THE FUSSELMAN OF THE PERMIAN BASIN: PATTERNS IN DEPOSITIONAL AND DIAGENETIC FACIES DEVELOPMENT ON A STABLE PLATFORM DURING THE LATE ORDOVICIAN—EARLY SILURIAN ICEHOUSE

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ABSTRACT

The Fusselman Formation of the Permian Basin consists of shallow-water carbonate sediments that were deposited on a regionally extensive, relatively stable platform along the southern margin of the Laurentian paleocontinent during the Late Ordovician to Early Silurian. Core studies show that the Fusselman is dominated by typical normal marine facies throughout most of its extent. Reservoirs are developed principally in basal ooid grainstones and overlying pelmatozoan packstones, both of which are areally extensive. Porosity development is largely associated with original interparticle porosity in ooid grainstones and leaching of carbonate mud fractions in pelmatozoan packstones. Evidence of karst processes, ranging from large, cave-fill successions to minor dissolution features, is locally apparent across the Permian Basin. Global studies indicate that the Fusselman was deposited during a period of icehouse climatic conditions, when high-amplitude sea-level rises and falls were common. Although there has been relatively little documentation of the sequence and cycle stratigraphy of these rocks, it seems certain that patterns of facies stacking and diagenesis within the Fusselman are tied to these icehouse eustatic fluctuations and that these patterns, although poorly known, are important keys to the reservoir heterogeneity.

INTRODUCTION

As of the year 2000, reservoirs developed in rocks assigned to the Fusselman Formation in the subsurface of the Permian Basin of West Texas and New Mexico had accounted for more than 356 million barrels of oil production (Dutton and others, 2005). Despite the economic significance of this geologic succession, relatively little detailed geological information is available about these rocks or the key aspects of reservoir development. Published data from subsurface regional and field-specific studies are generally limited in scope, and the thick outcrop succession of Fusselman rocks (in southern New Mexico) has been studied only superficially. Available global and regional data suggest that the Fusselman, which contains rocks deposited during the Late Ordovician to Early Silurian icehouse to waning icehouse climatic period, contains a depositionally and diagenetically complex succession of carbonate platform deposits. This report synthesizes existing global, regional, and reservoir specific data to describe the major controls on deposition, diagenesis, and reservoir development within this important carbonate succession in the Permian Basin.

PREVIOUS WORK

Early descriptions of the Fusselman were published by Jones (1953) and Galley (1958). McGlasson (1967), Wright (1979), and Canfield (1985) provided additional data on facies and stratigraphy. More recent studies by Geesaman and Scott (1989) and Garfield and Longman (1989) focus on local variations in facies and depositional setting in the Fusselman Formation in a small area in the Midland Basin. Canter and others (1992) proposed a model for sequence stratigraphic correlation of the subsurface Fusselman. Ruppel and Holtz (1994) described regional geological characteristics of the Fusselman and provided play-specific data on engineering attributes. Barrick (1995) demonstrated, on the basis of conodont biostratigraphy, that the Fusselman comprises a lower Upper Ordovician part and an upper Lower Silurian part (fig. 1). Lemone (1992), Lucia (1995), and Mazzullo (1993) described *karst* features in Fusselman *outcrops*. Several authors have concluded on the basis of wireline-log evidence that subsurface Fusselman rocks also display evidence of karsting (Mazzullo and others, 1989;

Mazzullo and Mazzullo, 1992). Mear (1989) and Garfield and Longman (1989) documented cave breccia deposits from cores.

REGIONAL SETTING

During deposition of the Fusselman Formation, the Permian Basin area lay in a tropical to low subtropical setting along the southern margin of the Laurentian continent (fig. 2). Although the eastern margin of Laurentia underwent tectonic deformation (the Taconic Orogeny) associated with the approaching continental landmass of Baltica at this time, the southern margin appears to have been an area of relative tectonic quiescence. This conclusion is consistent with the apparent widespread distribution and relatively uniform persistent facies character of the Fusselman throughout the region.

Deposition of rocks included in the Fusselman Formation of West Texas and New Mexico began during the Late Ordovician on an extensive shallow-water platform, whose development began with deposition of the Montoya Group during the Cincinnatian. Fusselman Formation carbonate deposits reflect the continued growth and development of this shallow-water platform from the Late Ordovician into the Early Silurian. The similarity of depositional facies across the region indicates that conditions were relatively uniform over great distances. Equivalent rocks in Oklahoma, for example, are lithologically similar (fig. 1; Barrick, 1995). Johnson (1987) presented data suggesting that this Early Silurian platform extended across most of the North American continent. Depositional analyses and worldwide stratigraphic equivalents of the Fusselman demonstrate that accumulation of these rocks was punctuated by at least five major rise and fall cycles of relative sea level (McKerrow, 1979; Johnson, 1987, 1996) of about 2-m.y. duration. Globally these eustatic events are reflected in unconformities and associated diagenetic alteration of these shallow-water carbonate facies. Clearly these hiatuses were associated with considerable erosion and/or long periods of nondeposition. Biostratigraphic evidence indicates that the 100 to 300 ft of preserved Fusselman in the subsurface of the Permian Basin spans an interval of about 10 m.y. (fig. 1; Barrick and others, 2005).

Widespread, shallow-water platform conditions characteristic of Fusselman deposition were abruptly terminated by sea-level rise probably associated with tectonic downwarping and drowning of the platform, most likely during the early Wenlockian (Ruppel and Holtz, 1994). This event and its impact of sedimentation in the Permian Basin are discussed more fully in the chapter on the Middle and Upper Silurian Wristen Group. Downwarping of the Fusselman Platform in Texas, and equivalent successions in Oklahoma and the Illinois Basin, may have been a product of early foreland deformation along the southern margin of the North American plate, which was associated with plate convergence that preceded later Ouachita tectonism in the region. Walper (1977) suggested that convergence of the North American and South American/African plates began as early as the Late Ordovician.

Distribution and Age

The Fusselman Formation was named by Richardson (1909) for thick intervals of dolostone of presumed Middle Silurian age that outcrop in the vicinity of El Paso, Texas. As defined in the subsurface, the Fusselman is much thinner but relatively continuous across much of West Texas. The Fusselman is readily recognized and mapped where underlain by the Sylvan Formation (shale of Late Ordovician age) and overlain by the Wink Formation of the Wristen Group (figs. 3, 4). Where the Wink and Frame Formations are absent (north of central Andrews County), it is very difficult to distinguish the top of the Fusselman from overlying shallow-water carbonates of the overlying Fasken Formation (Wristen Group). Similarly, where the Sylvan shale is absent (in the western part of the region), the Fusselman is difficult to separate from the underlying Montoya Formation.

The Fusselman attains maximum thicknesses of more than 600 ft in southeasternmost New Mexico and far West Texas and thins eastward (fig. 5). Average thicknesses where the Sylvan is present range from 50 to 200 ft. The northwest-trending subcrop margin of the Fusselman (fig. 5) coincides with the western margin of what is widely referred to as the Concho Arch, an assumed axis of intermittent and frequent uplift during the Paleozoic. However, it is unclear whether truncation of the Fusselman along this trend represents postdepositional truncation, penecontemporaneous thinning, or both.

On the basis of studies of faunas in outcrops at the type section in the Franklin Mountains, the Fusselman has long been considered of Early to Middle Silurian age (Wilson and Majewski, 1960; Harbour, 1972). More recent studies based on conodonts, however, reveal that the subsurface Fusselman is actually Late Ordovician (Hirnantian) to Early Silurian (Llandoverian) in age (J. Barrick, personal communication, 1989). This interpretation is consistent with ages established for nearly identical lithological successions in Oklahoma (Amsden and Barrick, 1986) and further suggests that the nearly 1,000 ft of section assigned to the Fusselman at the type section is equivalent to the Fusselman *and* the overlying Wristen Group in the subsurface (Wilson and Majewski, 1960). Faunal studies in the Marathon Basin of southern West Texas show that the subsurface Fusselman is equivalent to the Lower Caballos Novaculite of the Ouachita overthrust belt and that the Wristen correlates with the middle chert and shale member (Noble, 1993, 1994; Barrick and Noble, 1995).

Facies

The Fusselman comprises a diverse succession of shallow-water carbonate facies. Throughout the central part of the study area (for example, Andrews, Midland, Ector, Upton, Crane Counties) the Fusselman is composed of a consistent series of lithofacies (fig. 3). The base of the Fusselman is typically formed by a thin (>10-ft-thick) interval of ooid grainstone (fig. 6a, b). These deposits, which are of Late Ordovician (Hirnantian) age (Barrick, 1995), are typically well sorted and in some instances crossbedded. Basal ooid grainstone is widely distributed across the region (Canfield, 1985; Ruppel and Holtz, 1994; Barrick 1995). The equivalent Keel Formation in the Texas Panhandle and Oklahoma is virtually identical in lithology, as are coeval deposits in Arkansas and Missouri (Amsden and Barrick, 1986; Barrick, 1995).

Overlying the lower Fusselman ooid grainstone facies is an interval of fenestral mudstone (fig. 3) that locally displays shale-filled solution/erosion pits at its upper surface. This unit is generally thin (>3 ft) and is locally absent.

The upper Fusselman is most characteristically composed of gray to pink pelmatozoan grainstone and packstone (fig. 6c). These rocks, which are generally well sorted and locally crossbedded, are composed of pelmatozoans and subordinate bryozoans; brachiopods, ostracodes, corals and mollusks are locally present (fig. 6c, d). These grain-rich packstones and grainstones, which in some areas grade laterally into skeletal wackestone containing pelmatozoans, brachiopods, and ostracodes, overlie fenestral mudstone facies or rest directly on a basal ooid grainstone-packstone unit. Typically these deposits are composed of well-sorted skeletal sands; however, in some areas (for example, Winkler County) they are represented by poorly sorted rudstones that contain corals. Locally the pelmatozoan facies contains sediment- and spar-filled geopetal structures, some of which resemble stromatactoid structures. Some of these structures may indicate local carbonate buildup in this part of the Fusselman section (fig. 8). Other sediment- and cement-filled geopetal voids are also locally common within this facies (fig. 6e). These voids appear to be vugs produced by secondary leaching and subsequent sediment infill and cementation. In some instances, multiple successions of these voids appear to exhibit crosscutting relationships.

The upper Fusselman pelmatozoan facies is present across most of the study area except near the Fusselman subcrop margin (for example, in Terry and Glasscock Counties). Geesaman and Scott (1989) also reported the local absence of this facies in the Glasscock County area, where the unit apparently thins onto paleohighs (fig. 7). Thickness of the pelmatozoan grainstone-packstone facies appears to increase in parallel with total Fusselman thickness trends (that is, toward far West Texas and New Mexico). Grain size also increases to the west.

The upper pelmatozoan, grainstone-packstone facies of the Fusselman grades upward into more mud-rich facies, including wispy-laminated to nodular-bedded, locally siliceous wackestone containing ostracodes and less common pelmatozoans (fig. 3). These deposits resemble those typical of the overlying Wink Formation of the Wristen Group (Canfield, 1985; Mear, 1989; Ruppel and Holtz, 1994).

The contact of the Fusselman Formation with the overlying Wink Formation of the Wristen Group appears unconformable. This likelihood, suggested by thickness variations apparent on cross sections, is confirmed by core data. In central Andrews County (Austral Oil Co., University No. 1) for example, the uppermost Fusselman is a dolomitized and partly silicified breccia that is sharply overlain by burrowed siltstone (Ruppel and Holtz, 1994). Canfield (1985) described cores from Pecos and Midland County wells in which the upper Fusselman was sharply overlain by reported shales of the basal Wink. Small amounts of greenish-colored shale are locally common in the upper Fusselman, as are zones of multiple-stage, geopetal cavity fills (fig. 8b). Garfield and Longman (1989) also documented truncation of the Fusselman beneath the Wristen Group in the Martin/Midland/Glasscock County area. This hiatus, which has also been defined in temporally equivalent rocks in Oklahoma, corresponds to the Llandoverian/Wenlockian boundary (fig. 1).

Depositional Setting

The Fusselman Formation documents deposition on an open-marine, shallow-water carbonate platform that probably formed during Late Ordovician time. Underlying Montoya Group deposits represent the earlier development of this platform that extended across much of West Texas and New Mexico. Basal Fusselman ooid grainstones represent deposition in relatively high-energy tidal-flat to shallow subtidal conditions. The extent of these deposits indicates that the platform was broad and flat and extended across much of West Texas. Capping fenestral mudstones indicate at least local exposure of these deposits, which is supported by the occurrence of meniscus and pendant cements that are indicative of vadose diagenesis (fig. 8a). Virtually identical facies and cements have been reported from modern ooid sand shoals that have developed on intermittently exposed shallow water in the Bahamas (Harris, 1979). Regional data indicate that basal Fusselman ooid deposits may have experienced much longer periods of exposure. Biostratigraphic studies of coeval and overlying Silurian deposits in Oklahoma and elsewhere document a widespread late Llandoverian hiatus between the Fusselman and overlying Wenlockian strata (Amsden and Barrick, 1986; fig. 1).

The Fusselman pelmatozoan grainstone/packstone facies is thicker and more widespread than the underlying ooid facies, indicating that these deposits occupied an even broader area of the Early Silurian platform. The paucity of carbonate mud and good sorting in these facies suggest that much of this facies was deposited in high-energy shoals or bars. Deposits exhibiting stromatactis and sediment- and cement-filled geopetal cavities suggest local development of carbonate buildups. Coarser-grained, more poorly sorted sections of pelmatozoan/coral packstone in the western part of the study area (for example, Emperor field in Winkler County, Texas) may reflect buildup development in somewhat deeper water conditions. Fusselman encrinites are very similar to correlative rocks in Oklahoma (Cochrane and Clarita Formations; see Amsden, 1980), indicating development of a continuous, broad, shallow platform.

The overall continuity of Fusselman facies across the region indicates development of widely continuous depositional environments. There is evidence, however, that locally these extensive, sheetlike environments were interrupted by more complex depositional regimes created around topographic highs. Such relationships were documented by Garfield and Longman (1989) over paleotopographic highs in the Midland/Glasscock County area and are also common along the eastern subcrop margin of the Fusselman. On the basis of regional core studies, Canter and others (1992) inferred the presence of a general east-west platform margin with gradually shallower water middle- and inner-shelf conditions prevailing progressively to the north (fig. 9).

Stratigraphic and diagenetic patterns in the Fusselman indicate that deposition was punctuated by episodic rise and fall of relative sea level. Johnson (1987) documented five major sea-level falls during the time represented by Fusselman deposition. These sea-level rise/fall cycles (sequences) are well chronicled in the biostratigraphically well constrained Fusselman-equivalent outcrops in Oklahoma (Amsden and Barrick, 1986, 1988). This interpretation implies that (1) the lower ooid grainstone member of the Fusselman (which is equivalent to the Keel in Oklahoma) is separated from the upper pelmatozoan facies (equivalent to the Cochrane) by a long-duration hiatus (~4–5 m.y.) and (2) the upper pelmatozoan facies experienced at least four significant falls in relative sea level, including a hiatus of 1 to 2 m.y. at the end of Fusselman deposition (fig. 1). These conclusions are supported by diagenetic features recognized in Fusselman core successions (Ruppel and Holtz, 1994) and from correlative biostratigraphic and facies studies of Fusselman equivalents in Oklahoma outcrops (Barrick, 1995). The multiple generations of geopetally filled vugs in the pelmatozoan facies may be a record of both of these late Llandoverian sea-level falls. There is good evidence that episodic eustatic fall during the Late Ordovician and Early Silurian, which may be related to continental glaciation in North Africa at that time (Amsden and Barrick, 1986), left a strong depositional and diagenetic imprint on Fusselman rocks in the Permian Basin.

Mineralogy and Diagenesis

Mapping of the Fusselman by several authors (McGlasson, 1967; Wright, 1979; Mear, 1989) illustrates that the section is largely dolostone in the northern part of its extent but is predominantly limestone in the south (fig. 10). Ruppel and Holtz (1994) pointed out that the distribution of dolostone in the Fusselman closely parallels the extent of largely dolomitized shallow-water platform facies (Fasken Formation) in the overlying Wristen Group. This relationship suggests that dolomitization may have been associated with the repeated sea-level falls that characterized Wristen shallow-water platform sedimentation.

It is likely that parts of the Fusselman had already been subjected to variable degrees of diagenesis or alteration prior to the Wristen and post-Wristen dolomitization events discussed earlier. Evidence of meteoric diagenesis in the basal ooid grainstone/packstone facies, combined with regional indications of a widespread hiatus, indicates that these basal deposits may have locally undergone significant diagenetic alteration. In many instances, the ooid grainstone facies is dolomitized, and overlying Fusselman facies are not. This alteration may be related to episodic sea-level fall during Fusselman deposition. Successive generations of geopetally filled dissolution vugs in the upper Fusselman may record similar events. Such eustatic fluctuations are supported by studies of the Early Silurian worldwide (McKerrow, 1979; Johnson, 1987; 1996). Sharp contacts between Fusselman dolostones and basal Wristen limestones in some areas suggest that dolomitization may have also occurred during the last Fusselman sea-level fall event (before the onset of Wristen deposition).

There is good evidence that the Fusselman has undergone karst-related diagenesis. Sediment- and breccia- filled karst features are common in outcrops of the Fusselman in the Franklin Mountains (McGlasson, 1967; Lemone, 1992). (Note that outcrops assigned to the Fusselman almost certainly include Wristen rocks as well.) As previously discussed, dissolution features and breccias possibly related to karsting have been reported from several cores in the Fusselman (Mear, 1989; Mazzullo and Mazzullo, 1992; Troschinetz, 1989).

Sequence Stratigraphy

Global studies document one Ordovician and four Silurian sea level rise/fall cycles during the time represented by the subsurface Fusselman (fig. 1). The oldest of these cycles corresponds well with the lower Fusselman ooid-bearing succession of late Ordovician age. The upper Fusselman spans much of the Llandovery and thus may include as many as four sequences. Each of the sea-level drops that created these sequence boundaries was potentially associated with exposure-related diagenesis that may have enhanced or reduced reservoir quality. Thus, definition of the number and location of these events is important to accurate reservoir characterization in the upper Fusselman. Canter and others (1992) recognized two sequence boundaries within the upper Fusselman on the basis of apparent karst horizons. However, it is clear that further work based on well-dated cores will be necessary to accurately define both the number and placement of Fusselman depositional sequences.

Reservoir Development

Fusselman reservoirs in the Permian Basin have been assigned to the Fusselman Shallow Platform Carbonate Play (Ruppel and Holtz, 1994; Dutton and others, 2005). Ruppel and Holtz (1994) documented a total of 233 productive reservoirs in the Fusselman in 1989, only 47 of which had produced more than 1 MMbbl at that time. As of 2000, 63 Fusselman reservoirs had produced more than 1 MMbbl of oil (fig. 11); cumulative production from the play was 356.3 MMbbl (Dutton and others, 2005).

Reservoir Distribution

Fusselman rocks are productive in two major end-member settings (fig. 11): (1) on major, typically fault-bounded structures on the Central Basin Platform and adjacent Midland Basin and (2) along the Fusselman subcrop margin. Reservoirs developed along the subcrop margin can be considered a distinct subplay, in which production is developed primarily where the Wristen has been removed by erosion and the Woodford directly overlies the Fusselman (Ruppel and Holtz, 1994).

Porosity Development

Three general styles of pore development are observed in the Fusselman: (1) primary intergranular pores in basal ooid grainstones, (2) leached intergranular pores in pelmatozoan packstones, and (3) strongly leached, predominantly vuggy and intercrystalline pores at the top of the Fusselman (Ruppel and Holtz, 1994).

As discussed previously, primary intergranular porosity is developed locally in basal Fusselman ooid grainstones (figs. 3, 6a, b). Where these pores are preserved, these deposits make excellent reservoirs (for example, in Mound Lake, Emma, Warfield, and SW Midland fields).

Highest porosity is commonly developed in the upper Fusselman pelmatozoan packstone facies (Canfield, 1985). These rocks contain secondary porosity owing to leaching of skeletal packstone. Examples include Good SE, Lowe, Emma, Emperor, Pegasus, and SW Midland fields. This secondary porosity takes the form of intergranular pores, molds, and small vugs formed by meteoric leaching during one or more of the falls in relative sea level during and following Fusselman deposition.

Both styles of pore development are probably mostly associated with very early diagenesis, either during deposition of the Fusselman or shortly thereafter. Accordingly, this type of reservoir development can be observed throughout the Fusselman subcrop (Ruppel and Holtz, 1994). Much more extensive diagenesis is encountered where the Fusselman has been unroofed by erosion or faulted and fractured. In these reservoirs, which are located primarily in the northern part of the Fusselman subcrop and along the eastern subcrop margin (fig. 11), the top of the Fusselman section commonly displays more extensively leached zones. Reservoirs developed in these areas are commonly dolomitized (fig. 10) by processes of matrix replacement and partial pore filling by dolomite cements. Leaching and associated fabric-destructive dolomitization is most common where removal of the Fasken has allowed meteoric fluids more frequent access during Silurian and Devonian exposure events. This leaching is less strongly controlled by depositional facies and more a function of paleotopography and paleohydrology. Porosity in these highly leached and altered rocks typically takes the form of intercrystalline pores and large vugs. Strongly leached and altered reservoir successions are also encountered on major structural highs, where faulting has provided fluid conduits for entrance of diagenetic fluids (for example, Dollarhide field).

Traps, Seals, and Sources

Fusselman reservoir traps are both structural and stratigraphic. Most larger fields on the Central Basin Platform and in the Midland Basin are dominantly structural (for example, Dollarhide and Keystone). Structures that form most traps were formed during late Carboniferous foreland basin deformation associated with the collision of Gondwana and Laurussia plates. However, Mazzullo and others (1989) showed that there is good evidence that the Fusselman and overlying Wristen Group (and Thirtyone Formation) underwent significant deformation during Middle Devonian (pre-Woodford) time. Fields developed in this setting are actually compound structural traps (for example, Tex-Hamon and Wells). As Mazzullo and others (1989) pointed out, such structural traps are not reflected in the structure of the Woodford Formation and can thus be cryptic.

In most Fusselman fields, the top seal is provided by shales and mudstones of the Frame and Wink Formations of the Wristen Group (for example, Dollarhide and Keystone). In many fields along the eastern subcrop, the Fusselman is overlain and sealed by the Woodford (Mazzullo and others, 1989; Comer, 1991). Where the Woodford has been removed by erosion, Permian shales provide the seal (for example, Abell and Pecos Valley). On the basis of a comparison of produced Fusselman oil types and Permian Basin source rock character, Williams (1977) concluded that most of the oil charge in the Fusselman came from the Woodford Formation.

Opportunities for Additional Resource Recovery

Although basic Fusselman facies types and pore types are fairly well known, insufficient information is available regarding controls of cyclicity and diagenesis on reservoir development and architecture. A better understanding of these processes could elucidate new opportunities for focused field redevelopment. For example, facies stacking patterns, facies continuity, and the relative importance of depositional facies versus diagenesis on porosity are not well understood. Especially needed is a sequence stratigraphic framework, within which both depositional facies and diagenesis can be defined and modeled. Such a framework would lead to a better appreciation for the development and significance of Early Silurian global sea-level-fall events and their impact on reservoir architecture and porosity development. A detailed study of the excellently exposed Fusselman section in the Franklin Mountains would provide fundamental data and models needed for better interpretation of existing core and wireline-log data in the subsurface.

SUMMARY AND CONCLUSIONS

As conventionally defined in the subsurface of the Permian Basin, the Fusselman consists of shallow-water carbonate platform deposits of Late Ordovician and Early Silurian age. Lower Fusselman (Ordovician-age) rocks comprise ooid grainstones and interbedded mudstones. The upper Fusselman (Early Silurian age) commonly consists of deeper-water, more open marine facies, most typically crinoid grainstones and packstones. Evidence of exposure-related digenesis is present at several horizons within the Fusselman and is consistent with multiple episodes of high-amplitude, sea-level oscillation documented in deposits of similar age around the world. Reservoir porosity is most commonly associated with primary interparticle pore space in lower Fusselman grainstones and with dissolution-related interparticle porosity in the upper Fusselman crinoid packstones. Internal reservoir architecture is poorly known because of the general scarcity of cores and absence of detailed outcrop study. Large-scale karst features are common in some Fusselman reservoirs, but the timing, origin, cause, and geometry of these features and their impact on reservoir performance is known.

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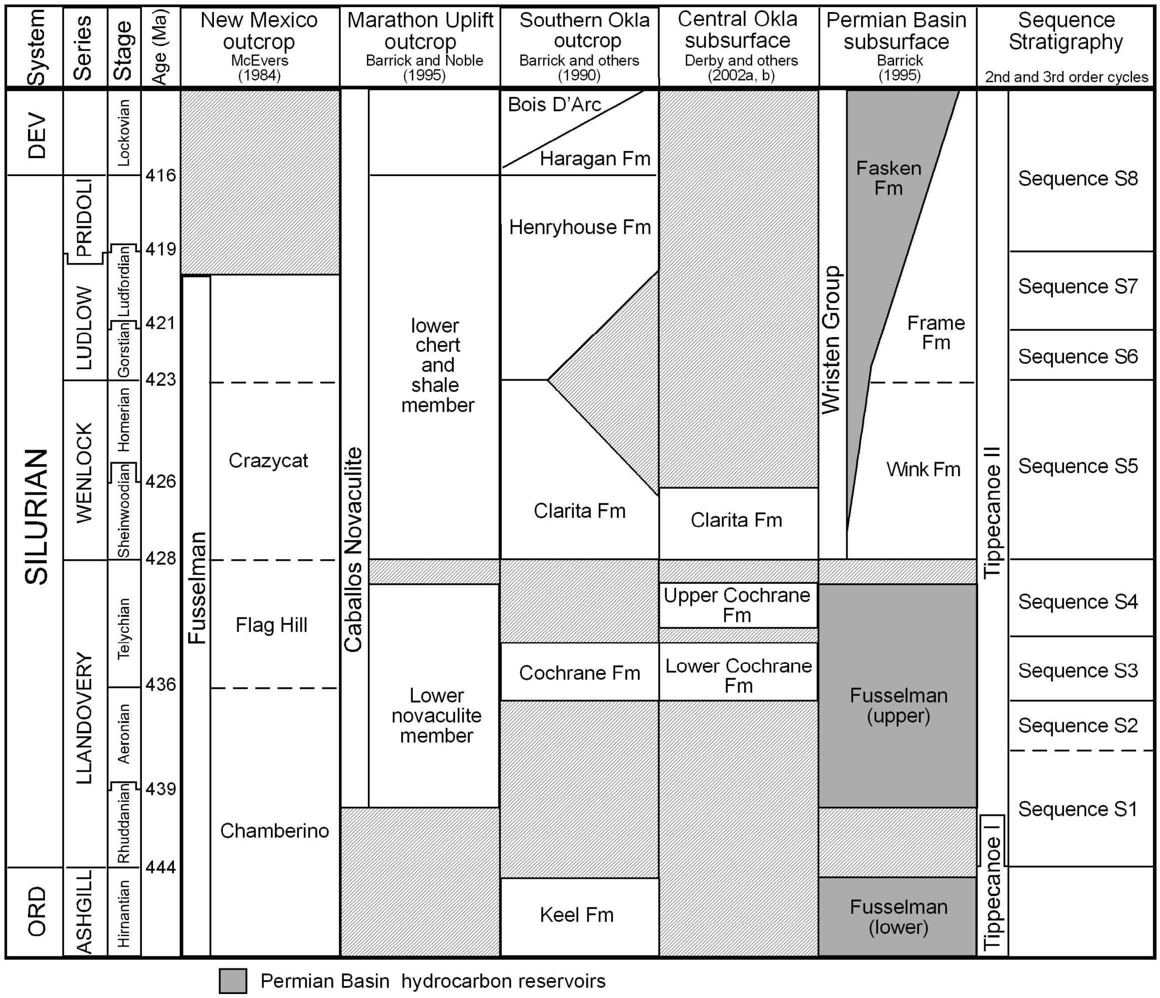
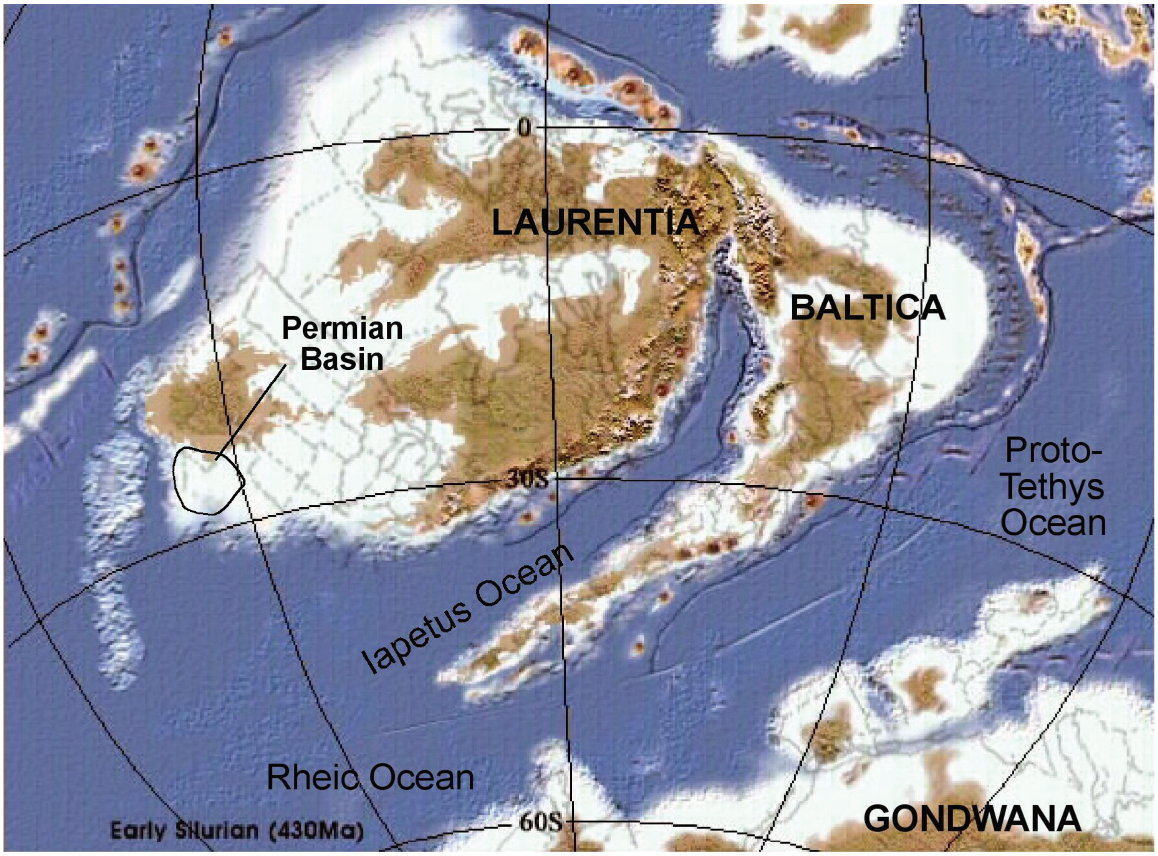


Figure 1. Correlation of Silurian Devonian strata in West Texas with successions in Oklahoma and the Illinois Basin (Indiana-Illinois). Age dates are from Kaufmann (2006).



From Blakey (2004): http://jan.ucc.nau.edu/~rcb7/430NAt.jpg

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Figure 2. Global reconstruction of the Laurentian continent for the Late Ordovician. Note that the Permian Basin area occupied the southern margin of the continent facing the open Iapetus Ocean. From Blakey (2004).

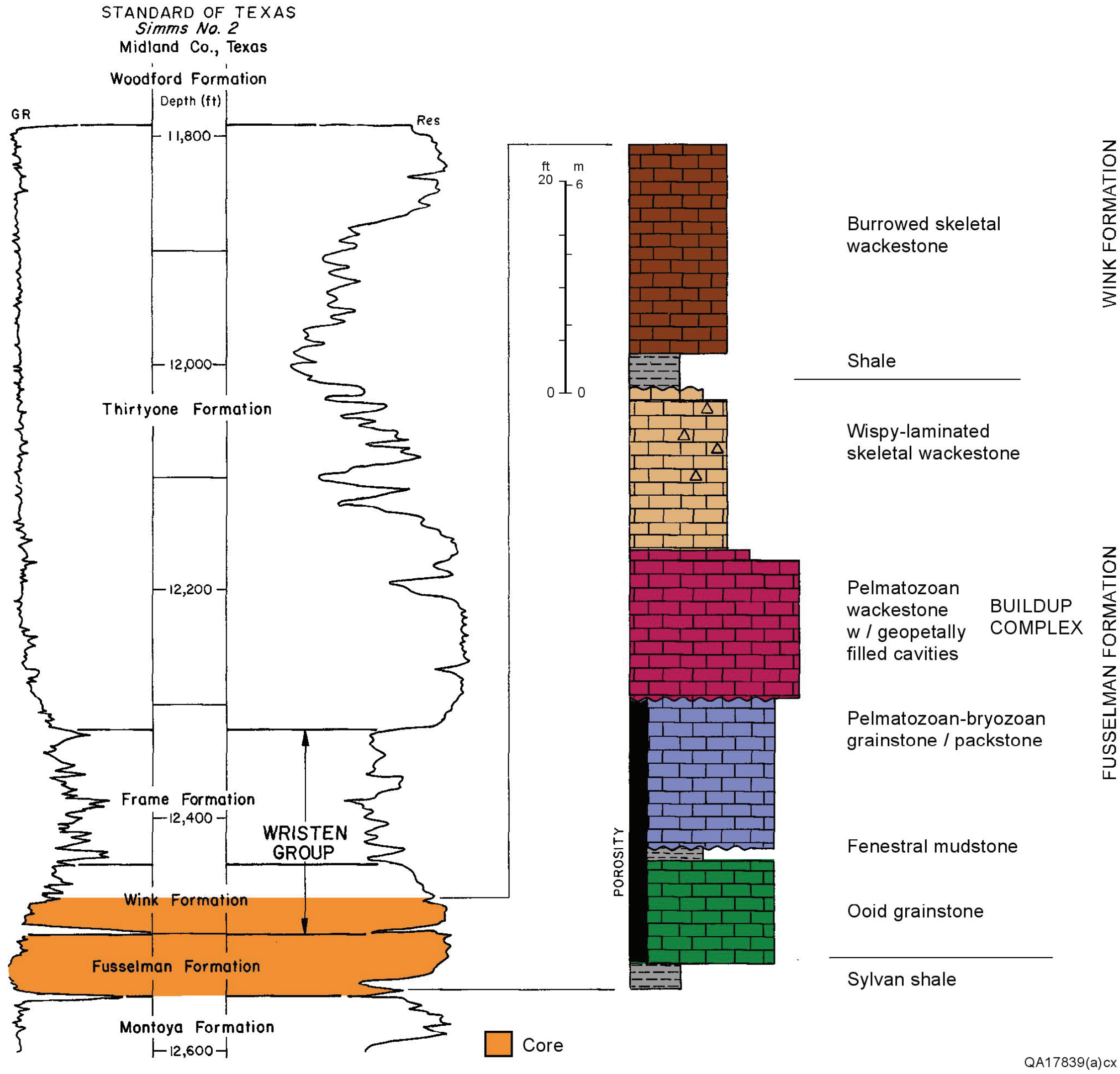
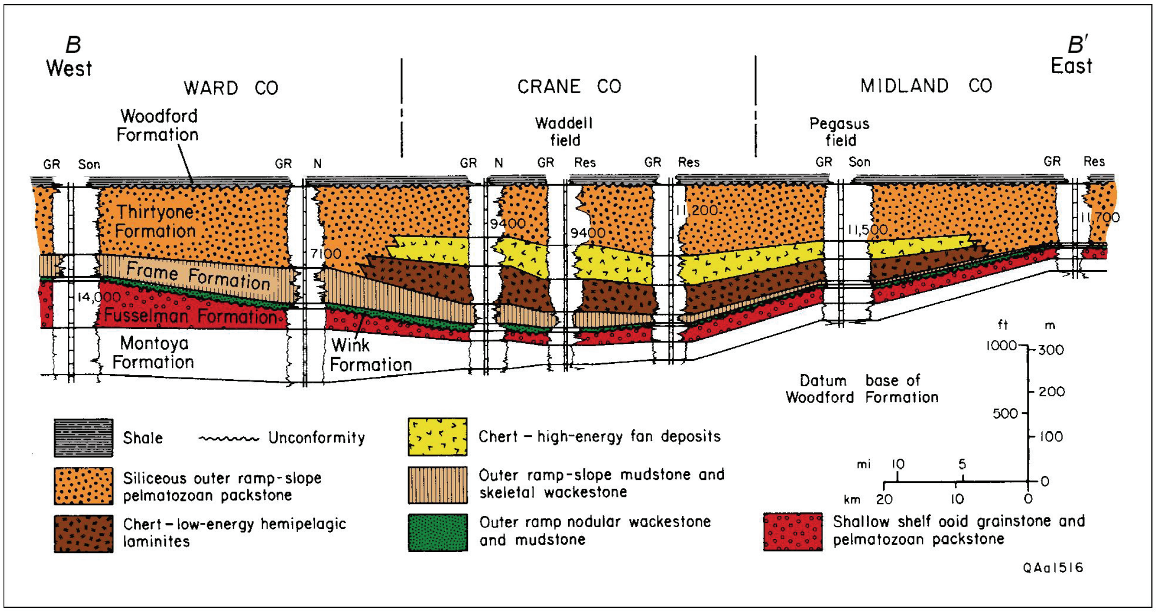


Figure 3. Typical log and facies succession for the Fusselman and adjacent deposits, Standard of Texas, Simms No. 2, Midland County, Texas. Facies are typical of the Fusselman throughout much of the area. Modified from Ruppel and Holtz (1994).



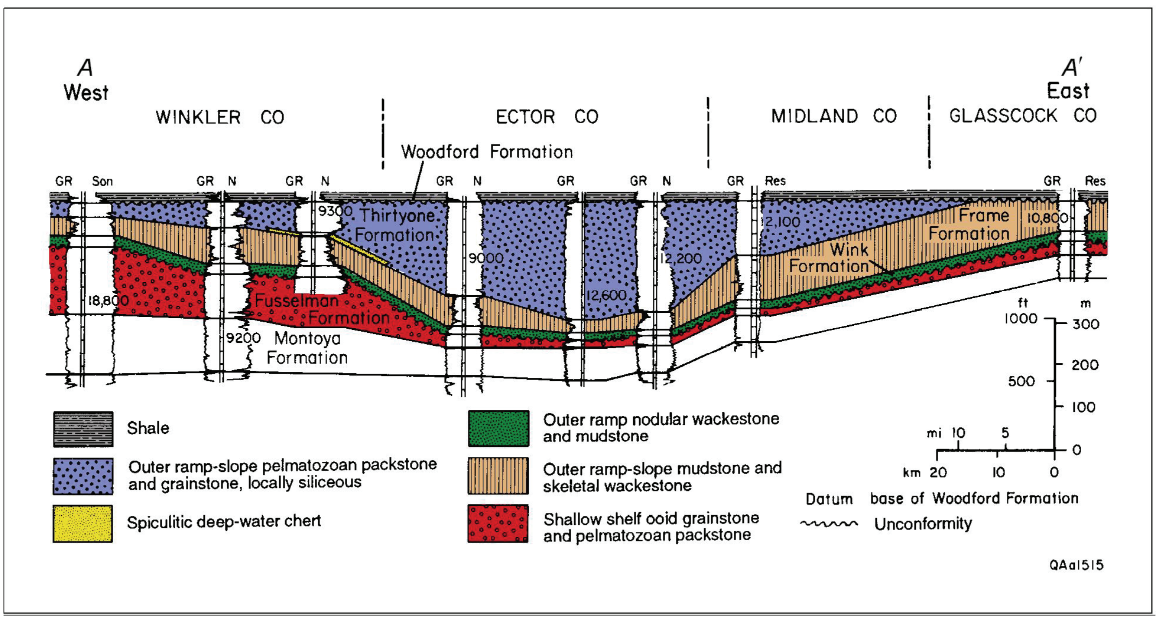


Figure 4. Cross sections showing thickness trends of Fusselman Formation and relationships to underlying and overlying Silurian and Devonian units. Both sections show the eastward thinning of the Fusselman. Lines of section shown on figure 5. Modified from Ruppel and Holtz (1994).

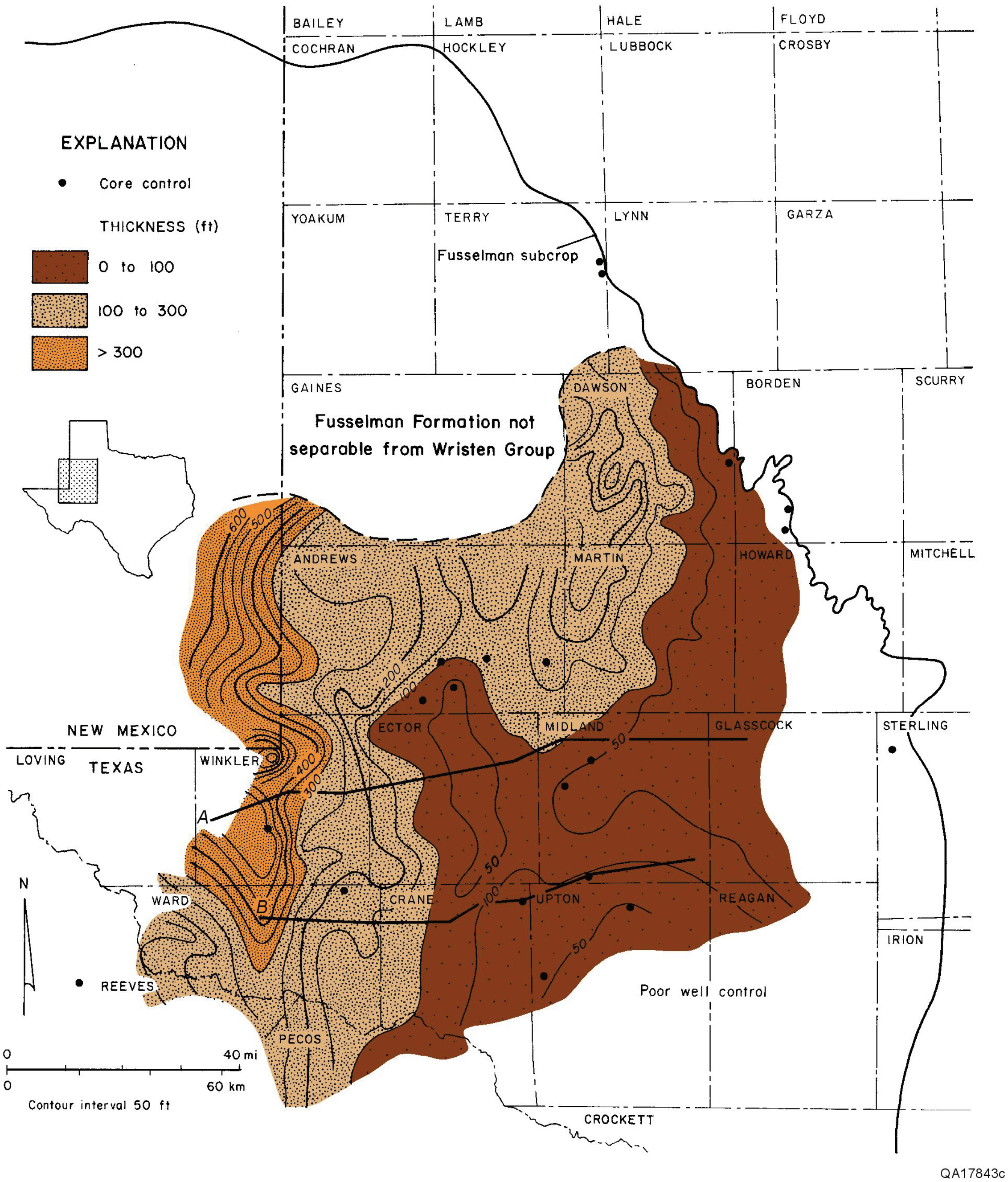


Figure 5. Thickness of Fusselman Formation in West Texas. Contours in the eastern part of the area are modified from Geesaman and Scott (1989).

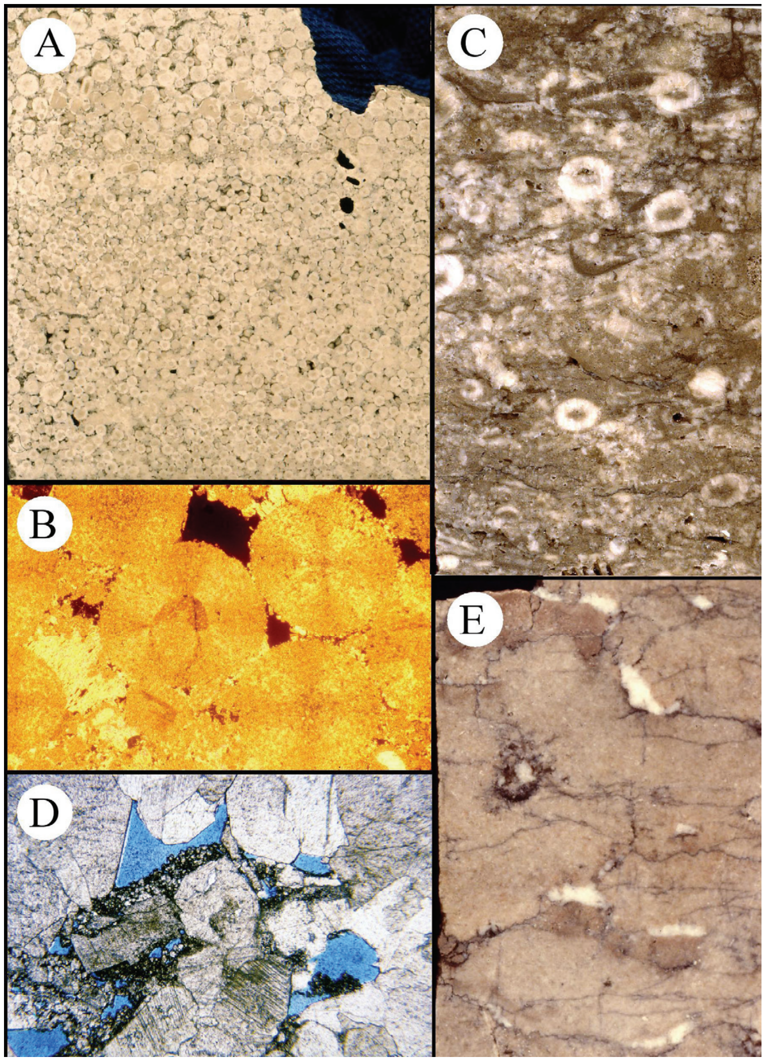


Figure 6. Typical facies of the Fusselman Formation. (A) Slab photograph of ooid grainstone facies showing large, well-sorted ooids with well-developed intergranular porosity. Depth: 12,536 ft. Slab is 6 cm wide. Standard of Texas, Simms No. 2, Midland County, Texas. (B) Cathodoluminescence photomicrograph of ooid grainstone facies. These rocks contain common interparticle porosity. Standard of Texas, Simms No. 2, Midland County, Texas. Depth: 12,536 ft. Field of view is 7 mm. (C) Slab of typical pelmatozoan grainstone-packstone facies. These light-colored encrinites are the most common lithology in the Fusselman throughout most of West Texas and constitute a major reservoir lithofacies. Large, geopetally filled vugs and smaller vugs containing dead oil are commonly developed below intrareservoir unconformities. Porosity is rare in grainstones but is developed as intergranular and intragranular pores in leached packstones. Slab is 8 cm wide. Seaboard, Meiners No. 1, Upton County, Texas. Depth: 12,693 ft. (D) Photomicrograph of pelmatozoan packstone facies. Standard of Texas, Simms No. 2, Midland County, Texas. Depth: 12,536 ft. Field of view is 3.5 mm. (E) Slab photograph of pelmatozoan packstone facies showing abundant geopetally-filled vugs. Many of these vugs are filled with sediment and cement, but some are open and contain hydrocarbons. Seaboard Meiners No. 1, Upton County, Texas. Depth: 12,690 ft. Slab is 8 cm wide.

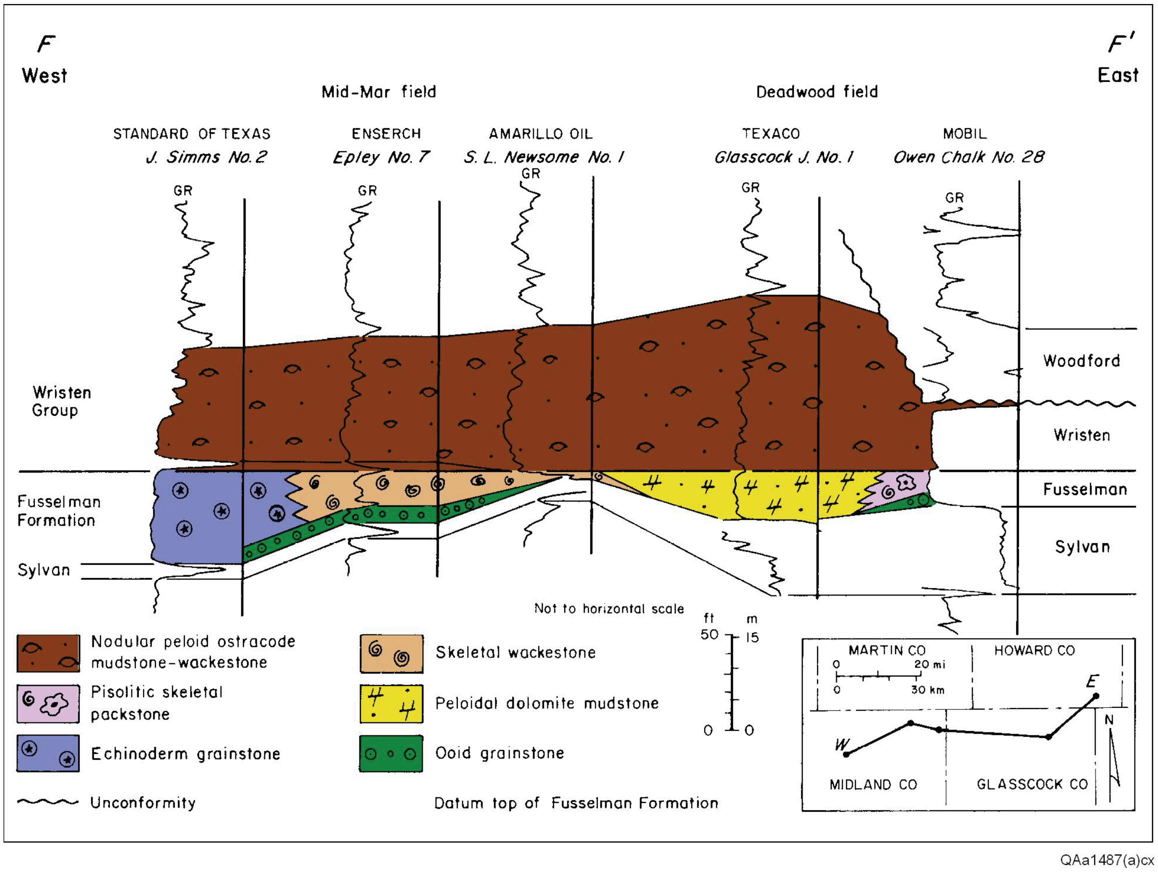


Figure 7. West-east cross section depicting facies changes associated with a paleotopographic high near the eastern subcrop margin of the Fusselman. Modified from Garfield and Longman (1989).

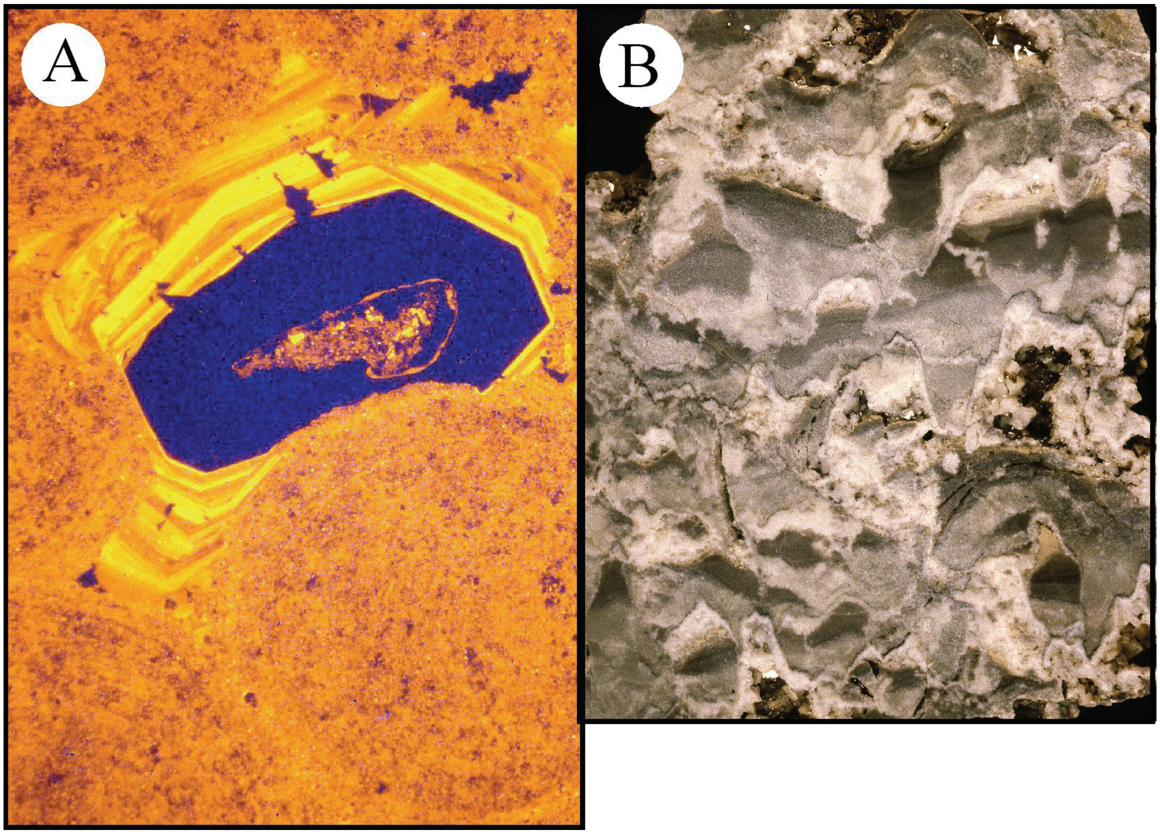


Figure 8. Styles of early and late diagenesis in the Fusselman. (A) Cathodoluminescence photomicrograph of Fusselman ooid grainstone showing well-developed intergranular pores and early fringing meniscus cement. Standard of Texas, Simms No. 2, Midland County, Texas. Depth: 12,536 ft. Width is 4 mm. (B) Slab photograph of upper Fusselman Formation showing multiple, late-stage dissolution and geopetal infilling sediment and cements. Rock is composed almost entirely of cavity fills that consist of greenish-gray silt/clay and drusy cements. Such fabrics are striking evidence of dissolution and karsting of the top of the Fusselman produced during sea-level fall prior to Wristen deposition. Austral Oil Co., University No. 1, Andrews County, Texas. Depth: 12,114 ft. Slab is 8 cm wide.

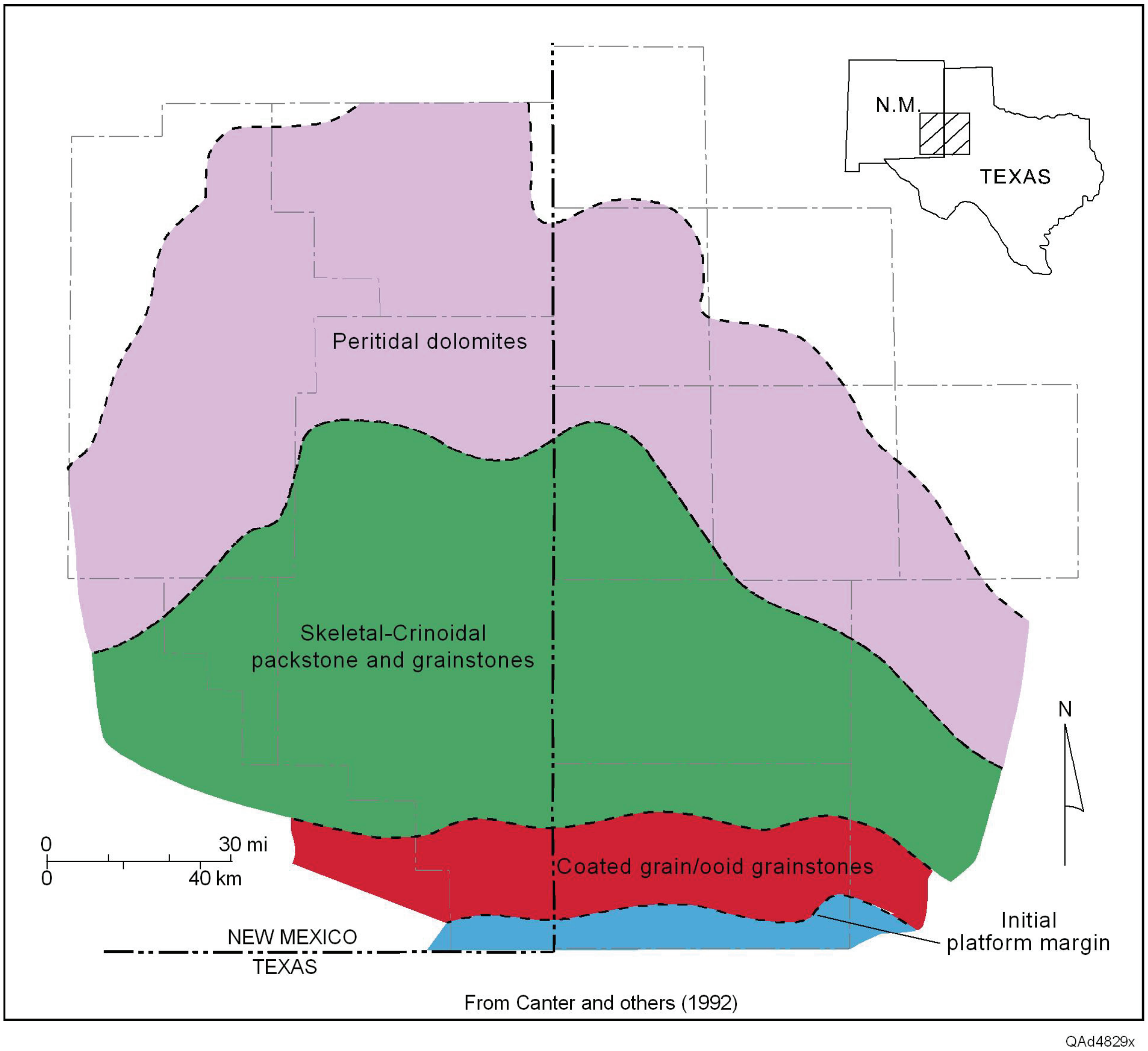


Figure 9. Paleogeographic reconstruction of middle to late Fusselman time.

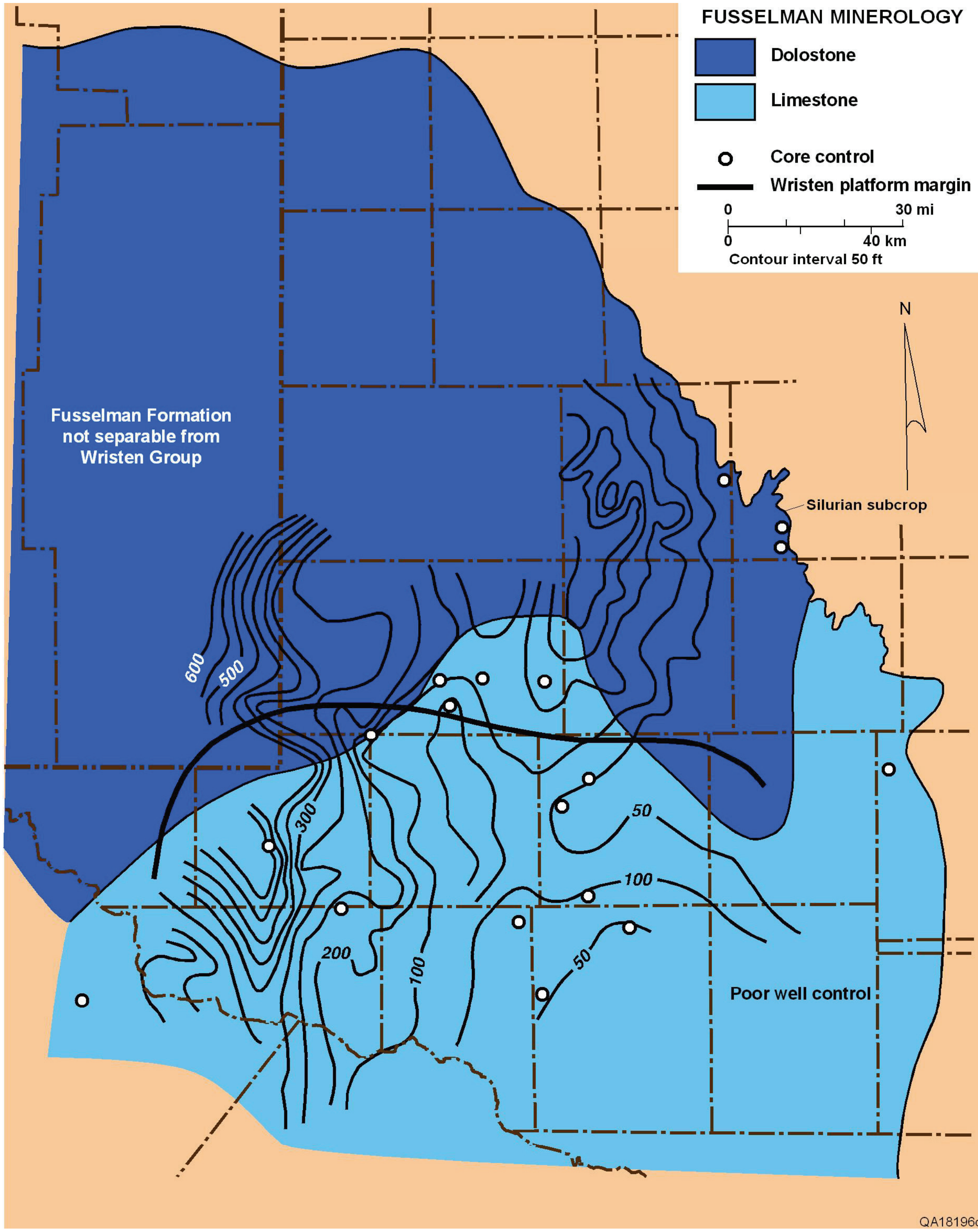


Figure 10. Distribution of dolostone and limestone in the Fusselman Formation. Although this map is highly generalized, the boundary between predominantly dolostone and limestone shown here follows the trend of the Wristen carbonate platform margin, suggesting that some diagenesis leading to dolomitization of the Fusselman was associated with sea-level fall prior to Wristen deposition and/or episodic fall during Wristen deposition (see text). Modified from McGlasson (1967) and Wright (1979).

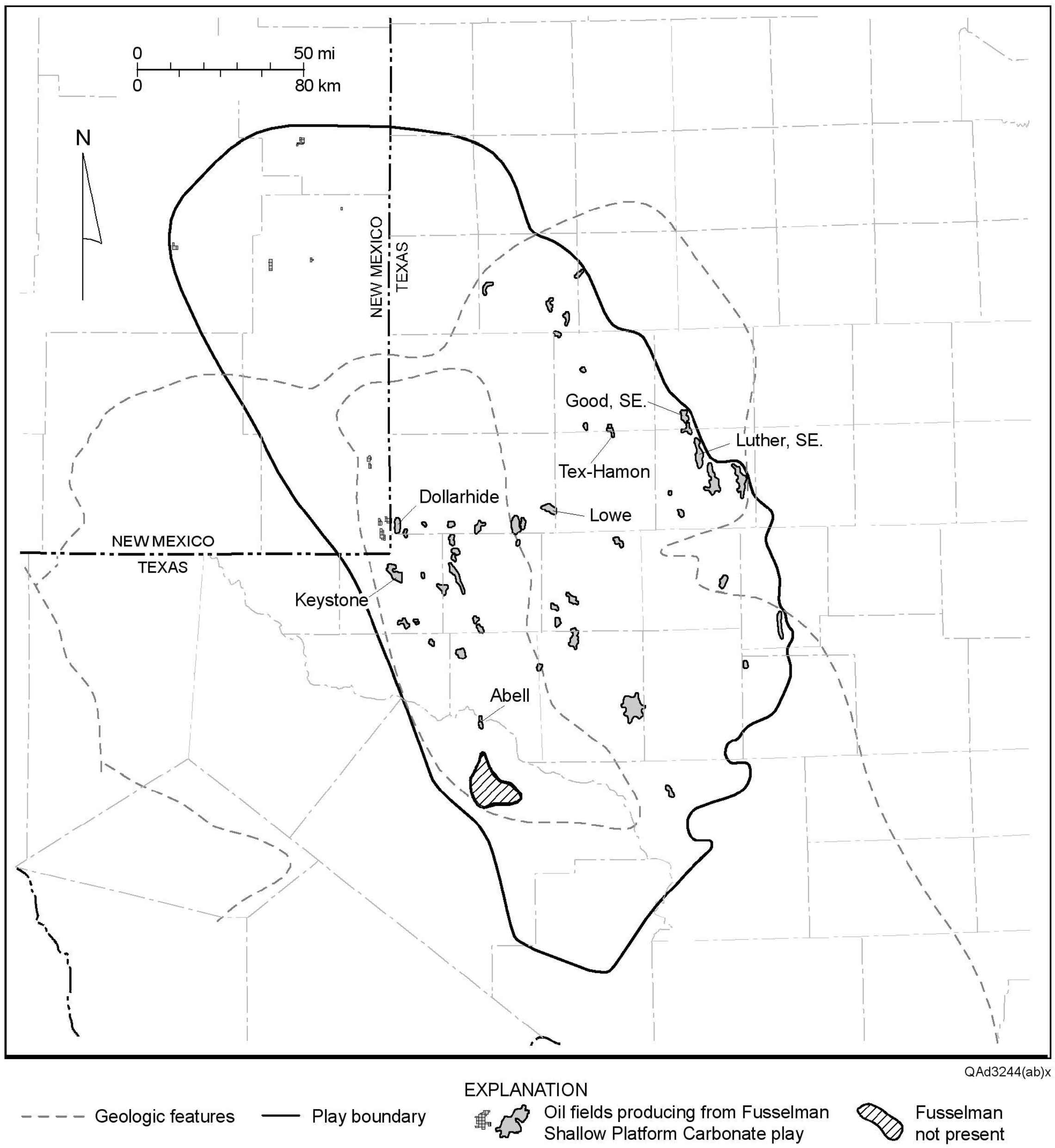


Figure 11. Map of West Texas and New Mexico showing location of Fusselman reservoirs, from which more than 1 MMbbl of oil has been produced (as of 1/1/2000). Cross sections are illustrated in figures 5 and 6. From Dutton and others (2005).