8	342.9	0	-
38* NE1/4 WW1/4 sec. 8, T48N, R12W, Boone County, MO	12	45.7	0	-
	11	91.4	0	-
	10	2.5	0	-
	9	129.5	0	+
	8	1196.3	+	+
39# sec. 12, T48N, R10W, Callaway County, MO	12	55.9	0	-
	11	0.0	0	-
	10	0.0	0	-
	9	45.7	0	-
	8	563.9	0	+
40# sec. 24, T48N, R10W, Callaway County, MO	12	55.9	0	-
	11	0.0	0	-
	10	0.0	0	-
	9	45.7	0	-
	8	853.4	0	+
41# sec. 16, T48N, R9W, Callaway County, MO	12	365.8	+	+
	11	243.8	0	+
	10	22.9	0	-
42# sec. 28, T48N, R9W, Callaway County, MO	12	457.2	+	+
	11	121.9	0	-
	10	38.1	0	+
43* NW1/4 NW1/4, sec. 17, T48N, R8W, Callaway County, MO	12	243.8	0	+
	11	264.2	+	+
	10	5.1	-	-
	9	76.2	0	-
44* SW1/4 NW1/4 sec. 6, T47N, R10W, Callaway County, MO	12	45.7	0	-
	11	30.5	0	-
	10	0.6	0	-
	9	81.3	0	-
	8	429.3	0	0
45# SE1/4 NW1/4 sec. 13, T47N, R11W, Callaway County, MO	12	45.7	0	-

Table 1. continued.

Locality	Stratigraphic Unit	Thickness (cm)	PO	PL
46# NE1/4 NE1/4 sec. 36, T47N, R9W, Callaway County, MO	8	335.3	0	-
47* SE1/4 SE1/4 sec. 17, T47N, R9W, Callaway County, MO	12	335.3	+	+
	11	132.1	0	0
	10	2.5	-	-
	9	27.9	0	-
48# NE1/4 NE1/4 sec. 13, T47N, R9W, Callaway County, MO	12	487.7	+	+
	11	45.7	-	-
	10	1.3	-	-
	9	30.5	0	-
	8	533.4	0	+
49* SW1/4 SW1/4 sec. 1, T46N, R10W, Callaway County, MO	12	365.8	+	+
	11	218.4	0	+
	10	5.0	0	-
	9	142.0	0	+
	8	749.3	0	+
50* NW1/4 NW1/4 sec. 7, T46N, R9W, Callaway County, MO	12	91.4	0	-
	11	61.0	-	-
	10	5.1	-	-
	9	134.6	0	+
	8	520.7	0	+
51* sec. 25, T49N, R7W, Callaway County, MO	11	121.9	-	-
	10	38.1	0	+
52* SW1/4 SE1/4 sec. 4, T49N, R6W, Montgomery County, MO	12	121.9	0	0
	11	340.4	0	+
	10	10.2	0	-
	9	91.4	+	0
	8	0.0	0	-
53* SE1/4 SW1/4 sec. 28, T50N, R7W, Audrain County, MO	12	76.2	-	-
	11	365.8	+	+
	10	22.9	0	-
	9	61.0	0	-
	8	61.0	0	-
54* sec. 21, T51N, R10W, Audrain County, MO	12	35.6	0	-
	11	198.1	0	+
	10	1.3	0	-
	9	45.7	0	-
	8	116.8	0	-
55# sec. 27, T51N, R9W, Audrain County, MO	11	61.0	0	-
	10	40.6	0	+
56# sec. 19, T51N, R9W, Audrain County, MO	12	30.5	-	-
	11	81.3	0	-
	10	66.0	0	+
57* sec. 24, T51N, R9W, Audrain County, MO	12	213.4	0	+
	11	231.2	0	+
	10	12.7	0	+
	9	38.1	0	-
	8	297.2	0	-
58# SW1/4 SE1/4 sec. 22, T51N, R6W, Audrain County, MO	12	121.9	-	0
	11	335.3	0	+
	10	45.7	0	+
	9	0.6	0	-
	8	0	0	-
59# NW1/4 sec. 34, T52N, R11W, Audrain County, MO	12	91.4	0	-
	11	91.4	0	-
	10	66.0	0	+

Table 1. continued.

Locality	Stratigraphic Unit	Thickness (cm)	PO	PL
60# SW1/4 sec. 25, T52N, R9W, Audrain County, MO	12	320.0	+	+
	11	243.8	0	+
	10	71.1	0	+
61# NW1/4 SW1/4 sec. 24, T52N, R8W, Audrain County, MO	12	213.4	0	+
	11	259.1	0	+
	10	63.5	0	+
	9	2.5	0	-
	8	0.0	0	-
62* SW1/4 SE1/4 sec. 12, T52N, R6W, Audrain County, MO	12	152.4	0	+
	11	304.8	0	+
	10	30.5	0	-
	9	1.3	0	-
	8	0.0	0	-
63* NE1/4 SW1/4 sec. 34, T53N, R8W, Audrain County, MO	12	274.3	0	+
	11	228.6	0	+
	10	27.9	0	-
	9	15.2	0	-
	8	0.0	0	-
64* NE1/4 SE1/4 sec. 29, T54N, R7W, Ralls County, MO	12	61.0	0	-
	11	218.4	0	+
	10	50.8	0	+
	9	5.1	0	-
	8	0.0	0	-
65* NE1/4 sec. 30, T55N, R12W, Monroe County, MO	12	152.4	0	+
	11	147.3	0	0
	10	50.8	0	+
	9	83.8	0	0
66* SE 1/4 SE1/4 sec. 32, T55N, R10W, Monroe County, MO	12	91.4	0	-
	11	167.6	0	+
	10	66.0	0	+
67* NE 1/4 SE1/4 sec. 18, T54N, R8W, Monroe County, MO	12	68.6	0	-
	11	167.6	0	+
	10	66.0	0	+
68* NE 1/4 NW1/4 sec. 28, T54N, R12W, Monroe County, MO	12	137.2	0	0
	11	50.8	0	-
	10	45.7	0	+
69* SE 1/4 SE1/4 sec. 23, T54N, R12W Monroe County, M O	12	162.6	0	+
	11	215.9	0	+
	10	33.0	0	0
	9	236.2	0	+
	8	0.0	0	-

Table 2. General Thicknesses and Characteristics of Desmoinesian Strata of the study area.

LITHOTYPE	PALEOLOWS	PALEOHIGHS
Sandstones and Sandy Mudstones	Thicken and increase in sand content and number of beds	Thin rapidly and decrease in sand content and number of beds
Underclays	Thicken gradually	Some thin rapidly to a clay parting; more commonly thicken gradually as underlying sandstones pinch out
Coals	Thicken rapidly and increase in rank	Thin rapidly to bone coal or carbonaceous smut
Black Phosphatic Shales	Thicken greatly, increase in fissility, calcium phosphate nodules common	Thin and grade into thin platy shales, calcium phosphate nodule rare.
Limestones	Thicken rapidly and become interbedded with calcareous shales, generally argillaceous calcilutites with thick flat bedding, large macrofossils are fragmented, small microfossils are undeformed	Thin rapidly, become wavy bedded intraclastic wackestones or calcilutite nodules in calcareous shale, all macrofossils are fragmented