Paleoslope and water depth estimate, lower Wolfcampian, Hugoton embayment of the Anadarko basin

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Abstract

Three criteria are used in combination to estimate paleoslope and maximum water depth during deposition of seven lower Wolfcamp (Council Grove Group) sedimentary cycles on a low relief shelf in Kansas and Oklahoma. Landward extent of paleo-shoreline establishes zero water depth at maximum flooding, and the updip extent of depth-specific fauna (fusulinids) establishes approximate water depth along a sub parallel linear trace. Slope is the depth divided by the distance between the two traces. Rate of change in thickness of a large interval of strata (most of Wolfcamp) serves as another estimate of slope for comparison. Maximum water depth on the basinward edge of the shelf is estimated by adding the depth along a trace established by fauna to additional depth determined by applying approximated slope to the distance between the faunal trace and the shelf margin. Paleoslope on the Kansas portion of the shelf is estimated to be 1 ft/mi (0.2 m/km). Beyond the shelf margin the slope increased by a factor of ten. Maximum water depths vary by cycle from a minimum of <50 ft (15 m) to a maximum of 110 ft (34 m).

Introduction

Shelf geometry (paleoslope) and water depth are important variables for understanding sedimentation patterns in the lower Wolfcampian Council Grove group (Figure 1) in southwest Kansas (Figure 2), and their determination is the object of this study. Rocks of the upper seven marine-continental, carbonate-siliciclastic sedimentary cycles of the Council Grove (Figure 3) were deposited in a shallow shelf setting in the Hugoton embayment of the Anadarko basin (Dubois et al., 2006). Marine carbonates thin landward and continental siliciclastics thin basinward in nearly reciprocal fashion (Figure 4). Paleoslope, a function of subsidence and sedimentation, and glacial eustacy controlled water depth (or elevation above sea level) on the shallow shelf and the rate of shoreline movement during sea level rise and fall. Paleoslope and water depth estimates are based on three criteria: 1) accommodation space indicated by isopachs of relatively large intervals, 2) paleo-shoreline location (updip extent of marine carbonates), and 3) updip extent of depth-specific fauna (fusulinids).

Shelf geometry

Present-day structure of Wolfcampian-age rocks was strongly influenced by a Laramide-age eastward tilt (Figure 5), whereas the Wolfcampian isopach (Figure 6) better reflects the shelf geometry at the time of deposition. From the west field margin, Wolfcampian strata thicken basinward (eastward) at a rate of approximately 0.24 m/km (1.3 ft/mi) to a position on the shelf where the rate of thickening increases by a factor of 10 to 24 m/km (13 ft/mi). The axis of thickening is coincident with an area of present-day steep dip and may mark a shelf margin or axis of a steepened slope. It is also nearly coincident with the edge of a Virgilian-age starved basin and transition from marine carbonate to marine shale (Rascoe, 1968; Rascoe and Adler, 1983). The minimum paleoslope estimated for the older Lansing-Kansas City (Pennsylvanian, Missourian) on the Kansas shelf was 0.1-0.2 m/km (0.5-1.1 ft/mi) (Watney et al., 1995), however, relief across the Kansas portion of the shelf in the Hugoton embayment during Council Grove deposition has not been estimated.

Subsidence history and sedimentation record

The Anadarko basin experienced maximum subsidence in early Pennsylvanian and by Permian subsidence had waned to the point that the entire basin had nearly filled (Kluth and Coney, 1981; Rascoe and Adler, 1983; Kluth, 1986; Perry, 1989). The isopach encompassing most of the Wolfcampian (upper thirteen cycles, from the top of the Chase Group to the base of the Grenola Limestone formation in the lower Council Grove Group) thickens only 80 ft (24 m), 480-560 ft (146-170m) in 60 mi (100 km) across the shelf, a rate of 1.3 ft/mi (0.24 m/km) (Figure 6). Individual cycles show considerably less thickening, but the rate of thickening within a single cycle cannot be considered a proxy for slope because the depositional systems were not efficient at filling accommodation space that varied rapidly in response to glacial eustacy. Two marine carbonate half-cycles in the middle of the Council Grove (B2_LM and B3_LM) pinch out at or near the west updip margin of the Hugoton field (Figures 4 and 7) pinning the water depth as zero along a linear trace, and marking the maximum extent of marine flooding on the shelf for those cycles. Other Council Grove cycles thin substantially, especially the B1_LM and B4_LM.

Fusulinid occurrence on the shelf

The use of fusulinids as paleo-water depth indicators in the Pennsylvanian and Permian has been debated extensively (e.g., Imbrie et al., 1964; Elias, 1964; Laporte, 1962; Laporte and Imbrie, 1964; McCrone, 1964). Fusulinids may live in a wide range of water depths and can transported into an even wider range of depths. Mazzulo et al. (1995) provides an overview of the debate and the writer agrees with their assessment that a typical minimum depth for Early Permian fusulinids is approximately 50-60 ft (15-18 m). All Council Grove cycles studied except the Eiss (B3_LM) and Morrill (B4_LM) have thin, distinctive fusulinid-rich intervals that are adjacent to or mark the maximum flooding of their respective marine half-cycles (Figure 8). Occurrences in cores studied are usually characterized by an abrupt appearance and disappearance (vertically) of very abundant, large (cm-size) fusulinids, in contrast with occasional scattered individuals, sometimes present in adjacent strata. Boardman and Nestell (1993) and Boardman et al. (1995) place the occurrence of fusulinid biofacies in the transgressive limestone and at the base of the regressive limestone, which are separated by the deeper-water core shale interval of the idealized Pennsylvanian-Permian cyclothem (Heckel, 1977). This places the biofacies in the approximate middle of the relative depth scale for outcropping cycles in eastern Kansas and northeastern Oklahoma. Recognized in this study is the notable absence on the Hugoton shelf of the dark, fissile “core shale” common to Wolfcampian cycles in outcrop (Mazzullo et al., 1995; Boardman and Nestell, 2000), suggesting that water depths on the Hugoton shelf were less than those at the present day outcrop 300 miles (480 km) to the east. The closest equivalent to the typical deep water lithofacies in Council Grove core in the Hugoton are dark marine siltstones found near the base of the marine carbonate intervals in two of the seven cycles studied, the Grenola (C_LM) and Funston (A1_LM).

The maximum updip extent of the fusulinid biofacies (Figure 7) by cycle form sub-parallel traces in a sequential pattern that may be related to systematic variability in sea level amplitude. Of the seven Council Grove cycles studied the fusulinid facies the furthest updip extent occurs in the two outermost cycles (A1_LM and C_LM), while the updip limit of fusulinids in the next cycles inward (B1_LM and B5_LM) are downdip slightly. Maximum updip position for the biofacies in the B2_LM is further downdip, and neither the B3_LM nor B4_LM have the fusulinid biofacies present in cores studied. If fusulinids occurred at similar depths from cycle to cycle water depths would have been at a maximum during A1_LM and C_LM deposition, and at a minimum during B2 through B4_LM deposition. Relative depths for B1_LM and B5_LM deposition would have been intermediate to the two extremes.

Furthermore, the lack of fusulinids in the cores studied for the B3_LM and B4_LM suggests the water never exceeded 50-60 ft (15-18 m) in the study area where core data are available (most of the Hugoton in Kansas and Oklahoma), if the fusulinid biofacies is assumed to be present in all cycles where water depths exceeded 50-60 ft (15-18 m).

Maximum updip position of shoreline and paleoslope estimate

Based on examination of approximately 200 examples of the transition from marine carbonate to continental siliciclastics in core from 29 wells, thinning and pinchouts of the Wolfcampian (both Chase and Council Grove) marine carbonates at the updip margin of the Hugoton are not a result of erosion. The maximum shoreline extent is defined for two of the Council Grove marine carbonates, B2_LM and B3_LM, by their updip limit (Figures 4 and 7). In the Middleburg (B2_LM) marine carbonate, the maximum extent of the fusulinid facies is approximately 50 miles (80km) from its pinchout (Figure 7), suggesting a slope of 1 ft/mi (0.2 m/km), assuming that the minimum water depth for the fusulinid facies is 50ft (15m). The estimated slope is very close to the rate of thickening in the Wolfcamp (1.3 ft/mi, 0.24 m/km). Noteworthy is the shoreline position for the B3_LM, which is basinward of that for the B2_LM, and that no fusulinids were observed in the B3_LM. This suggests that the water depth was shallower during the deposition of the B3_LM carbonate than for the B2_LM. Marine carbonate in the other four cycles (A1, B4, B5 and C) does not pinch out in core in the study area, but thins in a westerly direction (Figure 4). Based upon the spatial relationship between the updip limit fusulinid occurrence and paleo-shorelines, and overall rates of change in the Wolfcamp isopach, the paleoslope shelf is estimated to have been 1 ft/mi (0.2 m/km) during the deposition of Council Grove Group. Beyond the shelf break the slope may have increased by a factor of 10 to 10 ft/mi (2 m/km).

Maximum water depth

Based on criterion established above (paleoslope, updip extent of fusulinids and paleo-shorelines), the maximum water depth for the Council Grove marine intervals in the study area can be estimated. Points along a trace where the updip limit of fusulinids are established are assumed to have had a maximum water depth of 50 ft (15 m). The additional depth from the biofacies trace to the northwest portion of Seward County (proximal to the shelf margin) can be estimated as the product of paleoslope and distance that is added to the depth at the biofacies trace for maximum depth on the shelf (maximum depth = 50 ft + [1 ft/mi X distance]). Immediately northwest of the shelf margin in northwest Seward County I estimate water reached a maximum depth of approximately 110 ft (34m) during deposition of the A1_LM and C_LM, the outer two of the seven cycles studied. For the B1_LM and B5_LM, one cycle in from the end cycles, a maximum depth is estimated at 80ft (24m). Water depths for the middle three cycles are estimated to have reached 50 ft (15m) for the B2_LM and slightly less than 50 ft (<15m) for the B3_LM and B4_LM.

Inter-cycle variability in sea level and higher order cyclicity

As noted earlier, there appear to be systematic shifts in shoreline position of marine carbonate (Figures 4 and 7), updip extent of the fusulinid biofacies (Figure 7), and the estimated maximum water depth, all of which are synchronized. Within the seven cycles studied, maximums of the three variables occur at the outermost cycles (A1 and C), minimums occur at the inner cycles (B2, B3 and B4), and the cycles between are intermediate (B1 and B5). The ordered shift in sea level may reflect a higher order of glacial cyclicity (than for the individual cycles).

Conclusions

Paleoslope and water depths for the Hugoton embayment of the Anadarko basin can be estimated for the Council Grove by considering three criterion: 1) Wolfcamp isopach, 2) shoreline position indicated by the landward extent of marine carbonate, and 3) the updip extent of fusulinids. Paleoslope on the Kansas portion of the shelf is estimated to be 1 ft/mi (0.2 m/km). Beyond the shelf margin the slope increased by a factor of ten (10 ft/mi, 2 m/km). Maximum water depth on the shelf ranges from approximately 50 ft (15 m) in the innermost cycles to 110 ft (34 m) in the outer most cycles (top and bottom) of the seven cycles studied. Systematic inter-cycle variability in water depth may indicate higher order glacial-eustatic cyclicity.

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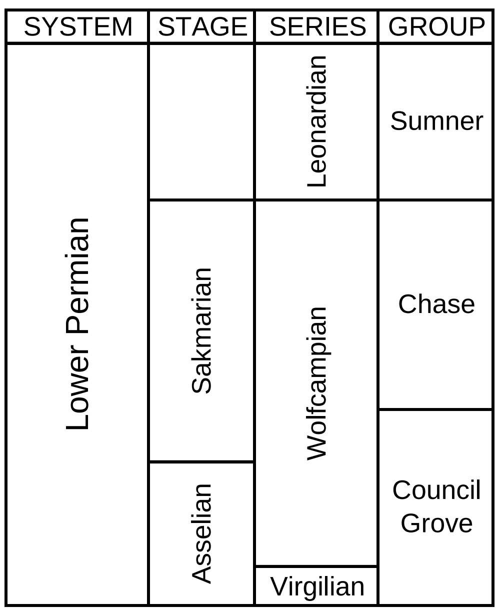

Figure 1. Lower Permian stratigraphy, Hugoton embayment of the Anadarko basin (compiled from Zeller, 1968; Sawin et al., 2006). Approximate position of Asselian-Sakmarian boundary is from Boardman and Nestell (2000). Readers are referred to Peterson (1980) for correlations to stratigraphic nomenclature in Ancestral Rocky Mountain basins. Hugoton field produces gas from the Chase while Panoma gas production is from the Council Grove. The two fields are likely one common reservoir system (Dubois et al., 2006) and are referred to collectively as the Hugoton in this study.

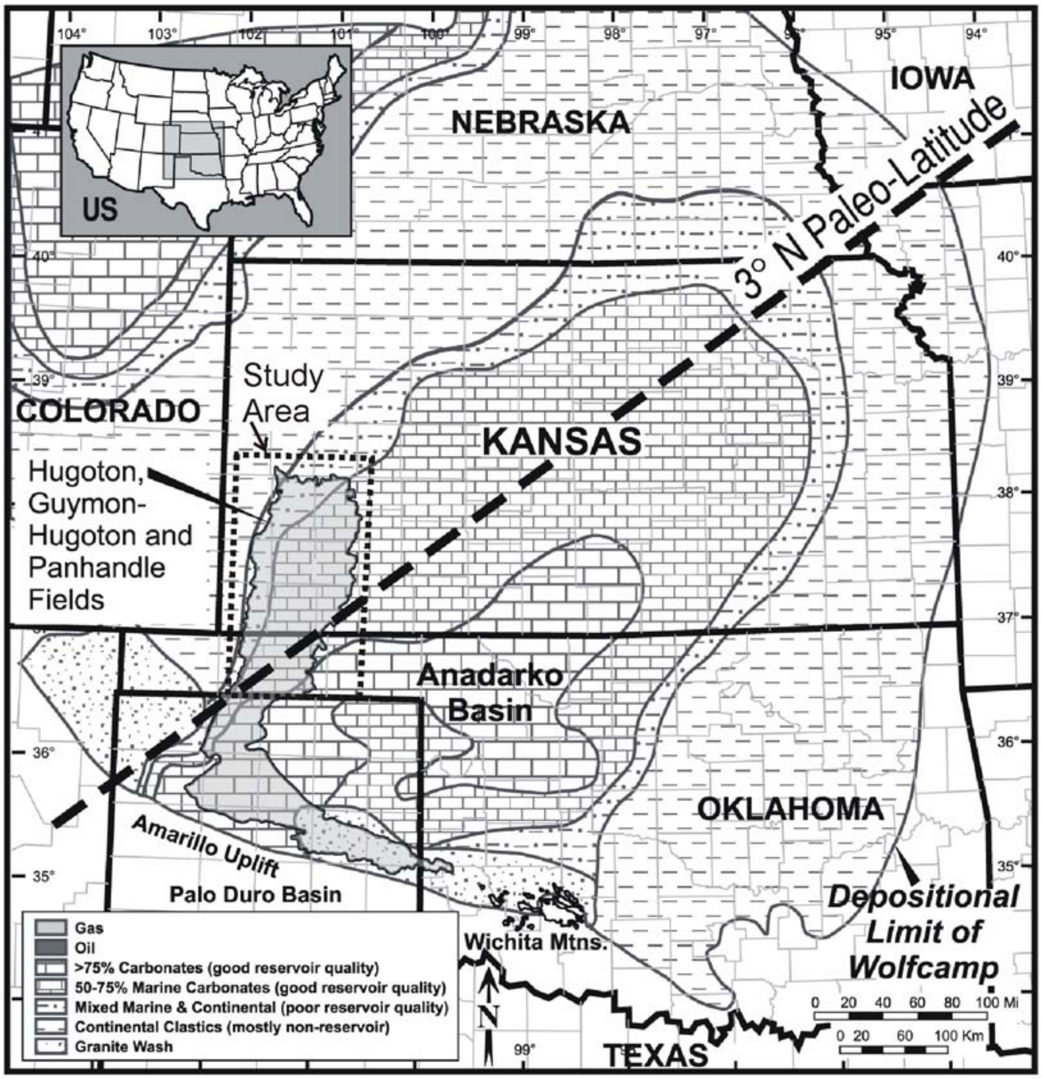

Figure 2. Distribution of major lithofacies in the Mid-Continent during the late Wolfcampian (modified after Rascoe, 1968; Rascoe and Adler, 1983; Sorenson, 2005). Approximate paleo-latitude was 3 degrees north (Scotese, 2004).

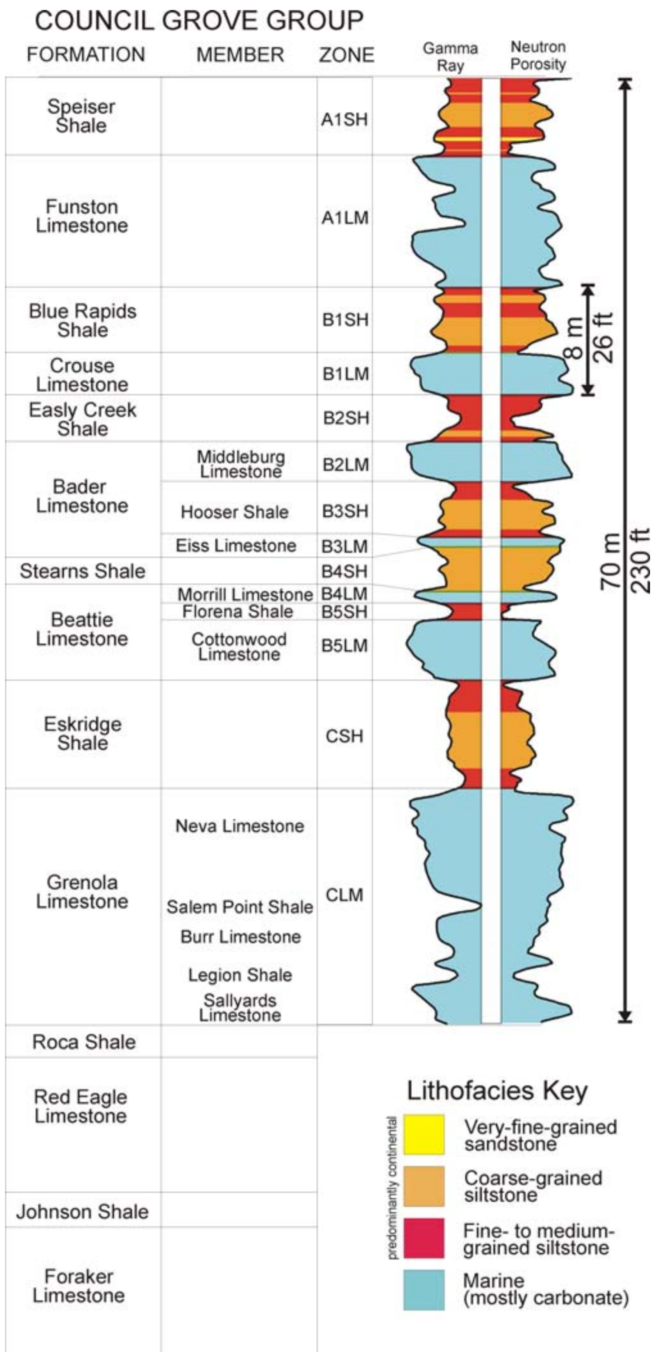

Figure 3. Formation and member level stratigraphy for the Council Grove, Hugoton embayment, in the Alexander D well. The upper seven of nine marine-continental cycles (color-filled wire-line log traces) are the subject of this study. Stratigraphic names that include “Limestone” are marine half cycles that when combined with an adjacent continental half cycle, intervals with stratigraphic names that include “Shale,” form a complete cycle. Informal alphanumeric zone designations commonly used in the field provide stratigraphic orientation and are used throughout the paper.

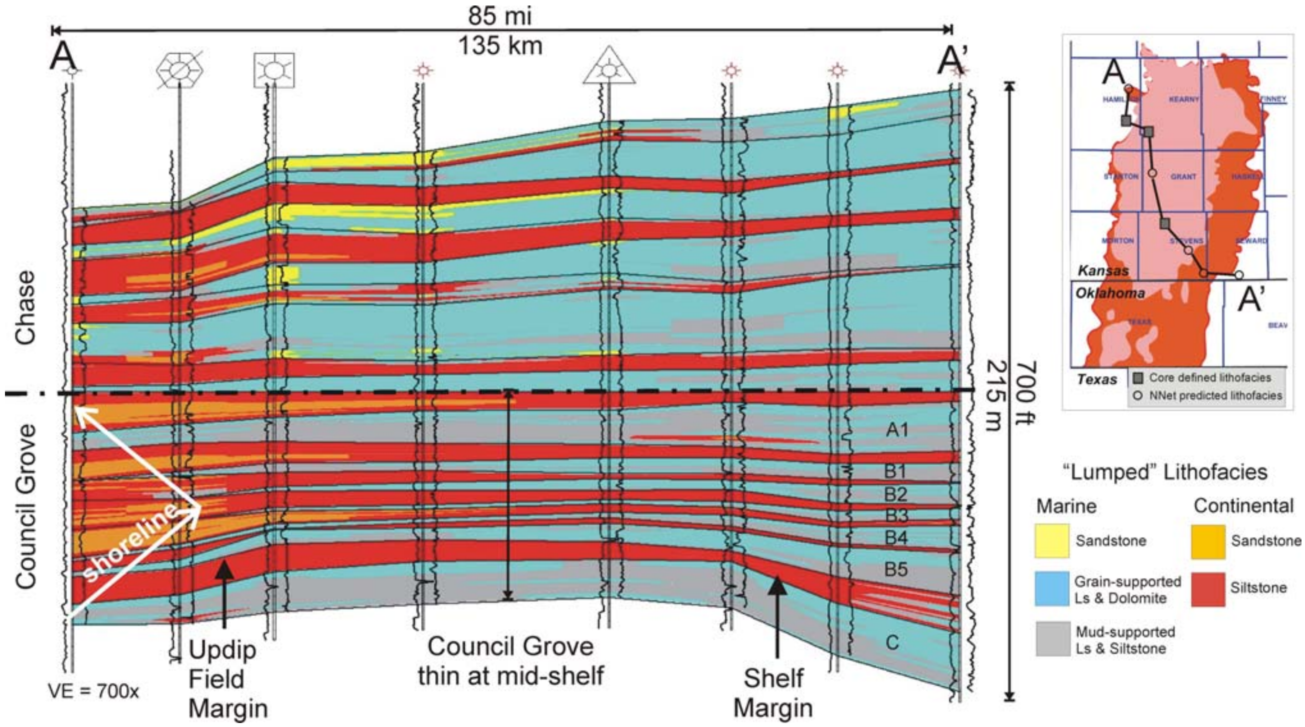

Figure 4. Regional stratigraphic cross-section of the Wolfcamp (Chase and Council Grove Groups) with the top of the Council Grove as the datum. At the wells, "lumped" lithofacies are from core (large symbols) or those predicted by neural network models (small well symbols) or and are interpolated in Geoplus Petra^{TM} between wells. The Upper seven cycles of the Council Grove are the subject of the study and are thinnest at a mid-field position. Log curves are gamma ray (left) and corrected porosity (right). (Modified after Dubois et al., 2006)

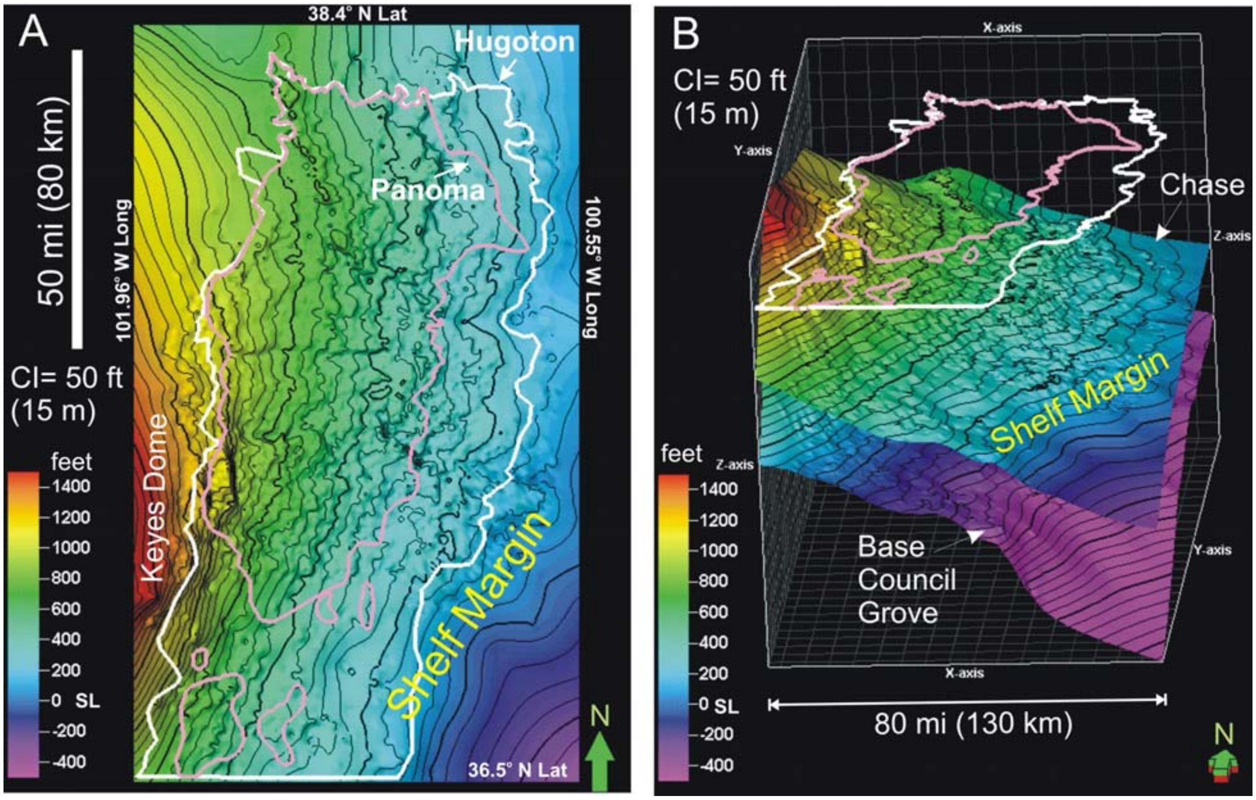

Figure 5. A) Present day structure on the top of the Wolfcamp (top of Chase Group) is mostly a function of eastward tilt during the Laramide orogeny. Note the “shelf margin” or area of steepened slope at the southeast boundary of the Hugoton fields. The Council Grove surface parallels the top of the Chase. **B)** 3-D view of the same area. Present day structure on the top of the Chase and a surface near the base of the Council Grove. (After Dubois et al., 2006)

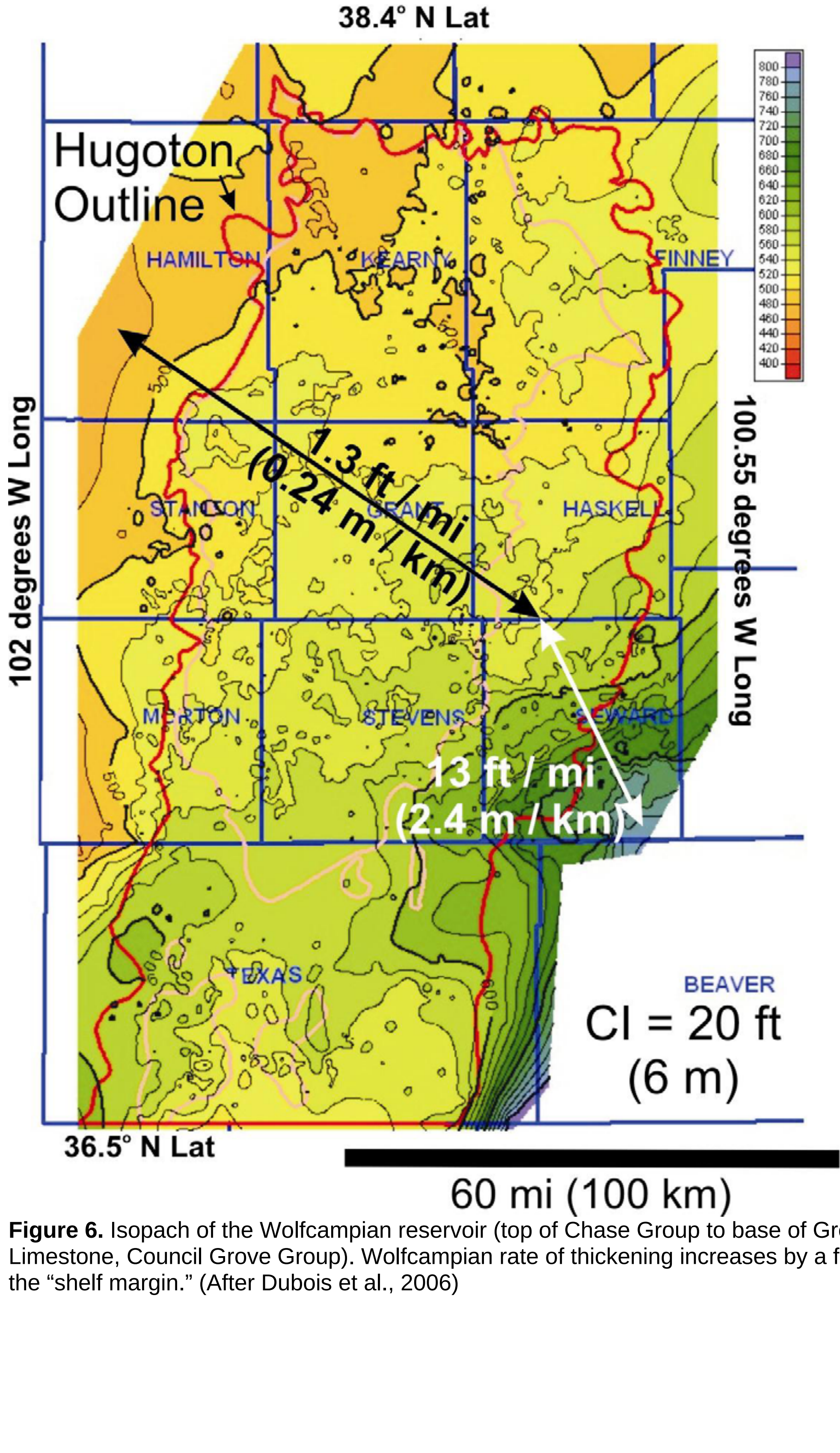

Figure 6. Isopach of the Wolfcampian reservoir (top of Chase Group to base of Grenola Limestone, Council Grove Group). Wolfcampian rate of thickening increases by a factor of ten at the "shelf margin." (After Dubois et al., 2006)

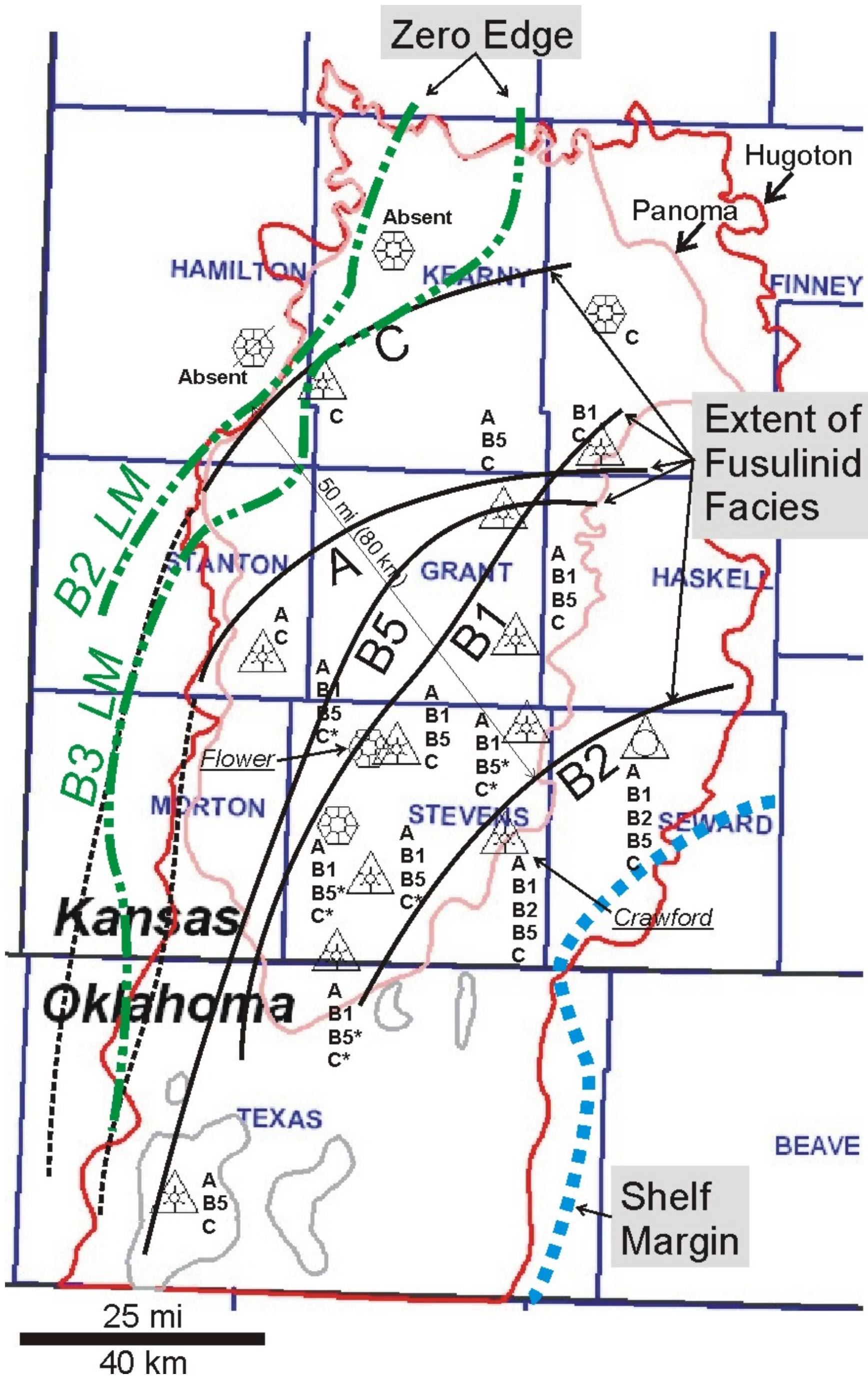

Figure 7. Study area showing updip limit of B2_LM and B3_LM (zero edge) and updip extent of fusulinid biofacies in five of seven Council Grove Cycles (not present in B3_LM and B4_LM). Occurrence of fusulinid biofacies in core is indicated by Council Grove cycle letter code adjacent to 17 wells in study. Asterisk (*) means interval was not cored but fusulinid biofacies is assumed to be present. No core was available below the shelf margin.

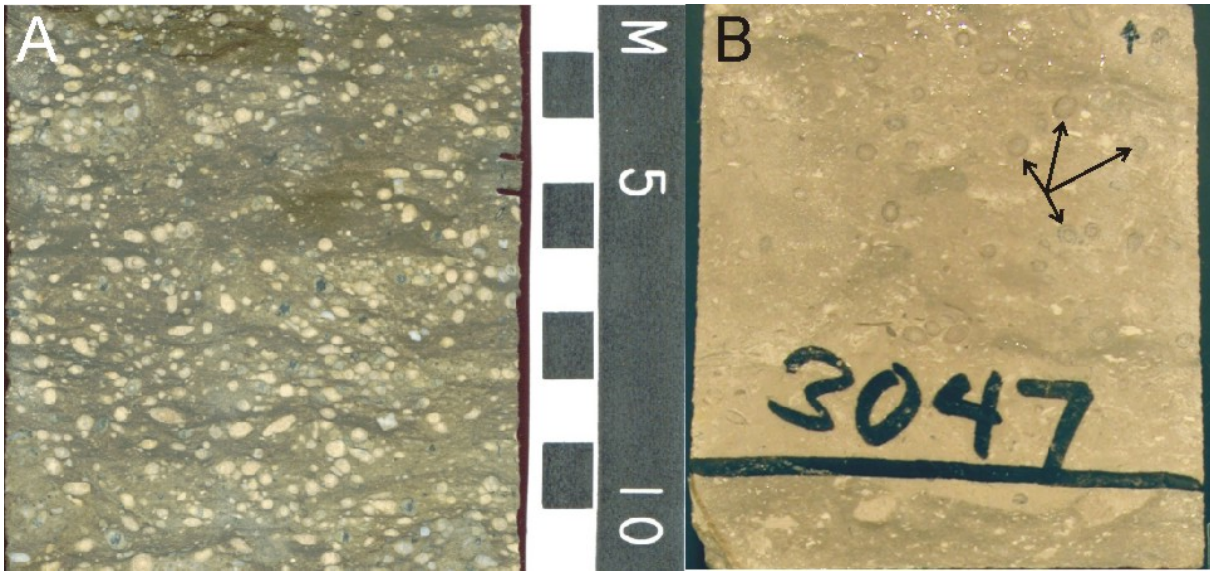

Figure 8. Fusulinid biofacies in core slabs. **A)** Abundant in fusulinid (white) dominated silty wackestone (upper part of transgressive limestone, subjacent to maximum flooding, in Funston, A1_LM, Flower A1 well). **B)** Scattered in fusulinid (arrows) -mixed skeletal wackestone (maximum flooding in Crouse, B2_LM, Crawford 2 well). Depth shown is in feet. Well locations are shown in Figure 7.