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Petroleum Reservoir Characterization
of Upper Pennsylvanian Cyclic Carbonates
in the Hugoton Embayment

by

W. Lynn Watney

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Kansas Geological Survey
1930 Constant Avenue
University of Kansas
Lawrence, KS 66047-3726

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Petroleum Reservoir Characterization of Upper Pennsylvanian Cyclic Carbonates in the Hugoton Embayment

Short Course

presented by

W. Lynn Watney

Kansas Geological Survey

Amarillo, Texas

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SHORT COURSE

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PETROLEUM RESERVOIR CHARACTERIZATION OF UPPER PENNSYLVANIAN CYCLIC CARBONATES IN THE HUGOTON EMBAYMENT

W. Lynn Watney

Kansas Geological Survey

Lawrence, Kansas

Notes to Accompany Short Course:

Petroleum Reservoir Characterization of Upper Pennsylvanian Cyclic Carbonates in the Hugoton Embayment

W. Lynn Watney
Kansas Geological Survey

Outline of Presentation:

1. Introduction to study area and depositional model for the Kansas City Group.
2. Structural-depositional framework of Hugoton Embayment/evaluation of structural trends.
3. Significant statistics on petroleum production in Kansas.
4. Examples of rocks as components of cyclothems and integration with wireline log signatures.
5. Regional mapping of cyclothems for reservoir assessment.
6. Factors important in prospect development.

INTRODUCTION

Cyclothems characterize the Mid Carboniferous through early Permian stratigraphic succession in Midcontinent of North America and other sites world-wide.

Repetitive sequences of lithofacies are common, widespread, and relatively constant in thickness on the craton. It is not unusual to be able trace beds less than 3 m thick over 450 km along outcrop.

Objective of this presentation is to address the character of these cyclothems and significance toward reservoir distribution, with new insights provided by regional correlation and analysis of 4 Missourian cyclothems. Correlation of cyclothems and regionally significant internal divisions of these cyclothems is based on extensive 3-D network of subsurface data covering >70,000 Km^2 (30,000 mi^2).

Specific objectives of study:

1) examine effects of configuration of the shelf on the nature of 4 cyclothems;
2) evaluate evidence for sea level change;

3) attempt to estimate the contribution of the potential causes of cyclicity: sea level change, tectonism, and sedimentation process itself;

4) identify factors responsible for accumulation of hydrocarbons in these carbonate reservoirs, establishing and evaluating productive trends or fairways and models for reservoir development.

Western Kansas and Hugoton Embayment were part of broad shelf bordering the Anadarko basin during much of the late Paleozoic, including the Missourian. Sampling in this study was sufficient to describe activity of subtle tectonic elements on this shelf and varying depositional setting of each cyclothem.

Flexure and subsidence of Missourian shelf in western Kansas were concurrent with rapid subsidence in the adjacent Anadarko basin. Local episodic movement on the shelf influenced the lithofacies distribution in each cyclothem, but the objective was to evaluate how much.

However, local tectonism does not account for the shelf-wide repeating patterns of lithofacies. Perhaps tectonism related to orogeny, sea level oscillation, or shifting of sedimentary environments were responsible for the cyclicity.

*Figure 1--Study area in western Kansas

47 counties, 30,000 mi^2 (77,000 sq. km); NW trending Central Kansas uplift (CKU) and Cambridge arch (CA); Major tectonism associated with these uplifts occurred in Late Mississippian-Early Pennsylvanian; Site of previous uplift during early Paleozoic; Uplift produced only 100's feet of relief, much less than that associated with block faulting and thrusting in nearby orogenic systems to south (Amarillo-Wichita-Arbuckles).

*Figure 2 -- core and log control

2300 well logs through Kansas City Group, one well per 34 km^2 or one well every 5.8 km (3.5 mi); Series of maps produced with data from these wells.

37 cores of portions of four cycle interval--slabbed and thin sections taken; Described carbonates using Dunham classification:

<10% grains in micrite matrix: lime mudstone

>10% grains in micrite-supported matrix: Wackestone

grain-supported framework but significant micrite matrix: packstone
micrite free and grain supported: grainstone.

Staining done with ALR-S and K-ferrocyanide; Fossil fragments abundant in these limestones.

Computer data base: includes name, location, 26 stratigraphic variables; Use Fortran programs for data entry, edit, and plotting (SURFACE II); Convert latitude-longitude coordinates to X-Y Lambert conformal conic projection; Conduct error analysis to check data on well with nearest neighbors; Display equipment includes line printer, flat-bed plotter, and color graphics terminal. Combine data with test and production information for productivity evaluation. Database management could be handled by appropriate microcomputer.

Statistical analysis: used trend surface analysis to assist in characterizing configuration of shelf and identification of local anomalies.

*Figure 3--Stratigraphic nomenclature (surface) and equivalency with informal subsurface units

Nomenclature

Missourian of Upper Pennsylvanian, Kansas City Group; A time nearing maximum inundation of the shelf by long-term rise in sea level that began during early Pennsylvanian time (1st order); Carbonate-dominated succession in Kansas; Each cycle is comprised of transgressive-regressive assemblage.

*Figure 4--Table of lithofacies comprising cyclothems in Kansas City Group in western Kansas

Subsurface: H, I, J, K cycles

Lower (transgressive) carbonate (base of cycle) (thin)

Lower (marine, core) shale (thin, but commonly with distinctive high GR)

Upper (regressive) carbonate--main petroleum reservoir, shallowing upward (thickest)

Upper (regressive) shale (top of cycle) (intermediate and variable in thickness)

PROBLEMS ASSOCIATED WITH CONCEPT OF CYCLOTHEMS

1) true repetition -- repetition of similar environments on shelf do not necessarily produce exactly the same lithologies; recurring environments with certain periodicity?
2) allocyclic vs. autocyclic processes possibly responsible for cyclothems

Common conclusion of most workers that slight changes in sea level caused a great migration of strandline over craton during the Pennsylvanian. However, Heckel's (1977) quasi-estuarine circulation model which requires relatively deep water to explain origin of black shale places a need for greater change in water depth well beyond typical thickness of cycle (<60 ft., 20 m). Late Paleozoic cyclic sedimentation is not simply the result of sediment progradation. Cyclothems here generally very thin, widely distributed successions of contrasting lithologies separated by sharp contacts which suggest more than simple aggradation of sediment over shallow platform. Terrigenous clastic influx is only of minor significance in western Kansas, unlike southeastern Kansas and eastern Oklahoma during Late Pennsylvanian. (Terrigenous influx does not explain cyclical nature of these deposits.)

Wanless and Shepherd (1936): presented a climatic model for generating cyclothems which is much discussed today; Called on repeated continental glaciation in Gondwanaland to produce global variations in sea level; For 20 years following publication of their paper these conclusions were viewed with considerable doubt due to insufficient record of glaciation in time and space to account for some 160 cyclothems recognized in the Late Paleozoic stratigraphic column.

Some workers called on oscillating tectonism (Weller, 1956) that affected uplift of the source of terrigenous clastics. Swann (1964) invoked a precipitation cycle causing a variation in stream discharge which affected their capability of transporting terrigenous detritus. George (1978) used a combination of eustacy and tectonics to explain sedimentary succession in British Dinantian (same interval studied by Ramsbottom (1979). Heckel (1977) revitalized the idea that continental glaciation was the cause for eustatic change in sea level which produced a marked contrast in successive depositional environments over wide region. (Change in sea level appears to have been significantly greater than entire thickness of stratigraphic interval of individual cycle).

Ultimate proof would be to find regionally correlative cycles that transcend depositional systems and represent regular periodic or episodic events. This would require an interregional mechanism independent of sedimentation or local tectonics.

Significant recent advances in understanding causes of eustatic sea level change and response in sedimentary record (particularly during last 150 m.y. interval) have occurred. Perhaps these observations are applicable to Late Paleozoic strata if one invokes eustatic model controlled by glaciation.

Plate Tectonics and Continental Glaciation, Climate Changes

Donovan and Jones (1979) -- Short term but significant effects on sea level caused by glaciation; Pleistocene glaciation produced 100-150 m change in sea level at a rate of approximately 1 cm/year. Sea floor spreading in contrast, causes sea level to change around 1 cm/1000 years with maximum of 300 m change, estimated range during Cretaceous. Cyclothem lasted approximately ~400,000 years with an estimated change in sea level probably less than 100 m.

Crowell (1978) use plate tectonics to explain why continental glaciation occurred during Late Paleozoic:

1) huge continent, Gondwana, over South Pole

2) during a time of intermediate sea level

Also extensive glacial deposits in areas which were once part of Gondwana described by Crowell. Fisher (1980) distinguishes between "ice-house state" (O-state), cool climate conducive to glaciation such as Cenozoic, vs. "greenhouse state" (G-state), warm climate such as during Cretaceous; Berger--proposed that there is an inherent instability in climate during changing sea level and at relatively low sea level climate is in state of flux typified by rapid, step changes.

(a) and (b) and (c) only as slides

(a) *MECHANISMS of cyclothem development

(b) *FACTORS CONDUCIVE TO ICE BUILDUP, (c) below

*Figure 5--Vail sea level curve/KS stratigraphic column. High stand warmer, low stand cooler which are opportune times for glaciation.

*Figure 6--Oxygen isotopic fluctuation in pelagic/benthic forams from Pacific Cenozoic deep sea sediments.

--falling sea level/G-climate state to O-climate state

--purturbations in climate (temperature) as inferred from <u>steps</u> in δO^{18}

--heavier isotope--cooler

--1st order trend--cooling; 2nd order steps abrupt cooling perhaps precipitated by climate feedback mechanisms, e.g., change of earth's albeto due to extent of ice, vegetation, or land area -- still duration millions of years

--longitudinal temperature gradient develop upon cooling and falling sea level; eventually ice near polar regions increasing albedo -- promote cooling (feedback)

(c) *detailed δO^{18} in deep sea core from Pleistocene sediments in Carribean

--rate sedimentation is known as intervals are age dated, planktonic foram provide data on oxygen isotopes

--less rapid, stepped increase in δO^{18} (isotopically heavier, cooler waters reflecting cooler climate with accentuated temperature gradient in ocean between tropics and polar regions)

--rapid decrease in δO^{18} -- warming, melting of ice during regime of higher sea level (resulting from transgression due to melting of ice)

--major periodicity every 100,000 years in Pleistocene thought due to eccentricity of earth's orbit; minor cycles -- cause is presently debated (feedback mechanisms versus orbital parameters; probably a combination)

Significance: if invoke continental glaciation to explain sea level fluct. as cause of Late Paleozoic cyclothems (Chester Mississippian through Lower Permian) -- perhaps knowledge of processes, rates, and frequencies of fluctuation recognized from Pleistocene sediments can be transferred to some extent to understanding of cyclothems; provides at least a working hypothesis to put facts into perspectve and to link them together with a common process.

*Figure 5--Sea level (coastal onlap) curve of Vail et al. and Wise

*Figure 6--Carbonate isotope fluctuation in Cenozoic deep sea sediments

RECOGNITION OF SEA LEVEL CHANGE IN SEDIMENTARY RECORD

Nature of periodicity of Pleistocene glaciation and resultant transgressions and regressions is well documented by analysis of δO^{18} and δC^{13} in nano-plankton from deep sea cores. Processes that be surmised here are thought to be transferable to the late Paleozoic.

Variations in eccentricity (distance from the sun) of earth's orbit could have provided 400,000 year periodicity compared to 100,000 dominate cycle of Pleistocene (Fisher, 1980).

Study of Pleistocene coastal sedimentary record have been important in inferring to what extent process of sea level change had on these sedimentary successions. If glaciation was an important factor in generation of cyclothems then there should be similarities to the Pleistocene, e.g., Frasier's (1974) study on Quaternary Gulf Coast sedimentation processes (sequence model developed).

Evans (1979): Provided evidence of sea level change in Quaternary sedimentary records in area lacking significant influx of terrigenous detritus resulting in predictable sedimentary sequences.

1) rapid inundation of shelf (transgression);
2) followed by development of condensed interval; e.g., diastem or hardground, accumulation of glauconite, phosphorite, carbonate debris representing high sea level stand (perhaps stagnation of tidal circulation during a stillstand).
3) Thicker, more rapidly deposited sediment heralding onset of regressive coastal sedimentation. But rapid influx of sediment also during slow transgression resulting in progradation, e.g., Mississippi River prograded 20 km/1000 years in last 5000 years during sea level rise.
4) Slow, stepwise fall in sea level during regression (slow, intermittent ice buildup) producing barrier bars, lagoonal and delta-plain deposits across coasts and shelves along Gulf and Atlantic. Isotopic shifts in oxygen ^{18} in nano-plankton from deep sea sediments suggests that intermittent fall in sea level occurred at rate that was slower than transgression. Intermittent stillstands produced prolonged development of shoreline deposits like barrier islands, offshore bars, carbonate banks, etc. which are common in the Quaternary sedimentation record.

5) Evans (1979) notes that even loose and friable sediment are typically not eroded away during subaerial exposure at a time of lowered sea level, e.g., coastal buildups of sand which later became coastal hills during subaerial exposure still maintain this depositional relief.

6) Weathered oxidized surfaces (paleosol) separate these sedimentary sequences. Form upper boundary (hiatus) to this period of sedimentation.

Together 1) stratal contacts, 2) geometry of sedimentary units, and 3) recognition of nearly isochronous bedding surfaces or surfaces of non deposition (transgression over an exposure surface) permit construction of comprehensive stratigraphic model. In chronostratigraphy this sedimentation would qualify as being referred to as "event" or "sequence" strata), see Frasier (1974). The evolution of sedimentary processes within these sequences can be highly variable, e.g., terrigenous clastic or carbonate, high energy or low energy, fast or slow sediment accumulation, etc., but boundaries representing a hiatus in sediment accumulation define and isolate these products (sequence or event model).

In order to accomplish conclusive identification of auto cyclicity: use 3-dimensional, regionally-correlated data; Need to look at large scale down to microscopic scale to interpret internal processes and recognize sequences.

POTENTIAL FOR UNDERSTANDING CYCLOTHEMS IN STUDY AREA

Late Pennsylvanian Missourian sediments are unmistakably repetitive as they occur elsewhere with similar characteristics: including Paradox basin, Midland basin, Colorado Plateau, Appalachian coal basin, Novia Scotia, Northwest Europe, and Russian platform. These sequences are comprised of carbonates, terrigenous clastics, evaporites, and mixtures. Thickness of these cycles are similar and estimated duration is comparable. A dozen alternating carbonates and clastics comprise the Lansing and KC Groups.

First order eustatic sea level was slowly rising (due to increase size of mid-ocean ridge presumably related to increased rates of sea-floor spreading) and the submergence of the craton was underway during Pennsylvanian.

Study area in western Kansas: a stable shelf during the Missourian following pronounced tectonism in early Pennsylvanian (Central Kansas uplift-CKU, Cambridge arch-CA, Nemaha uplift-NU). It provided a unique opportunity to study succession in 3-D: 1) gradual lateral variation in composition to cyclothems; and 2) predominance of carbonates that are sensitive to diagenesis and provide record of events of late stage of cycles; 3) assess epeirogenic movement on sedimentation over uplift and shelf--interval of strata noticeably thin over earlier uplift.

REVIEW TECTONIC DEVELOPMENT--FOCUS ON KANSAS SHELF

*Figure 7--Paleozoic interior basins (Lidiak)

Western Kansas-- area during Pennsylvanian was the shelfward extension of Anadarko basin, a "hybrid" foreland basin and reactivated, downdropped aulacogen. The Anadarko and Arkoma basins are immediately north of a tectonic suture formed by collision of Laurasia and leading plate boundary of Gondwana. Plate collision climaxed along Ouachita segment in Late Mississippian to Early Pennsylvanian with thrusting and uplifting of core region and downwarping of foreland basins (Anadarko-Arkoma basins). Concurrent movement of intracratonic uplifts (CKU, CA, Nemaha) and adjacent basins occurred with the deformation of the plate margin.

Kluth and Coney (1981): Proposed that an evolving stress pattern in the interior of the craton developed in response to deformation of orogenic system in late Paleozoic, changing due to migration of main orogenic activity to south-west (Appalachian E. Penn through E. Permian in Marathons). Reactivation of the basement occurred on craton during this time along pre-existing weaknesses. Research on tectonism along convergent plate boundary indicates that even if tectonism was episodic, it would be too long in duration to have been the cause for cyclothem development. One major result of appears to be clear distinction between lengths of tectonic deformation and estimated duration of cyclothemic sedimentation, e.g., compare approximately 400,000 year duration of cyclothems with several m.y. long tectonic episodes common along convergent plate boundaries. This deformation is also generally non periodic. Another component in the evaluation of structure is the recurrence of structural deformation and the effect of epeirogenic deformation on sedimentation.

Fath (1920): Described the origin of the granite ridge (Nemaha uplift) in northern midcontinent. Nemaha uplift is located along postulated series of pre-existing faults or other weaknesses in basement (Berendsen and Blair, in press) (basement provides template for deformation). Fath concluded that vertical movement in Late Paleozoic occurred as faulting along these pre-existing weaknesses.

Morgan (1932) named the Central Kansas Uplift (CKU). Trends on the CKU appear to follow Precambrian geophysical trends. Timing according to Morgan (1932) suggested that CKU was related to Appalachian folding event.

Powers (1925) described spasmatic movement of local uplifts that occurred throughout the Pennsylvanian and Permian in western Kansas. Successive rejuviation of buried hills occurred in a process he described as plains-type folding, i.e., ideas on subject are not new. Shelf is site of recurrent structural deformation of the thin sedimentary veneer.

*Figure 8--paleogeographic map of western Midcontinent (Rascoe and Adler, 1983).

Kansas: broad shelf; Compare the study area in western Kansas with the outcrop belt in southeastern Kansas; thinning in northwest; Anadarko basin underwent rapid subsidence resulting in the development of an abrupt shelf margin built by reciprocal sedimentation; Northeastern shelf margin of the Anadarko basin was estimated to have presented up to 450 m (1200 ft.) relief (Kumar and Slatt, 1984) across which periodic influx of terrigenous detritus alternated with carbonate deposition; Anadarko basin was then a sediment trap, not a source of sediment and blocked clastic influx from the southeast from the Ouachitas into western Kansas; Apron of coarse arkosic detritus was located adjacent to the Amarillo-Wichita-Arbuckle trend and Ancestral Rockies; keep in mind low latitude (tropical) setting of the Midcontinent.

--Lane (1979): study area along northern shelf margin of Anadarko in Missourian-Virgillian strata; Noted oolitic and phylloid algal-rich carbonates comprising massive limestone along shelf margin; Slope estimated only 1 degree, but relief estimated at ~120 m; Allodapic skeletal and oolitic debris comprise submarine fans at toe of slope;

Contrasts with terrigenous clastics in submarine fans to east and south in areas of study by Kumar and Slatt (1984), and Galloway et al. (1976); Periodic development of coralgal-capped phylloid algal carbonate banks also noted along southern Anadarko basin (Dutton, 1982, Becker, 1977).

--(General observation) While Permo-Penn. time occupy only 23% of Paleozoic time, this stratigraphic interval averages 45 to 75 percent of entire sedimentary column preserved in Kansas; Pennsylvanian strata onlap onto eroded terrain, locally resting on Precambrian schist, granite, and quartzite on CKU (Walters, 1946), 36 percent of OOIP in Kansas from Pennsylvanian reservoirs (5.8 billion bbls.); Over half of latest oil discoveries in Kansas from Pennsylvanian reservoirs; 75% of these are from Marmaton and Lansing-Kansas City.

*Figure 9--A-A' SW to NE strat. cross section.

H, I, J, K-Zones; 410 km long; GR, N, LL; Top of displayed log interval from 4200 ft. (1260 m) to 3200 ft. (960 m) below the surface; Note scale and vertical exaggeration: 500 X.

*Figure 10--Index map for cross sections B and C; structure X-Section C-C'.

*Figure 11--C-C' strat. section, 3800 ft. (1140 m) below surface.

*Figure 12--B-B' strat. and structure cross section.

*Figure 13--Data sheet.

*Figure 14--Isopach base K-Zone to base of Pennsylvanian.

Note: Thickness vary from 0 over the CKU to 410 meters in extreme southwest; Lower surface is regional unconformity; Progressive onlap through Pennsylvanian; L-KC deposited some 20 m.y. after major uplift. Thinning in eastern part of mapped area reflect NW-SE uplift of CKU; CKU is site of earlier uplift; A NW-SE oriented embayment to west received sediment in early Penn. (Morrow) in SW Kansas, paralleling the ancestral uplift; Little thrusting occurred in Wichitas during earliest Pennsylvanian and accordingly little indication here that there was concurrent parallel west-east oriented subsidence along this shelf in Kansas [Atokan represent first period of major thrusting].

*Figure 15--Isopach top H to base K (H, I, J, K), 3 m shaded intervals, black area >55 m thickness.

Thickness of interval vary from 60 ft (18.3 m) to over 250 ft. (76.2 m). Rate of thickening <2 ft/mi. (0.38 m/km) over 225 km distance or average 0.5 ft/mi. (0.1 m/km) thickening for each of four cyclothems.

Differential subsidence across shelf during accumulation of 4 cyclothems was low in any event; Gradual syndepositional structural movement cause regional thinning, for example, over CKU because very thin beds can be traced over structure; Minimum paleoslope ~0.5 ft/mi. (0.1 m/km), constrained by the rate of regional thickening; I will suggest later that the slope of this shelf was not constant during the deposition of each the cyclothems--i.e., the configuration of this shelf had a very important influence on nature of carbonate deposition and petroleum reservoir distribution.

Significant thinning: on this map along 2 centers: Cambridge arch (CA) and Rush Rib (under 60 ft. thick) on CKU; thinning coincides closely, but not exactly with earlier tectonic uplifts.

Notice more E-W strike in southern region of this isopach than isopach of earlier interval (lower Pennsylvanian)--appear to reflect time of increased subsidence in Anadarko basin and thrusting of Amarillo-Wichita-Arbuckle; Subsidence with west to east orientation as a consequence of active tectonism adjacent to shelf and resultant subsidence of shelf; positive in SW suggested by thinning (growth of Los Animas and Cimmaron Arch which bisects depositional trend of Morrow in eastern Colorado and western Kansas and is now an important oil province for Morrow).

*Figure 16--Top Stone Corral to top H-Zone, 60 m shading.

Thickening to south toward Anadarko continued in this interval; Reflected in facies in L. Permian as well as U. Penn.; Apparent shifting of structural deformation to west particularly in association with Los Animas Arch by E. Permian.

Slight epeirogenic movement significantly affected depositional environments.

*Figure 17 and 18--Configuration of Precambrian surface in western Kansas.

*Figure 19--Structure contour top K-Zone; 50 ft. (15 m) C.I., dashed lines are structural lineaments; Map represents sum of post-depositional deformation; Most pronounced deformation over CA; Lineaments oriented both NW and NE. Structure cross-cuts isopach trends.

*Figure 20--Oil and gas fields producing from L-KC.

Majority of production found to date is structurally controlled.

*Figure 21--3-rd order trend residual of structure K-Zone

*Figure 22--plot of trend order vs. goodness of fit to structure K-Zone

Trend surface mapping: means of partitioning local and regional elements of map; Remove regional dip to emphasize local structural anomalies.

Use polynomial trend-fitting program of SURFACE II, empirically select order to use, optimizing lowest order to preserve both regional and local variation (goodness of fit equals sum of squares due to regression divided by total sum of squares to calculate; Sum of squares of regression: departure of regression surface from original data; Total sum of squares: sum of variation of the data set.

3rd-order trend surface of structure K-Zone explains more than 90% of original variation; Higher orders contribute only small increments to this fit.

Finer details of residual map correspond closely with Precambrian surface, e.g., Rush Rib on CKU, also site of magnetic anomaly; perhaps intermittent, local, structural reactivation of this feature; Also note that outline of CKU closely corresponds with concentration of positive anomalies; Regional dip reversal occurs over CKU on horizon of K-Zone; Also CKU was a positive area following deposition; Favorable site for oil accumulation and entrapment.

Interval thickness of 4 cycles -- produce regionally uniform patterns; Paleohighs and breaks in depositional slope are perhaps revealed by such a map and, in turn, may give us clues about regional configuration of the shelf and patterns of sedimentation; Isopach of individual cyclothem would reflect changes of shelf configuration during each cyclothem; Technique helpful in assessing effect of structure on sedimentation, i.e., paleotopography: Help to explain locations of carbonate banks and shoals, terrigenous clastic deltas, offshore bars, etc.

Evidence for Recurrent Structural Activity in Western Kansas:

Similarity in structure and isopach maps of many intervals suggest episodic movement of structures that follow a template defined by underlying basement rocks; During Late Paleozoic: nearby Ouachita orogeny probably provided the driving force for epeirogenic deformation.

Weaknesses in basement include faults, fractures, and discontinuities; Use gravity and magnetic patterns to define trends and patterns, some which may be related to discontinuities in Precambrian crust.

*Figure 23--Dutch major geophysical trends in Precambrian.

Kansas: dominated by NW and NE trends; Also coincide with dominant joint trends found in rocks at surface; 3 distinct Precambrian terranes; Older orogenic terranes probably formed by continental accretion paralleling ancient Precambrian continental margin. These extensive terranes are cut by younger CNARS (Central North American Rift System).

Geophysical trends correlate with geology of Precambrian; Also some correlation to present structural trends.

*Figure 24--pole correction map of total magnetic field intensity for western Kansas.

Map of the distortion caused by earth's magnetic field is calculated and subtracted from original map of total magnetic field intensity (Yarger, 1983).

Low frequency NW trends probably represent deep-seated structure of Precambrian according to Yarger; Two prominent terranes are distinguished by heavy line; Hatured lines are major basement faults; Southern half of CA-CKU nearly parallels the magnetic anomaly map.

*Figure 25--2nd vertical derivative map of total magnetic field intensity for state.

Second vertical derivative map of the total magnetic field; Dark areas on map are where changes in magnetic field are the greatest. Areas of high rates of change probably represent steep contacts between rocks of contrasting magnetization (faulting or intrusion); This filtering enhances the short subparallel NE trending linears probably associated with the <u>shallow basement</u> CNARS (Central North American Rift System). This is a 1.1 billion year old graben/horst system.

*Figure 26--Precambrian terranes in Kansas (integrated geologic-geophysical map).

The areas of attenuated magnetic signature are interpreted to denote thick, Precambrian sedimentary strata filling the rift; Note: 1) edge of rift basin defined by the attenuated signature coincides with the SE termination of CKU, 2) the southern CKU is sliced by NE-trending linear magnetic anomalies, which coincide with terminations of local NW-trending anticlines on the CKU; 3) Pratt anticline parallels the NE trending magnetic lineaments; 4) most structure contour and isopach maps have local anomalies that parallel the northeasterly trend located on the east side of mapped area overlying the rift. West-northwesterly trends dominate the area west of the CKU.

[Oil and Gas Production Data Insert]

*Figure 27--Structure contour map of Swope Ls. in Collier Flats field.

*Figure 28--Isopotential map of Swope Ls. in Collier Flats field.

OVERVIEW OF CYCLOTHEM CONCEPT

*Figure 29--Basic Kansas cyclothem of Heckel (1977).

*Figure 30--Detailed sea level curve of Middle and Upper Pennsylvanian strata in the Midcontinent outcrop (Heckel, 1985).

*Figure 31--Patterns of atmospheric circulation during Late Pennsylvanian.

*Figure 32--Paleogeography during maximum transgression.

CYCLOTHEMS AND STRATIGRAPHIC SUCCESSION

*Figure 33--Gamma ray neutron wireline log display and lithologies of cycles H, I, J, K.

H, I,J,K; Marine and non-marine divisions, based on cyclothem concept (genetic).

*Table 2 -- Components of cyclothem

4 members, comparable to "Kansas Cyclothem" of Heckel (1977), carbonate-dominated; In order to understand reservoir unit (upper limestone) important to know characteristics of rest of cycle.

Upper shale = regressive shale

Upper carbonate = regressive carbonate

Lower shale = marine shale

Lower carbonate = transgressive carbonate

TRANSGRESSIVE CARBONATE

Thin, but widespread, generally less than <1.5 m thick; Sharp basal contact; Deepening of water upwards in deposit; Evidence of minor erosion common below lower contact; Common to have clasts incorporated in base; Sharp contrast in depositional environment with onset of new cycle; Locally sandy carbonate or coarsening-upward sandstone capped by brachiopod-crinoid coquina (to 3 m thick) which is locally productive; Oolitic (9 m thick) bars are developed over upthrown block of prominent basement fault in Ellsworth County and are oil productive (Hopkins, 1977).

Examples of Transgressive Carbonate

Findlay 3742.5 feet (J) -- Sharp contact of limestone with shale of underlying cycle; Diverse marine skeletal debris in quartz siltstone matrix; Underlying shale appears to be nonmarine; Evidence of desiccation and subaerial exposure and not fossiliferous; Carbonate clasts are caliche.

Findlay 1120 m (3742.5 ft.) (J) -- Thin section of same samples of transgressive carbonate -- algal-coated skeletal carbonate grains in silty matrix; Deposited in moderate energy in shallow water (densely packed).

Ainsworth 900 m (2986 ft.) (J) -- Reworked carbonate clasts at base of transgressive carbonate; Rounded clasts with mixed lithologies in shaley, fossiliferous carbonate matrix.

Ainsworth 870 m (2914.5 ft.) (G) -- Transgressive limestone, but at top of interval -- lower-energy environment, with open marine fauna indicates deepening of water as shelf was submerged; Some organic matter preserved in carbonate matrix; Pyrite is also common; Commonly darker-colored carbonate; White dots here are crinoid oscicles.

Depositional Environment of Transgressive Carbonate

Thickness:length ratio exceeds 5 X 10^5; Widespread marine unit overlying non-marine stratum; Short duration for transgression affecting large area of shelf; Speed of transgression very fast, i.e., not related to tectonics; Rapid transition from restricted to normal marine environments; Commonly high energy at base to subtidal, quiet water accumulation in upper portion.

Diagenesis of Transgressive Carbonate

Slow grain-to-grain compaction in absence of early cementation; Unstable grains have been neomorphosed in absence of leaching (Heckel, 1983); Fine crystalline pyrite common and preservation of flecks of organic matter--suggest low oxygen condition during late transgression.

MARINE SHALE

Important and controversial lithofacies; Green or olive to gray-green, massive, silty or clay-rich to gray or black, carbonaceous, fissile clay shales; Black shale separated by gray shale from adjoining lithofacies; Green and gray fossilif. is open marine with common to abundant benthic organisms while black shales contain nektonic and nektobenthonic organisms, few benthic, if any, and abundant pelagic organisms.

Unusual abundance of conodonts, fish debris, but lack common marine invertebrates in black shales.

Moreover, black shales commonly contain non-skeletal phosphorite, pyrite, and large amounts of finely comminuted organic matter; Minor elements in elevated concentrations are well documented in literature; these shales are typically described as fissile, non-burrowed, and hard.

Black shale grade laterally to dark gray and gray and locally thin significantly over paleohighs; Phosphate nodules from mm to cm-sized--correlates with high levels of organic matter and pyrite.

Non-skeletal PO_4--apatite, commonly with preserved, abundant and diverse radiolarians and nautiloids and fish debris; Kidder (1983) interpreted PO_4 precipitated from interstitial water unto radiolarian tests displacing sediment; Source of PO_4--planktonic organisms, fecal material, or perhaps solution and suspension from river water; Similarity of these to modern phosphorites suggest slow deposition, predominantly marine derived.

In study area the marine shale generally averages 0.6 m thick or less, but up to 6 m of non-black, open marine shale on northern shelf; Pinches out locally over CKU on a surface that appears to represent a lag concentration (phosphate pellets, fossil fragments).

Depositional Environment of Marine Shale--Lower Shelf

Notably different depositional conditions compared to adjacent lithofacies and characterized by rapid transition to adjacent lithofacies; Marine shale represents lowest energy, probably deepest water conditions; Restricted, anoxic or dysaerobic conditions common and widespread during accumulation of this shale.

Evidence for low rate of accumulation: 1) abundant phosphate; 2) concentration of normally sparse fossils; 3) concentration of organic matter;

4) horizontally-oriented clay mineral plates in face-to-face contact--called parallel horizontal bedding of Potter et al. (1980) interpreted to have resulted from episodic suspension sedimentation in still water in absence of bioturbation.

River water is commonly laden with suspended clay-sized particles which upon mixing with sea water, produce flocs or aggregates of hundreds of randomly oriented, clay-sized particles (Gibbs, 1983); In contrast, Reineck and Singh (1975) describe single-grain sedimentation, resulting from very slow accumulation when low density suspended particles are too distant from each other to come in contact with one another in the water column; In general, overburden and compaction alone have been shown to not be sufficient to orient clay flakes from originally flocculated condition. Thus, the horizontally-oriented state of the clay is thought to be due to extremely slow rates of accumulation.

Examples of Core Shale

Reese F-5, 1011 m (J) -- Gray green shale with carbonate mottling, diversely fossiliferous, carbonate mottles are burrows.

Denker (K) -- Dark gray to gray shale with many marine fossils.

Ohlson (G) -- Black shale, few visible fossils, gray shale burrows.

Conover (K) -- Black shale with no visible fossils.

Other Evidence for Water Depths During Deposition of Black Shale

1) Stagnation due to limited circulation on the sea floor in the interior regions of the shelves -- poor circulation and resultant stagnation.

2) Warm tropical climate would induce thermal stratification with elevated temperatures in surface layers (Black Sea Model); Thermally stratified lakes in East Africa have thermocline developed near 70-100 m below surface, but fluctuate.

3) Large volumes of freshwater carry suspended organic matter could be dispersed over the shelf and settle into stagnant areas and remove or significantly lower the oxygen content.

4) Geochemical Trends: Expect areas of upwelling to be richest in organic matter and minor elements; but increase of organic content inland (north); Trends observed do not appear to support a simple model. For example, Molybdenum (Mo) over 1160 parts per million and

zinc high concentrations in central craton in the Excello Shale, a Des Moines age black shale; Phosphate, uranium, organic matter and other trace metals in the same shale are about twice the levels in the eastern craton compared to samples of the same zone in the western midcontinent; Phosphate content correlates with the uranium content.

5) Phosphate may be derived from river water, but studies of modern rivers indicate amount of phosphate in water average around 10X greater in marginal ocean settings and areas of upwelling.
6) Average hydrocarbon yield (extractable organic matter (bitumen) divided by total organic carbon) is higher in the western Midcontinent than in the eastern belt--in general, liquid hydrocarbons would be evolved in greater concentrations from marine organic matter unless terrestrial matter was lipid rich -- such as from algae. Organic matter in much of the craton may have an important terrestrial component and would be expected to increase eastward.

Pelagic sedimentation--no specific depth connotation, only open marine; exclude marginal marine; >50 m water depth to insure exclusion of strong wave and light influence and preclude growth of most shallow-marine carbonate flora and fauna (Scholle and Arthur, 1983, and Ekdale, 1984).

Pelagic sedimentation is characterized by slow grain-by-grain setting of material biochemically produced in surface water; However, in Paleozoic "starved-basin facies," little evidence of calcareous microplankton (diatoms, coccoliths) such as in Cenozoic, mainly organic walled, phosphatic, or siliceous varieties (radiolarians, conodonts) and ammonites, nautiloids.

Recognition of pelagic conditions during accumulation of marine shale: 1) no planktonic forams or diatoms in Paleozoic, but radiolarians and other plankton and nektons, e.g., conodonts in generally great abundance; 2) condensed interval; 3) hardgrounds--bored, encrusted, lithified; 4) fine-grained and great lateral extent; 5) mm-rhythmic bedding; 6) skolithos and zoophycos burrows; 7) gradual lateral facies transitions.

REGRESSIVE CARBONATE

Greatest diversity in thickness, depositional environments, and diagenesis; Shallowing-upwards sequence from open marine to restricted marine; Gradational base with marine shale, with interval of gradation markedly extended along periphery of shelf where clastic influx was more significant.

Lower part of the regressive carbonate--diversely fossiliferous, tan to gray, burrowed wackestone with brachiopods, crinoids, fusulinids, corals, peleoypods, tubular and encrusting forams, bryozoa; Phylloid algae are locally abundant where important components of broad, low relief carbonate buildups (H-Zone).

Eugonophyllum is the dominant phylloid alga, originally aragonite and easily dissolved.

Examples of Lower Portion of Upper Carbonate

Dorr (H) -- Burrowed wackestone with diverse fossils, wispy shale laminations.

Ainsworth (G) -- Brown, slightly shaley, micrite-rich, diversely fossiliferous (lower energy, open marine).

Findlay (J) -- Clean micritic carbonate alternating with thin layers of shale.

Findlay (J) -- Thin section, diversely fossilif. (note trilobite fragment).

(1) Burrowing pervasive on northern shelf in light-colored wackestone while on the southern shelf--less frequent burrowing and more rhythmic-bedded dark shale in darker, less fossiliferous carbonate matrix; (2) Occasionally carbonate with elevated gamma ray (GR) log values on south coincide with units with greater concentration of dispersed organic matter; (3) GR spectralog reveals higher concentration of uranium; (4) Also quartz silt concentration is greater in south and also extreme north; (5) Concentrations of fossil debris and zones of pyrite-rich shale suggest periods of decreased sedimentation on southern shelf. Recurring, episodic, dysaerobic bottom conditions typify lower regressive carbonate on southern shelf.

Heckel (1977) noted lack of micritization of grains in lower portion of upper carbonate; Concluded too deep for proliferation of blue green or green algae (~100 m); However, endolithic fungal borings down to nearly 800 m in modern ocean; Unabraided skeletal fragments still indicate relatively deep water.

I-Zone: unusual in that (1) shallow-water indicators throughout cyclothem along entire northern shelf; (2) Regressive carbonate pinches out along northern border in relatively thin upper shale; (3) Pinchout of carbonate not because overwhelmed by terrigenous detritus; (4) Prominent paleosol seen in core on northern shelf in interval of red shale where marine portion of I-Zone should be; Suggest slow sediment accumulation during emergence of northern shelf; Marine I-Zone to south and exposure to north support regional slope to shelf.

Upper Part of Regressive Carbonate

Lighter colored, thickest lithofacies, shallow water conditions, high and low energy, but much variability; limited fauna: mudstones with high spired gastropod, concentrations of ostracods, tubular forams, small bivalves; peloids, laminations, mudcracks, fenestral fabric is common, algal stromatolites; On upper shelf grainstones are more commonly only lightly coated bioclasts (0.5 to 2 m in thickness); Grains are generally poorly preserved, usually micritized or dissolved.

Environments interpreted to be shallow or restricted (shelf, bay, lagoon), intertidal, and supratidal--a complex facies mozaic (unlike terrigenous). No significant influx of terrigenous detritus during this time in contrast to southeast Kansas.

Environmental conditions represented:

Restricted: impoverished fauna, low biotic productivity, low diversity, abundant mud, abundant burrows; suggesting slow-water circulation, abnormal salinity, depleted nutrients, temperature extremes, slow sedimentation.

Intertidal: laminations, fenestrae, oncolites, mud cracks, vertical burrows, intraclasts.

Supratidal: stromatolites, mud cracks, flat-pebble conglomerate, intrastratal dolomite, evaporites, horizontal laminations (no burrows).

Shallow-water mozaic sedimentation, diachronous across an inclined slope; Early diagenesis is variable but pronounced, varying according to position on shelf, from longest period of early diagenesis on north to shortest on south; Slope perhaps inclined 0.5 ft/mi. (0.1 m/km) minimum; Shallow water deposits comprise thin veneer only several meters thick at most locations perhaps limited by restriction of time that shelf is occupied by shallow water conditions; Model is important in developing concept for reservoir trends on shelf; Need to reconstruct shelf configuration and go through development of cycle. Use abundant wire-line logs to piece lithofacies together. Noted differences in character of cycles exist in this area.

Generally thicker or greater proportion of grainstones over CA and CKU than NW shelf; Local paleohighs are sites where concentrations of grainstones occurred (Watney, 1980).

Oolites dominate upper portion of upper carbonate across southern shelf in 3 of the 4 cycles studied; Thickness of oolitic grainstone in south exceeds that of entire cycle on northern shelf; Must reflect change in shelf setting. Use regional maps to aid in interpretation.

General limited thickness but extreme areal extent of shallowest water facies; Abrupt transition from subtidal, open marine deposits to shallow-water sediments suggest shallowing developed independent of sedimentation, i.e., not simply progradation and aggradation of shelf.

Examples of upper portion of regressive carbonate:

Nicholson (D) -- Light-colored micrite with restricted fauna.

Rathė (D) -- Burrow mottled, very silty wackestone, sparsely fossiliferous, scattered brachiopods and crinoids.

Ohlson (J) -- Laminated limestone with intervals of fenestral fabric; some of voids filled with internal sediment and quartz silt.

Dorr (H) -- Algal stromatolite.

Ainsworth (H) -- Birdseye structure, irregular fractures, brown altered rim around fractures and vugs, internal quartz sediment.

Bartosovsky (H) -- Thin section vuggy, clotted, pelloidal lime mudstone, unfossiliferous.

Stegman (K) -- Base of skeletal grainstone with patches of oil saturation; sharp basal contact.

Conover (K) -- Cross stratified oolite.

Litsey (K) -- Oolitic grainstone with molds of cemented oolite; partial dissolution and collapse of cement and molds of ooids.

Findlay (J) -- Significant dissolution of a lime wackestone with infiltration of internal sediment--green silty shale, altered oil-stained rim around voids.

Findlay (J) -- Unfossiliferous mudstone cut by vertically oriented voids filled by green shale, also fracturing of carbonate. (.3 meters above last sample).

Dorr (J) -- In situ breccia of pelloidal mudstone, originally mudcracked and probably ripped up.

Riedel -- Similar to previous slide with fitted clasts of lime mudstone infilled by shale.

<u>Diagenesis of Regressive Carbonate</u>

Early freshwater diagenesis is very important in porosity development and porosity occlusion; Early diagenesis is critical to development of oil and gas reservoirs in LKC. Later stage dissolution may be locally important. Also fracturing.

*Dissolution of unstable grains and skeletal material, particularly:

phylloid algae

oolite

bioclasts

Provide secondary porosity; dissolved carbonate may also occlude what was once primary porosity: intergranular or framework; Relative significance of fabric selective late stage dissolution has yet to be demonstrated.

Examples shown in slides:

Prentice -- Subaerial crust -- brown, wavy laminated accretionary micrite lying on skeletal packstone; Voids are fenestral-like and interpreted as root casts.

Prentice -- <u>Thin section</u> of crust -- crinkly laminated, microcrystalline calcite with rounded, vertically oriented voids interpreted as root casts.

Miller Z-1 -- <u>Thin section</u> -- horizontal fracture filled with rounded clasts of wall rock carbonate; Some clasts are coated; Edge of fracture is encrusted with brown microcrystalline micrite (caliche).

Beauchamp (H) -- Thin section, packstone or grainstone; Grains are solution pitted and coated by brown, dense micritic cement followed by fine calcite spar; Some of dense micritic cement has pendant shape and distribution (hanging beneath grains). Pore system described as rectilinear.

Stegman (L) -- Top zone, subaerial crust.

Ohlson (H) -- Diagenetic calcite, dense brown caliche clasts in chalky white calcite; Also caliche matrix precipitated during expansion or swelling of original carbonate fabric with precipitation of chalky calcite in expanded framework. (Displacive growth, circumgranular and intragranular cracking, dissolution of quartz grains).

Rathe (G) -- Mixed-pebble carbonate conglomerate in red, silty-shale matrix; White, powdery micritic calcite surrounds clasts interpreted as caliche.

Ohlson (H) -- Unfossiliferous lime mudstone cut by root casts.

Denker (H) -- Top, grade downward to fitted clasts (*in situ* breccia) with solution rounding, shale infiltration.

Palmer (J) -- Thin section of wall of fissure in carbonate filled with wall rock debris; notice unweathered limestone with fusulinid.

Palmer (J) -- Thin section, within fissure of previous slide, corroded grains of skeletal carbonate covered by brown, dense, micritic carbonate.

Blair (K) -- 4mm across base, alizerin-red-K ferro cyanide stain and blue plastic impregnation; dissolved ooids or replaced with fine blocky, low Fe calcite suggesting cementation by oxidizing meteoric waters; oolites common along southern shelf.

Conover (K) -- Fine blocky calcite cement, dolospar as void fill and replacement. Syntaxial overgrowths of calcite.

Nicholson (D) -- Overpacked bioclastic packstone, many molds, darkened solution embayed edges.

Prentice (G) -- Exterior of core with large vugs.

Repeated subaerial exposure of tops of each upper carbonates noted; defined by carbonate crusts, paleosols with calichification containing root casts caliches, soil-like textures, and freshwater vadose features.

Spacial variation in diagenetic overprinting in regressive carbonate:

(1) Irregular micritic cements, (2) caliche-like fine-crystalline calcite cements, (3) irregular, menisus, pendant, blocky, and sparry crystalline cements; (4) Diagenetic breccias and conglomerates restricted to northern shelf and locally over CA and CKU; (5) Oxidation and red-colored silicification.

Pervasive dissolution of ooids to produce oomoldic porosity with local cementation of primary pore space.

Solution fissures: to 6m below surface of upper carbonate filled with red-brown, silty shale and carbonate debris. Channeling and Karst in north.

Local anhydrite lenses and caliche-like patches in red shales along northern shelf.

Net effect of subaerial exposure and freshwater percolation: 1) leaching of grains, and matrix, 2) recrystallization of micrite; 3) disturbance of original depositional fabric by vugs, solution cavities; 4) still best continuous porosity in grain-supported textures, i.e., important to identify nature of depositional environment.

More intense diagenesis over CKU and CA; CKU is a site without significant shale infiltration to occlude pores: Abundant situ breccias, solution channels, nontectonic fractures on CKU; Suggest that this location on shelf was more positive.

Less intense diagenesis to south, still evidence for subaerial exposure in south with thin crusts and attendant dissolution, root penetrations, calichification, and rectilinear, micritic cement.

Calichification Associated with Regressive Carbonate

Examples:
*Ohlson 3097.5

Nodular-chalky caliche carbonate exhibited in top of H-Zone.

1) displacive growth of finely crystalline diagenetic calicite;
2) circumgranular and intragranular cracking;
3) dissolution of quartz grains, little if any original depositional fabric preserved.

*Wertz

Circumgranular cracking in thin section, 4 mm unstained plane-polarized; All of example shown is diagenetic calicite (micro crystalline and spar); Circumgranular cracking in a clotted texture; Part and parcel of soil formation during extended weathering in semi-arid environment (evaporation >precipitation).

*Palmer 10

Clasts of wall rock debris settled in vertical cavity, interpreted as a solution pipe, lined with caliche crust (brown, clotted, micro-crystalline calcite).

*Prentice

Laminated and pisolitic caliche crust.

Crusts common: early lithification and better chance of preservation vs. soft caliche or soil.

Also dolomitization and intense recrystallization (mottling) important on southern shelf: mixing of waters, greater hydrologic circulation due to extensive oolite development.

REGRESSIVE SHALE

Relatively thin (<9 m) except in NW and extreme SW; Continental deposit here, but marginal, marine deltaic sedimentation was common in eastern Kansas.

Typically, only a veneer of shale present; Thickness slowly decreases southward.

Passively fills depositional and structurally-formed paleotography; Red-brown argillaceous siltstone on north to green and gray silty shale to south; Soil development is common; Caliche mottling abundant on north associated with preservation of root casts, oxidation, and anastomosing shrinkage cracks, circumgranular cracks; Some root casts have oriented-clay skins (cutans).

Examples of Regressive Shale

LKC strat column

Bartosovsky (J) -- Color-mottled, silty shale; Nodules are micritic carbonate caliche nodules; Fractures, vertical fissures lined with caliche, and root casts are abundant.

Bartosovsky (J) -- Vertical tubes filled with softer shale.

Reese F-5 (K) -- Red-brown, oxidized, silty shale with caliche nodules.

Wertz (D) -- Thin section. Clotted fabric within caliche nodule with clast-like areas surrounded by sparry calcite (circumgranular cracking). Shades of darkening indicating periods of calcite precipitation; Fabric developed by displacive growth of microcrystalline calcite.

Bartosovsky -- Thin section. Caliche nodule within quartz silt matrix, dissolution of quartz grains and precipitation of sparry calcite.

Bart -- Thin section. Root casts surrounded by micritic caliche calcite.

Regressive shale succeeded regressive carbonate in subaerial setting rather than concurrent deposition; Thinning over CKU suggests that this location was an elevated portion of shelf as previous evidence indicate.

* (slide only) Depositional model--Irwin
* (slide only) Wilson model of carbonate shelf

Black and white photos in these notes:

*Figure 34--Lower portion of upper carbonate on southern shelf.

*Figure 35--High-energy grainstone facies in the upper portion of upper carbonate

*Figure 36--High-energy facies in the upper regressive carbonate.

*Figure 37--Restricted marine, shallow water facies, with low faunal diversity.

*Figure 38--Carbonate cements

*Figure 39--Fracturing

*Figure 40--Evidence of subaerial exposure in regressive shale.

Petroleum Geology LKC production map for Kansas

L-KC major contributor to oil and gas production in Nebraska, Kansas, and Panhandles of Oklahoma and Texas; Ultimate recovery from Pennsylvanian rocks in Midcontinent 8.8 billion bbls. (1.26 billion metric tons), 3.79 of which from giant fields (>100 million bbls.), 2.7 billion barrels from significant fields (25-100 million bbls.); one-fourth ultimate oil production estimated will come from smaller fields.

Hall-Gurney discovered in 1931 now occupying Russell and Barton counties, Kansas; The only giant oil field in Kansas producing primarily from L-KC; 139 million bbls. produced.

OOIP (Pennsylvanian reservoirs) = 5.75 billion (.82 billion metric tons)

Ultimate oil production from (Pennsylvanian reservoirs) = 2 billion (.29 billion metric tons)

All field OOIP = 16 billion (36 % Penn Co_3)

All field ultimate = 5.1 billion (39% Penn Co_3)

Recent discoveries in LKC 50-300 BOPD (7-43 metric tons per day)

* (slide only) Frequency distribution of field size (# wells) versus numbers of fields; 8 divisions of study area; include median field size ranging from 2 wells to 5; productive surface area ranging from 0.41 percent to 14 percent in each area.

CKU one of most densely drilled and most active province in U.S.; Very mature; Distribution of field sizes in this area approximates hyperbolic distribution; Less defined distribution in developing areas like western Kansas.

*Table 4 (not included) -- Field data of selected reservoirs

Selected field data on LKC reservoirs; Arbitrary on what is available from published literature; Recovery factors complicated by some commingled production; Certain wells in Gove and Trego County produce as much as 150,000 bbls. over 15 year average lifetime; Production in excess of 10,000 bbls. per day was common early in history of larger fields on CKU: only when encountered high porosity and fracturing, with long oil column.

Primary reservoir drive: water and pressure depletion with gas cap to south.

2ndary recovery by waterflooding in these reservoirs can come close to doubling the primary production; Significantly reduced sweep efficiency in many reservoirs due to highly discontinuous porosity.

--Carbon dioxide injection: (miscible flood) are a possibility for these carbonate reservoirs; Miscibility pressures shown experimentally to be 1200 to 1500 psi and are within range of original reservoir conditions.

Nearly half of original oil in place may still be in a reservoir after primary and secondary recovery methods; Incremental recovery from tertiary methods like carbon dioxide has been around 15% of the original oil in place; Feasibility studies need to be done; Knowledge of the geology of these reservoirs is essential.

Over 1/3 of all oil discoveries from LKC in boom period in 1981, 1982; small fields, stratigraphic component increasingly important.

Collier Flats field

Recent example of successful drilling, 54 wells have produced in excess of million bbls. from single zone in LKC, the K-Zone; IP of wells commonly exceeded 100 BOPD; Southerly plunging anticline; Dry hole updip where porosity pinchout occurs.

Western Kansas; Limited structure closure, areal restriction of porosity; Many small single payfields are common; However still potential for multipay; e.g., Cahoj field discovered in 1959 produced over 6.9 million bbls. from 28 wells from all zones; Field located on prominent dome with demonstrable paleo relief during deposition (Watney, 1980).

Exploration philosophy: think subtle, combination structures and stratigraphic traps; Lithofacies distribution is an important part of porosity distribution. Development of models to classify reservoir systems based on lithology, pore types--primary and secondary, geometry of reservoir quality rock.

Integration of Lithofacies and Wireline Logs

Log response generally not unique to lithofacies because bulk composition of rock can vary considerably. Wireline logs respond to change in lithology, pore volume, and composition of fluid in pores.

Modern logs are standardized and calibrated; Some are more sensitive to lithology; Measure new properties of rock and therefore are more directly applicable to interpretation of physical and chemical nature of rocks because of characteristic responses.

Well logs have been crux of exploration program in western Kansas since the 1940's: porosity, detection of hydrocarbons, lithology; Most effective and economic suite: GR (gamma ray), N (neutron), R (guard, lateralog, focused induction).

Identify lithology when tied closely to core, i.e., limestone, shale, sandstone.

X-plots of wells to compare wells in different areas or reveal vertical trends in a cyclothem.

Figure 41--GR-N, Bierig well; SW margin of study; Readings at one foot increments over K-Zone; cuttings description.

Area of clastic influx, thin mudstone-wackestone, regressive shale and marine shale not distinguishable (intermediate GR-N); Frequency plot of GR values sampled on per foot basis expressed as normalized percent--bimodal with small peak for limited clean carbonate.

Similar to wells on NW shelf--low GR marine shale, thick regressive shale, and thin regressive carbonate; Clustered points more characteristic of terrigenous influx.

Figure 42--GR-N cross plot.

*Hughes well in Thomas County, NW Kansas.

Note wide spread of GR frequency plot ranging from clean carbonate to marine shale; Marine shale above 160 API units, is dark gray shale.

Circular pattern of lithofacies succession on GR-N cross plot; Significant spread between the lithofacies; Suggest significant differences in environment on shelf.

Figure 43--GR-N cross plot in oolitic bearing cycle on southern shelf (Lee well).

Can distinguish 4 components of cyclothem on wireline log for reasons previously described (Watney, 1979).

[Please note that the following figures (3-16) are only references to a publication and are not included in notes.]

Figure 3, p. 82, Watney, 1979--Index map

Figure 4, p. 85, Watney, 1979--Conceptual strat. cross section, NW Kansas-SW Nebraska.

Figure 5, p. 86, Watney, 1979--N-S lithofacies X-Section with wireline logs.

Figure 6, p. 87, Watney, 1979--GR-N X-plot of representative, inner shelf well, 6 cyclothems carbonates distinct from shales.

Figure 7, p. 88, Watney, 1979--GR-N X-plot; landward position

Same 6 cyclothems, no dark shale but have spread between limestone and shale, i.e., carbonate is relatively pure.

Figure 8, p. 89, Watney, 1979--GR-N X-plot northwest shelf, off CA.

Area of more clastic influx; Substantial decrease in contrast between marine and regressive shale (composition, oxidized); Regressive carbonates less pure--more silt and shale intercolations and dispersed, also infiltration of shale into pore space; Nearshore marine carbonate and continental shales with decreased difference, eventually converge and distinctive log signatures are lost.

Figure 9, p. 90, Watney, 1979--Shale: carbonate ratio map of G-Zone, clastic domination in northwest; gradient steeps in NW sector.

Figure 10, p. 91, Watney, 1979--Max. GR deflection in marine shale of G-Zone.

Peak reaches plateau at just over 200 API units; minimum, shale base line around 80 API units (GR floor for shale), which is same as regressive shale; Therefore essentially loose distinction between two shales in northern region.

Figure 11, p. 92, Watney, 1979--Major peak heights from x-ray diffraction for selected minerals distinguished as to marine or regressive shales; Quartz and feldspar peaks constantly greater for regressive shales; 100 A peak of mica and illite also usually higher in regressive shales; Muscovite more abundant in regressive shale.

Calcite and dolomite generally higher in marine shale; Also clay fraction greater in marine shale.

Average dark shale's uranium context vary from 3-250 ppm; Heebner shale 30-50 ppm; Average shale 3.7 ppm uranium with range of 1-13 ppm.

Lower regressive carbonate -- elevated GR thought due to uranium found in dispersed organic matter; Shale fraction generally not great enough to account for GR level; Organic matter is observed in thin section in these carbonates.

Figure 16, p. 97, Watney, 1979--X-plot of G-Zone with phylloid algae.

MAPPING WITH WIRELINE LOGS IN K-ZONE

Use available cores (framework) to ID lithofacies and translate to wireline logs. Well density in this study averages 1 well per 34 km^2 or every 5.8 km (2300 wells).

Objective of mapping:

1) Define the configuration of shelf.
2) Determine the effects that the shelf configuration had on lithofacies distribution.
3) Define patterns and trends on maps to help interpolate very limited lithofacies data and relate to reservoir development.
4) Evaluate possible causes of cyclicity.

<u>Marine Interval Isopach</u>

Figure 44--Marine interval isopach of K-Zone.

Thickness of marine shale is generally insignificant, compared to thickness of regressive carbonate. Exception to this is in extreme NW and SW mapped area where influx of terrigenous detritus occurred. Carbonate buildups resulted from accumulation of grainstone (high energy), or mudbank consisting of lime mud trapped by organisms like phylloid algae (e.g., Watney, 1980; Ebanks and Watney, 1985).

Grainstone can also occupy pre-existing bathymetric low or alternately, along bathymetric highs without significant addition to thickness. For example, grains such as oolite could be formed on positive shelf locations and reworked into adjacent lows.

Identify favorable reservoir rock most rapidly assessed by magnitude and kind of porosity. Need to interpret depositional environment (and assign facies) and determine extent of diagenesis and their relationship to porosity in order to identify parameters to map and predict reservoir development.

Best reservoir quality in LKC most commonly associated with rocks deposited originally in high energy environments. Grain support provides rigid architecture and network that assists in perculation of undersaturated waters and leaching of grains and mud.

Thick mudbanks are possible sites for early leaching by meteoric water as shelf becomes emergent or constrains flow of undersaturated subsurface waters.

Marine interval isopach map regionally thickens southward or basinward and suggests differential subsidence increased to south. Sedimentary facies and diagenesis do vary across shelf sympathetic to this trend and suggest differential relief during deposition of the cyclothem.

Trends recognized on map of marine interval of K-Zone, lowermost of cycles studied:

1) thickening along arcuate trend, concave to west; 32 km wide which runs 240 km from Wallace County to Stanton County;
2) thick lobate volume in Haskell County;
3) elongate multilobed area extending W-NW to E-SE;
4) narrow N-S trending lobe in Rice and Reno counties;
5) generally a marked regional southward thickening south of 35-40 foot contours.

Note, all significant local anomalies occur in the southern region. Marine interval is thin over the northern shelf and along the CKU (outline).

*Figure 45--Thickness of porous carbonate

Map depicts thickness of porous carbonate above 8 percent porosity. Pore space above 8 percent is generally permeable (>0.4 md). Another method is to use the porosity-feet map. Both are good indices of favorable reservoir rock except for: 1) oomoldic carbonate rock, commonly with low permeability, but high porosity (>20%); 2) porosity in fractured carbonate rock (permeable even below 8% porosity).

Porosity is commonly restricted to upper portion of regressive carbonate. May want to map porosity distribution in upper and lower intervals of this carbonate.

Close correspondence with marine interval thickness:

1) lobate pattern in southwestern mapped area 16-24 km wide;
2) belt of multilobed porous carbonate development along 240 km line extending from NW to SE; Closely coincides with 35-foot isopach of marine interval thickness;
3) substantial porosity development in excess of 8m in southwest; Area is immediately south of site of local thinning; Area of thinning on this map is also thin on marine interval isopach map; Porosity and interval thickness vary closely across shelf; Both are thin across northern shelf.

Figure 46--marine interval percentage

Regressive shale at top of K-Zone typically has many characteristics of soil development. Watney (1980) illustrated that the unit characteristically thins over paleohighs in NW Kansas and SW Nebraska. Paleotopography was created because of buildup of underlying carbonate or structural growth. The regressive shale is interpreted to passively fill in and diminish this relief. Regionally, the regressive shale: 1) thins dramatically to the south; 2) thins over the CKU; 3) on the southern shelf it reaches the minimum detection limit on wireline log (1-2 ft.); 4) local lobe of thickened regressive shale in the SW-mapped area coincide with a thinning of the marine interval isopach and thickness map of porous carbonate.

Regional distribution of the regressive shale forms a broad apron of terrigenous detritus thickening toward source area in the north. Regressive shale is up to 3 m thick in areas with mapped values here of <70% marine interval.

Mapped values here of >90% typify southern shelf. Map reveals an arcuate buildup of carbonate in the southwest. Southern CKU also is an area of >90% marine interval, i.e., very thin regressive shale. An area of maximum thinning of marine interval occurs in Barton and Rush counties over a feature called the Rush Rib. It is a Precambrian horst where the Kansas City Group rests directly on Precambrian. The area is thought to lack terrigenous detritus because of its topographic relief.

Figure 47--Maximum GR map

GR values >160 API units are associated with black shales. Those shales rich in certain organic matter, also have elevated GR values thought to be related to uranium (Watney, 1979)

In the northern study area the GR values of the regressive shale and marine shale vary between 70-100 (low values, average for non-organic rich shale).

Many areas on the CKU are sites of low GR values in marine shale. Thickness of shale under 0.5 m would fall below resolution of GR tool--including some areas on uplift. Cores however confirm change of black shale to non-black facies over crest of CKU and local pinchout of marine shale altogether.

Sites of low GR values on CKU are also locations of (1) thin marine interval, (2) regressive shale, and (3) thin overall Kansas City interval.

CA and Pratt anticline are also location of low GR values. GR values are also low in SW Kansas, but marine interval here is thicker. This thickening in the local southwestern area appears to be primarily due to an increase in terrigenous clastics, suggesting that this area was likely a positive location on the shelf.

Cimmaron Arch immediately off the map to the west may have extended eastward into the mapped area during the deposition of this cyclothem. The map of maximum GR may reflect (a) circulation near sea floor during deposition of the marine shale, (b) rate of sedimentation, or (c) level of anoxic bottom conditions. Most significantly, the mapped distribution may be a function of bathymetry which affected the (1) degree, (2) frequency, and (3) duration of anoxic conditions.

Only 6 m of thinning of the marine interval is noted over the CKU. This probably represents minimum relief, but appears to have been enough to affect the level of anoxic conditions or current action which may have winnowed shale from these paleohighs.

Figure 48--Percentage thickness of K-Zone in four cycle package.

1) In excess of 35% around arc in southwest Kansas (around positive area);
2) also high percentages in south-central; and
3) along N-S trend in southeastern mapped area.

Trends of greater interval percent in SW correspond to greater thicknesses of porous regressive carbonate (see Figure 32). Implied here that depositional relief apparently affects thickness of succeeding cycles (compensation).

<u>Summary</u>

Regional thinning of marine interval is supported by lithologic data indicating positive shelf locations; Other maps also support this interpretation.

Subdivisions of shelf:

1) Shelf: broad, gentle subsidence during K-Zone;
2) positive areas: less subsidence;

3) areas of flexure--areas of greater subsidence and tilting along southern shelf.

Positive: CKU-CA, southwest; flexure: southern shelf area, facies.

Integration of Wireline Log and Rock Descriptions

Upper regressive carbonate: Most change is expected in this interval because of shallow water environment in which it was deposited. (A) Greater restricted shallow water facies exist on northern shelf and on CA and CKU. (B) More than half of the carbonate in these locations are intertidal and supratidal varying from low to high-energy deposits. (C) Thick oolitic grainstone are common in southwestern wells while (D) thin, abraided bioclastic grainstone are locally developed on northern shelf.

Figure 49--Index map locating core-log examples.

Figure 50 a and b--Combined wireline log and core description and interpretation (including Dorr, Thompson, and Lemon wells).

Dorr well, poorly sorted, heavily micritized grainstone, few concentric laminations around particles.

Graphic descriptions utilize gamma ray, neutron, and density logs; lithologic column; environmental interpretation ranging from open marine, stagnant marine, slightly restricted, restricted, very restricted, non-marine.

*Figure 51--Core description of 2-D Stegman well

*Figure 52--Core description of 4 Litsey well

*Figure 53--Core description of #6 Lemon (from Lemon Ranch-Collier Flats field in Commanche County, Kansas)

*Figure 54--Legend for Figures 51 to 53.

Note expression of oolite on wireline log (Figure 50b). Formation and accumulation of oolite required persistent tidal action in shallow water (<2 or 3m). The oolite is recognizable on wireline logs as very clean and porous (>15%) intervals. Thicker porous carbonate near top of regressive carbonate is generally oolite along central and southern shelf.

Northern shelf is a broad platform with a low paleoslope which dampened most of the current action; Predominant current activity probably resulted from episodic local storms which winnowed fines. Only significant paleohighs apparently had sufficient relief on northern shelf to locally produce oolitic grainstone (Jennings Anticline).

Southern shelf apparently was a steeper shelf according to interpretation of isopach maps. Abrupt thickening of porous carbonate occurs along the northern edge of southern shelf. Cores and cuttings from along this trend indicate that oolitic grainstone corresponds to locations of abrupt thickening of the marine interval. The break in slope apparently was the focus for currents and waves during late regression.

Southwest positive is rimmed on its south side by unusually thick oolitic grainstone where perhaps the greater slope developed in proximity to the southern, open marine shelf margin.

Figure 55--Hand contoured version, thickness of porous carbonate.

Reveals trends not recognized by computer contouring. Note lobate patterns of porous carbonate (6-19m maximum thickness 2 to 8 km long--8 to 16 km wide); Lobes extend northward where they pinchout along the zone of flexure on the shelf. Lobes are thought to be analogous to modern prograding spillover lobes of oolite developing along coast and reworked landward by storms in the Bahamas; However, these are 5X larger then modern examples.

The modern deposits of oolite are developed on a platform edge facing the open ocean. In this ancient example, storm surges pushed ooids northward or landward. As sea level dropped, the shoreline retreated southward across shelf. The oolite formation required proximity to good circulation with significant wave energy.

How long did it take for the oolite shoals to develop: the cycle is estimated to average around 400,000 years in length; Oolite formation during latest regression perhaps took only 5% of this time or ~20,000 years, comparable to the time taken by the Pleistocene-age Miami oolite to develop in southern Florida. The Miami oolite is also similar in size to this deposit.

Oolite prograded to the south with time and is therefore oldest on northern side. Oolite accumulation probably occurred while a great part of the northern shelf was emergent.

Figure 56--S-N lithofacies cross section of K-Zone, 350 km, exaggerated.

Sequence of events in formation of cyclothem: widespread transgressive limestone deposition with little reworking of underlying sediment, locally sandy. Black shale accumulation in south and central (a reflection of slow accumulation under anoxic conditions); Perhaps marine shale reflect pelagic accumulation (>50 m water depth over much of shelf). Dark silty poorly fossiliferous--lower regressive carbonate on southern shelf began carbonate accumulation during shallowing of the water following accumulation of the marine shale; During late regression the upper shelf was exposed while ooid accumulation occurred in south. Limited influx of terrigenous detritus occurred on northern shelf during latest regression. Local channeling and solution of carbonates occurred on the upper shelf (DuBois, 1979; 1985).

If assume simple ramp model for 480 km wide marine shelf from western Nebraska across Kansas with a 0.5 ft/mi. (0.1 m/km) paleoslope to south based on average rate of thickening of isopach maps of marine intervals the minimum relief across the shelf would be 48 m less the amount of aggradation averaging some 9m across the southern shelf. This would leave 39 m minimum change in sea level if shelf totally exposed at conclusion of regression. Maximum water depths to establish anoxic conditions on the shelf would presumably mean somewhat greater water depths while the amount of fall in sea level to permit extended exposure of shelf may have also extended the range of sea level change.

*Figure 57--Chronostratigraphic cross section

The duration of the cyclothem is approximately 400,000 years; Erosional boundaries isolated the deposit in time. Also subsequent rapid transgression following emergence helps to define these sequence boundaries. The sequences, constrained by changes in sea level, are comparable to Frasier's (1974) Quaternary sequences, except that those of the Quaternary sediments of the Gulf Coast are dominated by terrigenous-clastic

*Figure 58--Frasier (1974) time-depositional model for terrigenous clastic coastal sedimentation.

Structural Implications of Mapping

Paleohighs coincide with earlier, prominent tectonic uplifts and secondary trends, e.g., zone of flexure.

Origin of locations of flexure: Tectonic stress created by subsiding Anadarko basin probably related to thrusting of Wichita-Arbuckle Mountains (several m.y. long episodes); Location of flexure perhaps related to structural grain in Precambrian revealed by filtered magnetics intensity map.

Nature and significance of SW positive area: Later in Permian the SW positive became an important area of uplift, while earlier pre-upper Pennsylvanian activity was insignificant. Upper Pennsylvanian uplift was precursor to later structural activity.

In contrast, dominate NE trend in southeastern mapped area coincides with magnetic linears associated with CNARS. This NE trend cross-cuts older Precambrian grain almost at right angles. CNARS trend is younger and perhaps less well healed and weaker than older trend. Also inherent nature of rift includes complex faulting perhaps more easily reactivated by later tectonic forces.

Compare K-Zone with J-, I-, and H-Zones

Intercyclothem variation--Changes in shelf configuration

*Plates 3, 4, 5 (J, I, H) (See display)

Use polynomial trend surface modeling of thickness of marine interval for 4 cyclothems to summarize changes in lithofacies between cyclothems (Watney, 1985--see paper for maps).

J and K-Zones both have extensive areas of oolite development on southern shelf. I and H are notably different, where H-Zone has widespread accumulations of micritic buildups.

Marine interval is a good map to summarize changes between zones because it: 1) depicts structural changes on shelf and 2) local variations in carbonate accumulation.

One of constraints to method is to determine best statistical fit using lowest order trend surface. Residuals allow focus on local anomalies so desire to distinguish between geologically significant regional and local patterns.

Goodness of fit, R2 == (sum of squares residual/sum of squares total) *100 (%).

Skewness, third moment about mean.

Plot of goodness of fit, versus order of trend for H, I, J, K Zones. (Slide only).

4- and 5th-order surfaces fit somewhat poorer for K-Zone then in I or J. Marine interval thickness data of H-Zone is least well fit by trend surfaces (all orders below goodness of fit of 50%), i.e., because surface is more complicated and lacks definitive regional trend described by polynomial surfaces.

Skewness of Residuals (SLIDE ONLY)

At higher orders, the skewness of residuals is appreciably reduced for H, J, I while skewness increases with trend order for the K-Zone (positive skewness is an asymmetrical plot of the frequency of residuals with more positive deviations than negative). In order to optimize the statistical fit would have to minimize this skewness, but we are also interested in preserving the geological significance of the residuals.

4th-order trend surface for each zone was chosen to represent each cycle and were used for comparison. This order provides the best fit at lowest order. Higher orders contributed smaller increments of fit.

K-Zone 4th-order trend surface (SLIDE ONLY)

Line of flexure interpreted at 35 foot (10 m) separating two areas of contrasting rates of thickening. Oolite is developed south of this line. Rate of thickening (north) = 2.4 m/51 km = 0.05 m/km. Rate of thickening on southern shelf = .07 m/km, slightly greater than to north.

K-Zone 4th-order trend surface residual (SLIDE ONLY)

Note the SW positive anomaly associated with adjacent oolite shoals interpreted to surround it. This feature probably accounts for the positive skewness. Note the very thick anomalous strata which are adjacent to the southern flanks of the CKU. Also note that the Rush Rib is the site of very thin marine interval as previously described. Notice also the NW-SE trend in the western mapped area and the NE-SW trend in the southeastern mapped region.

Top J-Base J isopach (5 - 27 meters) (SLIDE ONLY)

J-Zone 4th-order trend surface (SLIDE ONLY)

Broadened region of thinning occurs over northern area compared to the underlying K-Zone which extends significantly west of CKU. More pronounced thinning is noted over the CA than in the K-Zone. More regionally uniform southward thinning is apparent over mapped area in J than in the K-Zone with no notable thinning in SW. 35 to 40 foot contours identify the northern limit of rapid change in thickness. This regionally abrupt change in thickness is comparable in location to that of the K-Zone, but displaced slightly southward. Rate thickening on northern shelf = 2.1 m/50 km = 0.04 m/km. Rate thickening on southern shelf = 8.4 m/50 km = 0.17 m/km, which is greatest rate of regional thickening recorded in the four successive depositional sequences.

A Greater amount of oolite is developed across the southern shelf in the J-Zone than in any of the other cycles studied.

General comments about J-Zone: (1) Depositional grain of the J-Zone is more W-E than K-Zone; 2) dip more perpendicular to shelf margin; 3) SW positive is now an insignificant structure; 4) more extensive higher energy conditions expected across shelf in the northern region during deposition of the J-Zone due to the greater inclination of the shelf. More E-W oriented trends in response to southward flexing of shelf.

Prominent N-S trend in southeast.

*4th-order trend residual of thickness J-Zone marine interval isopach.

Local thicks (oolite) in J offset those in K, compensating and probably filling in bottom relief. This is more evidence that transgression did little major modification to earlier deposits, i.e., must have been fast. Enos and Perkins (1979) describe relict Pleistocene topography which is common along shelf margin of South Florida. There may be an analogous situation here where underlying depositional topography on oolite lobes influenced sedimentation of succeeding deposit. The transgressive deposit of the Holocene sequence is relatively thin and commonly was deposited in a high energy environment.

*Plate 3 (display): Maps of J-Zone

Maximum Gamma radiation in marine shale: Similar locations of minimum GR to K-Zone (<160).

Very low GR levels recorded over Rush Rib, an area also with a thin marine interval. Elevated GR values noted in structural sag between CA and CKU. Variability of GR appears to be more than depth related: perhaps variation in bottom circulation, presence of local depressions on sea floor, and availability of organic matter.

Percent marine interval thickness in J-Zone: position of CKU appears to have restricted thickness of terrigenous clastics due to topographic relief; a separate lobe of terrigenous sedimentation appears to originate from SW.

Porous carbonate in J-Zone: southern shelf in excess of 3 m thick; J-Zone comprises >40% and 50% of entire 4-cyclothem interval in Ford and Clark counties. This thick, extensive deposit of carbonate rock represents a significant accumulation where sedimentation processes were probably important in contributing to southerly progradation of the shoreline.

Figure 59--Index map for logs and mapped area, J-Zone oolite shoals.

Figure 60--Wireline logs 1 and 2 on index map.

Figure 61--Wireline logs 3 and 4 on index map.

Figure 62--Hand contoured J-Zone porous carbonate.

Figure 63--Perspective diagram of thickness of porous carbonate of J-Zone in outlined area.

More northward finger-like projections of porous carbonate similar to K-Zone; Oolite indicated from cutting sample is facies in which porosity is developed.

Much more subtle changes over NW Shelf, CKU-CA

(This set of illustrations are slides only)

*Index study area

*Structure

*Rwa calculation

*Rwa map (>4 X Rw~<50%SW) = .28

>.2 colored on map

*Regressive shale isopach

*min O/W-delimit producing area

*POR-FT only >8%

*Reg. Co_3 isopach (GR)

*Marine interval isopach (Neutron)

*Lithofacies

Points

1. Paleohighs important on northern shelf--sites of grainstone accumulation and/or more intense weathering, and consequent extensive secondary porosity or occlusion of primary porosity.
2. Thin deposits of reworked carbonate grains do not necessarily result in significant thickening of regressive carbonate.
3. But location of paleohigh may be reflected in subtle changes in thickness of marine interval (marine shale + regressive Co_3) - earlier initiation of Co_3 accumulation on paleohighs because of less tubidity than adjacent areas.
4. Need to examine several lines of evidence to establish shelf setting.
5. Diagenesis--another problem because it is complicated by multiple events.

Top to base H-Zone isopach trend surface mapping

H-Zone 4th-order trend surface (SLIDE ONLY)

Youngest cyclothem which is characterized by 1) marked change in the configuration of the shelf; with much less range in thickness up to 12 meters thick versus 15 to 24 m in other cycles; 2) no southward thickening, 3) no significant oolitic facies in south; 4) broad area of thick carbonate rock in west central portion of mapped area (160 km X 80 km in size) with up to 12 m of carbonate. Rate of thickening of upper shelf is 0.36 m/50 km = only 0.007 m/km (very small). Rate of thickening of lower shelf in SW is same as north. General shelf configuration is close to level according to this data. In extreme SE the rate of thickening is 0.06 m/km to south, which is perhaps the only location in the mapped area of the H-Zone that can be considered a shelf flexure.

H-Zone 4th-order trend surface residual (SLIDE ONLY)

Dominate NW-SE trend to residuals is similar to other cycles, but significant thickened carbonate in west-central mapped area which probably contributes to such poor fit of the polynomial trend surface in H-Zone. Thickened complex is micrite-dominated carbonate.

SW positive developed during K-Zone accumulation appears to have been active again and perhaps provided (1) southern barrier to currents and waves generated in the south. The (2) relatively level, protected area to the NE became the site for a very large complex of micrite-dominated carbonate buildups during mid-regression.

The (3) less inclined slope and general stability of shelf (quiescence in tectonic activity?) appears to have produced a low energy shelf setting, at least relative to the earlier cycles. The nearly flat shelf allowed the waves and currents to more easily dissipate with the exception over local paleohighs, in turn providing environments conducive to the accumulation of lime mud. Alternately, perhaps more rapid regression occurred during the H-Zone limiting the time when shoreline could rework sediments on the shelf and deposit significant accumulations of grainstone. The former seems to be best supported here.

(4) Pronounced thinning also is noted along SE margin of CKU extending southward off the mapped area. This appears to reflect progressive southeastward migration of the positive area associated with the CKU through the period of time represented by these four cyclothems. The period of most rapid extension and migration of this positive area began during deposition of I-Zone.

On maximum GR map of marine shale the gamma ray readings are generally lower in the H-Zone than the J and K, particularly over CKU. This suggests that the level of inundation of the sea may have been slightly less limiting the time during which anoxic conditions could be developed. This correlates with an overall thinning of the H-Zone compared to J and K. This thinning may be attributed to somewhat shorter period of inundation of the H-Zone. CA not as positive, i.e., the GR values are not as markedly low as in the J- and K-Zones.

The high GR values in the area of carbonate buildup in the west-central mapped area suggests that the location was a slightly lower shelf setting and site of accumulation of organic matter. Later, during regression, this area became a protected area which led to proliferation of phylloid algae and accumulation for lime mud and eventually the development of carbonate mounds.

Regressive shale is more uniformly distributed across the shelf in the H-Zone as one might anticipate on a flatter shelf. Shale is thinnest: 1) in east central CKU; 2) across the Pratt anticline; 3) in the SE portion of SW positive; 4) where the thick marine interval in Scott County is located.

% contribution of H-Zone to 4 cycle interval: CA interpreted to have not been as positive as supported above: H-Zone occupies >40% of the 4-cycle interval in Graham County, compared to less than 20% contribution to the four-cycle interval along the southern shelf.

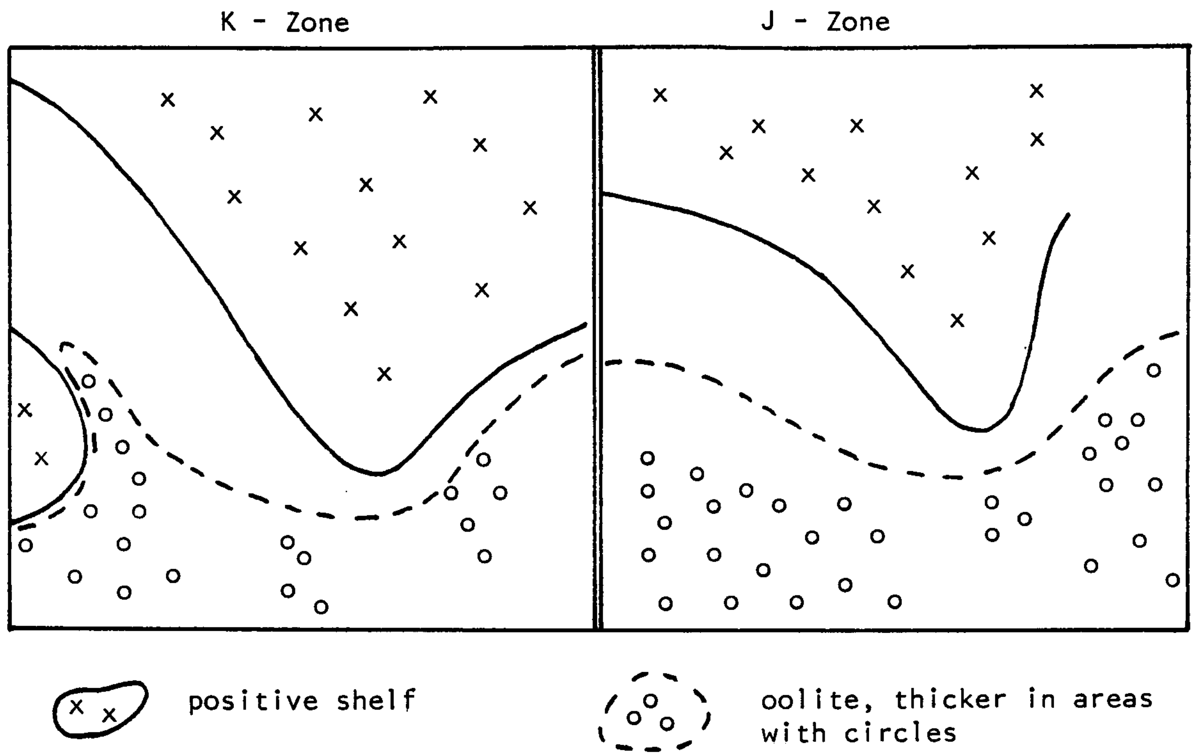
Cores indicate sediments are predominantly open marine in NW in contrast to the J- and K-Zones. Furthermore, there is a greater proportion of the interval comprised of restricted marine deposits in the SE suggesting that this area was most positive (#3 Denker is most restricted).

Differential relief across the shelf changed gradually and produced secondary, albeit important effects on sedimentation patterns. This is not revealed or suggested by studying gross interval isopach of four cyclothems alone.

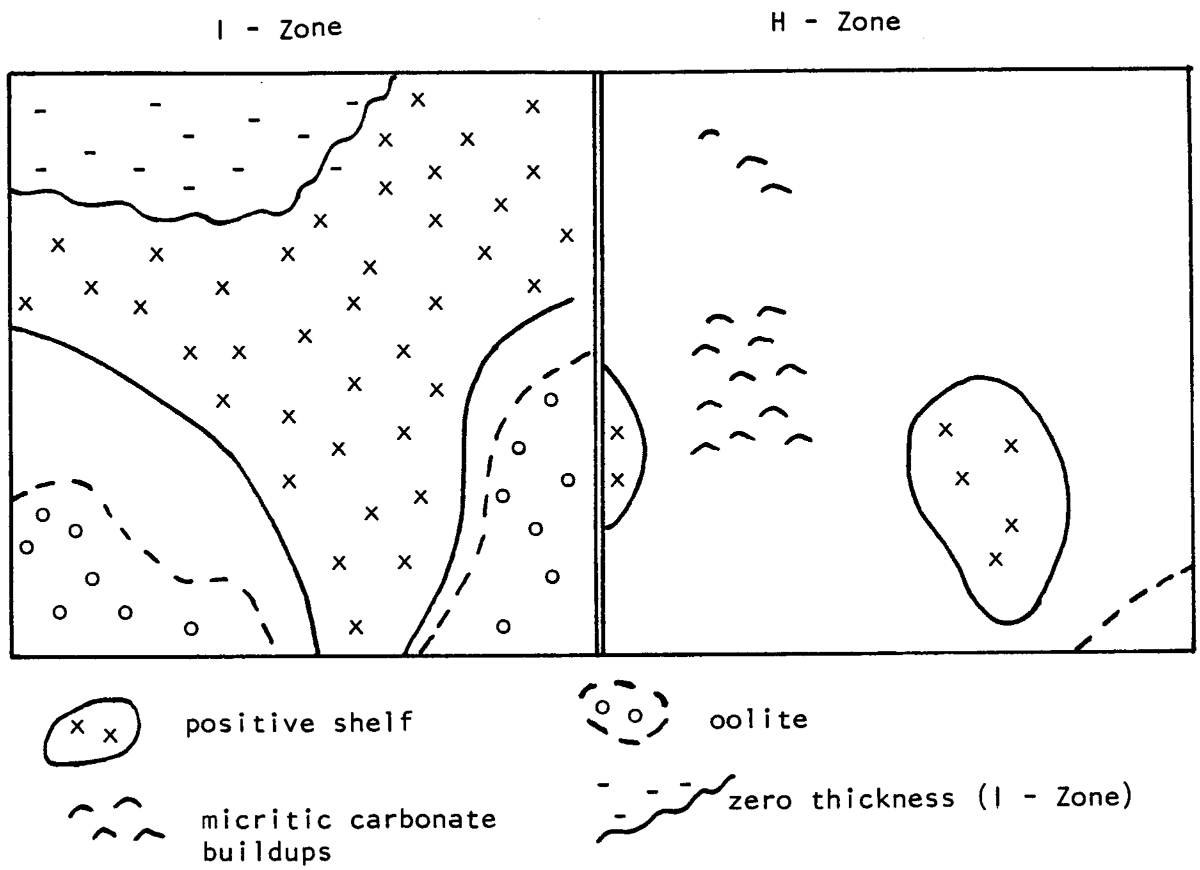
Phylloid algal mounds (slides only)

*Rawlins Co. study area
*Carbonate isopach H-Zone, Rawlins Co., Ks
*Regressive shale isopach H-Zone, Rawlins Co., Ks
*Lithofacies map of regressive carbonate H-Zone
*slab photo of oil-stained algal carbonate

** CONCLUSIONS FROM REGIONAL MAPPING



K-Zone and J-Zone: (1) strike of shelf becomes increasingly more east-west in constrast to pattern established in early Pennsylvanian; (2) extensive black shales and thick sequences of regressive carbonate reflecting major inundation of shelf; (3) pronounced change in regional thickness in central and southern shelf interpreted as a response to greater subsidence near the Anadarko basin (active epeirogenic movement); (4) extensive tracts of oolite on southern shelf and grainstone on northern shelf in response to sloping, energetic shelf (ramp); (5) good petroleum reservoir potential over much of western Kansas in both K- and J-Zones.



I- and H-Zones: (1) broadening of positive area on northern shelf and along CKU; (2) regional thickening to south restricted to extreme southwestern edge of map in I and not present in the H-Zone interpreted as a general quiescence of epeirogenic movement, i.e., reduced subsidence into Anadarko basin; (3) I-Zone experience loss of marine deposits across northwest shelf, no recognized deposits of marine shale, and predominately shallow-water carbonates, together suggesting a lesser inundation of the shelf during the I-Zone; (4) patchy black shale development, thinner regressive shale in the H-Zone suggest intermediate inundation of the shelf during the H-Zone; (5) H-Zone with isolated thickening of micrite-supported carbonate some identified as phylloid algal mounds; (6) predominance of micrite-rich carbonate rock in H-Zone reflects a relatively flat shelf (platform) upon which waves and currents dissipated to produce a dominant, low-energy setting.

Summary--Intercyclical Variation, Causes and Effects

1) Differential structural movement of shelf occurred as it tilted and subsided in conjunction with downwarping of Anadarko basin.
2) Formation of 1st- and 2nd-order structural activity (uplifts and flexure lines) appear to be related to basement heterogeneity and weakness indicated by a) sites of ancestral uplift, b) faulting, c) geophysical anomalies. Isopach mapping important to identify timing with respect to sedimentation and oil migration.
3) Precambrian is segmented into geologic terranes, each with varying physical strength, i.e., rigidity, encouraging propensity to operate independently. Some blocks are strong, unitized and generally positive while others are weak and possibly fractured or faulted.
4) Mechanical integrity, orientation and location, sense and direction of forces define extent of movement of these blocks.
5) Evolution of a single tectonic event causes variation in stress.
6) Oscillation (up and down movement) of shelf-wide structural deformation is not demonstrated, i.e., did not cause the change in sea level needed to produce cyclothems; Shelf was dominated by varying degrees of subsidence during successive cyclothems.
7) Western Kansas and northern shelf of the Anadarko basin during late Pennsylvanian was a southward tilted ramp modified by local, resistant, positive elements. Subtle ridges, domes, and flexures significantly affected sedimentation and diagenesis. Porosity distribution is linked closely with grain-supported rocks which either provide the primary porosity or avenues for fluid migration to create secondary porosity. Late stage dissolution may also be focused along these structures.

GENERAL CONCLUSIONS:

1) Pennsylvanian and Permian sedimentation on North American craton is repetitive, generally an alternation between marine and non-marine conditions in both clastic and carbonate rocks.
2) Sedimentary sequences begin with a thin transgressive facies followed by considerably thicker regressive deposits. The sequences in clastic deltaic succession are commonly obscured by downcutting of the younger deposits into the older extensive areas of deposition with slow subsidence.

3) Maximum transgression is frequently marked by accumulation of thin black shale. Fossils, phosphate, and clay texture suggest that the deposition of the black shale was very slow and water was relatively deep (pelagic) and anoxic (without oxygen). Some deposits of black shale are basin wide and preliminary work has provided correlations into other regions and basins. These black shales owe their color to the abundance of organic matter which is commonly oil-prone. However, the level of thermal maturation of these Upper Pennsylvanian shales is low and appear to be oil or gas generative in southern Kansas and Oklahoma.
4) The later stages of development of these cyclothems are usually characterized by terrestrial, subaerially exposed conditions. If the environment is favorable a thin soil can be formed. These deposits appear to be extensive, yet their recognition is commonly based on identification of subtle features. These surfaces conveniently form sequence boundaries.
5) The characteristics of Pennsylvanian cyclothems strongly suggests that interbasinal processes are active in the formation of these deposits, namely eustatic sea level change.

<u>Holocene Analog to Western Kansas Carbonate Shelf</u>

<u>Ramp model</u>, Arabian Gulf (Wilson and Jordan, 1983)

Arabian Gulf is a shallow inland sea in a low latitude with clear water. The Great Pearl Bank residing on the shallow western side of the Gulf measures 150 X 100 km. The entire Arabia Gulf covers 1000 km X 350 km, a shallow shelf ranging from 20 to 80 deep.

Floor of much of the Gulf was laid bare by Late Pleistocene sea level lowering. Exposure resulted in karst drainage and formation of terraces and cuestas. The slope in the Gulf is 0.5 m/km compared to the estimated 1 m/km paleoslope in Western Kansas. Local highs on the sea floor are sites with shoal-water, bioclastic grainstones, many now in relatively very deep waters during the present period of high sea level stand. Dark argillaceous carbonate mudstones and wackestones are now accumulating below ~50 meters water depth. While in shallow-water, molluscan wackestones and packstones are accumulating.

Average Holocene sediment thickness: only <u>2m</u>, but only relatively short time has passed (~5000 years) since sea level began to rise.

Barrier islands have formed along the Trucial coast, an area along the southwestern portion of the Arabian Gulf where the coast is relatively steep. Here bioclastic carbonate sands are flanked by oolitic sands forming beaches and aeolian dunes, some up to 20 m high. If the slope is great enough, oolites are likely to form along the shoreline. During gradual lowering of sea, then oolites prograde across shelf.

Another possible analog to western Kansas carbonate shelf--Yuccatan shelf (Sellwood, 1979).

Yuccatan shelf located 20-23 degrees N in Gulf of Mexico. It is a peninsula comprised of a low undulating karstic plain without surface drainage. The shelf covers 34,000 km^2 (similar in size to western Kansas), on which a thin veneer of modern sediments have been deposited covering relict Pleistocene deposits. This shelf is 160 to 290 km wide, and is now 82 to 315 m below sea level along its outer reaches.

Pertinent aspects about geologic history of Yuccatan shelf: 1) terraces cut into shelf during Holocene rise in sea level; 2) all of shelf is now open to the influence of the ocean; 3) coastal dune ridges parallel a relict (Pleistocene), submerged wave-dominated shell beach. These ridges, evidence of high energy conditions, formed along an area of increased slope of the shelf. The Wisconsin low stand is marked by a dune ridge at 130 meters. The inner shelf is now covered by mollusc-rich skeletal sand and coquina deposited over submerged carbonate banks and scattered shoal water deposits formed during lower sea level. Prior to inundation widespread Karst was developed on this shelf. Ooid-pellet grainstones were locally generated seaward of the series of conical Karst Rims (paleohighs). The outer shelf now lies below 60 m in water depth, the location of the Pleistocene shoreline. This area is mantled by a thin veneer of relict ooids, peloids, and intraclasts originating from of the Pleistocene unit with little modern sediment contribution. The shelf below 90 m is primarily composed of modern deposits of planktonic forams (pelagic environment in oxygenated water column) overlying portions of the outermost high-energy Pleistocene deposits of the Yuccatan shelf margin.

The Yuccatan shelf is a simple ramp where high-energy conditions typify the present day shoreline as it did in the past during lowered sea level.

The shoreline migrated as sea level varied during the Quaternary. The greatest concentration of oolite deposits on this shelf are concentrated around its outer part where the slope as greatest. This shelf setting appears to be similar to that of the Missourian in the Hugoton embayment.

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Figure 8. Generalized paleogeographic map of the western Midcontinent during the Missourian illustrating major depositional facies and provenance areas for the siliciclastic sediments (from Rascoe and Adler, 1983). Contours shown represent thickness of Missourian strata in feet. Dominant terrigenous clastic source is the uplifted Ouachitas mountains (OM) in southeastern Oklahoma and Arkansas. Amarillo-Wichita-Arbuckle uplifts (A-W-A), Ancestral Rocky mountains (AR), and Cimmaron arch (CIA) provided coarse-grained terrigenous debris only locally. The only seaway permitting easy access of open marine waters onto the craton during the Late Pennsylvanian was the approximately 100-mile-(160 km) wide pass between the Amarillo-Wichita-Arbuckle uplifts and the Ancestral Rocky mountains (Rascoe and Adler, 1983; Heckel, 1977). Carbonate bank along southeastern Anadarko basin margin is Belle City Limestone.

Figure 9. Southwest to northeast stratigraphic cross section A-A' of a portion of the Kansas City Group including the H, I, J, and K-Zones. Section extends 260 miles (410 km) northeastward from the southern part of the study area across the northern end of the Central Kansas uplift into the Salina basin. Logs used include gamma ray (GR), neutron (N), and Laterolog (LL). Scales for these logs are provided. Datum is the base of the J-Zone. Bases of H- and K-Zones are ruled in on each log but are not connected. A structural cross section of the same wells is included as an inset on this illustration. Measured depth from the ground surface to the top of the displayed log sections range from 4200 feet on the southwest to 3200 feet on the northeast. Top and bottom of zones are identified. Index to wells included on cross section:

Well	Well Name	Location
1	Thunderbird #1 Maxwell	NWSW 32-23-29W
2	Goff #1 Chennel	SWSW 21-21-28W
3	Kern-Landis #1 Ward	SWNE 4-19-26W
4	Hawley Tr. #2 Brungardt	SWNE 13-15-25W
5	Slawson #1-A Weedin Tr.	SWNW 1-14-22W
6	Conoco #9 Morel	NENENE 15- 9-21W
7	Imperial #1 Lesage	SESENE 18- 7-20W
8	Nat. Assoc. Pet. #1-A Lafferty	NWSWSE 19- 4-19W
9	Dreiling et al. #1 Conway	NESWSE 3- 3-13W

Figure 10 and 11. (Figure 10) Index map for section A-A', B-B', and C-C' and structural cross section of C-C'. (Figure 11) West-southwest to east-northeast stratigraphic cross section C-C' across the extreme southwestern portion of the study area intersecting with and including well #4 in section B-B'. Western portion of section begins on the southwest positive area, probably an extension of the Cimmaron arch in southeastern Colorado. Measured depth to the top of displayed log sections range from 3860 feet on the west to 3830 feet on east. Bases of H- and K-Zones are ruled on logs. The index of wells included in this cross section are:

Section #	Well Name	Location
1	TXO #1 Bierig	NWSESW 34-30-42w
2	Pan American #1 Dewell	SWNE 19-30-39w
3	La Cima Corp. #1 Jones	NWNE 21-29-34w
4	Ashland #5 Ray	NWSE 21-29-34w
5	Jones and Pellow #1 Wedel	NWNWNW 15-29-31w
6	Pan American #1 Gamble	SWSE 22-29-28w
7	Kewannee #1 Burnett	SWSESW 22-28-25w
8	Five Nations #1 Copeland	NWNWNW 25-28-23w
9	Rains and Williamson #1 Sloan	SESE 27-28-20w
10	Glen Rupe #1 Titus	SWSW 4-26-19w
11	Knight #3 Ewing	NWSENE 4-23-17w

Figure 12. West to east stratigraphic cross section B-B' constructed as Figures 6 and 8 extending across the southern portion of the area of study including the southern end of the Central Kansas uplift. Bases of H- and K-Zones are ruled on logs. Measured depth to the top of displayed log-sections range from 4350 feet on the west to 2830 feet on the east. Index to wells included in the cross section shown in figure 2.5:

Well	Well Name	Location
1	Deep Rock #1 Schartz	NWNE 33-24-28w
2	Dunne and Gardner #1 Benish	W/2NWNE 9-24-24w
3	Markley #1 Brake	NWNE 6-24-20w
4	Knight #3 Ewing	NWSENE 4-23-17w
5	Sunray #1 Keenan	SESWNE 2-22-14w
6	Pan American #A-5 Teichman	NENWSE 10-22-12W
7	Veeder #4 Diets	SESESE 6-21-11W
8	Tomlinson #7 Bressler	SWNWNE 14-20-10w
9	Conoco #A-7 Warner	NWSWNW 36-18- 8W
10	Conoco #5 Carlson	SWNWNE 36-19- 6w
11	NCRA #1 LPG	NENWSE 29-19- 4w

Figure 13. Example of output for database.

Figure 14. Shaded isopach map of the study area of the interval from the base of the K-Zone to the base of the Pennsylvanian. Lower surface is a major unconformity. Interval includes Morrowian, Atokan, Desmoinesian, and lower Missourian. Variable shading donotes intervals of 100 feet (30 m) with darker areas representing thicker strata. Heavy black line surrounds the location of the truncated margin of the Mississippian strata on the Central Kansas uplift (CKU) and Cambridge arch (CA). Hachured, segmented lines are

Precambrian basement faults (from Cole (1976). Downthrown side of fault is hachured. Light dashed rectangles outline counties in western Kansas. Northern border is the the Kansas-Nebraska border. This structural information will be used for reference on most of the succeeding maps.

Figure 15. Shaded isopach map of the interval from the top of the H-Zone to the base of the K-Zone. Intervals are shaded in increments of 10 feet (3 m). Labeled contours represent 20 feet (6 m) intervals. Black areas along the southern margins of the study area exceed 180 feet (55 m) in thickness. County boundaries are lighter dashed lines. Noticeable thinning occurs over the crest of the CKU and CA. Minor thinning is noted over the southwest positive area.

Figure 16. Shaded isopach map of the interval from the top of the Stone Corral Formation (Leonardian, Lower Permian) to the top of the H-Zone. Intervals are shaded increments of 200 feet (60 m) and labeled contours are at 400-foot intervals (122 m). Outlines of the counties and the CKU and CA are shown.

Figure 17 and 18 (a and b). Contour map of configuration of the Precambrian surface for western Kansas from Cole (1976): (a) western study area and (b) southern study area. Countour interval is 50 feet (15m). Dots represent both estimated depths to Precambrian and actual penetrations. Southern border of study area indicated by heavy line.

Figure 19. Structural contour map of the top of the K-Zone regressive (upper) carbonate. Sea level reference datum is used. Contour interval is 50 feet (15 m). Heavy dashed lines are structural lineaments identified by visual interpretation of the contours. Black areas are selected large L-KC oil fields lying off of the CKU and along prominent positive structural features. They are identified as follows: C - Cahoj, J - Jennings, PP - Pleasant Prairie, E - Eubanks, VI - Victory, VO - Voshell, and B - Burrton. Counties are indicated with dashed lines and names are abbreviated. Townships are shown using light solid lines that are labeled along the perimeters of the mapped area.

Figure 20. Oil fields of western Kansas (see index map inset). Fields that are identified here as solid black areas produce oil from the Lansing and Kansas City groups. The heavy solid lines identify the area of study. Much of the production is from the northwest-trending CKU and more subtle subparallel trends in western Kansas. Northeasterly-trending narrow anticlines are sites of additional oil production from the Lansing and Kansas City groups in the southeastern area of the southern Salina and Sedgwick basins.

Figure 21. Contour map of the third-order trend surface residual of top K-Zone. Contour interval is 50 feet (15 m). County lines are dashed and the outline of the CKU and CA is noted by the heaviest black line. The faults that offset the Precambrian basement are noted by the hachured dashed lines.

Figure 22. Goodness of fit in percent versus trend order for top K-Zone.

Figure 23. Precambrian geology and geophysical trends in the northern Midcontinent (after Dutch, 1983). Map of simplified basement terrane and linear gravity and magnetic trends, paralleling elements of the Precambrian terrane. Prominent northeast trend of the 1.1-billion-year-old Midcontinent rift system CNARS or Central North American Rift System cuts the older accretionary terrane which is dominated by a northwesterly trend over the southern mapped area including Kansas. CKU parallels the northwesterly trends and the Nemaha uplift the northeasterly trends.

Figure 24. Filtered map of the total magnetic field intensity of Yarger (1983) depicting the second vertical derivative of the magnetic field. Dark shaded lineaments and patterns illustrate where the gradient in the magnetic field is greatest. The map identifies probable steep contacts between rocks of contrasting magnetization in the shallow basement such as might be produced by faulting or intrusion of mafic igneous rocks (Yarger, 1983). Filtering enhances the short, subparallel, northeasterly-trending magnetic pattern of the CNARS. Line segments likely represent graben and horst system intruded by gabbros. The area of attenuated magnetic signature outlined on this map denotes thick clastic sedimentary strata of the Precambrian Rice Formation, sedimentary rock which filled the rift feature.

Figure 25. Filtered aeromagnetic map of western Kansas (modified from Yarger, 1983). Map is a pole correction of the total magnetic field. The distortion caused by the earth's inclined magnetic field is calculated and subtracted from the original map of the total magnetic field intensity. Yarger concluded that the low-frequency, generally northwesterly trending elements shown here probably represent deep-seated structure of the Precambrian. Yarger identified a prominent boundary between the two terranes of contrasting age shown on this map by the heavy line crossing the mapped area. CKU and CA with the basement faults are also shown on the map.

Figure 26. Precambrian terranes in Kansas and immediate adjacent areas (after Yarger, 1983, modified from Bickford et al, 1981).

Figure 27. Structural contour map of the top of the Swope Limestone (K-Zone) in the vicinity of Collier Flats field in Comanche County, Kansas. All but two holes penetrate the Swope. Contour interval is 25 feet. Oil wells concentrated along crest of a southerly plunging anticline. The structurally higher, northern edge of the Collier Flats field is the site of dry holes (Watney and Paul, 1983).

Figure 28. Isopotential map of Swope Limestone reservoir in Collier Flats field. Illustration accompanies Figure 20 (Watney and Paul, 1983).

Figure 29. Basic Kansas cyclothem characterizing with minor modification all major and many intermediate marine cycles of deposition across northern Midcontinent Shelf and representing one sufficiently slow and extensive inundation and withdrawal of the sea to produce both transgressive and regressive limestones and intervening black, phosphatic shale facies across most of shelf. Phases of deposition reflect ranges of sea-level stand. Conodont information derived from Heckel and Baesemann (1975) and Swade (1985) supplemented by thesis and other unpublished data. Modified from Heckel (1984b).

Figure 30. Sea-level curve for part of Middle-Upper Pennsylvanian sequence along Midcontinent outcrop belt and near-subsurface, based on shoreline positions estimated from (1) farthest basinward extent of exposure surfaces (///) and fluvial-deltaic complexes (...) for low stand, and (2) farthest shelfward extent of marine horizons for more minor cycles, and deepest-water facies preserved at northern erosional outcrop limit for more major cycles, to estimate high stand. Names of marine cycles are on left side of curve. Size of letters reflects classification of cycles as major, intermediate, or minor. Minor cycles detected in regressive phase of Dennis cycle at Stops 5A & 7 are not shown. Heckel, 1985.

Figure 31. Paleogeographic map showing probable facies relations of Upper Pennsylvanian Midcontinent sea during deposition of marine (lower) shale along Midcontinent outcrop at phase of maximum transgression (from Heckel, 1980). Hachured lines show approximate location of outcrop (solid) and subcrop (broken) limits of Upper Pennsylvanian strata. Short dashes show facies boundaries and north limit of Anadarko basin. Long dashes show extent of sea. Lithologic symbols are standard, with some explaination or emphasis added. Key for abbreviations of U.S. cities for location are as follows: CA - Casper, Wyoming; FW - Fort Worth, Texas; T - Tulsa, Oklahoma; KC - Kansas City, Missouri; D - Des Moines, Iowa; C - Chicago, Illinois; L - Louisville, Kentucky.

Figure 32. Pattern of atmospheric circulation and upwelling for Westphalian (Late Carboniferous) (from Parrish, 1982). At the center of this hemispheric map is the Appalachian mountains in the eastern U.S. Base maps from Scotese et al. (1979). The upper map illustrates the locations of high and low atmospheric pressures and associated circulation pattern of surface winds during the northern winter. The lower map is the same area for the northern summer. Fine double diagonal-crossed (darkest) pattern are areas of potential upwelling. Areas with the fine dotted pattern are prominent positive areas.

Figure 33. Gamma ray-neutron wireline log display and interpretive lithologies of Veail #1 Peterson well from northern portion of the study area. Scale of gamma-ray curve is API units. Neutron curve is scaled in counts per second (cps). Four cyclothems are identified as the H-, I-, J-, and K-Zones. The top of each interval is the regressive (upper) shale and the base of the cyclothem is the transgressive unit (lower carbonate). Note that both the transgressive unit and the marine (lower) shale are not distinctive units in the log in the I-Zone. The marine portion of the cyclothem, the focus of the isopach mapping described later, includes all divisions of the cyclothem except the regressive (upper) shale.

Figure 34. Dark mudstone and wackestone in lower portion of upper carbonate facies on the southern shelf. Photomicrographs in plane-polarized light.

A. KRM #2-X Lemon, 4779 feet, lower portion of K-Zone upper carbonate. Bar scale equals 0.5 mm. Photomicrograph of very silty, argillaceous bivalve wackestone containing abundant opaque pyrite as finely disseminated crystals and replacement of bivalve shells. Bivalves are concentrated as intermittent layers of broken shells. Stringers of amber-red semiopaque organic matter (?) (a) are common. Crinoids, brachiopods, and bryozoan and rythmic dark gray shale layers are scattered throughout the interval from which thin section was taken.

B. Texaco #4 Litsey, 3762.3 feet, lower portion of upper carbonate of K-Zone. Bar scale equals 0.5 mm. Photomicrograph of dark gray shale laminae in gray lime mudstone interval. Scattered silt-sized quartz grains. Scattered red flecks and stringers, perhaps of organic matter, are oriented parallel to bedding. Thin section is from immediately below 0.5-feet thick, dark-gray to black mudstone containing rare crinoids and tubular foraminifera.

C. Texaco #4 Litsey, 3762.3 feet. Bar scale equals 1 mm. Two very shaley wackestone seams expanding laterally (to the right) into more carbonate-rich intervals with wispy shale laminations. See D below.

D. Texaco #4 Litsey, 3762.3 feet. Bar scale equals 0.5 mm. Top half of the photograph is comprised of carbonate matrix with abundant discontinuous wisps of shale. The irregularity of the shale and the etched bioclasts within these intervals suggest that some or all of these wisps of shale represent insoluble residue remaining after dissolution of the carbonate matrix (incipient stylolites).

E. Texaco #4 Litsey, 3762.3 feet. Bar scale equals 0.5 mm. Echinoid fragment in shaley carbonate matrix. Fritted edges of echinoid fragment attributed to dissolution.

Figure 35. High-energy grainstone facies in the upper portion of upper carbonate.

A. Clinton #2-D Stegman, 3393 feet, top of the I-Zone upper carbonate. Photomicrograph in plane-polarized light, 1 mm scale. Heavily micritized bioclastic grainstone contains rounded fragments of foraminifera, crinoids, and molluscs. Some grains are rimmed with fine, blocky, pachous calcite spar (a). Some pores lack cement (bright intergranular areas). Coarser late-stage, Fe-calcite spar occupies some of the intergranular pore space. Syntaxial, coarse calcite spar forms overgrowths on echinoderms only visible within field of view (b). Much of the pore space is occupied by dark residual oil (c). This grainstone is typical of that on the northern shelf-lightly coated grains and heavily micritized, commonly these grainstones are also overcompacted. Other examples are shown in Watney (1980).

B. Cities Service #E-2 Thompson, 4554 feet, upper portion of upper carbonate of K-Zone. Slab photograph, bar scale in centimeters. This oolitic grainstone contains abundant oomolds (0.05 mm diam.), and dark oil stain is visible in some pores.

Figure 36. High-energy grainstone facies in the upper regressive carbonate.

A. Cities #E-2 Thompson, 4552.5 feet, slab photograph of upper portion of upper carbonate of K-Zone (Bar scale in centimeters). Oolitic grainstone alternates with intervals of abundant bioclastic grainstone consisting of primarily fragments of crinoids and bivalves. Most bioclasts have superficial oolitic coating. Molds of both ooids and bivalves are present. Scattered coarse dolomite fills some of the voids. Dogtooth calcite spar lines most pore space.

B. Cities Service #E-2 Thompson, 4554 feet, photomicrograph of top portion of the upper carbonate, K-Zone. Plane-polarized; bar scale is 1 mm. Neomorphosed and oomoldic grainstone contains well-preserved brachiopod fragment (a) and dissolved or recrystallized mollusc fragments recognizable only by outline (b). Intergranular porosity is common with some solution enhanced and rimmed by irregular, fine, blocky calicte spar. Concentric laminations in cortex of some ooids are still discernable as faint lines in fine calcite mozaic (c). Blue plastic impregnation of sample before thin sectioning did not contact these pores, suggesting that these do not represent effective porosity.

Figure 37. Restricted marine, shallow-water, facies faunal diversity. Slab photographs of cores; bar scale in centimeters.

A. Cities Service #F-5 Reese, 3455 to 3458 feet, slab photograph of the uppermost portion of the upper carbonate of the I-Zone. Top most portion of core is upper left and bottom is on lower right. Upper sample is mixed-clast carbonate conglomerate (a) with millimeter- to centimeter-sized particles of rounded, pitted carbonate pebbles and grains comprised of composite-pellet grainstone and unfossiliferous lime mudstone. Some grains have thin darkened rims. Matrix is vivid green shale. Underlying pieces are an in situ breccia (b) of solution pitted, fitted clasts of lime mudstone with some darkened rim of brown microcrystalline calcite. Only fossils noted are scattered small bivalves at 3457 to 3457.5 feet. Vertical and horizontal fractures and solution channels (centimeter in diameter) cut the rock. Channels are filled with clasts of rock that border the void, green shale, and coarse clear calcite spar.

B. Cities Service #506W Dorr, 3347.8 feet, slab photograph of upper portion of upper carbonate of J-Zone. Upper 10 feet of this carbonate rock (3343 to 3353 feet) are unusually sparsely fossiliferous. Interval down to 3348 feet is dominated by pellet mudstone with rare gastropods. Slab is from bottom of dense brown lime mudstone cut by solution channels (a) that are filled by green shale or coarse clear calcite spar. Dark-gray intraclasts of mudstone in lighter mudstone (b) matrix forms lower half of slab.

C. Cities Service #506W Dorr, 3300.5 feet, slab photograph of uppermost portion of upper carbonate of H-Zone. Thin, uniformly laminated, tan to brown lime mudstone. Layers are disrupted by vertical, centimeter-sized cylinder (a) of mixed, more homogenous lime mudstone bounded by unturned edges of laminated mudstone. Laminations suggest algal stromatolite and cylinder resembles a fluid escape structure. Overlying laminations in adjacent slab are continuous over disrupted structure.

Figure 38. Carbonate cements. Photomicrographs in plane-polarized light.

A. Clinton #2-D Stegman, 3393 feet, near top of upper carbonate of I-Zone. Bar scale equals 0.5 mm. Porous oil-stained grainstone contains with good inter-particle porosity with fine, blocky, irregularly distributed fringing cement followed by much coarser Fe-calcite spar shown here with euhedral crystal termination (bottom center). Black areas are oil in interstitial porosity.

B. Tideway #1 Beauchamp, 3933.7 feet, immediately below top surface of upper carbonate of the H-Zone (subaerial crust). Bar scale is 0.5 mm. Photo taken with cross-polarized light. Fibrous calcite cement forms a pendant beneath a crinoid fragment separated from crinoid by a thin micrite rim. Note that crinoid is at extinction and cement is not providing evidence that these are not in optical continuity. The edges of this pendant have been etched and coated with dark brown microcrystalline calcite cement (opaque rind) very similar to that in the overlying caliche subaerial crust. Pendant cement is perhaps a vadose cement developed during initial exposure of sediment in marine or freshwater conditions. During continued exposure partial solution of the existing carbonate sediment and cement occurred followed by precipitation of the micritic cement.

C. Tideway #1 Beauchamp, 3933.7 feet. Bar scale equals 1 mm. Oolitic grainstone lies immediately beneath subaerial crust. Photo shows pendants of faintly, irregularly laminated to dense, micritic calcite cement (a) beneath several coarse calcite spar-filled oolites and bioclasts. Note fibrous pendant calcite (b) cement beneath an optically extinct bioclast (crinoid?).

D. Conoco #9 Morel, 3612.5 feet, immediately below nodular caliche of upper carbonate of K-Zone. Bar scale is 1 mm. Photomicrograph illustrates dissolution of grains and micritic matrix preceded first cement forming large secondary pores. Clast-like nodular areas now consist of micritized recrystallized bioclasts (a) and clotted slightly silty micrite (b). Cementation consists of very thin light gray microcrystalline dolomite cement (d) irregularly distributed around particles. Dark, dense micrite rims (endolithic algal borings) partially surround some carbonate clasts (c). This is followed by a layer of isopachous drusy cement (e) which is followed by void-filling coarse crystalline Fe-calcite (f). Large pores now filled by calcite spar highlighted by dark microcrystalline cement resemble reticulate channels even in thin section. They do not resemble a typical intergranular pore system but rather solution enhanced pores associated with dissolution of grain and matrix. The development of the porosity and the later precipitation of the finely crystalline (dense, micritic) cement are concluded to be associated with the development of the overlying subaerial crust.

Figure 39. Other examples of carbonate diagenesis.

A. and B. Conoco #9 Morel, 3604 feet. Slab photograph (bar scale is in centimeters) of base of packstone in middle portion of upper carbonate, J-Zone. Three sets of vertical, open fractures cut the core approximately 2 centimeters apart including left side of core in A. A side view of core looking at surface of fracture is shown in B. Coarse crystalline calcite with corroded, Fe-oxide stained surfaces lines the fracture. Note curved and discontinous nature of fractures suggesting some minor-compressional deformation of the fractures after formation. Overlying I-Zone is similarly fractured.

Figure 40. Evidence of subaerial exposure in regressive shale.

A. Cities Service #A-1 Knudson, 4276 feet, slab photograph (bar scale in centimeters) of lower portion of very silty green to gray, mottled yellow upper shale of K-Zone. Abundant longitudinal and transverse cuts of pedotubules (a) some surrounded by a thin halo of brown microcrystalline calcite cement (b). Lighter areas are concentrations of microcrystalline calcite interpreted as caliche nodules.

B. Gore #5 Findley, 3742.5 feet, photomicrograph (plane-polarized, bar scale 1 mm) from upper shale of K-Zone. Irregular lighter-shaded fissures (a) filled with mixture of microdolospar and argillaceous dolomicritic quartz siltstone. Larger sparry cement is dolospar. Fissures surround denser cemented matrix (b) resembling circumgranular cracks. Sample is interpreted to display incipient calichification with intermittent desiccation.

Figure 41. Gamma radiation (GR) plotted versus neutron porosity (ØN) for the Gulf #1 Hughes well located in SWSW Section 22-9s-29w found in the north-central portion of the study area. Points are plotted on one-foot increment. Points are identified by lithofacies in the legend. Vertical profiles of the GR and ØN signatures are shown on the upper portion of the illustration. Normalized GR for the one-foot samples from the K-Zone are plotted in the upper left.

Figure 42. Gamma radiation (GR) in API units plotted versus neutron porosity (ØN) in percent for the Texas Oil and Gas (TXO) #1 Bierig well located in W/2 E/2 SW Section 34-30s-42w in the extreme southwestern portion of the area of study. Points represent readings at one-foot increments over the K-Zone. The points are identified by lithofacies based on sample cuttings and corelation of the well to cored wells with known lithofacies. Mudstone-wackestone is in the mid and lower regressive carbonate interval. Note the presence of only a relatively thin interval of low GR and clustered

pattern of these points. Distinction between the marine shale and regressive shale on this plot is not possible. Both have intermediate GR and ØN. Vertical distribution of GR-ØN is shown on right side of illustration with vertical scale in feet. A small plot in the upper left illustrates the frequency of GR values sampled on a per foot basis is expressed as normalized percent for the K-Zone. GR values are bimodal with a small peak for the limited clean carbonate and a broader more prominent peak for the shaley lithofacies.

Figure 43. Gamma radiation (GR) in API units plotted versus neutron porosity (ØN) in percent for the Amoco #A-2 Lee well located in SWNW Section 4-26s-36w in the southwestern portion of the area of study. Points represent readings at one-foot increments over the K-Zone. The points are identified by lithofacies based on sample cuttings and nearby core:log combinations. Mudstone-wackestone is in the mid and lower regressive carbonate interval. Note the very low GR and relatively high ØN values for the oolitic facies. Vertical distribution of GR-ØN is shown on top of illustration with vertical scale in feet. Frequency of GR values sampled on a per foot basis is expressed as normalized percent for the K-Zone is shown as a small plot in the upper portion as well. GR values are predominately low values indicative of clean carbonate rock which comprise much of the cyclothem at this position on the shelf.

Figure 44. Thickness of the marine interval of the K-Zone in the study area of western Kansas including the top of the regressive carbonate to the base of the cycle. Interval of shading is 5-feet (1.5 m) while the contour lines highlight only the 20-foot (6.1 m) intervals. Black areas represent thicknesses in excess of 65 feet (20 m). Selective counties are labeled for reference in text. Subcrop of the Mississippian strata surrounding the CKU and CA is indicated here by a heavy line. Major faults that offset the Precambrian basement are illustrated with heavy dashed hatured lines. Curved line segments identify trends in thickened marine interval described in the text. Counties are abbreviated as follows: WA - Wallace, WH - Wichita, ST - Stanton, SC - Scott, HS - Haskell, FI - Finney, HG - Hodgeman, EL - Ellis, ED - Edwards, KW - Kiowa, RC - Rice, and RN - Reno.

Figure 45. Thickness of porous carbonate rock in the K-Zone regressive carbonate. Shaded interval is 4 feet (1.2 m) which is equal to the contour interval. The black area represents thickness in excess of 24 feet (8 m). Wallace (WA) and Kiowa (KW) counties are identified.

Figure 46. Marine interval percentage of the K-Zone. Low values indicate a greater fraction of regressive shale. Contour interval is 10 percent. Russell (RS), Barton (BT), and Rush (RH) counties are identified.

Figure 47. Maximum gamma radiation recorded by the wireline logs in the marine shale of the K-Zone. Contour interval is 80 API units. Greeley (GL), Hamilton (HA), and Stanton (ST) counties are identified.

Figure 48. Percentage thickness of the K-Zone in the entire four-zone interval, H to K. Shaded interval is 5 percent while the contour interval is 10 percent. Small arrows in the southwestern mapped area indicate the location of relatively thin K-Zone, while the bold arrows in the south highlight the regions of relatively thick K-Zone. Wallace (WA), Wichita (WH), Stanton (ST), Kiowa (KW), Reno (RN), and Rice (RC) counties are identified.

Figure 49. Index map locating core-log examples illustrated in Figures 30, 31, 32, 33, and 34.

Figure 50 a and b. Combined wireline logs and core descriptions of the K-Zone for five wells in the study area. Gamma ray (GR), porosity (O) from sonic, neutron, and density ( ) logs are shown. Sonic and density porosity is determined for a limestone matrix. "X" in graphic core column represents no core. The despositional environment for specific intervals of core are indicated in the right-most block. The vertical line segments lie beneath one- and two-letter codes defined as follows: NM - nonmarine; VR - very restricted (unfossiliferous to low diversity fauna); R - restricted; SR - slightly restricted (mixed fossil assemblage, but not all normal fauna present or abundant; O - open marine; SM - stagnant, anoxic marine (black marine shale). Certain features about the rock are mentioned in the right margin including: fen. lam. - fenestral laminated mudstone. Results of drill stem (DST) or production tests are written below the core description including Pf - perforated; F - flowed; R - recovered; FP - flowing pressure; O - oil; GCM - gas cut mud. Depths are in feet below the surface. Productive zones are abbreviated in the title: ABC - Arbuckle; KC - Kansas City; MISS - Mississippian; SP - Simpson; MARM - Marmaton; CHER - Cherokee; MOR - Morrow. In well (C), #E-2 Thompson, the oolite contains an upper portion that is more porous than the bottom. The information at the bottom of that illustration indicates that water saturation (SW) in this oolite is 28 % and 37 % for the upper and lower intervals using the resisitivity logs and the Archie equation with water resistivity (R_w) of 0.05 ohm-m and a cementation exponent (m) of 2. The interval in fact was capable of producing hydrocarbon at the time the interval was logged.

Figure 51. Core description of Clinton 2-D Stegman located in the senwne Sec. 11, T16S, R17W, Rush County. Depths along left margin in feet, graphic column with symbols described in Fig. 35 and facies and diagentic overprinting symbols also in Fig. 35. Cores described using Dunhams's (1962) classification of carbonates (from Watney, 1985b).

Figure 52. Core description of Texaco 4 Litsey located in nenenw Sec. 25, T31S, R6W, Harper County, Kansas (from Watney, 1985b).

Figure 53. Core description of KRM Corp. 6 Lemon located in sese Sec. 14, T34S, R20W, Comanche County (from Watney, 1985b).

Figure 54. (A) Legends of codes and descriptions of depositional facies and diagenesis for Figs. 51, 52, and 53. (B) Additional legends providing symbols for particles, fossils, and lithologies used in graphic columns of these figures.

Figure 55. Hand-contoured map of the thickness of porous carbonate rock of the K-Zone in the study area of western Kansas. Compare with the computer-generated version in Figure 25. This map more clearly shows the elongate lobes formed by the porous carbonate rock. In particular the thick (greater than 5 feet) occurrences are interpreted from available cores, selected cutting, and log signature to represent oolitic grainstone.

Figure 56. Diagrammatic north to south lithofacies cross section of the K-Zone cyclothem in the study area in western Kansas. Thin transgressive (trans) portion of the cyclothem below the marine shale covers the entire area. Dark grey to black marine shale extensively developed over the southern shelf grades into thicker non-black shale in the north. Local thinning and pinchout of marine shale over the CKU is not illustrated. This shale thickens at the expense of the lower regressive carbonate in the extreme northern area of investigation (southern Nebraska and northern-most Kansas). Dark, silty lowermost regressive carbonate on southern shelf with medium-level gamma radiation is inferred to be restricted to lows although it was not mapped separately. Uppermost regressive carbonate is exposed across the entire shelf, while the northernmost portion is noticeably eroded as indicated by the local channeling. Regressive shale prograded unto the carbonate-dominated shelf from a source to the north after the shelf was subaerially exposed.

Figure 57. North-south chronostratigraphic cross section across the study area in western Kansas. Horizontal axis is distance, approximately 200 miles (124 km). Vertical axis is time which is estimated to be approximately 400,000 years for top to bottom of the cycle. Central portion of cross section illustrates the effects on sedimentation over a positive area on the shelf.

Figure 58. Chronostratigraphic section of depositional event bounded by hiatal surfaces. Basinward is to left (modified from Fraiser, 1974).

Figure 59. Index map for examples of wireline logs from wells that contain oolitic grainstone facies in the J-Zone in Figures 60 and 61. Wells are located on this map by index numbers and named on the wireline log themselves. Outlined region on this map identifies an area of detailed mapping of the thickness of porous regressive carbonate of the J-Zone shown in Figure 62.

Figure 60 and 61. Series of four wireline logs illustrating the varied log signatures for J-Zone with and without prominent oolitic grainstone facies. Solid dots at center of log denote position of marine shales. Wells #1 and #2 have a very well developed section of porous oolitic grainstone, from 4037 to 4085 feet in well #1 and 4405 to 4464 feet in well #2. Notice low GR and exceptionally high porosity.

Figure 62. Hand-contoured version of thickness of porous regressive carbonate for the J-Zone indexed in Figure 47. Contours are in feet. Heavy, dashed, northwest trending line denotes general location of zone of flexure which is the northern border of regional southern thickening of this interval (see Plate 3). Abbreviation are as follows: GO - Gove County; TR - Trego County; LE - Lane County.

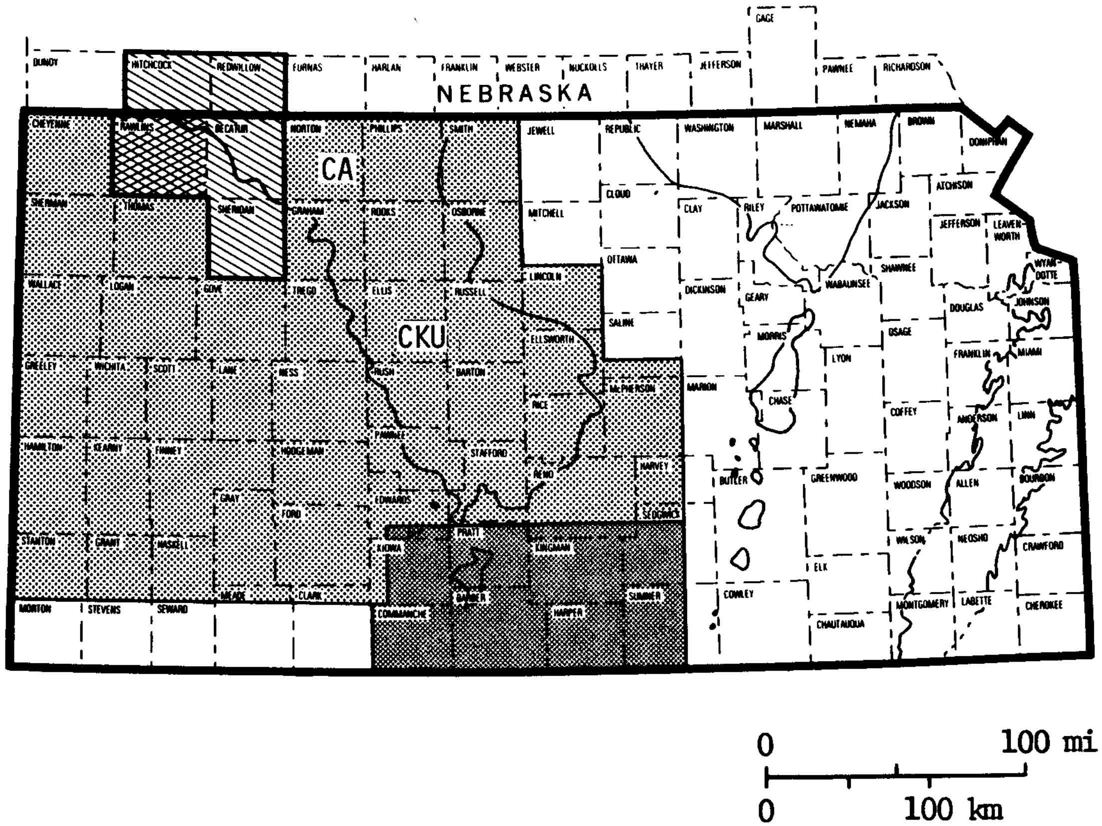
Figure 63. Perspective diagram of thickness of porous carbonate for J-Zone in mapped area defined in Figure 59.

Figure 64. Unusually thick transgressive carbonate, E-Zone, containing phylloid algae. (See Ebanks and Watney, 1985, for more details.)

Figure 65. Thickness of transgressive E-Zone carbonate in Rawlins County, northwestern Kansas (Watney, 1980).

Figure 66. West to east stratigraphic cross section of the J-Zone (E-Zone in Nebraska), Hitchcock County, Nebraska (modified from DuBois, 1979 as found in DuBois, 1985).

Figure 67. Complex statigraphic section of the J-Zone in the Meeker Canal field in Hitchcock County, Nebraska (DuBois, 1979).



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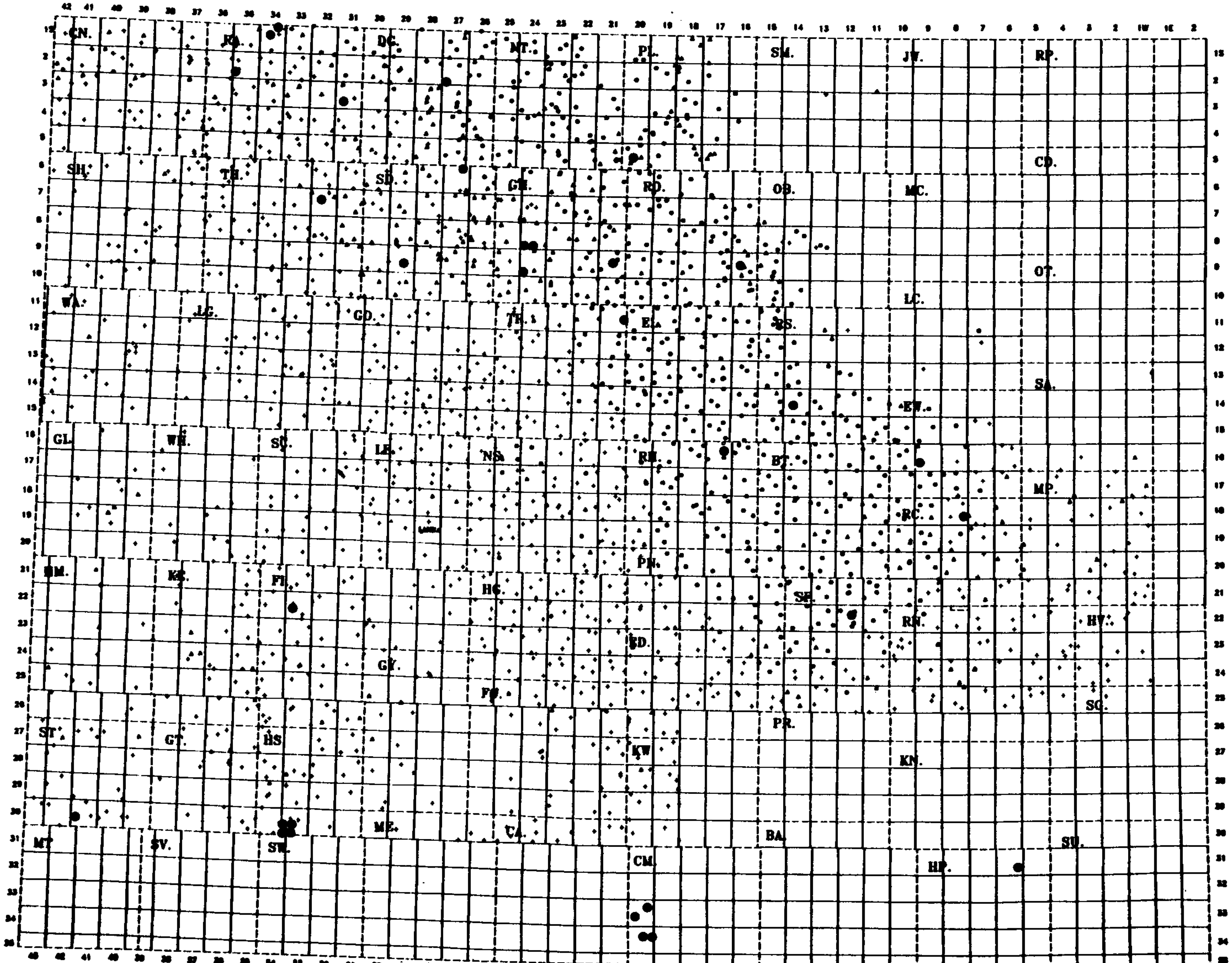
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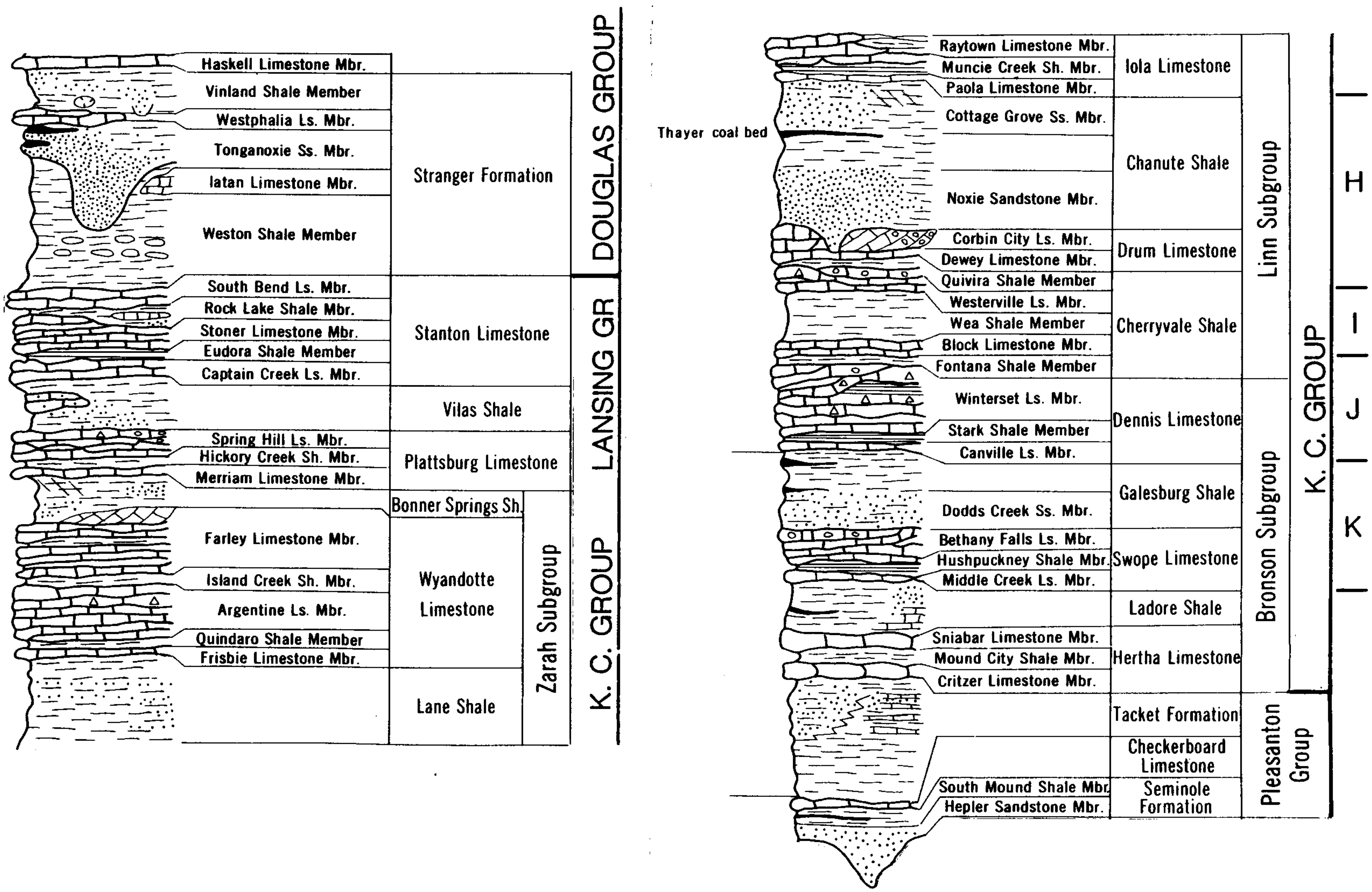
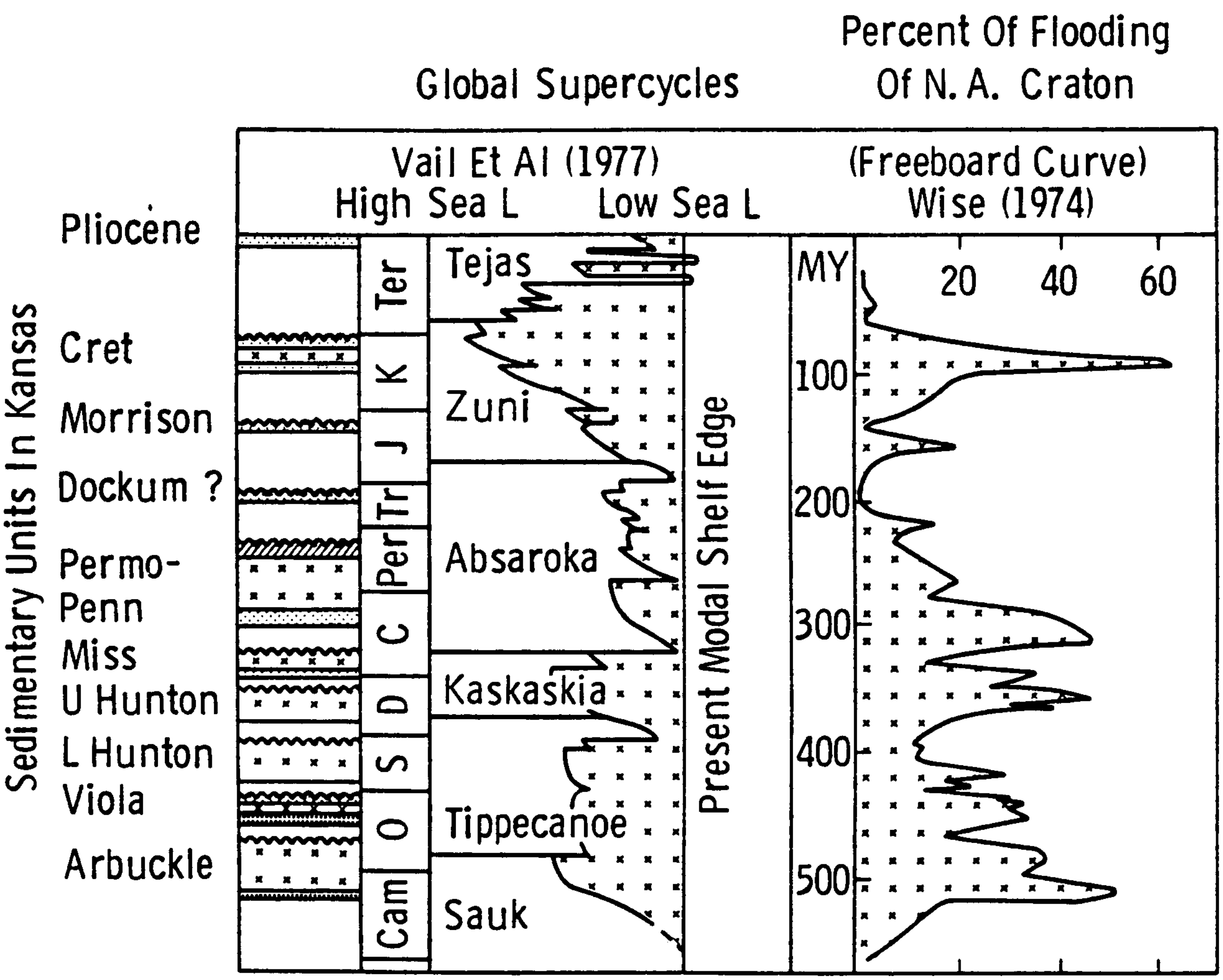
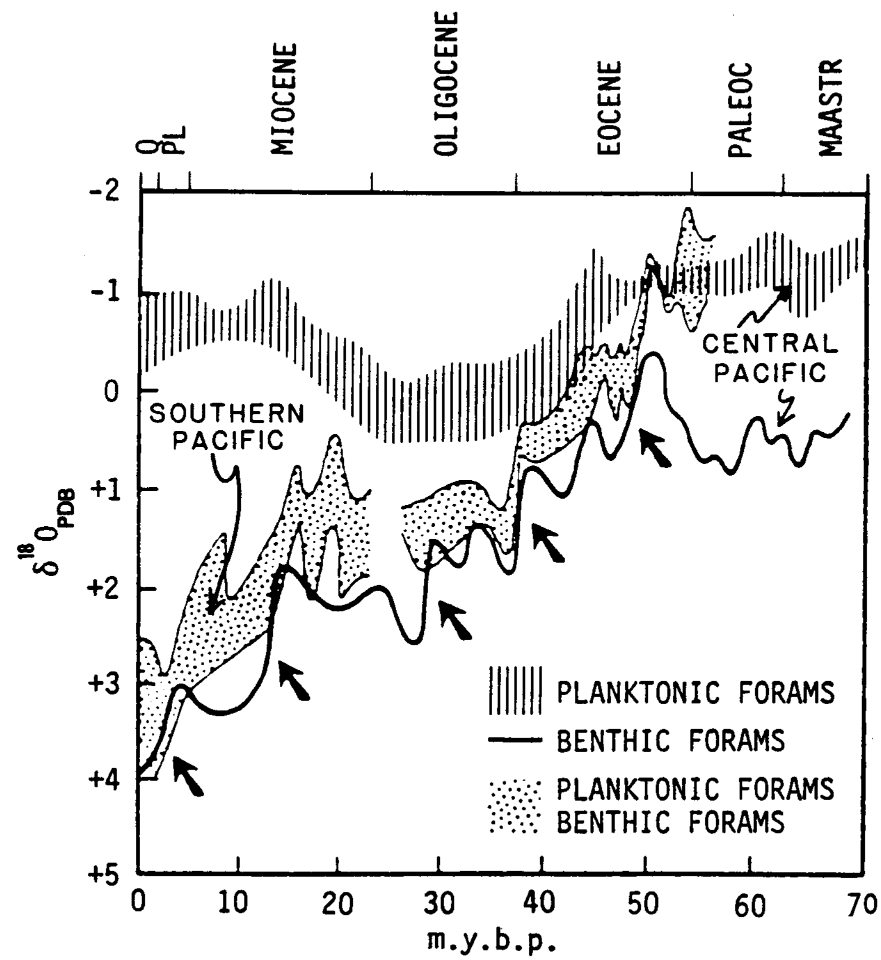
RH.
BT.
MP.
RC.
HM.
KC.
FI.
HG.
PN.
SF.
RN.
HV.
GY.
BD.
FO.
SG.
ST.
GT.
HS.
PR.
KW.
KN.
MT.
SV.
SW.
ME.
CA.
BA.
CM.
HP.
SU.

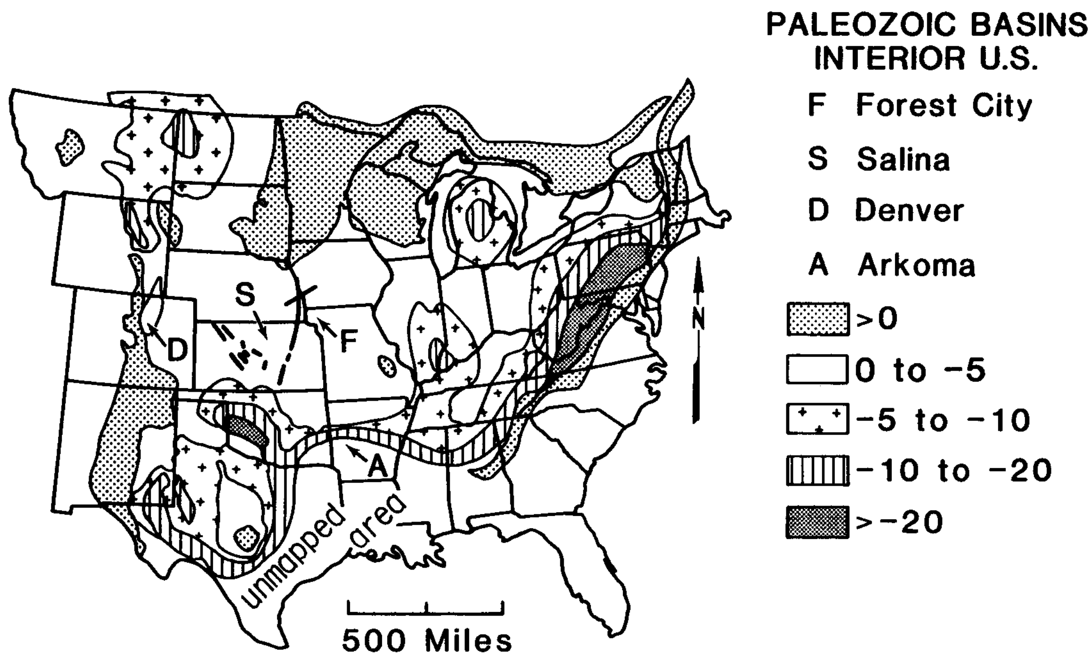

Haskell Limestone Mbr.
Vinland Shale Member
Westphalia Ls. Mbr.
Tonganoxie Ss. Mbr.
Iatan Limestone Mbr.
Weston Shale Member
Stranger Formation
DOUGLAS GROUP
South Bend Ls. Mbr.
Rock Lake Shale Mbr.
Stoner Limestone Mbr.
Eudora Shale Member
Captain Creek Ls. Mbr.
Stanton Limestone
Vilas Shale
Spring Hill Ls. Mbr.
Hickory Creek Sh. Mbr.
Merriam Limestone Mbr.
Plattsburg Limestone
LANSING GR
Bonner Springs Sh.
Farley Limestone Mbr.
Island Creek Sh. Mbr.
Argentine Ls. Mbr.
Quindaro Shale Member
Frisbie Limestone Mbr.
Wyandotte Limestone
Lane Shale
Zarah Subgroup
K. C. GROUP
Thayer coal bed
Raytown Limestone Mbr.
Muncie Creek Sh. Mbr.
Paola Limestone Mbr.
Iola Limestone
Cottage Grove Ss. Mbr.
Noxie Sandstone Mbr.
Chanute Shale
Corbin City Ls. Mbr.
Dewey Limestone Mbr.
Drum Limestone
Quivira Shale Member
Westerville Ls. Mbr.
Wea Shale Member
Block Limestone Mbr.
Fontana Shale Member
Cherryvale Shale
Linn Subgroup
Winterset Ls. Mbr.
Stark Shale Member
Canville Ls. Mbr.
Dennis Limestone
Dodds Creek Ss. Mbr.
Galesburg Shale
Bethany Falls Ls. Mbr.
Hushpuckney Shale Mbr.
Middle Creek Ls. Mbr.
Swope Limestone
Ladore Shale
Sniabar Limestone Mbr.
Mound City Shale Mbr.
Critzer Limestone Mbr.
Hertha Limestone
Bronson Subgroup
K. C. GROUP
Tacket Formation
Checkerboard Limestone
South Mound Shale Mbr.
Hepler Sandstone Mbr.
Seminole Formation
Pleasanton Group
H
I
J
K

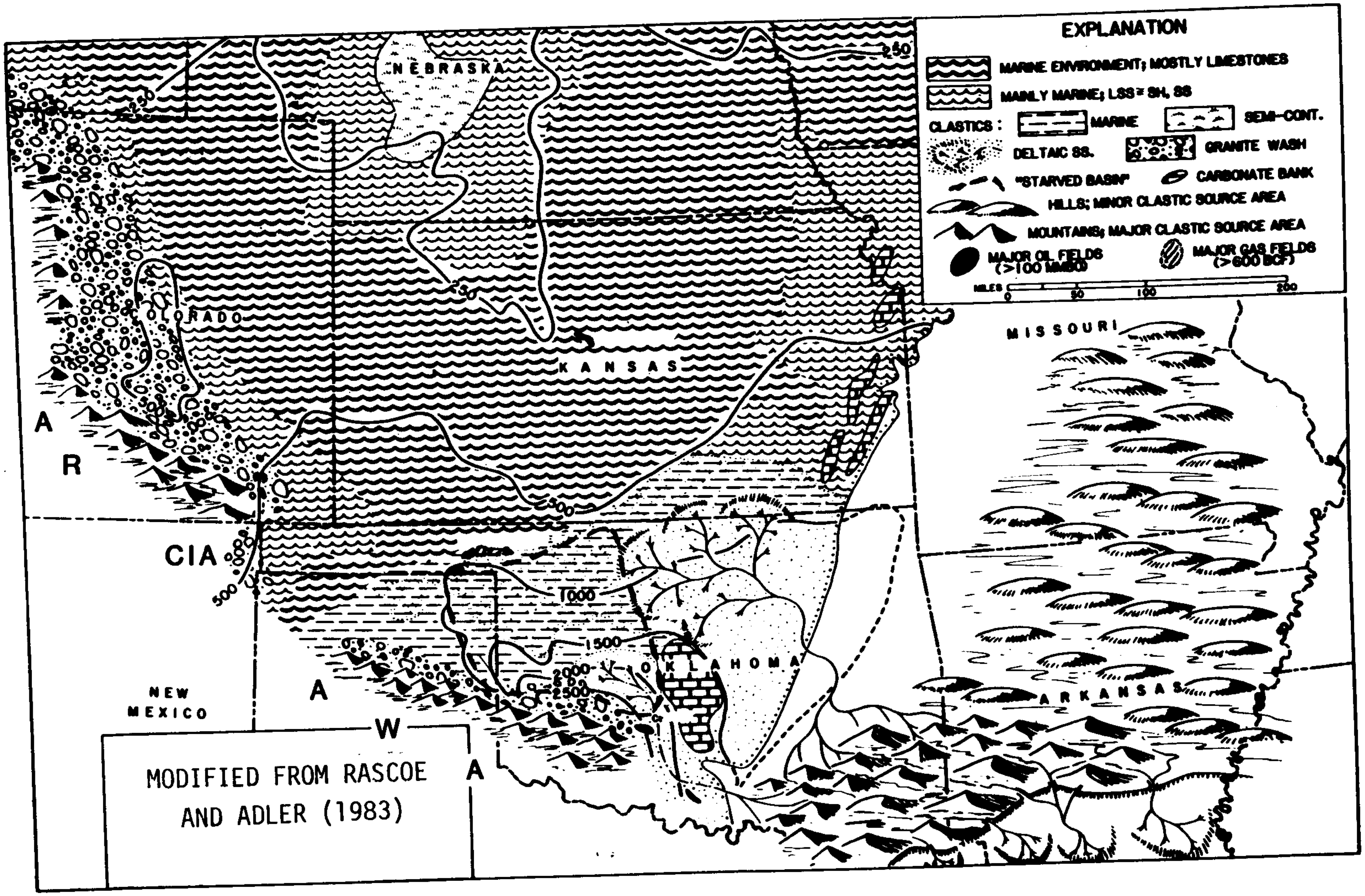
LITHOFACIES	GENERAL INTERPRETATION	THICKNESS
UPPER SHALE	NONMARINE, PALEOSOLS	0-20 FT. (0-6 m)
		SHARP
UPPER CARBONATE	SHALLOWING UPWARD MARINE	10-60 FT. (3-18 m)
		ABRUPTLY GRAD.
LOWER SHALE	MARINE, COMMONLY ORGANIC-RICH	2-6 FT. (.5-2 m)
		ABRUPTLY GRAD.
LOWER CARBONATE	UPWARD DEEPENING MARINE	0-10 FT. (0-3 m)
		SHARP
		↑ BOUNDARY


Percent Of Flooding
Of N. A. Craton
Global Supercycles
Vail Et Al (1977)
High Sea L
Low Sea L
(Freeboard Curve)
Wise (1974)
Sedimentary Units In Kansas
Pliocene
Cret
Morrison
Dockum ?
Permo-
Penn
Miss
U Hunton
L Hunton
Viola
Arbuckle
Ter
K
J
Tr
Per
C
D
S
O
Cam
Tejas
Zuni
Absaroka
Kaskaskia
Tippecanoe
Sauk
Present Modal Shelf Edge
MY
100
200
300
400
500
20
40
60

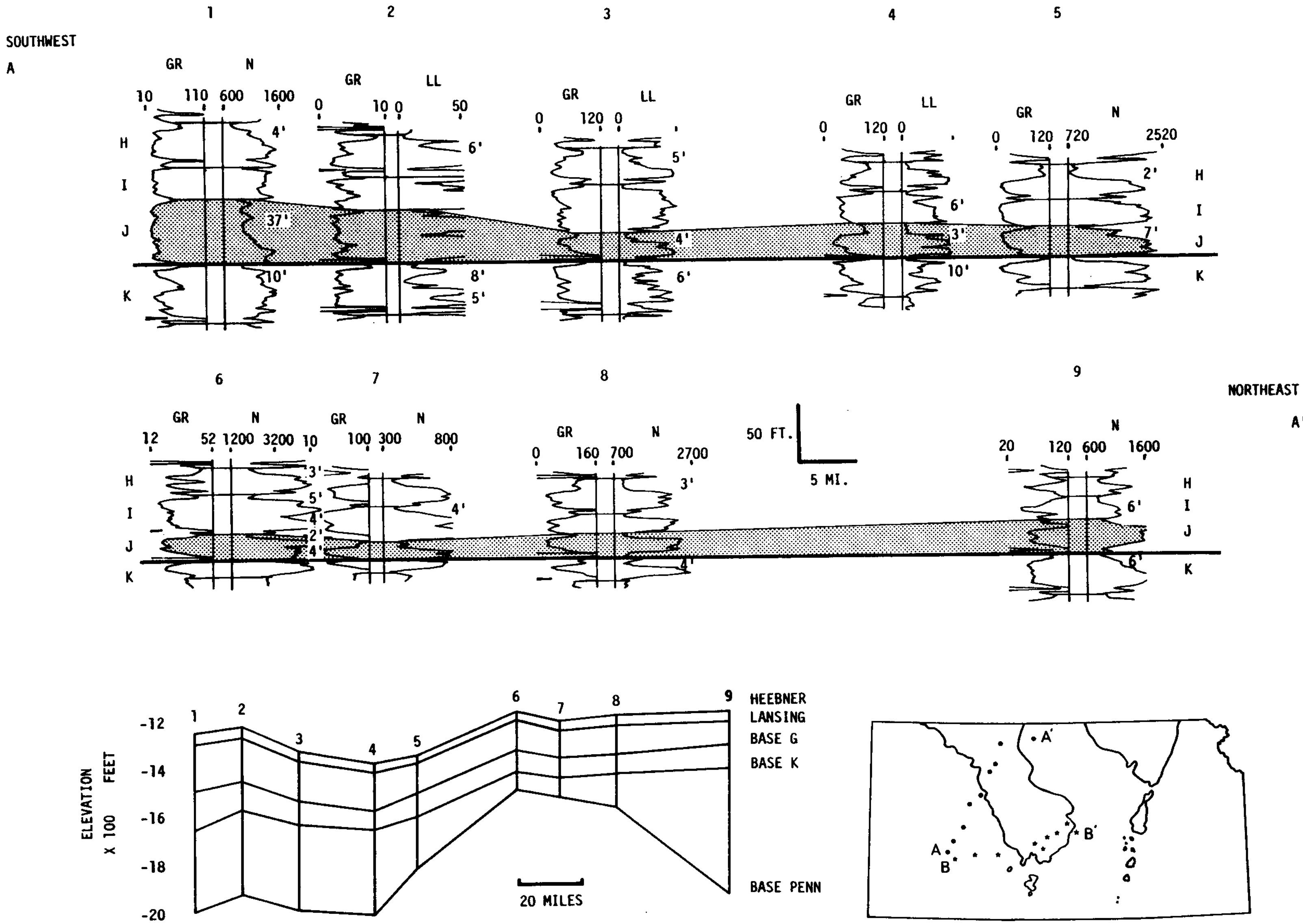


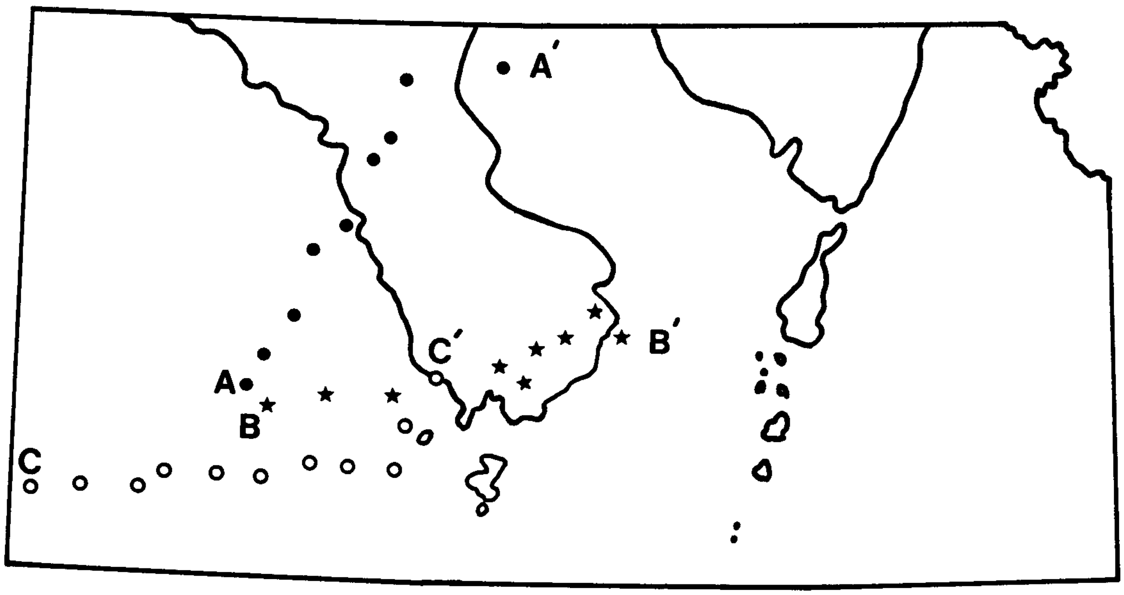
Q
PL
MIOCENE
OLIGOCENE
EOCENE
PALEOC
MAASTR
-2
-1
0
+1
+2
+3
+4
+5
δ18OPDB
SOUTHERN
PACIFIC
CENTRAL
PACIFIC
PLANKTONIC FORAMS
BENTHIC FORAMS
PLANKTONIC FORAMS
BENTHIC FORAMS
0
10
20
30
40
50
60
70
m.y.b.p.

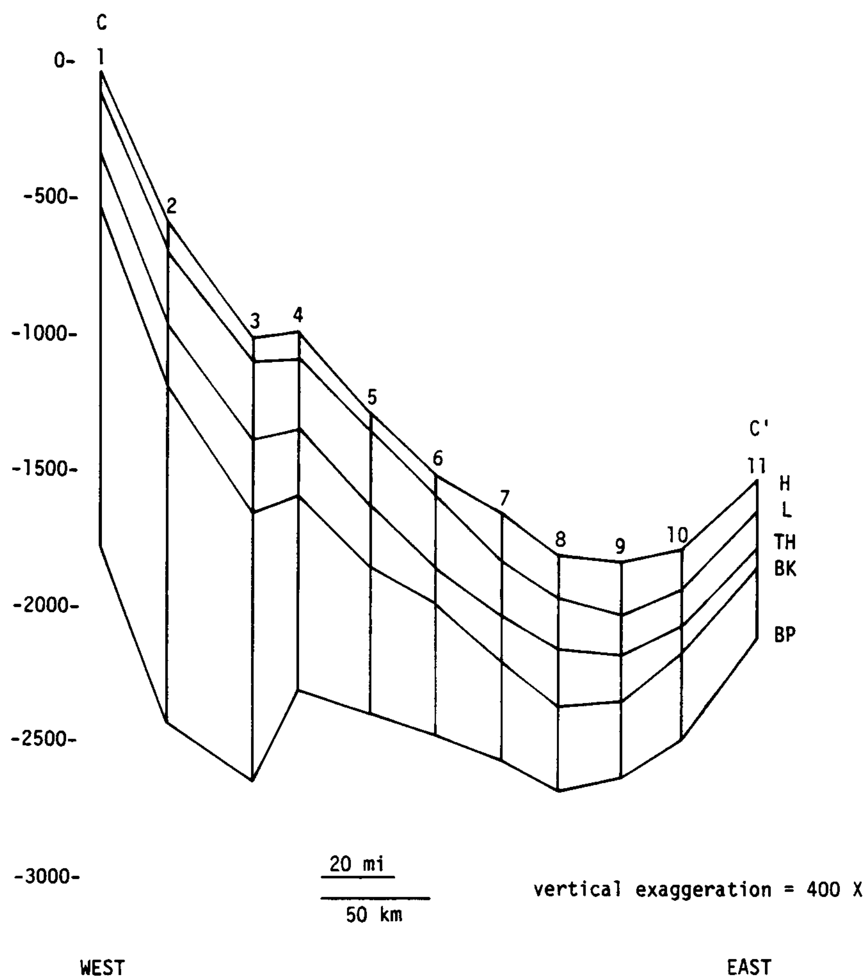

PALEOZOIC BASINS
INTERIOR U.S.
F Forest City
S Salina
D Denver
A Arkoma
>0
0 to −5
−5 to −10
−10 to −20
>−20
S
F
D
A
N
unmapped area
500 Miles

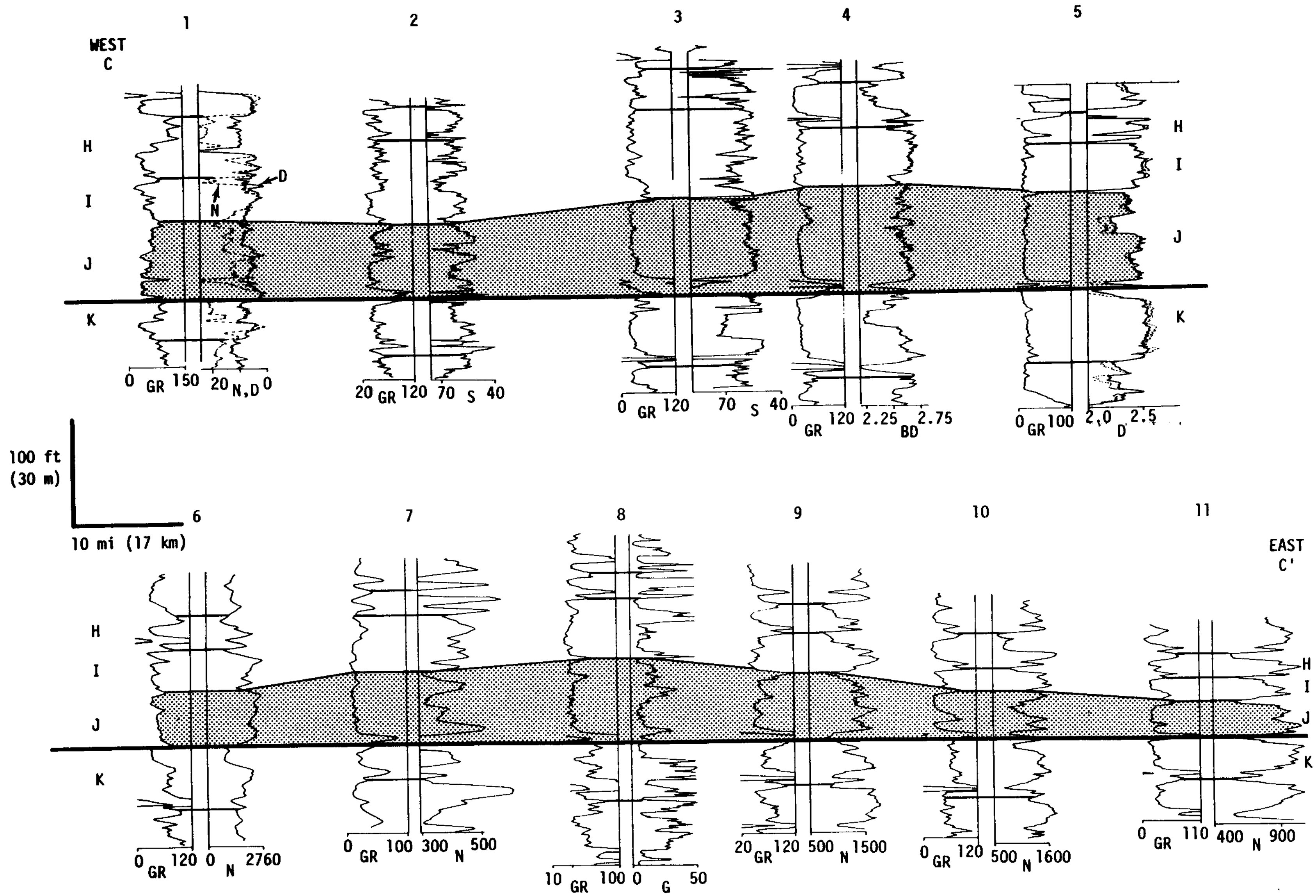


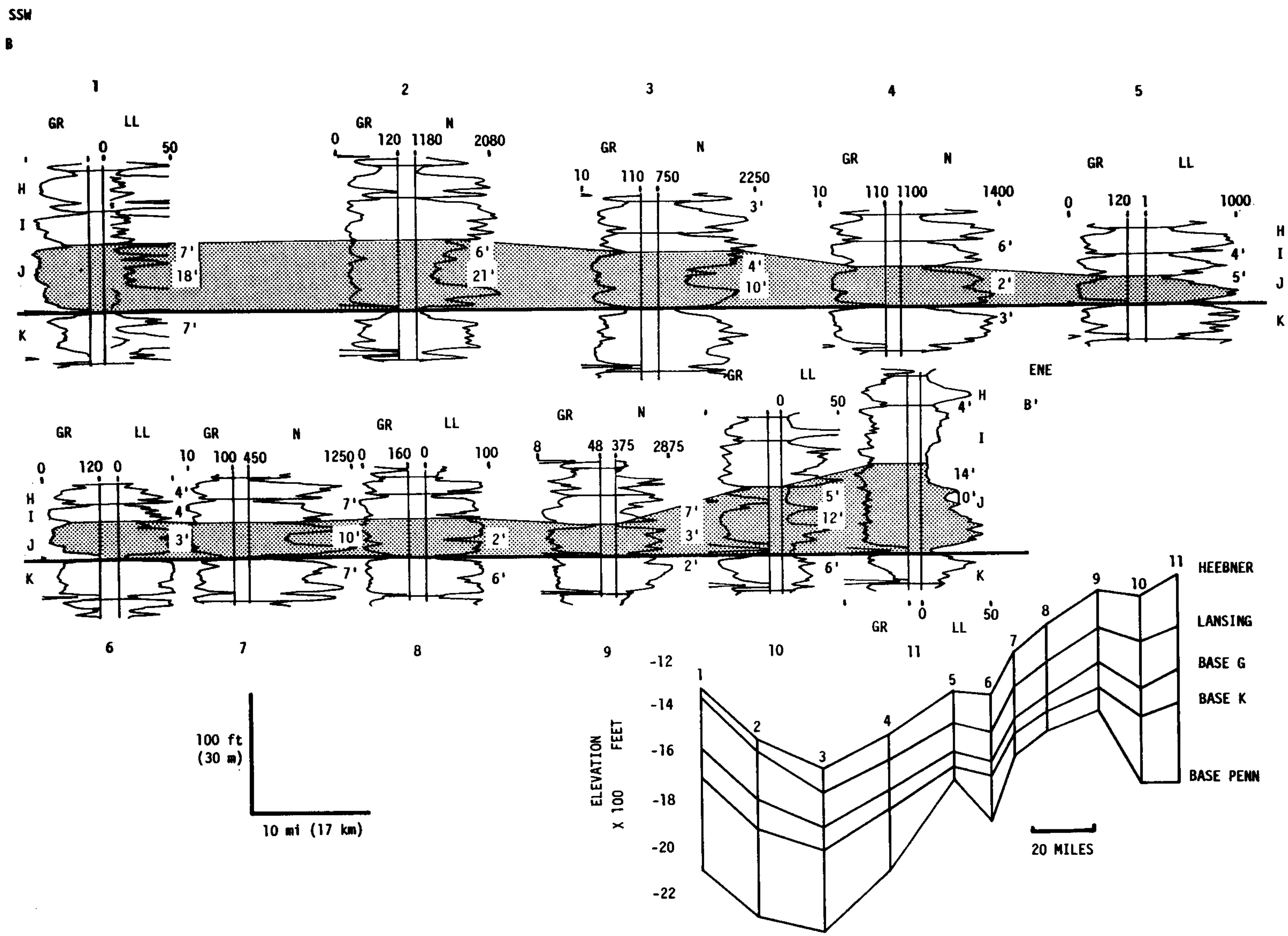
MODIFIED FROM RASCOE AND ADLER (1983)


SOUTHWEST
A
NORTHEAST
A'
1
2
3
4
5
6
7
8
9
GR
N
LL
H
I
J
K
37'
50 FT.
5 MI.
ELEVATION
X 100 FEET
-12
-14
-16
-18
-20
HEEBNER
LANSING
BASE G
BASE K
BASE PENN
20 MILES
A
A'
B
B'


A'
C'
B'
A
B
C


C
0-
-500-
-1000-
-1500-
-2000-
-2500-
-3000-
1
2
3
4
5
6
7
8
9
10
11
C'
H
L
TH
BK
BP
20 mi
50 km
vertical exaggeration = 400 X
WEST
EAST

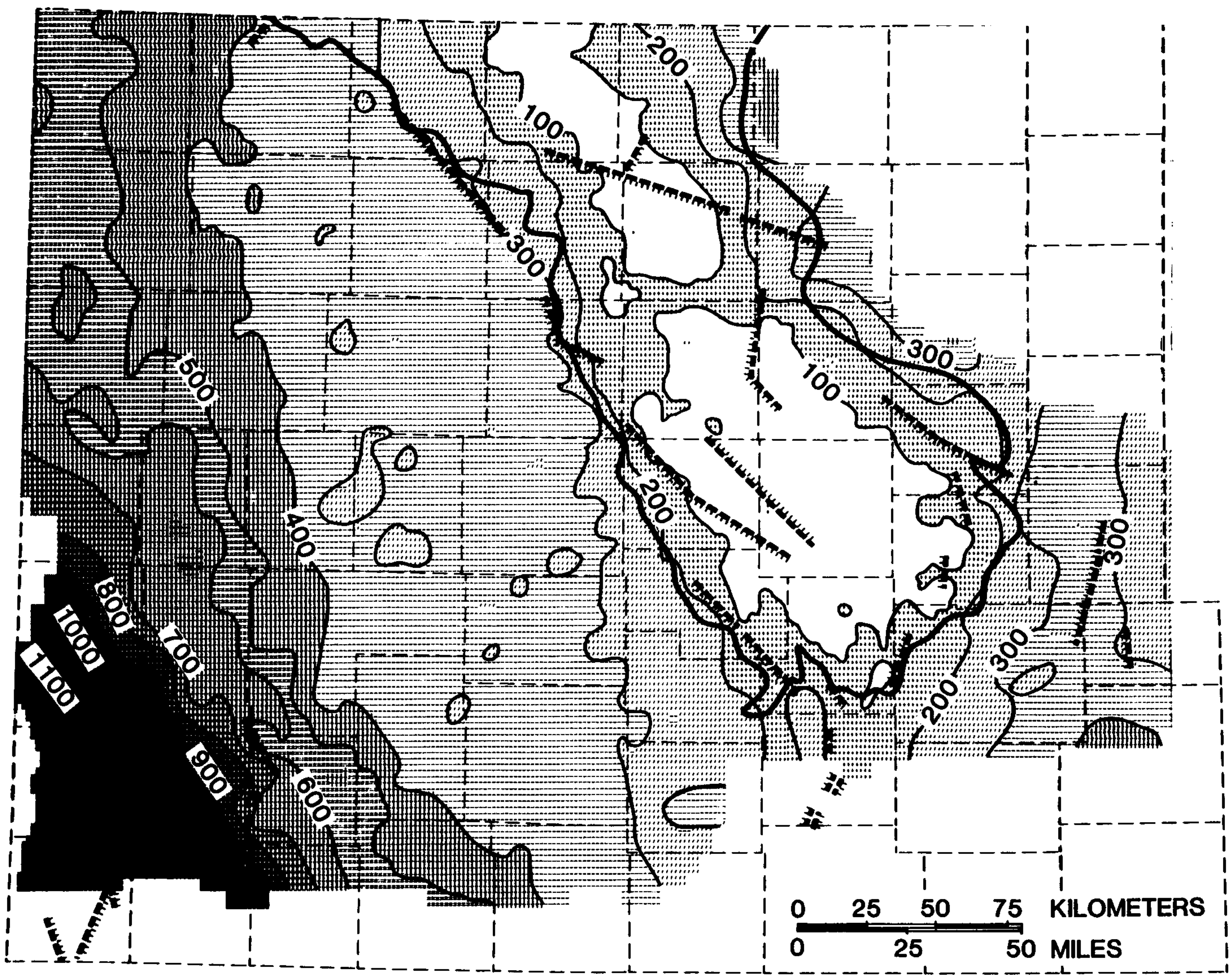

WEST
C
1
2
3
4
5
H
I
J
K
D
N
0 GR 150 20 N,D 0
20 GR 120 70 S 40
0 GR 120 70 S 40
0 GR 120 2.25 BD 2.75
0 GR 100 2.0 D 2.5
100 ft
(30 m)
10 mi (17 km)
6
7
8
9
10
11
EAST
C'
0 GR 120 0 N 2760
0 GR 100 300 N 500
10 GR 100 0 G 50
20 GR 120 500 N 1500
0 GR 120 500 N 1600
0 GR 110 400 N 900


SSW
B
ENE
B'
GR
LL
N
H
I
J
K
7'
18'
6'
21'
3'
4'
10'
2'
5'
14'
12'
100 ft
(30 m)
10 mi (17 km)
ELEVATION FEET X 100
-12
-14
-16
-18
-20
-22
HEEBNER
LANSING
BASE G
BASE K
BASE PENN
20 MILES

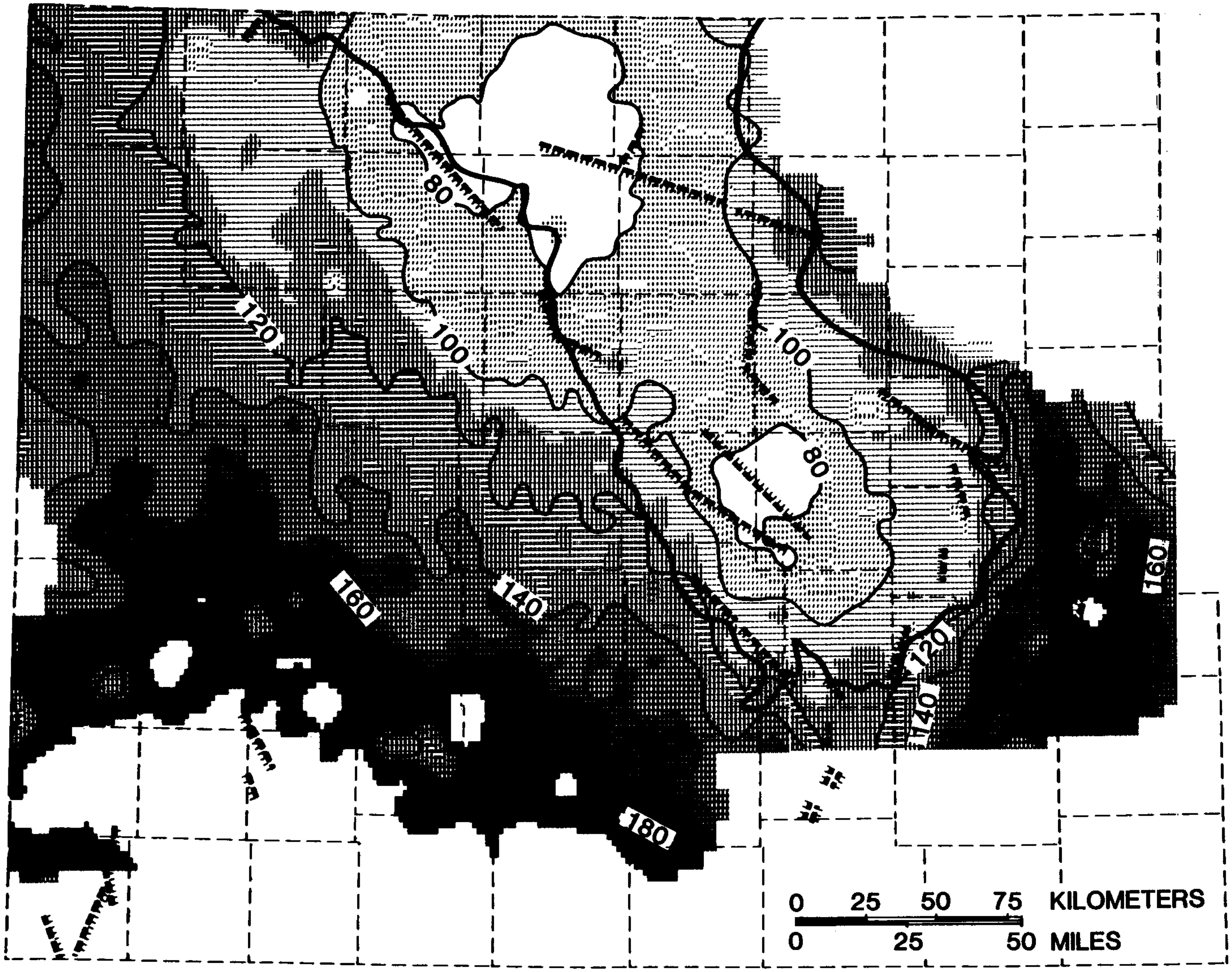
K A N S A S   C I T Y   S T R A T I G R A P H I C   R E C O R D S

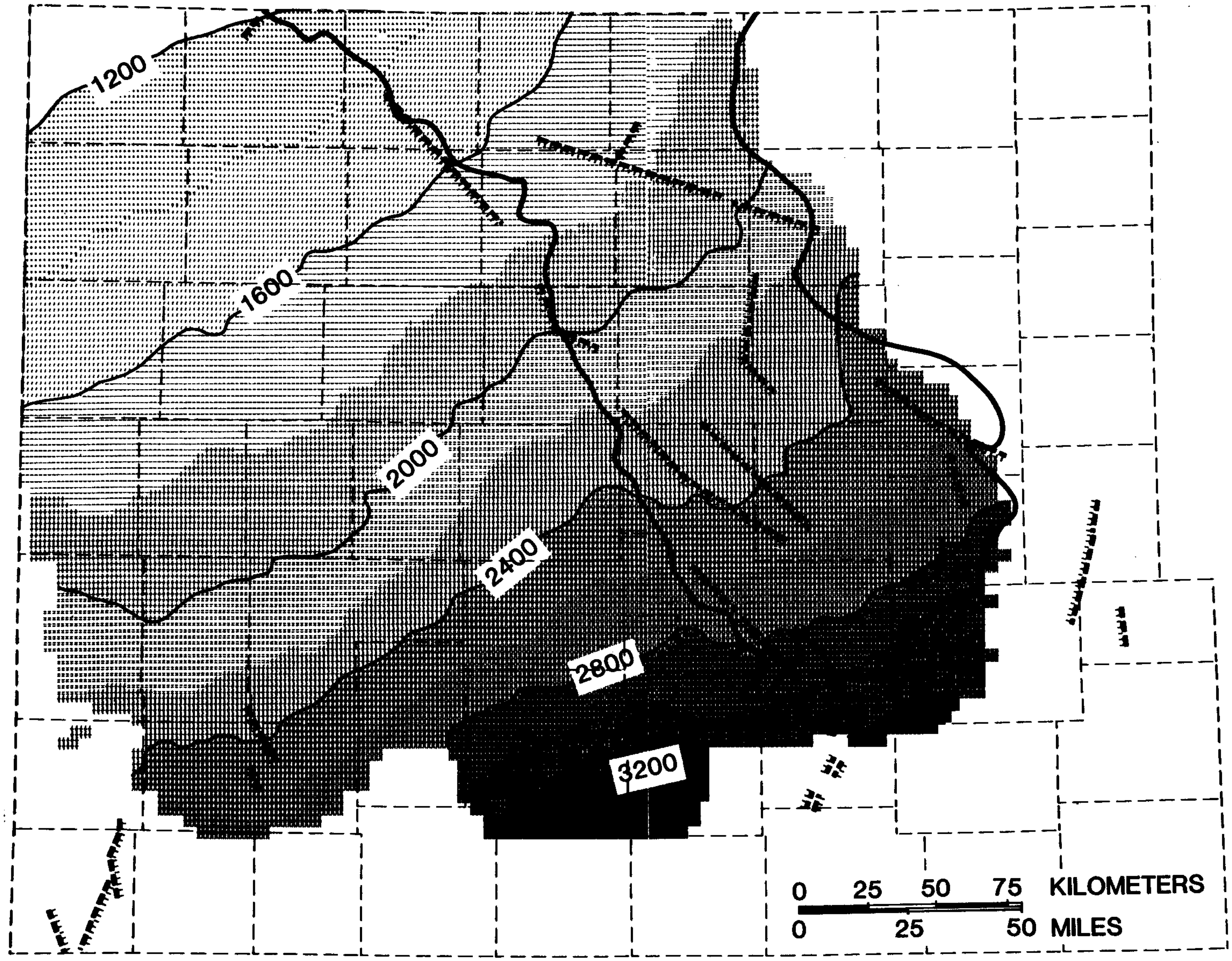
ID	WELL NAME	LOCATION	STR	E/W	LOG TYPE	SCALE	KB	STCRL	HEEB	LANS	B-G	B-PSLV	T-MSSP
1	T.L. FERRIER 1 FISCH	NENENE	352424	W	GRNG	2.5	2472.	1598.	4028.	4097.	4306.	4820.	4820.
2	LANDES EXPL. 1KELLY	NESWSW	72313	W	GRNGC	2.5	1512.	-1.	3340.	3497.	3611.	3842.	3842.
3	PET. MAN 1 LANMAN	NESWSW	050117	W	GRNG	2.5	2104.	-1.	3336.	3384.	3509.	-1.	-1.
4	L.BAIRD 4 WALKER	SENWSW	030118	W	GRNG	5.	2029.	-1.	3202.	3247.	3364.	-1.	-1.
5	ARGONAUT 1 GORACKE	NWNW	130118	W	GRGS	5.	2162.	-1.	3379.	3417.	3537.	-1.	-1.
6	PET. MAN. 2 RAKESTRA	W2NENE	310118	W	GRNG	5.	2250.	1825.	3394.	3441.	3553.	-1.	-1.
7	FELCT-MAYTAG 1 MEKEN	CSESE	250119	W	GRNG	2.5	2209.	1792.	3363.	3407.	3522.	-1.	-1.
8	FITZGERALD 1 NELSON	CNESW	330120	W	SPRS	2.5	2104.	1615.	3369.	3411.	3529.	3750.	-1.
9	NAT. ASSOC A-1 BOCK	CNWSW	350120	W	GRN	2.5	2142.	1815.	3372.	3417.	3532.	3786.	-1
10	EMPIRE 1 ATENS EST.	SESESW	060122	W	SPR	2.5	2387.	1527.	3354.	3397.	3502.	3648.	-1.
11	SINCLAIR 1 RORABAUGH	CSENE	200122	W	GRRS	2.5	2414.	1982.	3440.	3482.	3584.	3745.	-1.
12	C-G DRLG 1 KINDALL	NENENE	310122	W	SPRM	2.5	2433.	2001.	3455.	3500.	3600.	3755.	-1.
13	FREDRICK 1 BALLINGE	CNESW	140123	W	GRRS	2.5	2360.	1895.	3320.	3362.	3465.	3602.	-1.
14	SAUVAGE 1 MELROY	NWNWSW	220123	W	SPRS	2.5	2443.	-1.	3393.	3435.	3536.	3687.	-1.
15	RAYMOND 1 SAVER	CSWNW	310123	W	GRRS	2.5	2472.	2008.	3414.	3458.	-1.	3708.	-1.
16	RAYMOND 1 MCKINNEY	CNWNW	150124	W	GRRS	2.5	2373.	1855.	3259.	3298.	3392.	3546.	-1.
17	TILCO 1 QUENZER	CSENW	270124	W	GRN	2.5	2420.	1543.	3330.	3362.	3468.	3643.	-1.

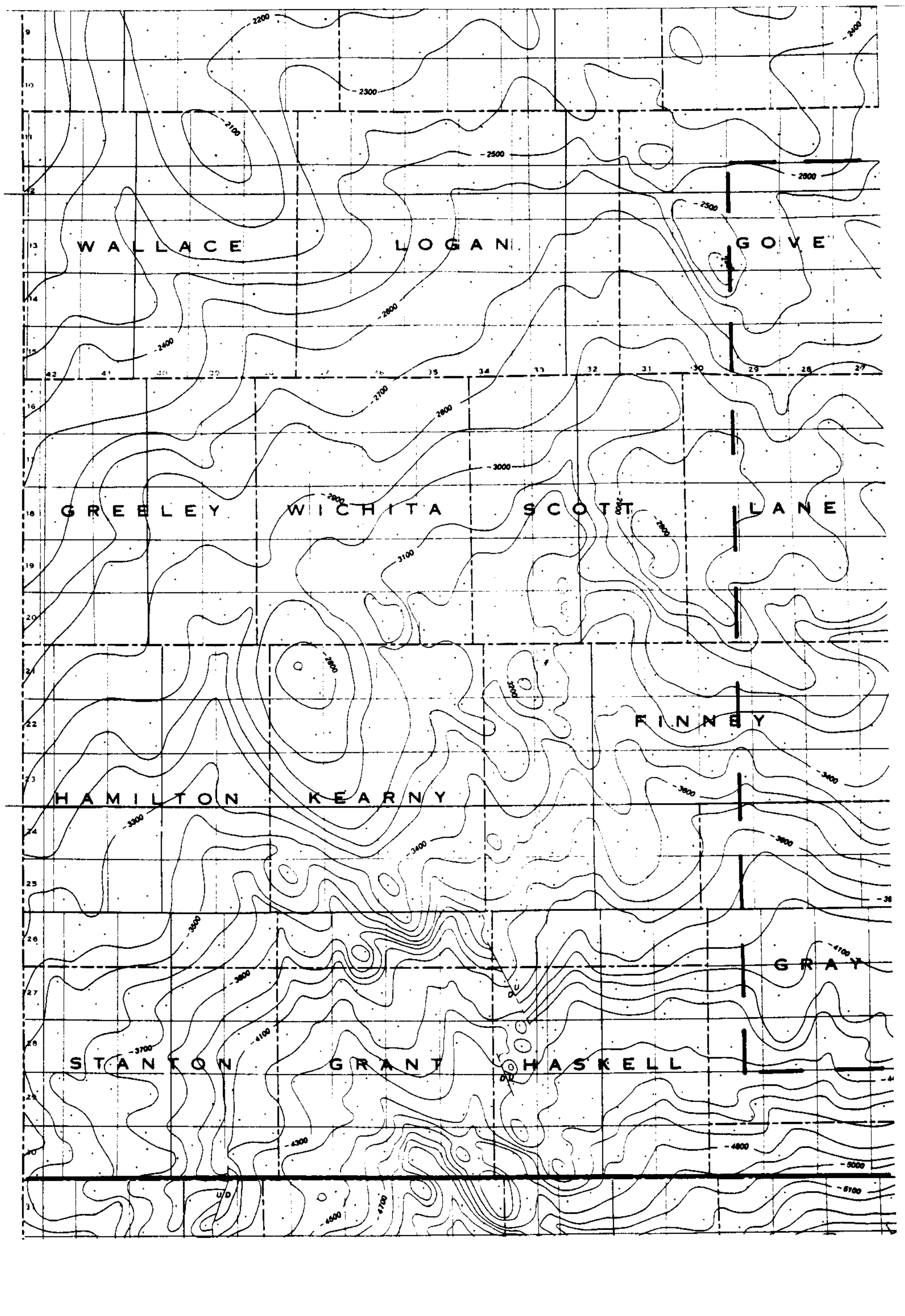
ID	TOP H	BASEH	CU	QL	GRH	TOP I	BASEI	CU	QL	TOP J	BASEJ	CU	CL	GRJ	TOP K	BASEK	QU	QL	GRK
1	4310.	4334.	0	0	166.	4336.	4358.	0	0	4359.	4434.	52	0	284.	4434.	4477.	0	0	282.
2	3614.	3629.	3	0	62.	3631.	3646.	0	0	3648.	3676.	5	4	106.	3678.	3713.	8	0	150.
3	3520.	3541.	0	0	170.	3542.	3554.	0	0	3562.	3584.	0	2	266.	3589.	3610.	0	2	270.
4	3372.	3391.	0	0	125.	3394.	3404.	0	0	3414.	3430.	0	0	215.	3439.	3457.	0	0	240.
5	3547.	3568.	0	0	135.	3572.	3582.	0	0	3590.	3610.	0	0	225.	3617.	3637.	0	0	200.
6	3563.	3582.	2	0	95.	3588.	3599.	3	0	3604.	3620.	0	0	170.	3629.	3649.	2	0	210.
7	3523.	3532.	2	4	120.	3555.	3567.	0	0	3574.	3596.	0	1	190.	3598.	3618.	4	0	220.
8	3539.	3554.	0	2	-1.	3562.	3568.	0	0	3574.	3590.	2	0	-1.	3593.	3613.	0	0	-1.
9	3545.	3563.	4	2	235.	3568.	3575.	2	0	3584.	3595.	0	0	140.	3602.	3615.	5	0	180.
10	3506.	3527.	0	0	-1.	3544.	3550.	0	0	3560.	3574.	0	0	-1.	3582.	3595.	0	0	-1.
11	3594.	3610.	2	0	-1.	3620.	3621.	0	0	3631.	3640.	0	0	-1.	3644.	3662.	2	0	-1.
12	3609.	3626.	2	0	-1.	-1.	-1.	0	0	3644.	3651.	0	0	-1.	3658.	3673.	0	0	-1.
13	3472.	3491.	0	0	-1.	-1.	-1.	0	0	3506.	3514.	0	0	-1.	3518.	3540.	4	5	-1.
14	3541.	3562.	0	0	-1.	3572.	3574.	0	0	3576.	3582.	0	0	-1.	3588.	3613.	10	0	-1.
15	3564.	3582.	0	0	85.	3592.	3594.	0	0	3599.	3606.	0	0	-1.	3618.	3635.	0	0	-1.
16	3401.	3421.	3	0	110.	3436.	3437.	0	0	3442.	3450.	4	0	89.	3462.	3477.	0	0	-1.
17	3477.	3489.	0	0	-1.	-1.	-1.	0	0	3513.	3520.	0	0	-1.	3534.	3548.	0	0	148.

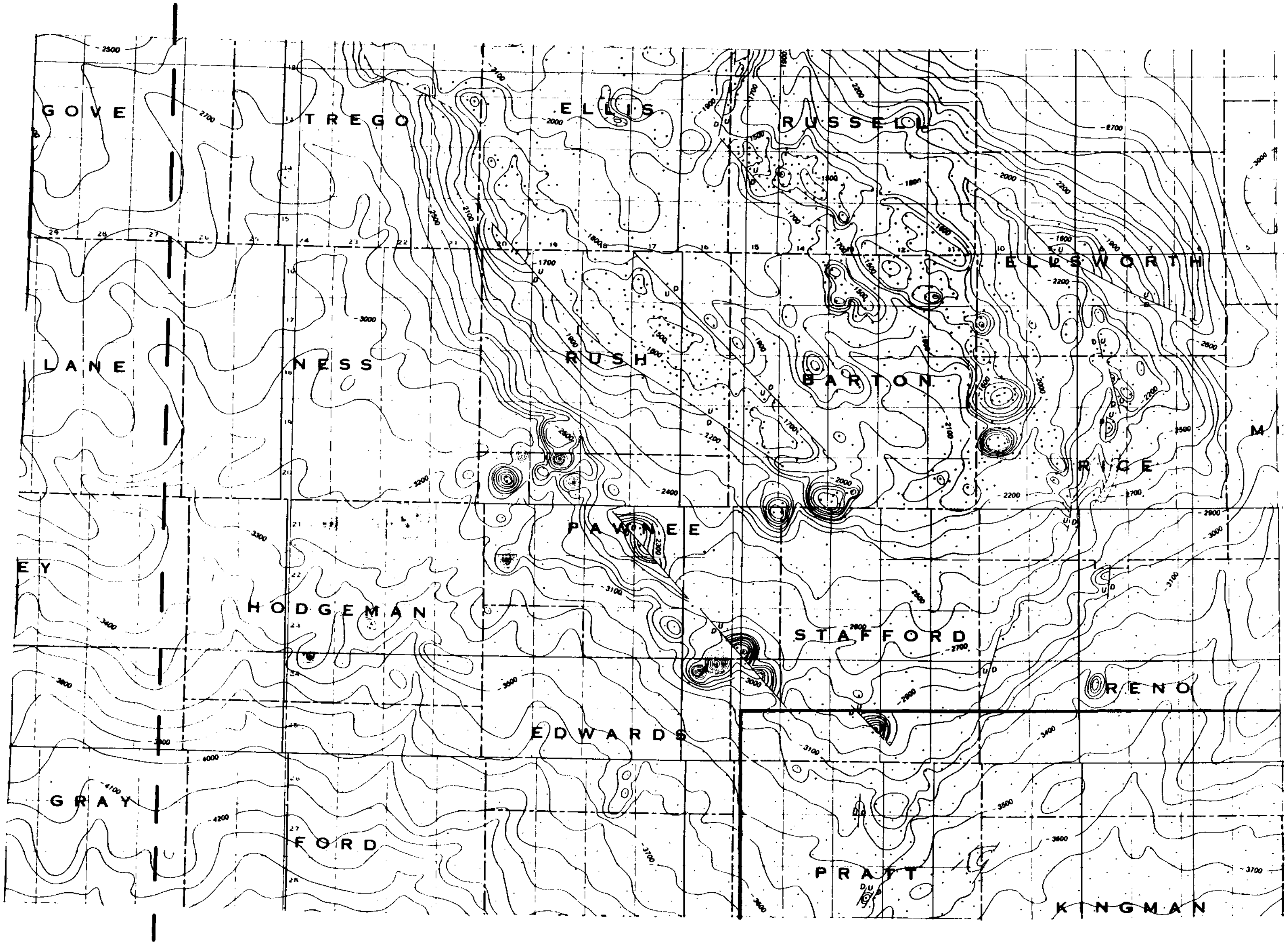


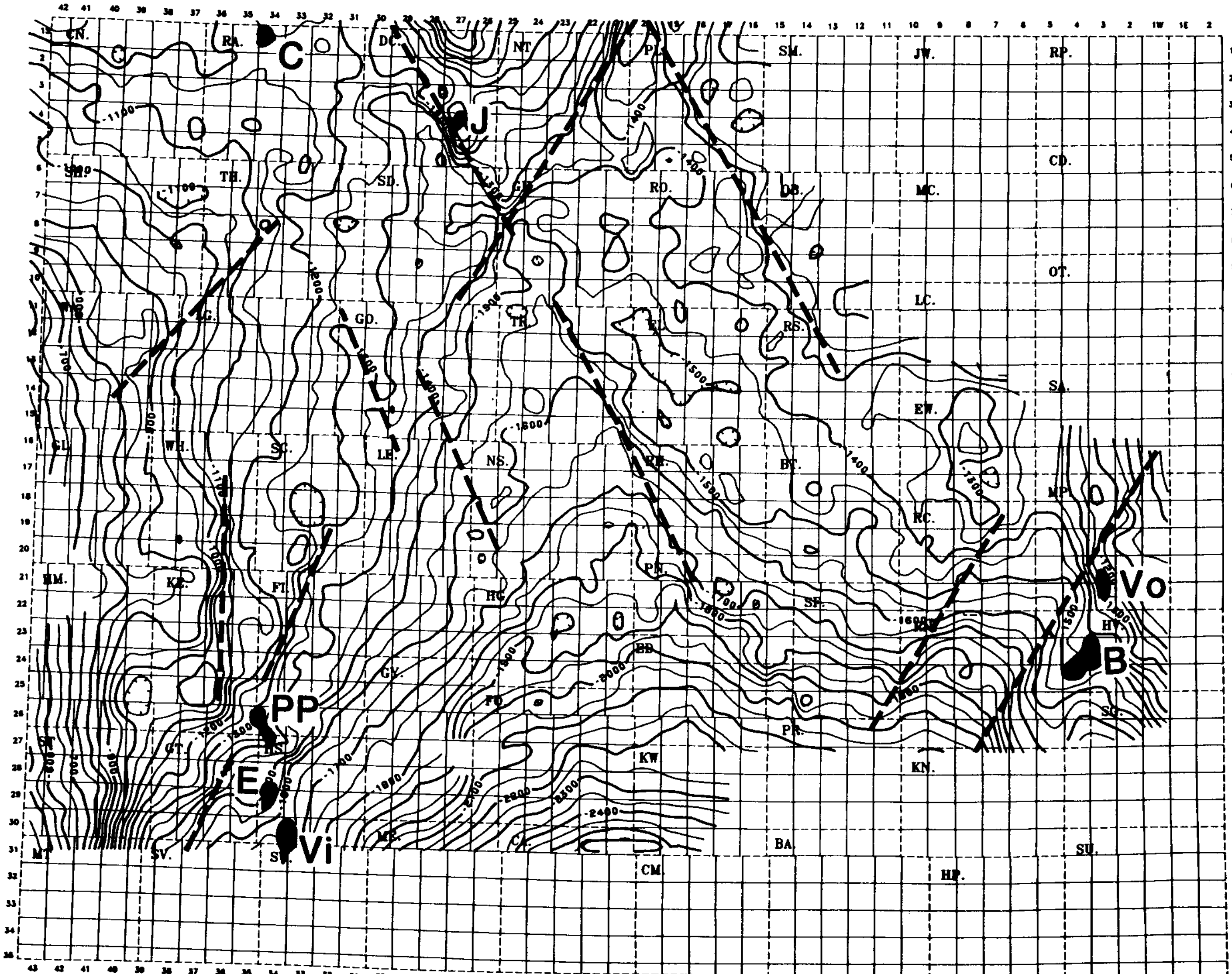
100
200
300
400
500
600
700
800
900
1000
1100
0 25 50 75 KILOMETERS
0 25 50 MILES


80
80
100
100
120
120
140
140
160
160
180
0 25 50 75 KILOMETERS
0 25 50 MILES

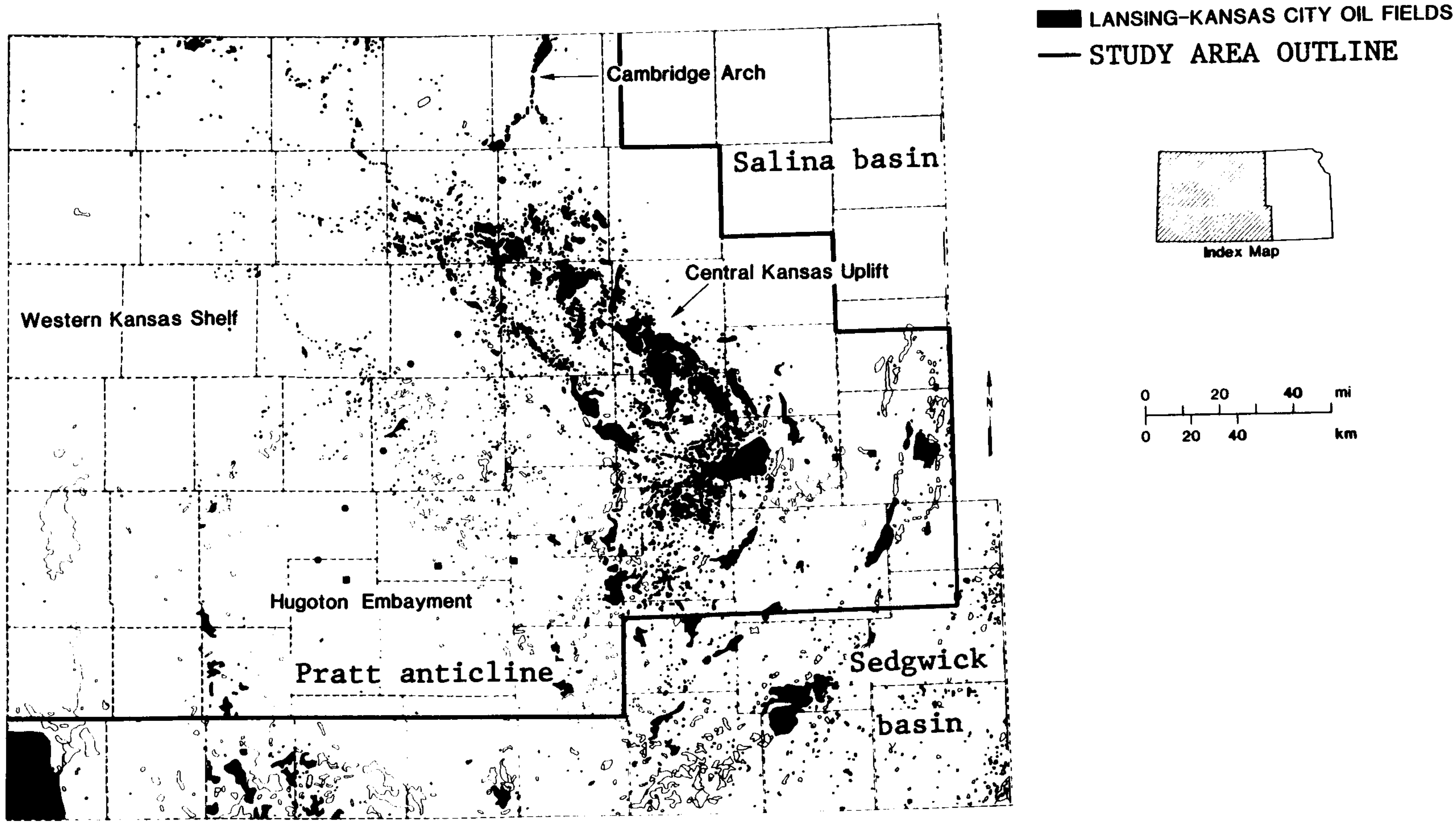

1200
1600
2000
2400
2800
3200
0 25 50 75 KILOMETERS
0 25 50 MILES


WALLACE
LOGAN
GOVE
GREELEY
WICHITA
SCOTT
LANE
FINNEY
HAMILTON
KEARNY
GRAY
STANTON
GRANT
HASKELL
-2200
-2300
-2100
-2500
-2600
-2400
-2700
-2800
-3000
-3100
-3200
-3300
-3400
-3600
-3700
-3800
-4100
-4300
-4600
-4800
-5000
-5100
U/D
D/U

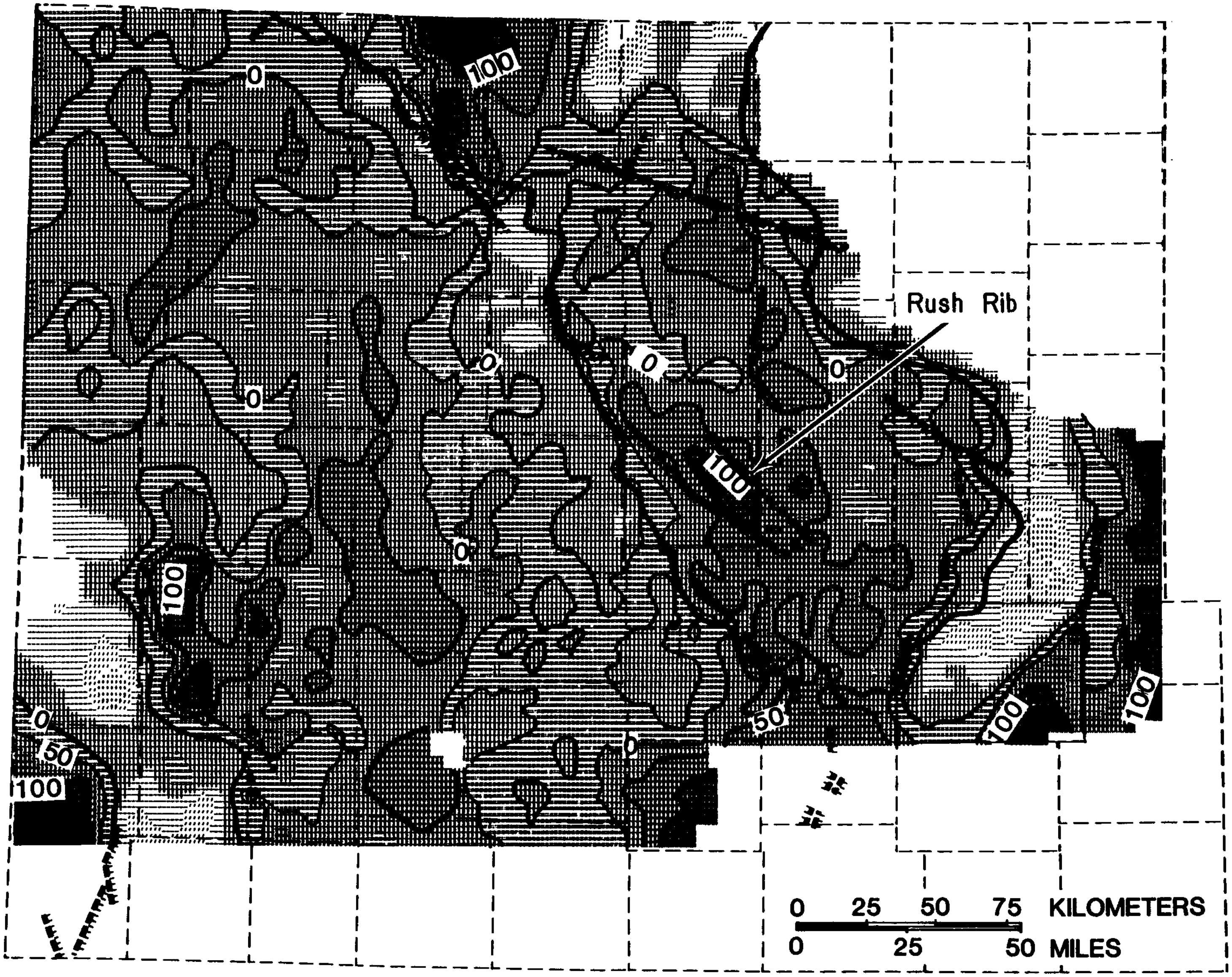

GOVE
TREGO
ELLIS
RUSSELL
ELLSWORTH
LANE
NESS
RUSH
BARTON
RICE
PAWNEE
HODGEMAN
STAFFORD
RENO
EDWARDS
GRAY
FORD
PRATT
KINGMAN



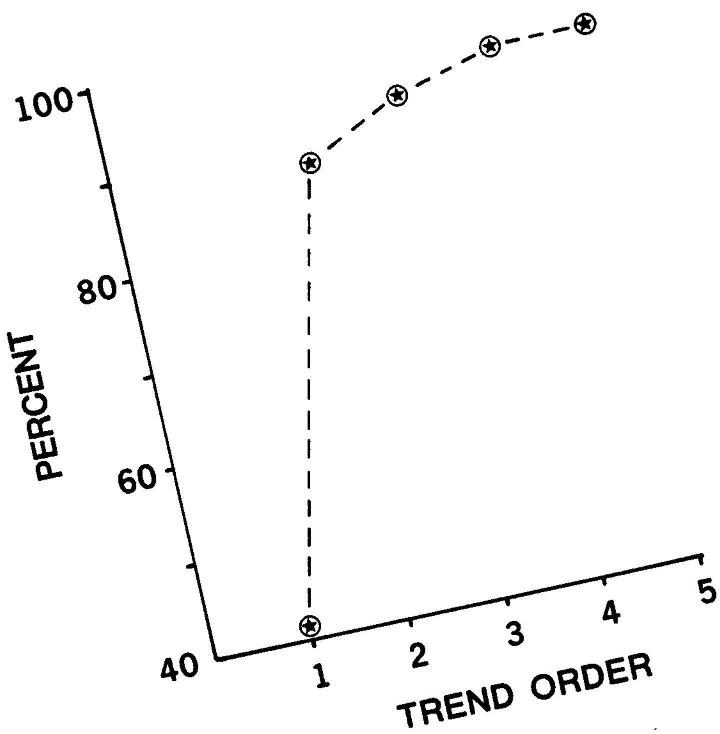
C
J
PP
E
Vi
Vo
B

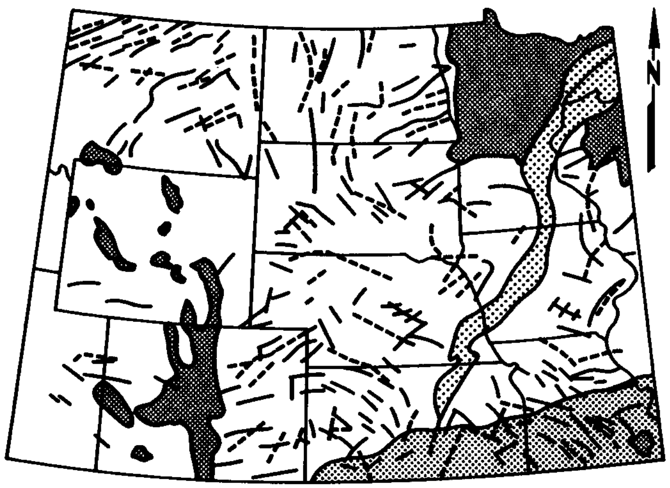


LANSING-KANSAS CITY OIL FIELDS
STUDY AREA OUTLINE
Cambridge Arch
Salina basin
Central Kansas Uplift
Western Kansas Shelf
Hugoton Embayment
Pratt anticline
Sedgwick basin
Index Map
0 20 40 mi
0 20 40 km
N



0
100
Rush Rib
50
0 25 50 75 KILOMETERS
0 25 50 MILES


100
80
60
40
PERCENT
1
2
3
4
5
TREND ORDER



PRECAMBRIAN GEOLOGY AND GEOPHYSICAL TRENDS

Linear gravity trends

Magnetic trends

C.N.A.R.S.

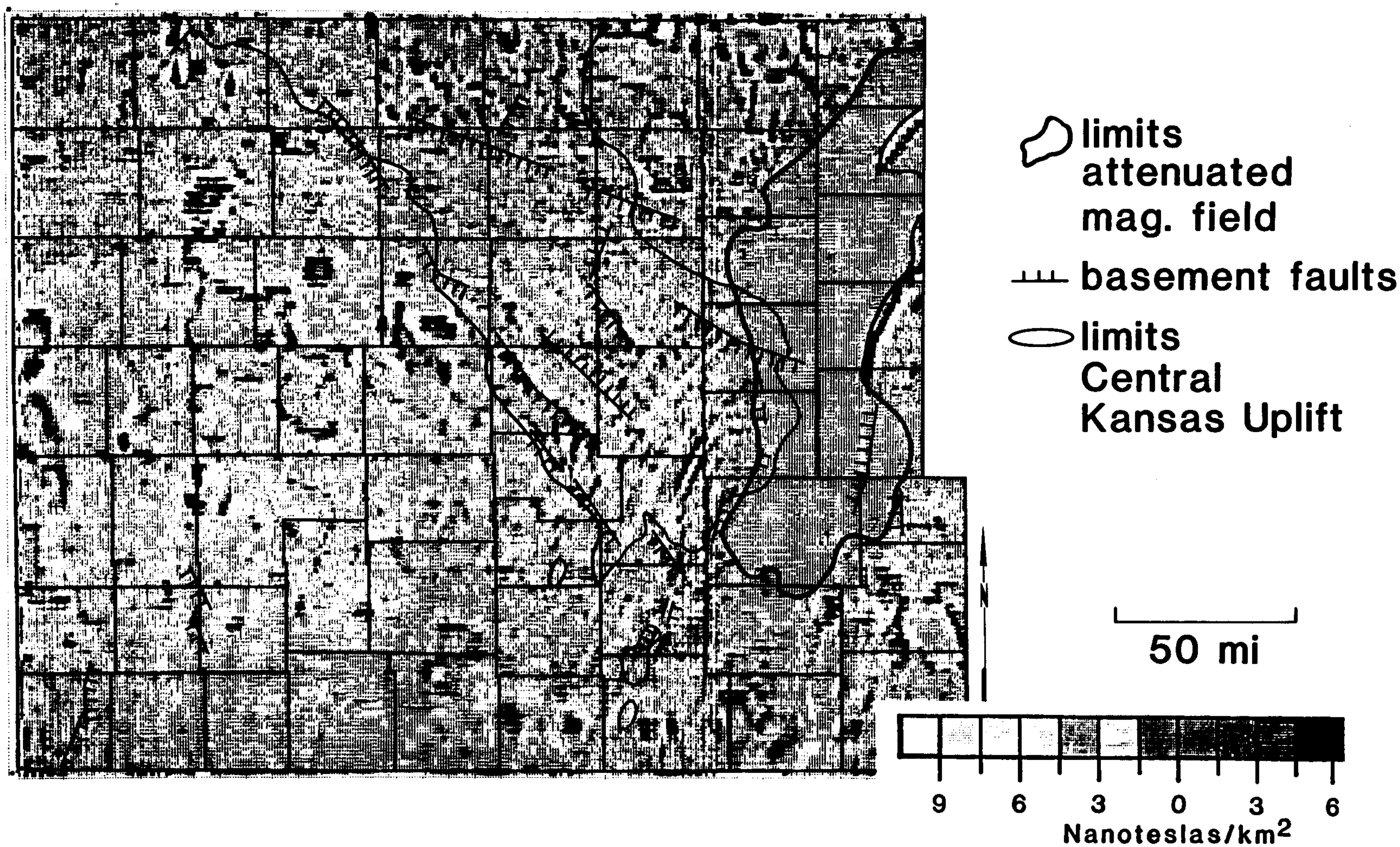
Rhyolite-granite terrain (1500-1300 m.y.)
Bickford etal. (1981)

Exposed Precambrian Rock

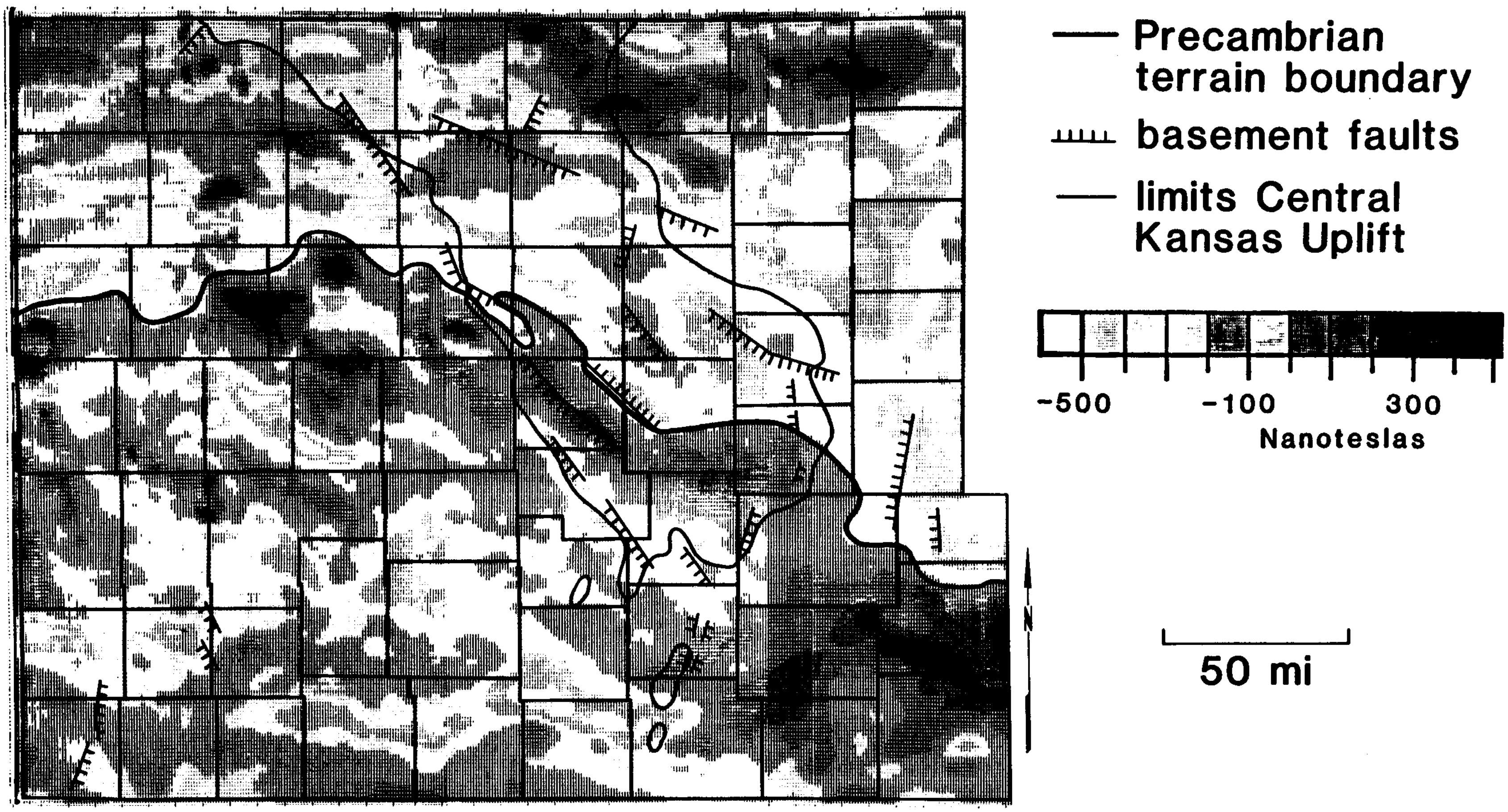
100 Miles

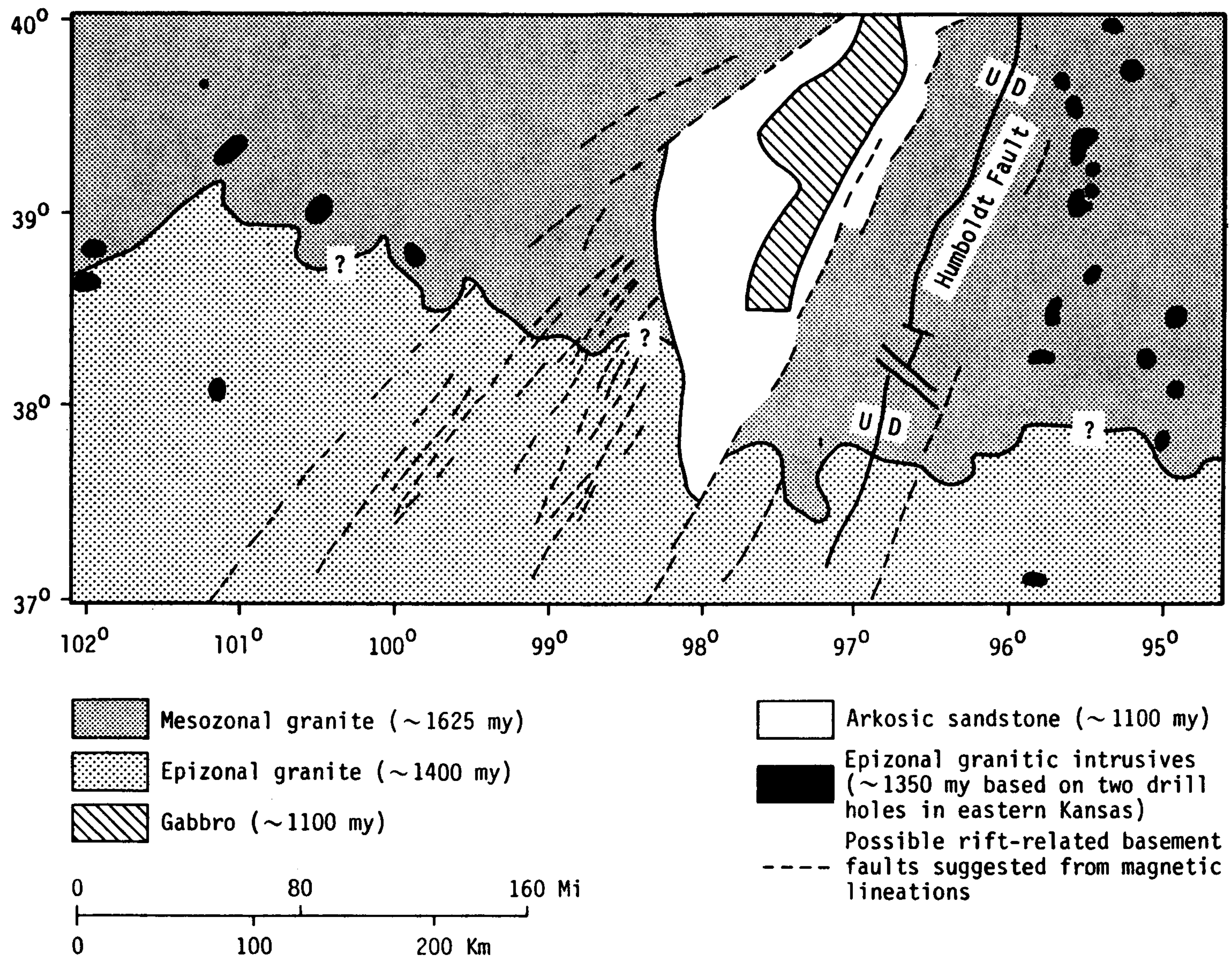
from Dutch (1983)

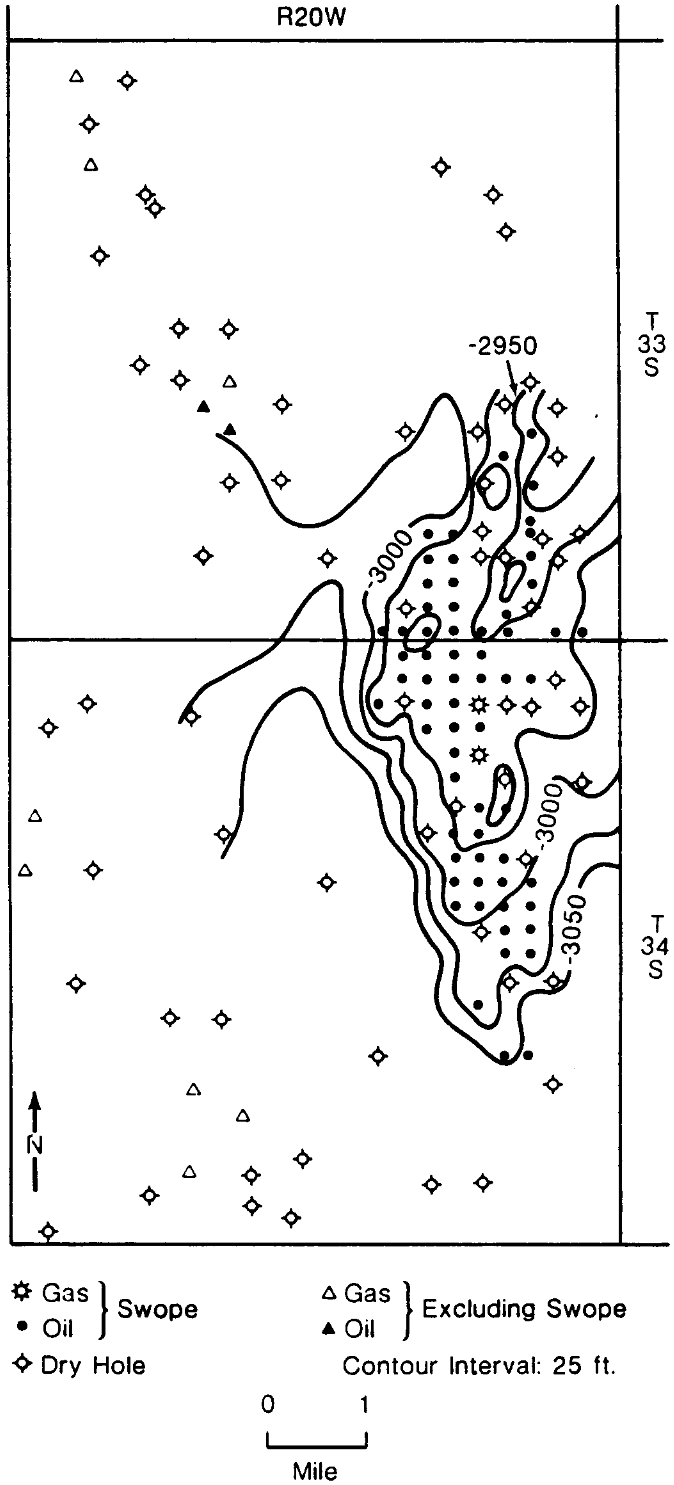
2nd Vertical Derivative of Mag. Field (Yarger, 1983)

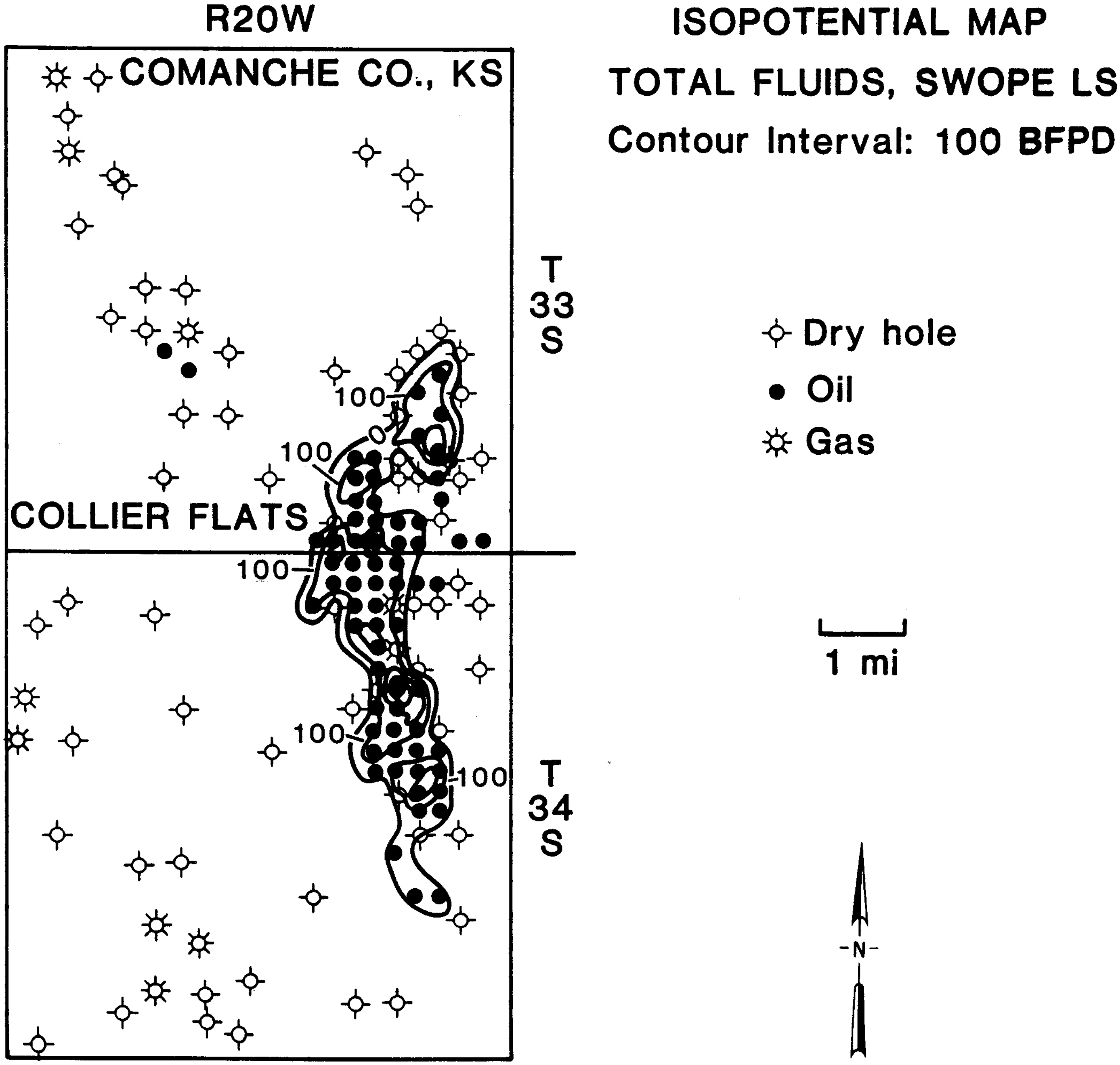


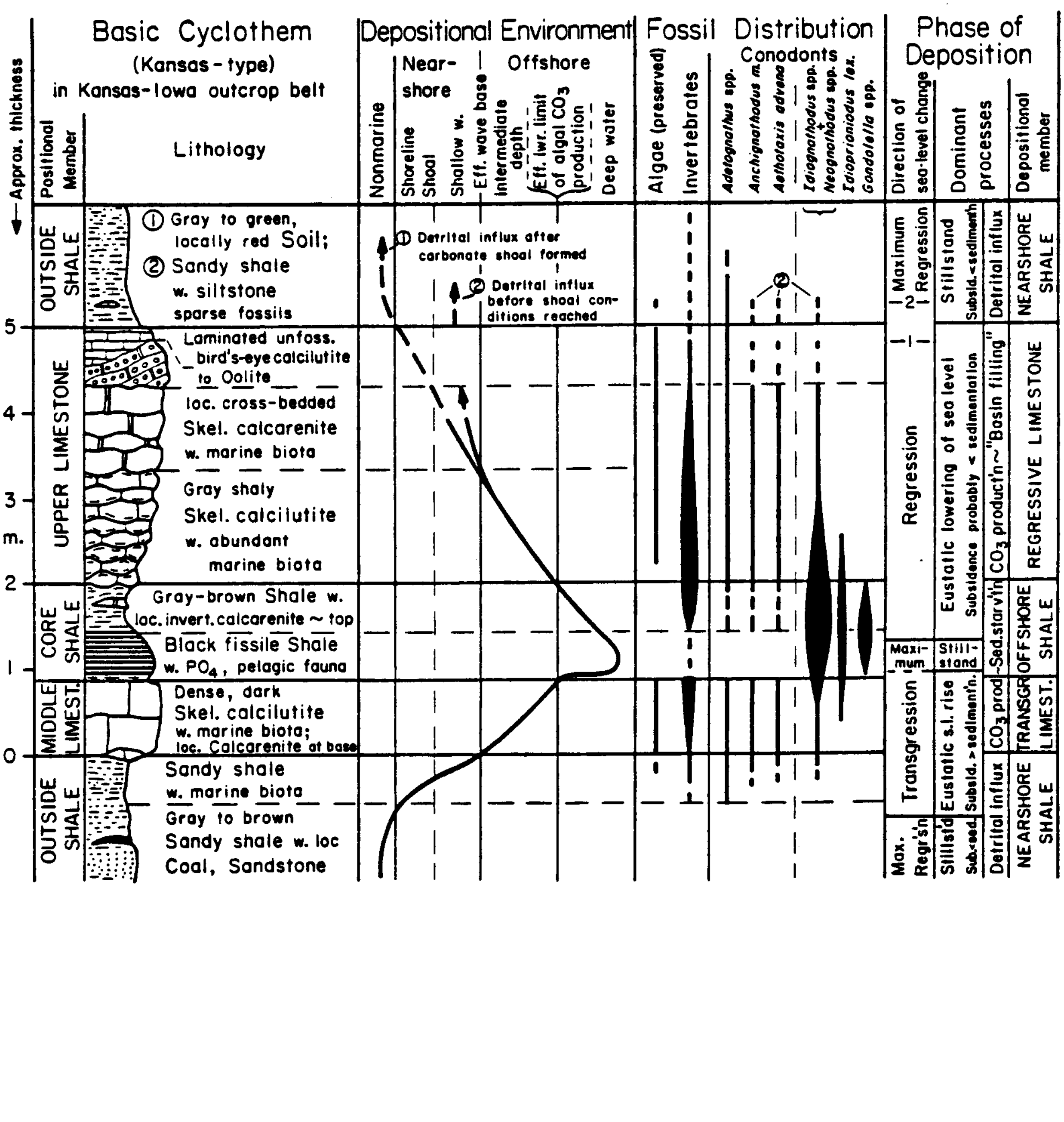
Pole Correction Map of Magnetic Field (Yarger, 1983)

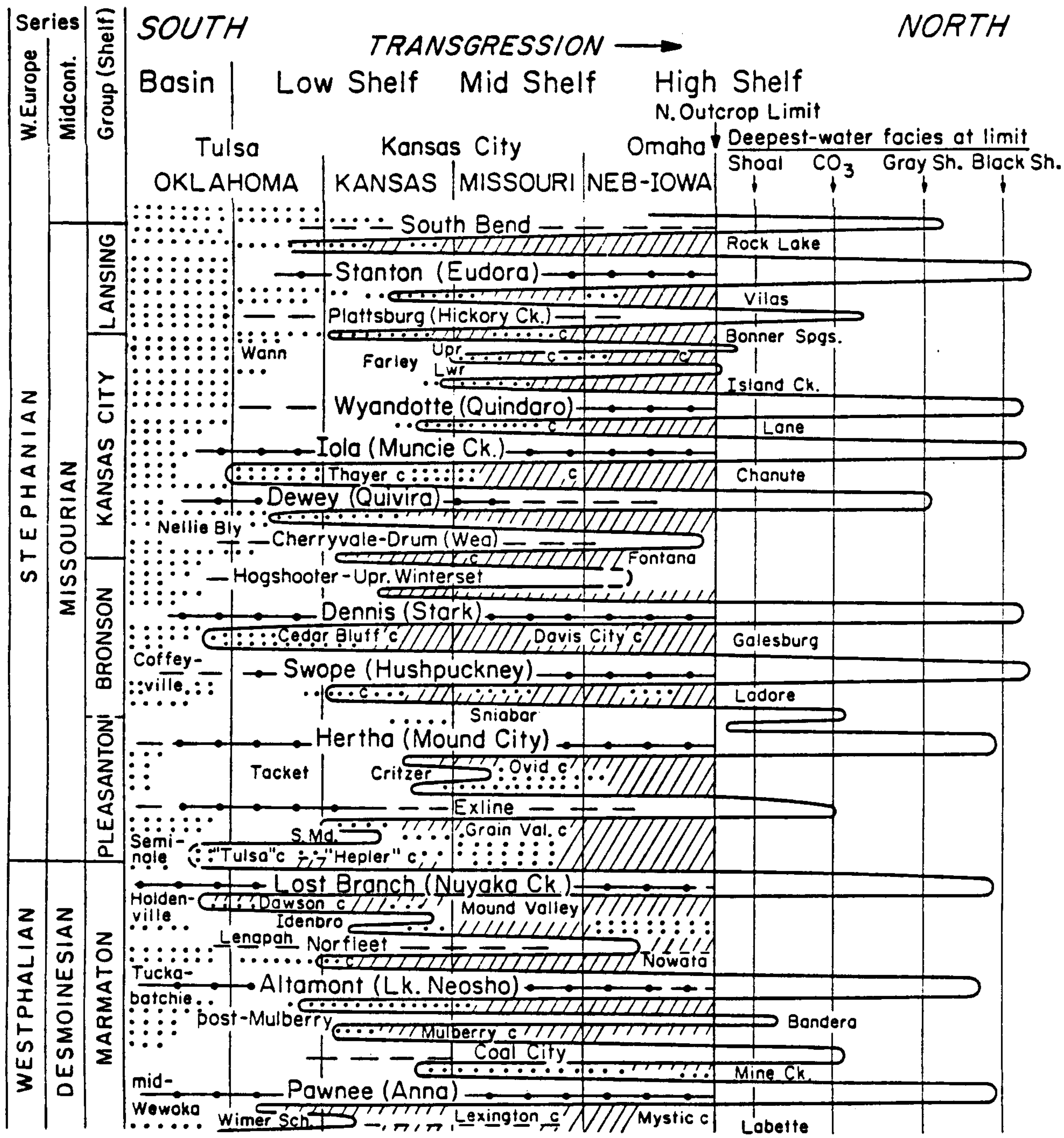



40°
39°
38°
37°
102°
101°
100°
99°
98°
97°
96°
95°
U D
Humboldt Fault
U D
?
?
?
Mesozonal granite (~1625 my)
Epizonal granite (~1400 my)
Gabbro (~1100 my)
Arkosic sandstone (~1100 my)
Epizonal granitic intrusives (~1350 my based on two drill holes in eastern Kansas)
Possible rift-related basement faults suggested from magnetic lineations
0
80
160 Mi
0
100
200 Km


R20W
-2950
-3000
-3000
-3050
T 33 S
T 34 S
N
Gas
Oil
Swope
Dry Hole
Gas
Oil
Excluding Swope
Contour Interval: 25 ft.
0
1
Mile

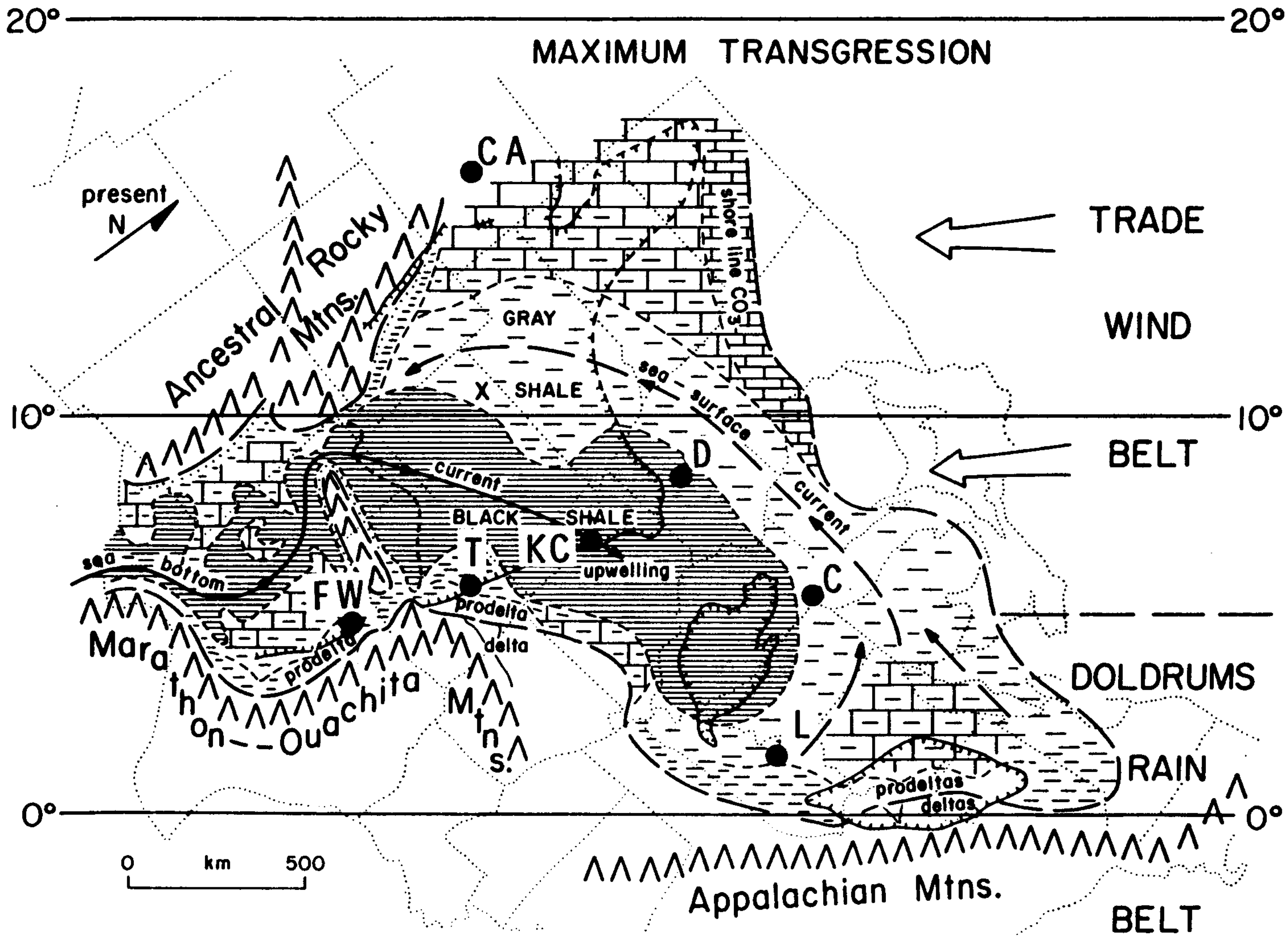

R20W
COMANCHE CO., KS
T
33
S
100
100
COLLIER FLATS
100
100
100
T
34
S
ISOPOTENTIAL MAP
TOTAL FLUIDS, SWOPE LS
Contour Interval: 100 BFPD
Dry hole
Oil
Gas
1 mi
N

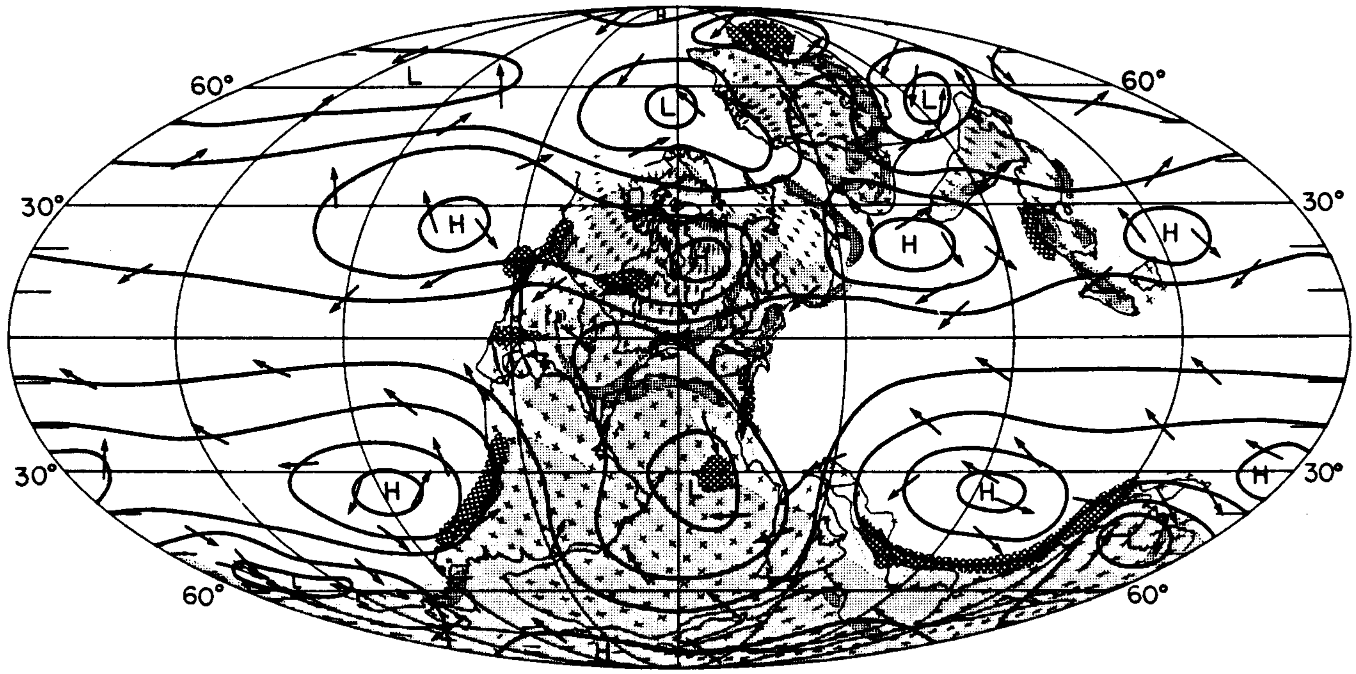

Basic Cyclothem
(Kansas-type)
in Kansas-Iowa outcrop belt
Approx. thickness
Positional Member
Lithology
OUTSIDE SHALE
① Gray to green, locally red Soil;
② Sandy shale w. siltstone sparse fossils
UPPER LIMESTONE
Laminated unfoss. bird's-eye calcilutite to Oolite
loc. cross-bedded Skel. calcarenite w. marine biota
Gray shaly Skel. calcilutite w. abundant marine biota
CORE SHALE
Gray-brown Shale w. loc. invert. calcarenite ~ top
Black fissile Shale w. PO4, pelagic fauna
MIDDLE LIMEST.
Dense, dark Skel. calcilutite w. marine biota; loc. Calcarenite at base
OUTSIDE SHALE
Sandy shale w. marine biota
Gray to brown Sandy shale w. loc Coal, Sandstone
5
4
3
m.
2
1
0
Depositional Environment
Near-shore
Offshore
Nonmarine
Shoreline
Shoal
Shallow w.
Eff. wave base
Intermediate depth
Eff. lwr. limit of algal CO3 production
Deep water
① Detrital influx after carbonate shoal formed
② Detrital influx before shoal conditions reached
Fossil Distribution
Algae (preserved)
Invertebrates
Conodonts
Adetognathus spp.
Anchignathodus m.
Aethotaxis advena
Idiognathodus spp. + Neognathodus spp.
Idioprioniodus lex.
Gondolella spp.
Phase of Deposition
Direction of sea-level change
Dominant processes
Depositional member
Maximum Regression
Regression
Maximum
Transgression
Max. Regr'sn
Stillstand
Subsid. < sedimen'th
Eustatic lowering of sea level
Subsidence probably < sedimentation
Still-stand
Eustatic s.l. rise
Subsid. > sedimen'n.
Stillst'd
Sub. < sed.
Detrital influx
CO3 product'n ~ "Basin filling"
Sed. starv'tn
CO3 prod
NEARSHORE SHALE
REGRESSIVE LIMESTONE
OFFSHORE SHALE
TRANSGR LIMEST.



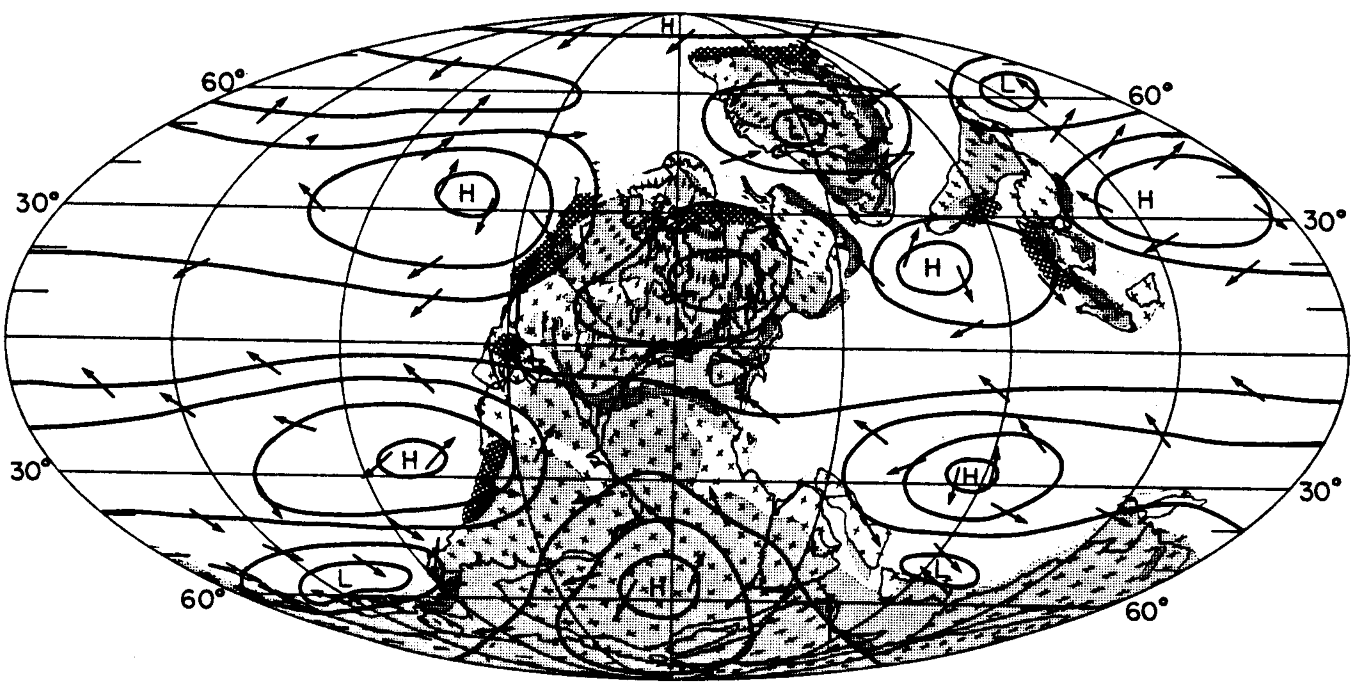
Series
W.Europe
Midcont.
Group (Shelf)
SOUTH
TRANSGRESSION
NORTH
Basin
Low Shelf
Mid Shelf
High Shelf
N. Outcrop Limit
Deepest-water facies at limit
Tulsa
Kansas City
Omaha
Shoal
CO3
Gray Sh.
Black Sh.
OKLAHOMA
KANSAS
MISSOURI
NEB-IOWA
STEPHANIAN
WESTPHALIAN
MISSOURIAN
DESMOINESIAN
LANSING
KANSAS CITY
BRONSON
PLEASANTON
MARMATON
South Bend
Rock Lake
Stanton (Eudora)
Vilas
Plattsburg (Hickory Ck.)
Bonner Spgs.
Wann
Farley
Upr
Lwr
Island Ck.
Wyandotte (Quindaro)
Lane
Iola (Muncie Ck.)
Thayer c
Chanute
Dewey (Quivira)
Nellie Bly
Cherryvale-Drum (Wea)
Fontana
Hogshooter-Upr. Winterset
Dennis (Stark)
Cedar Bluff c
Davis City c
Galesburg
Coffeyville
Swope (Hushpuckney)
Ladore
Sniabar
Hertha (Mound City)
Tacket
Critzer
Ovid c
Exline
S. Md.
Grain Val. c
Seminole
"Tulsa" c
"Hepler" c
Lost Branch (Nuyaka Ck.)
Holdenville
Dawson c
Mound Valley
Idenbro
Lenapah
Norfleet
Nowata
Tuckabatchie
Altamont (Lk. Neosho)
post-Mulberry
Mulberry c
Bandera
Coal City
Mine Ck.
mid-Wewoka
Pawnee (Anna)
Wimer Sch.
Lexington c
Mystic c
Labette

UPPER PENNSYLVANIAN PALEOGEOGRAPHY, CENTRAL U.S.

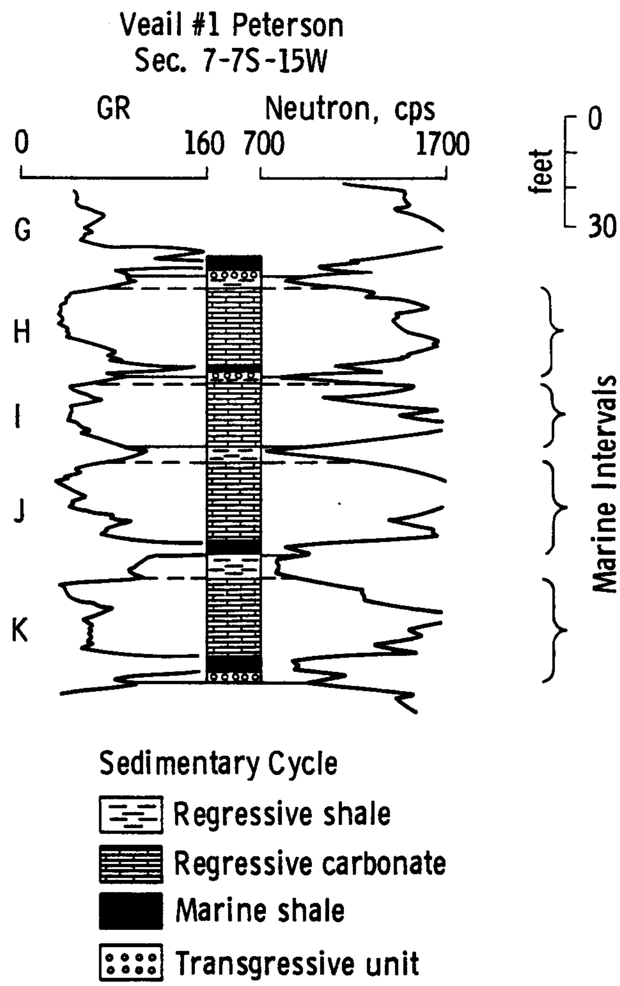




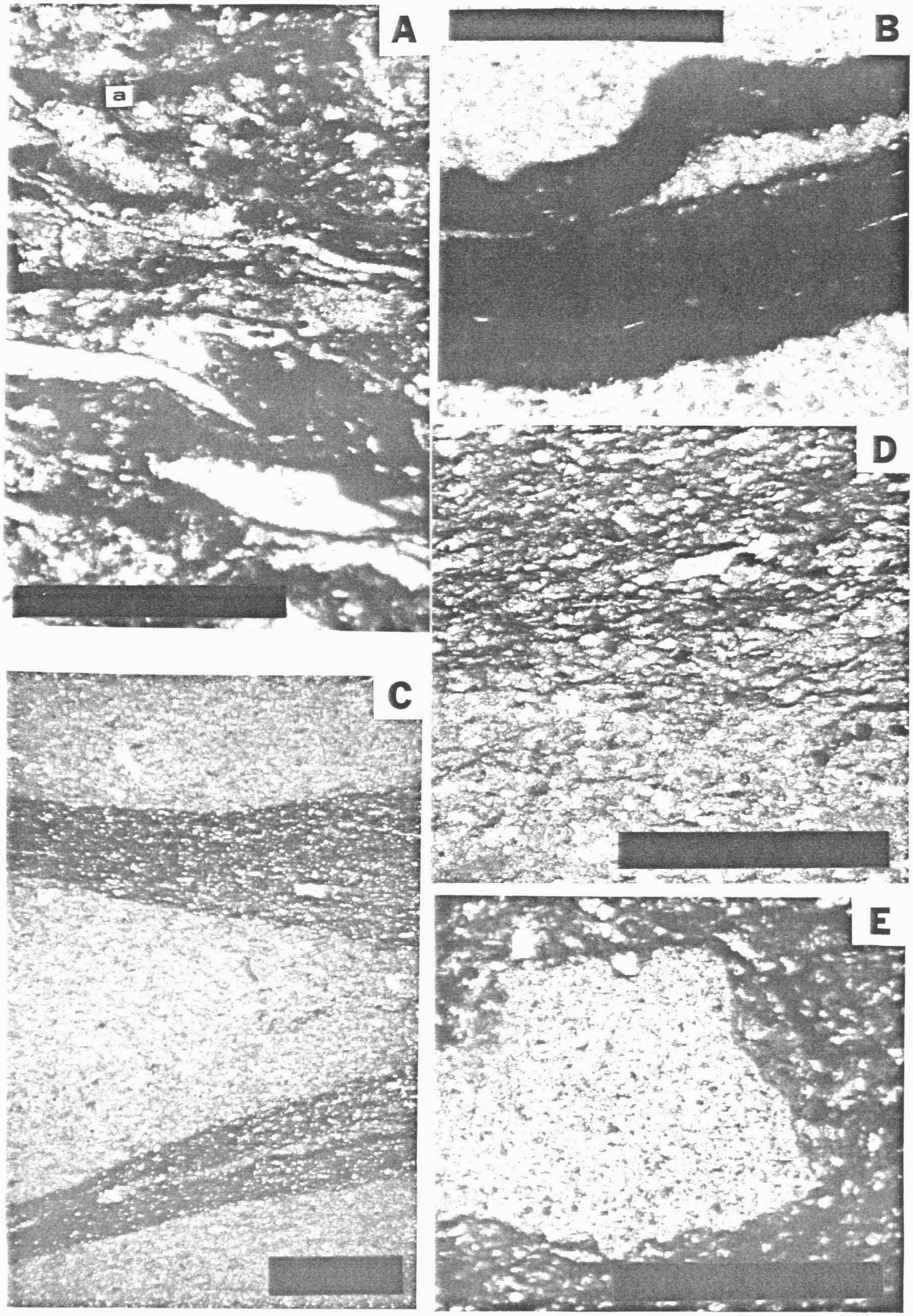
60°
60°
30°
30°
30°
30°
60°
60°
L
L
L
H
H
H
H
H
L
H
H
L
H



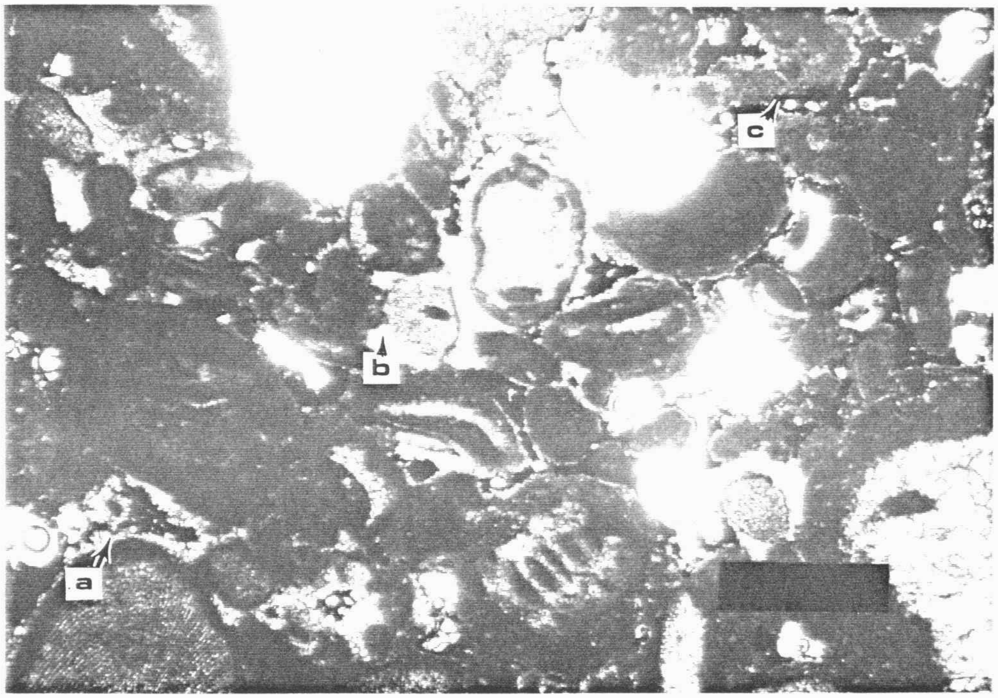
H
60°
60°
30°
30°
30°
30°
60°
60°
L
L
H
H
H
H
H
L
L
H



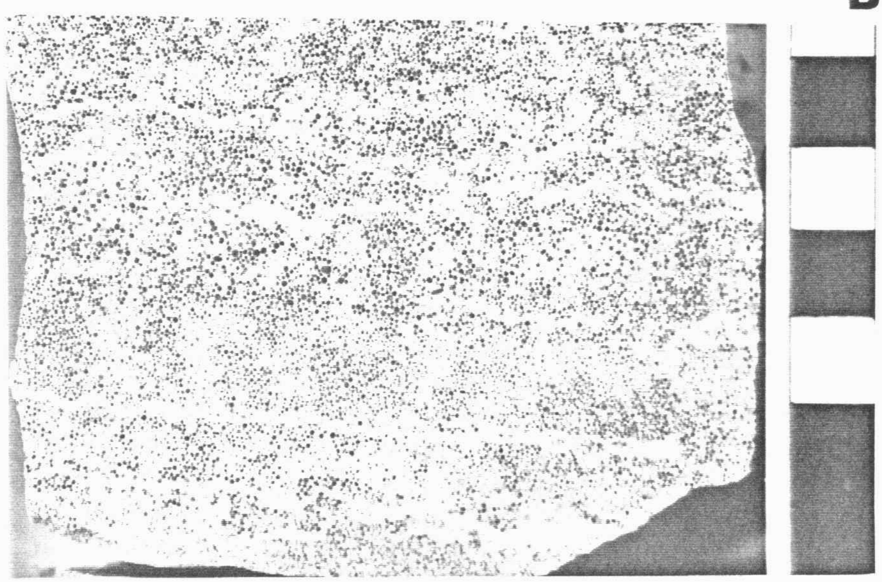
Veail #1 Peterson
Sec. 7-7S-15W
GR
0
160
Neutron, cps
700
1700
feet
0
30
G
H
I
J
K
Marine Intervals
Sedimentary Cycle
Regressive shale
Regressive carbonate
Marine shale
Transgressive unit

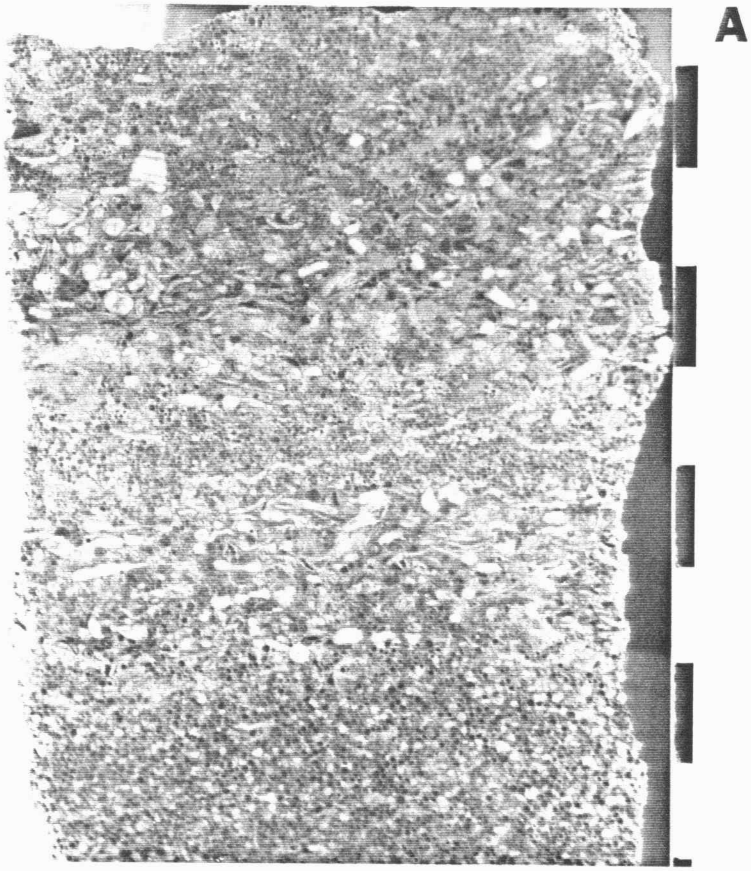

A
a
B
C
D
E

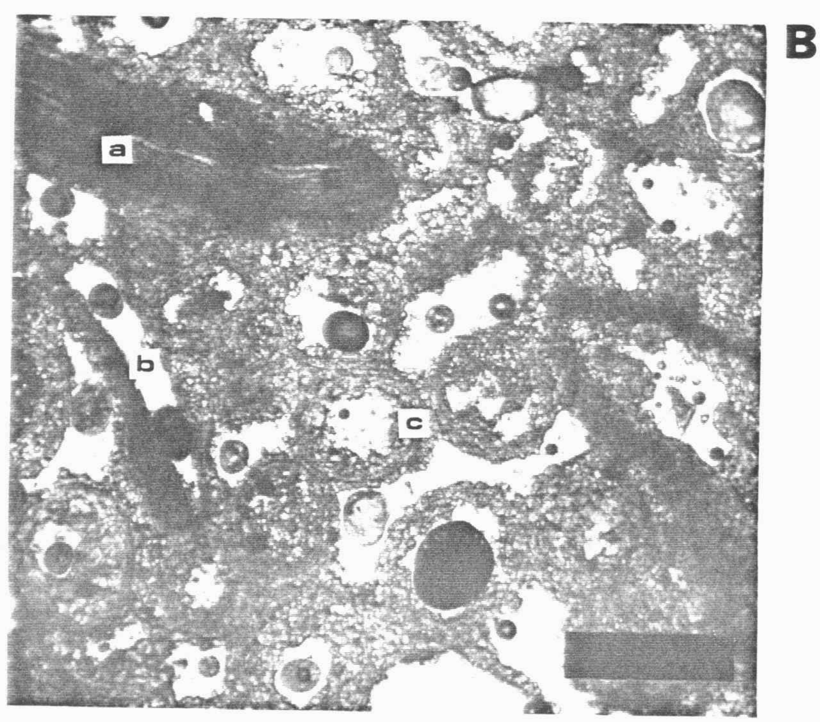
A



B



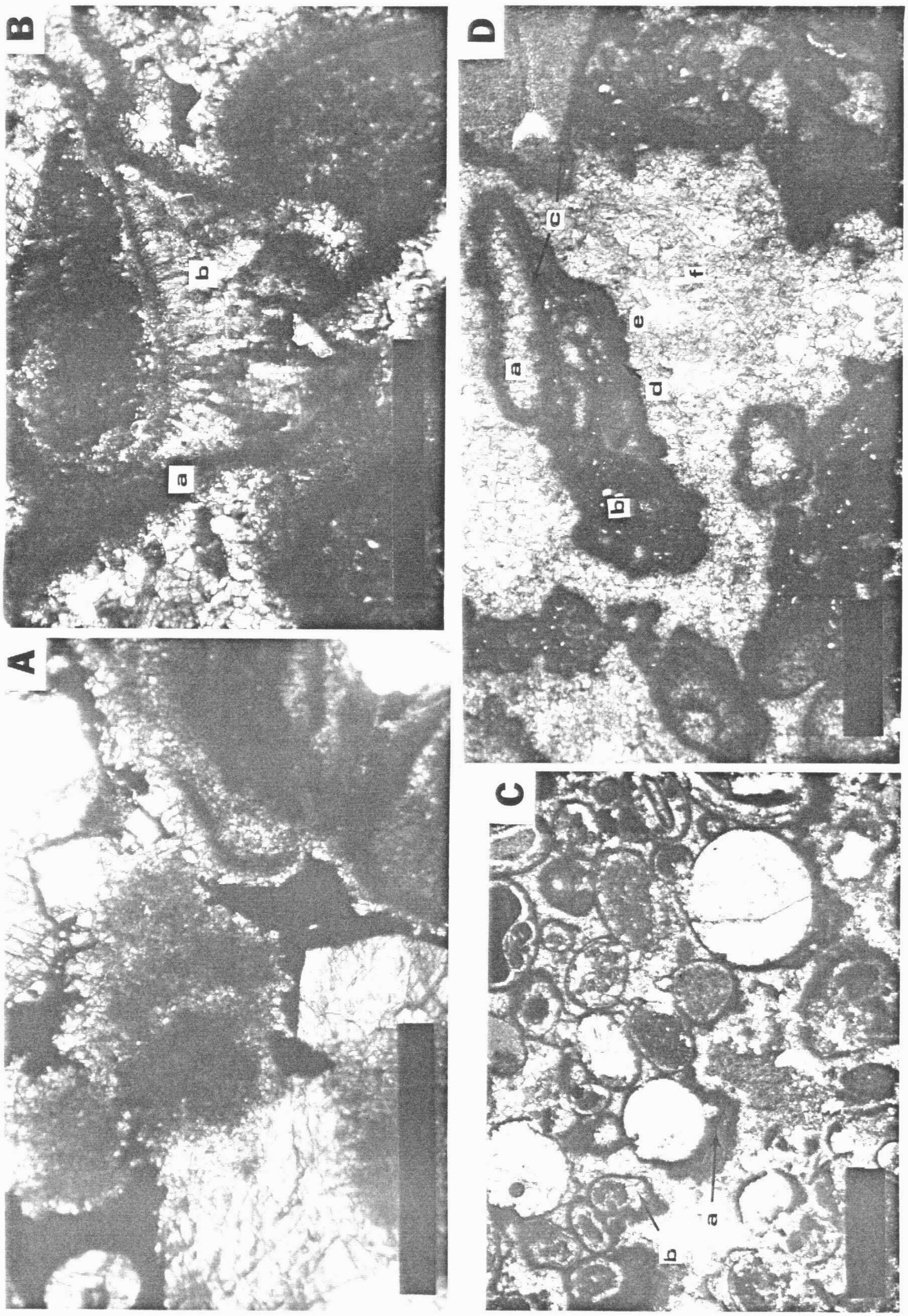

A


B
a
b
c

Kansas Geological Survey

Open File Report 1986-01

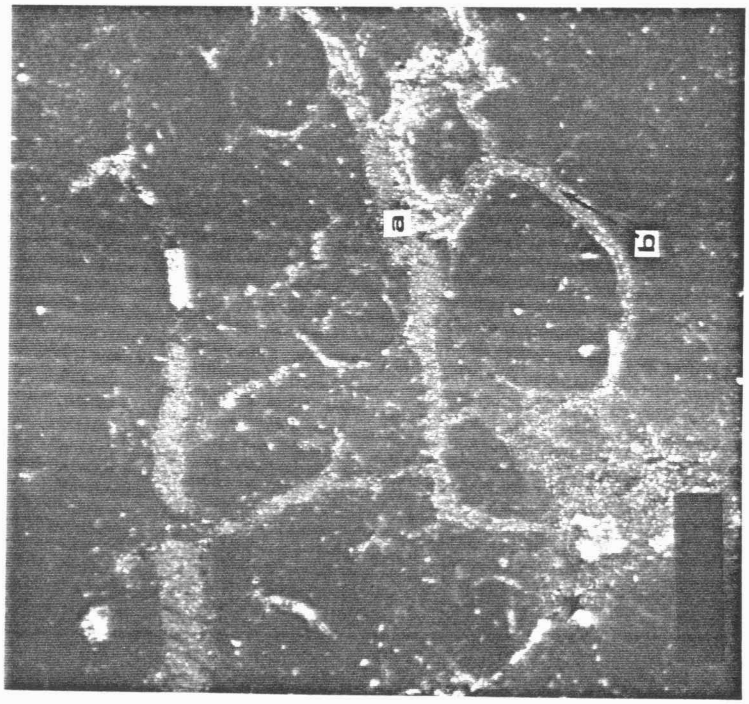
Missing Figure #37A, B, C


B
A
D
C

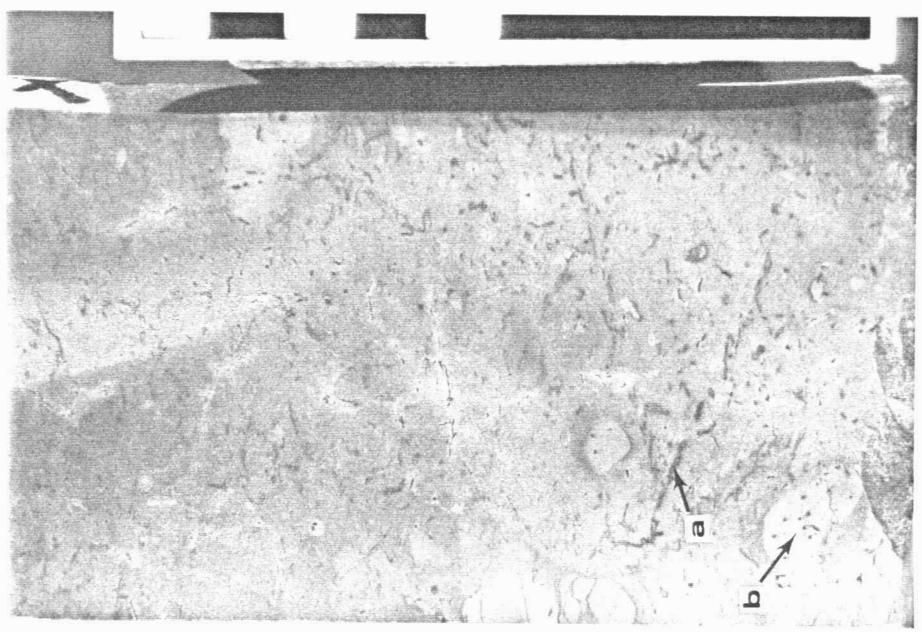
B

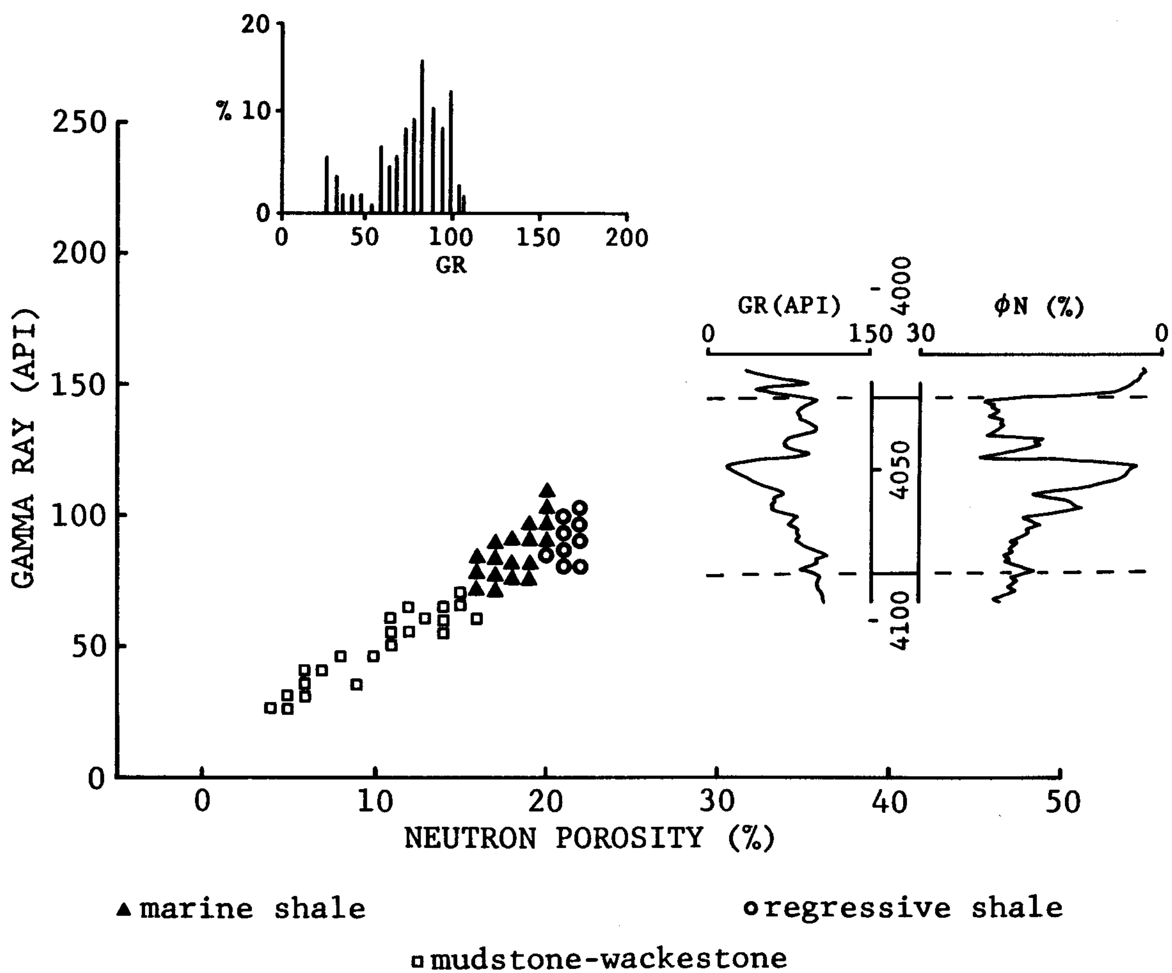
A

B

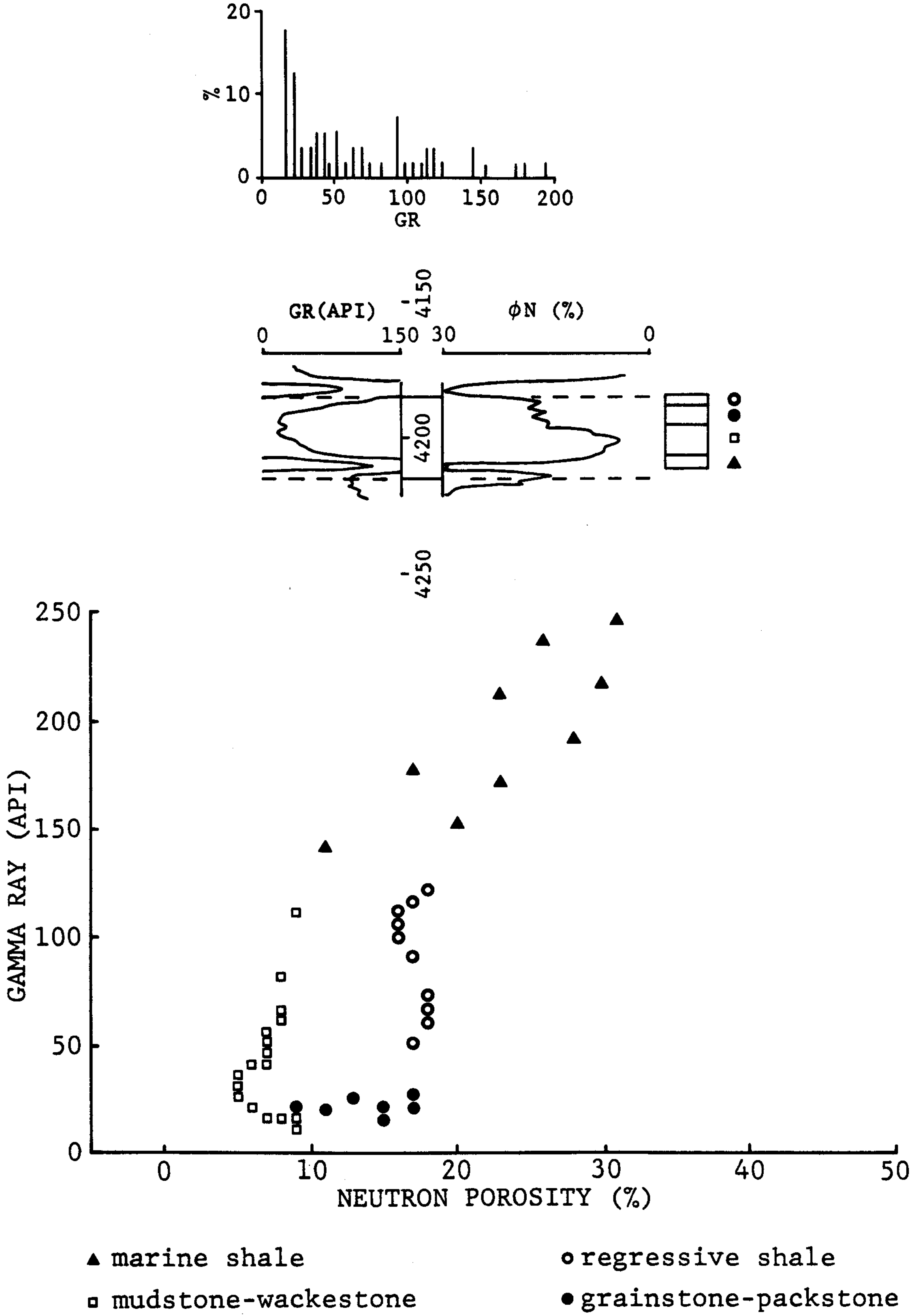


A

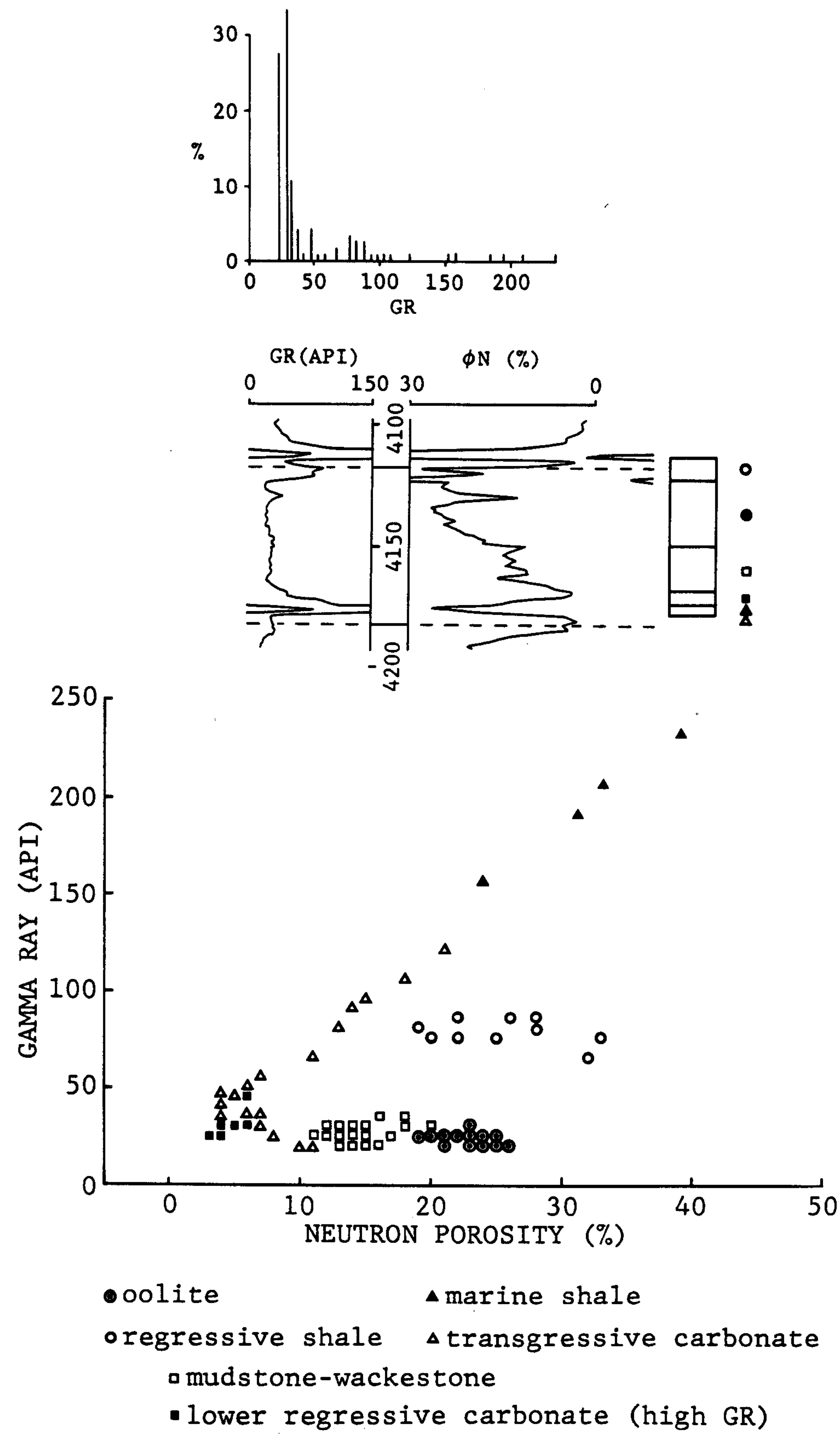


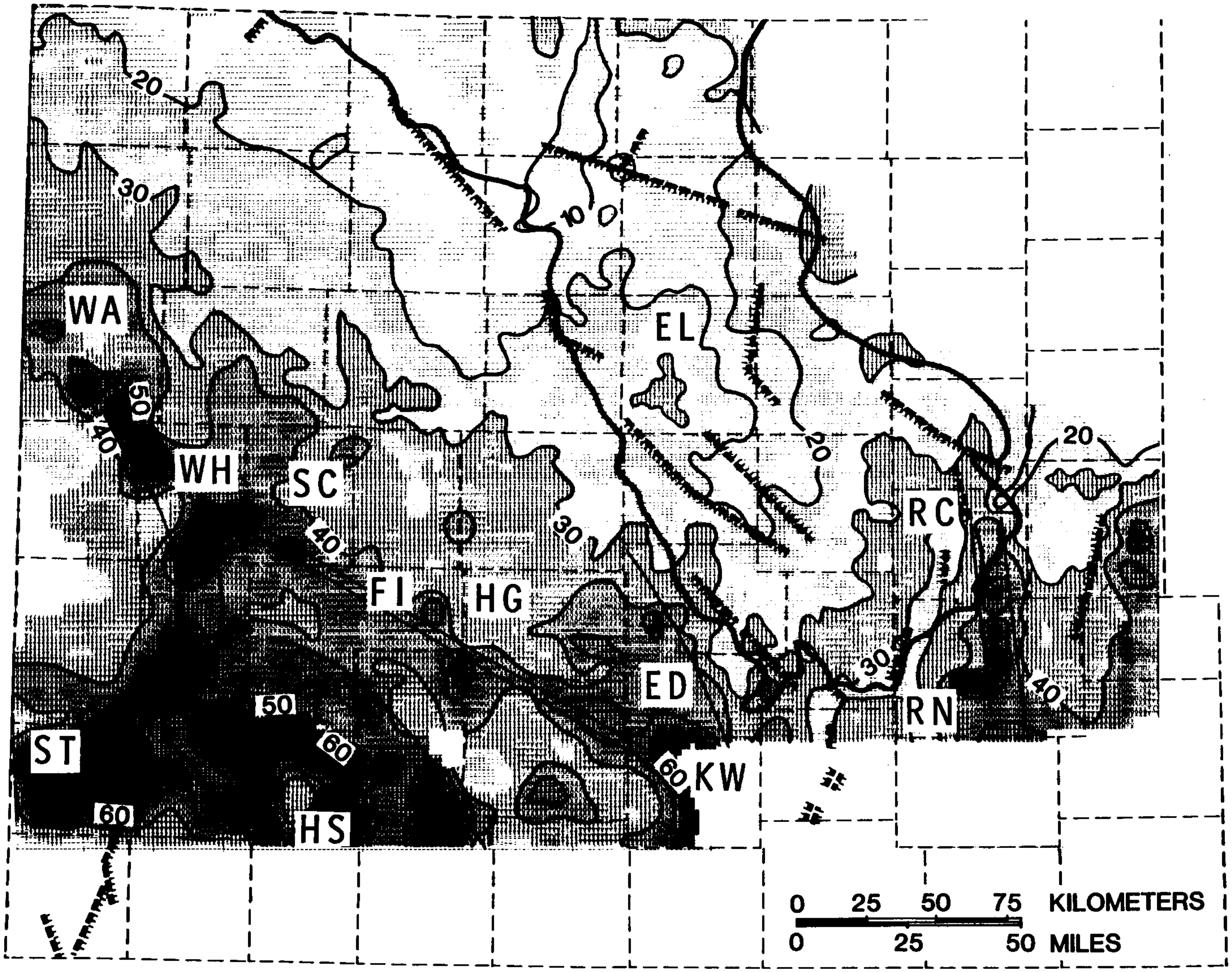


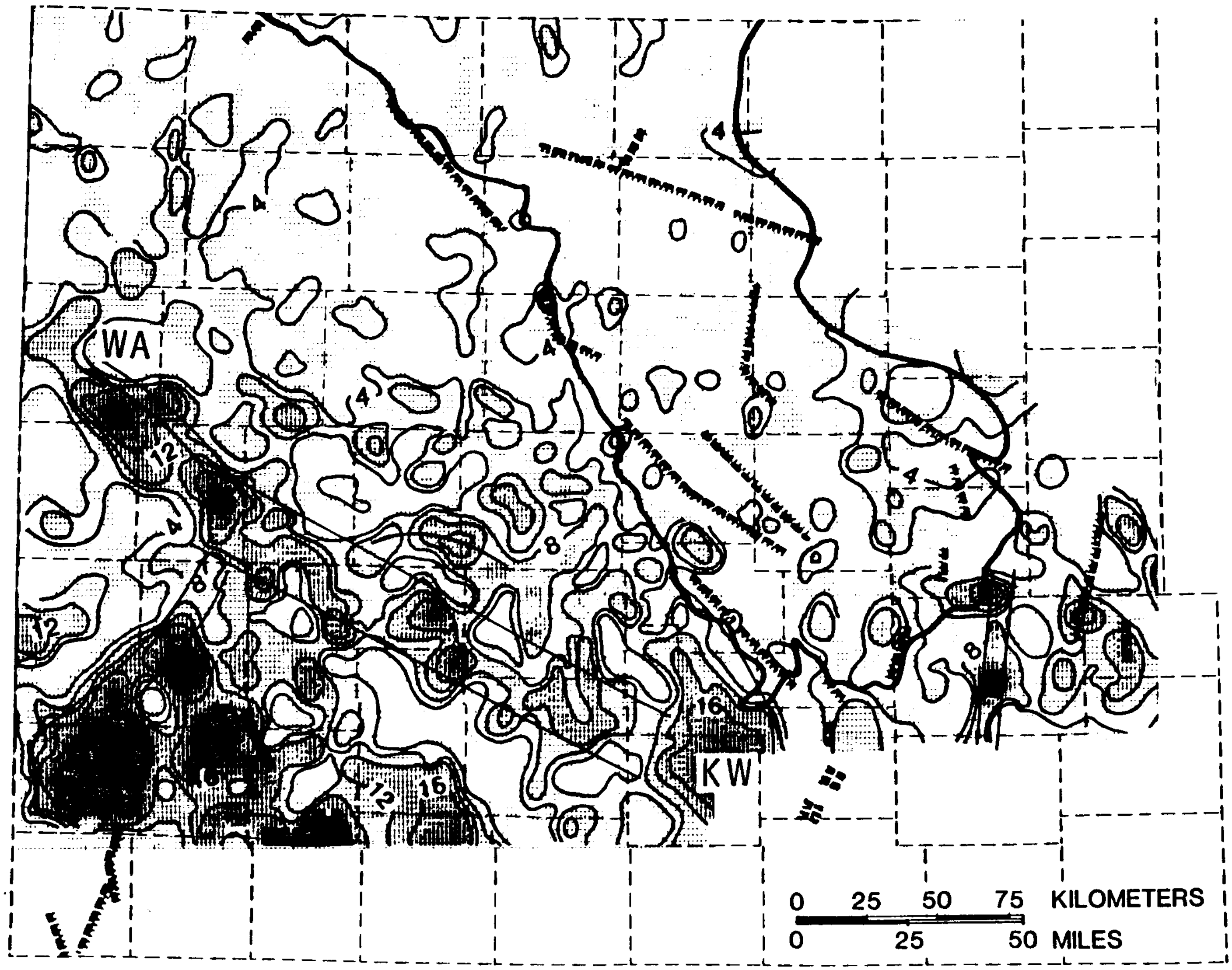
20
% 10
0
0
50
100
150
200
GR
GAMMA RAY (API)
250
200
150
100
50
0
NEUTRON POROSITY (%)
0
10
20
30
40
50
GR(API)
0
150
30
ϕN (%)
0
4000
4050
4100
▲ marine shale
o regressive shale
▫ mudstone-wackestone

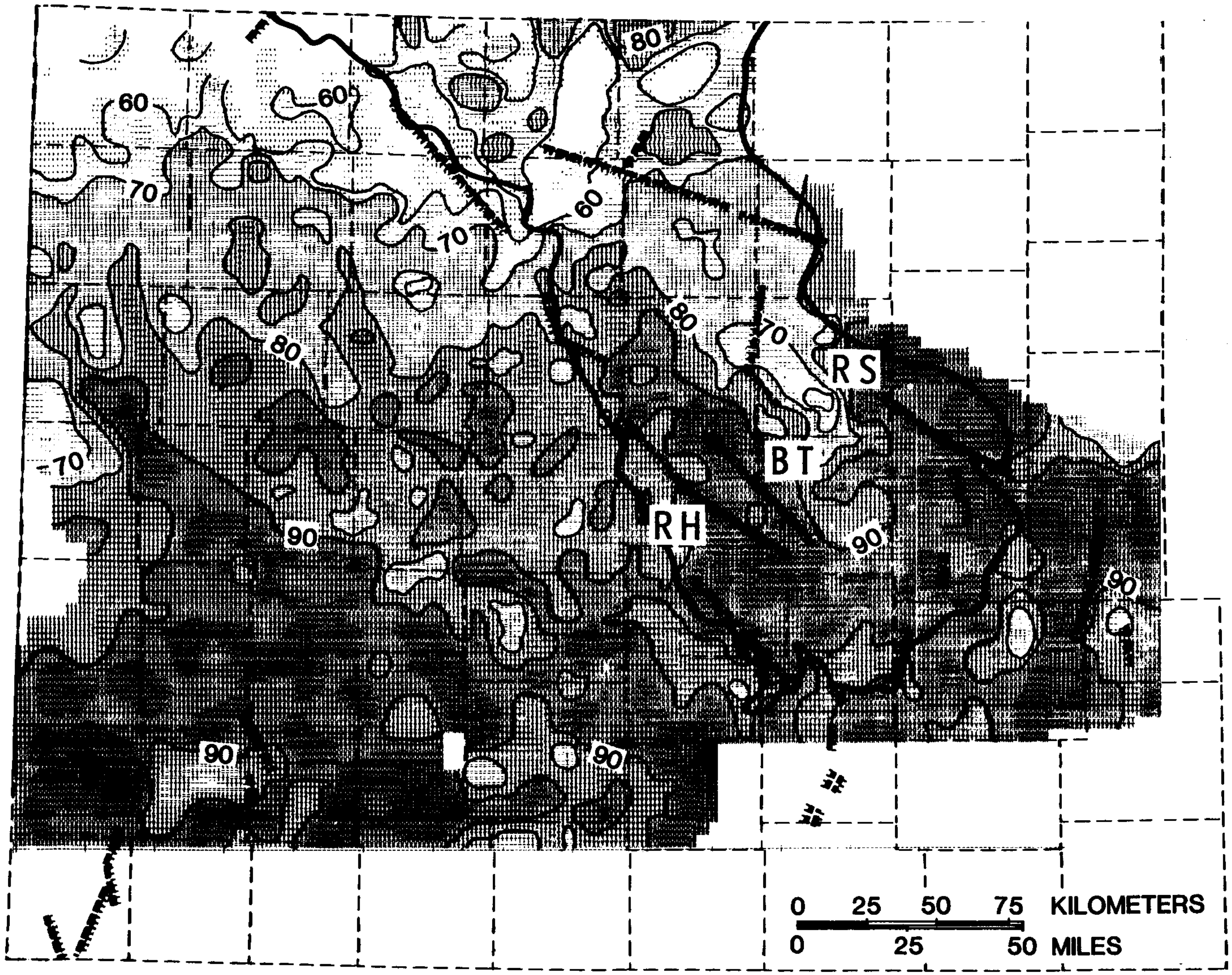


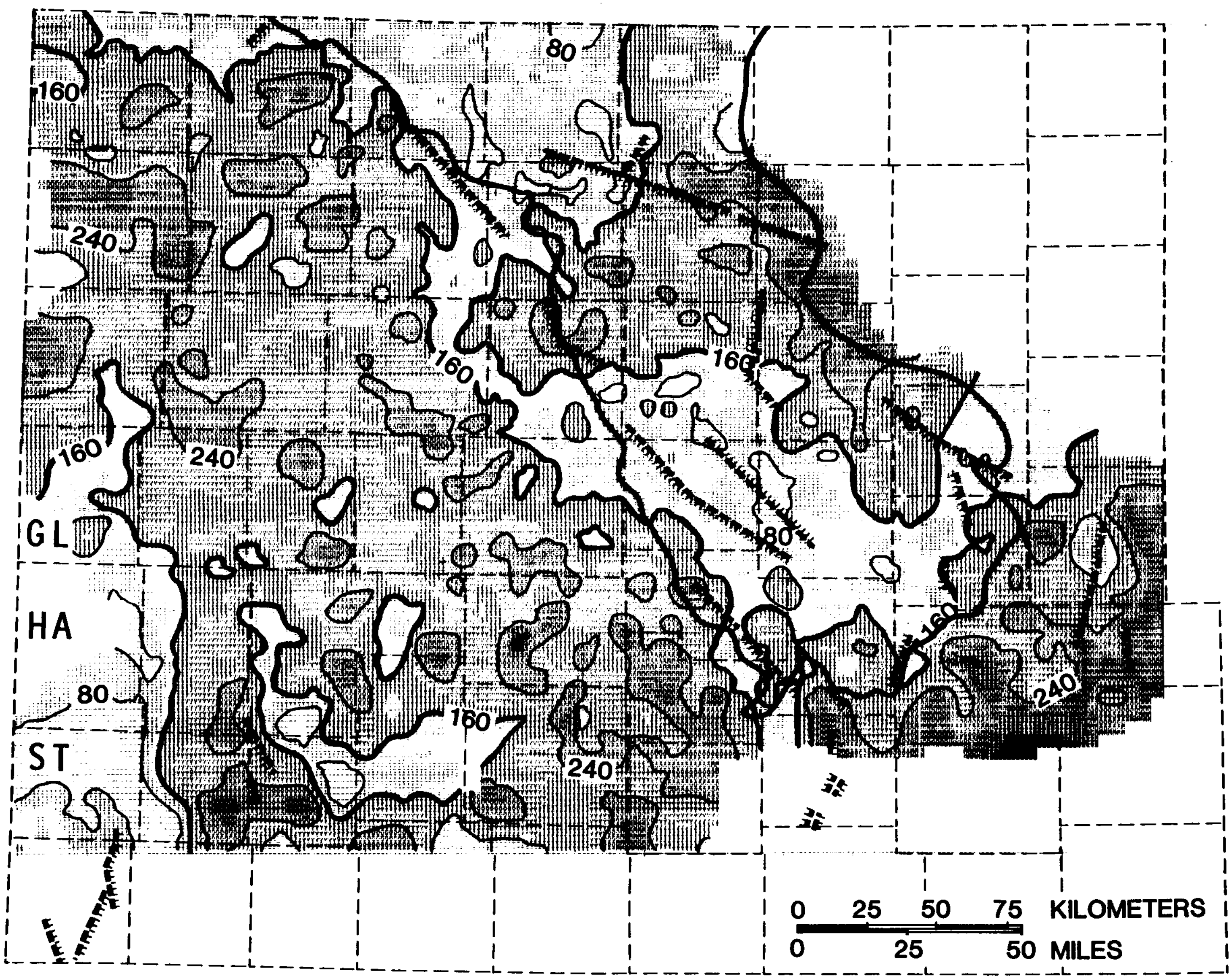
%
GR
GR(API)
φN (%)
4150
4200
4250
GAMMA RAY (API)
NEUTRON POROSITY (%)
▲ marine shale
□ mudstone-wackestone
○ regressive shale
● grainstone-packstone

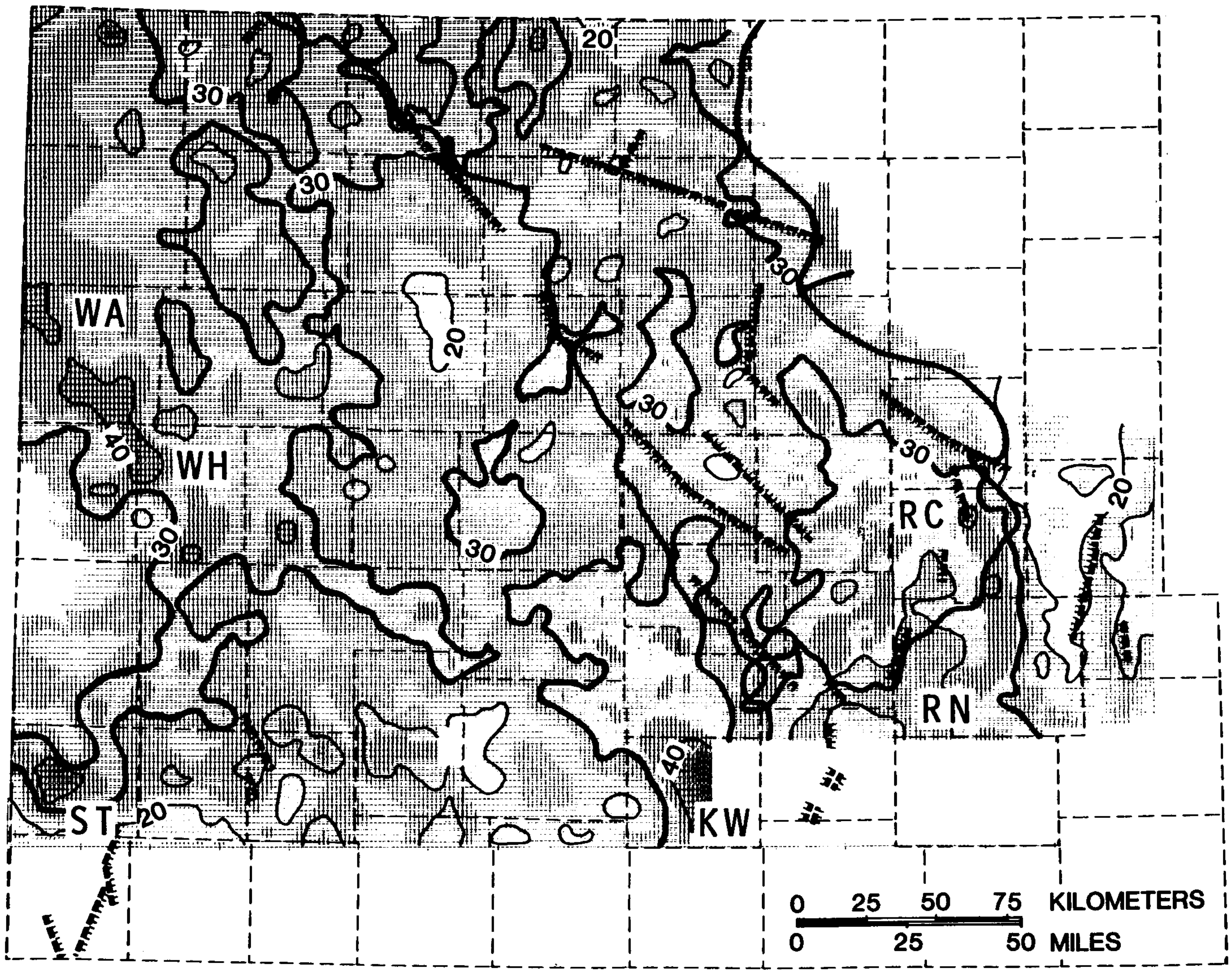

%
GR
GR(API)
φN (%)
4100
4150
4200
GAMMA RAY (API)
NEUTRON POROSITY (%)
oolite
marine shale
regressive shale
transgressive carbonate
mudstone-wackestone
lower regressive carbonate (high GR)

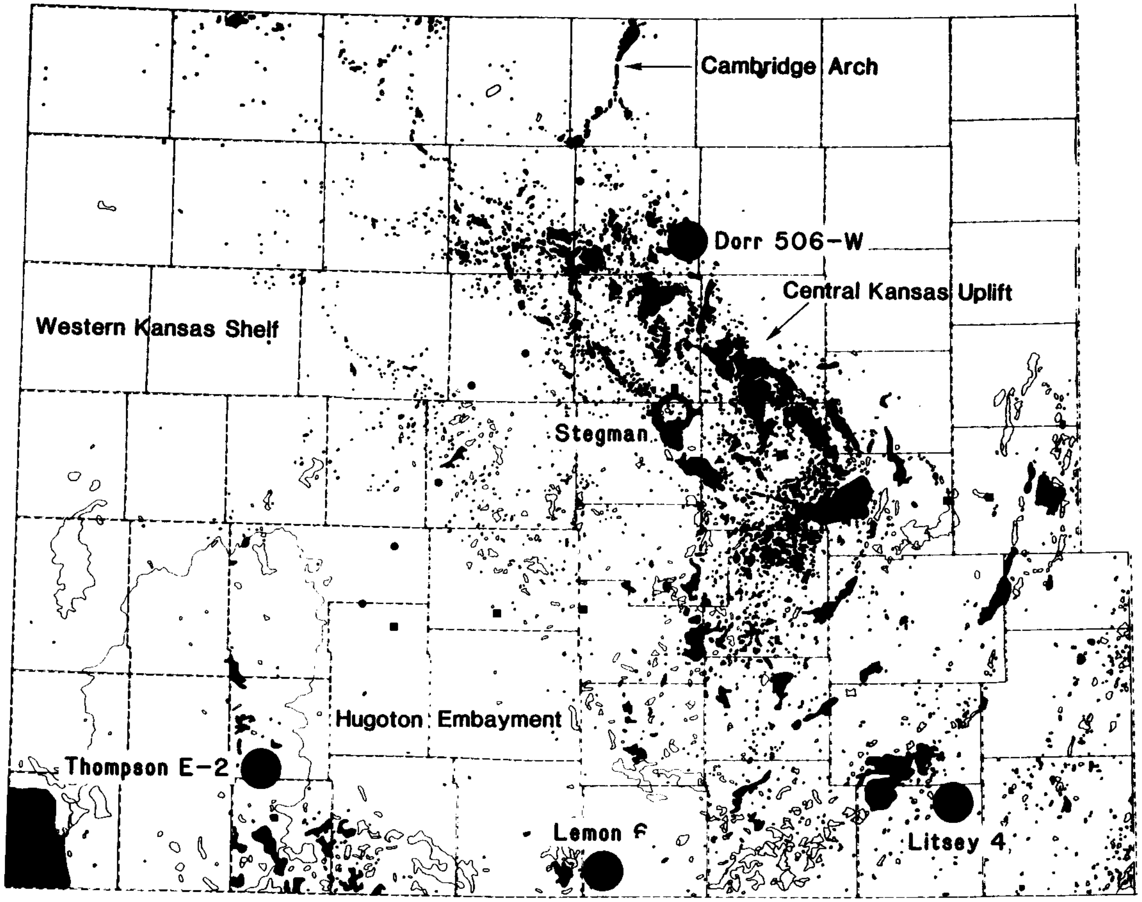

WA
WH
SC
FI
HG
EL
ED
KW
RC
RN
ST
HS
10
20
30
40
50
60
0 25 50 75 KILOMETERS
0 25 50 MILES


WA
KW
4
8
12
16
0 25 50 75 KILOMETERS
0 25 50 MILES

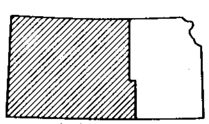

60
60
80
70
60
70
80
70
80
RS
70
BT
RH
90
90
90
90
90
0 25 50 75 KILOMETERS
0 25 50 MILES

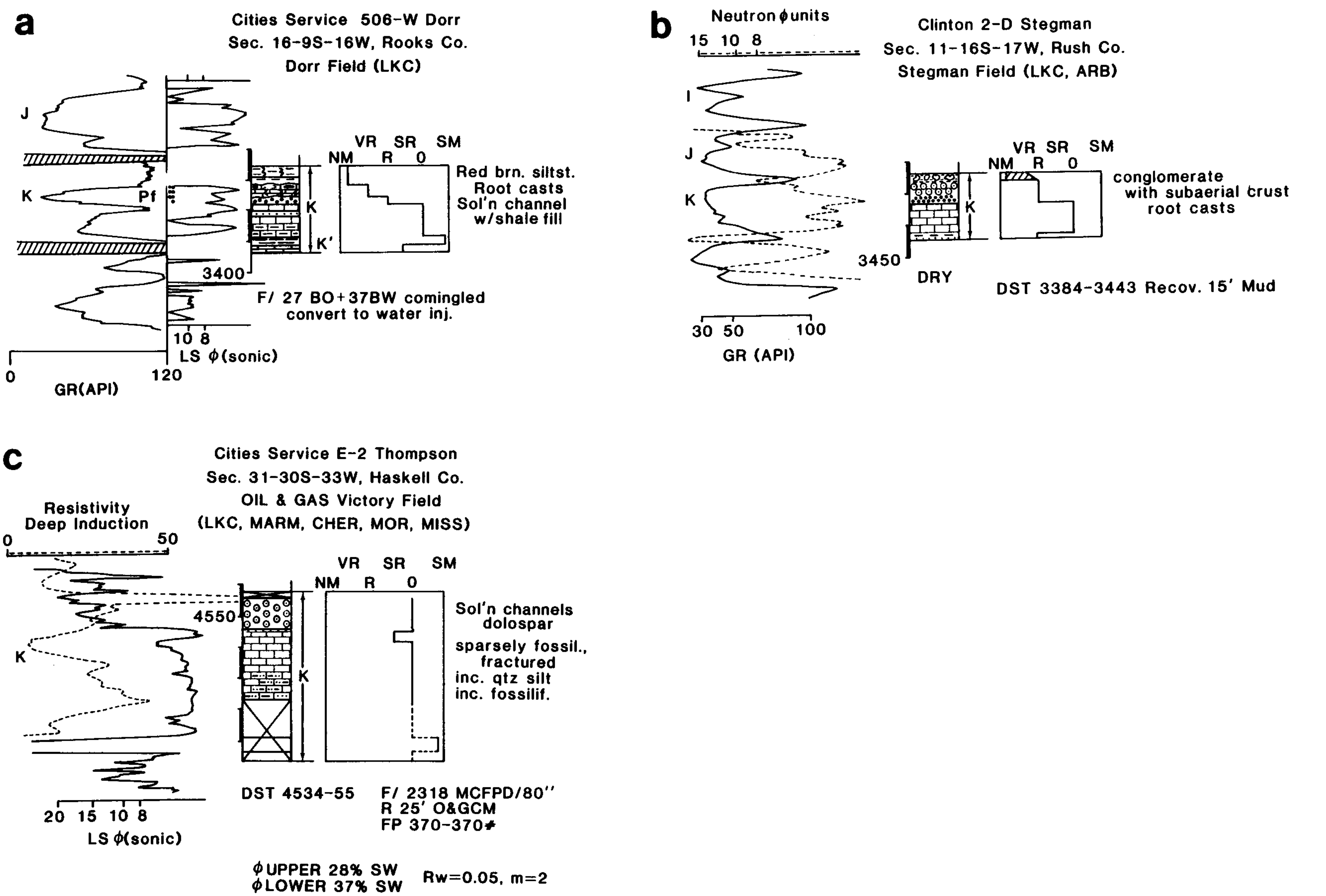

80
160
240
160
160
160
80
GL
HA
80
ST
160
240
160
240
0 25 50 75 KILOMETERS
0 25 50 MILES

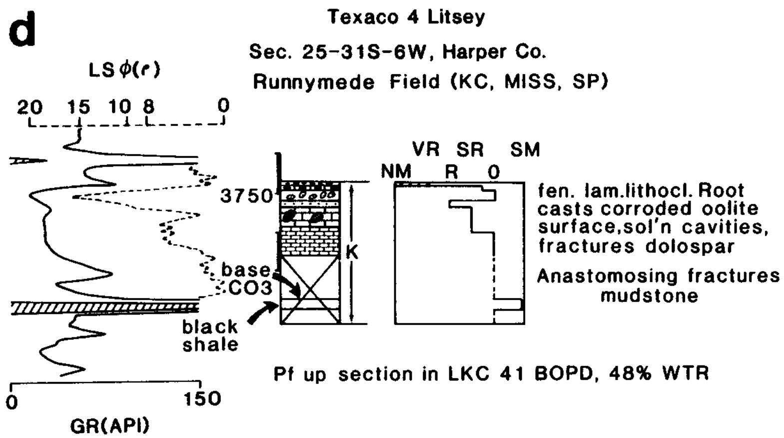

WA
WH
ST
KW
RC
RN
20
30
40
0 25 50 75 KILOMETERS
0 25 50 MILES

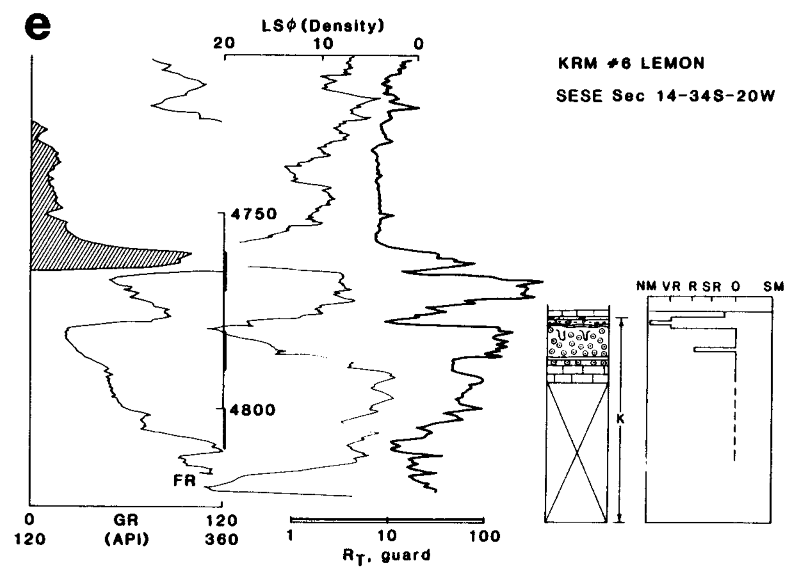


LANSING-KANSAS CITY OIL FIELDS

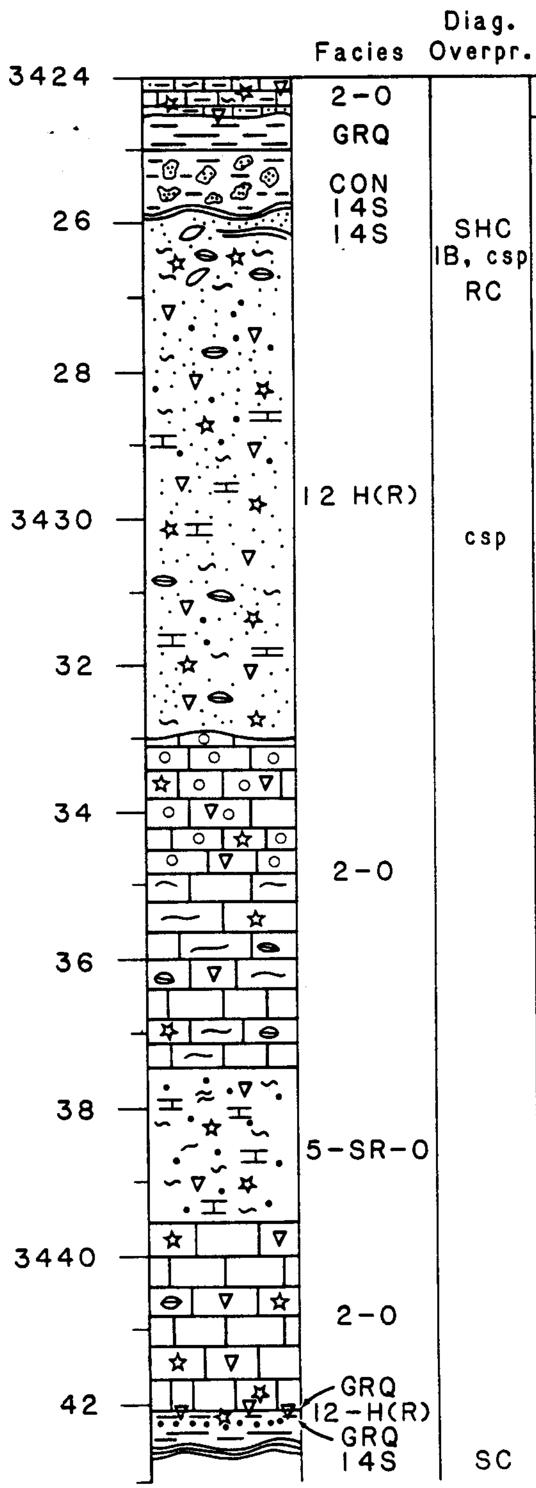



a
Cities Service 506-W Dorr
Sec. 16-9S-16W, Rooks Co.
Dorr Field (LKC)
J
K
Pf
3400
K
K'
VR SR SM
NM R 0
Red brn. siltst.
Root casts
Sol'n channel
w/shale fill
F/ 27 BO+37BW comingled
convert to water inj.
10 8
LS ϕ(sonic)
0 120
GR(API)
b
Neutron ϕ units
15 10 8
Clinton 2-D Stegman
Sec. 11-16S-17W, Rush Co.
Stegman Field (LKC, ARB)
I
J
K
VR SR SM
NM R 0
conglomerate
with subaerial crust
root casts
3450
DRY
DST 3384-3443 Recov. 15' Mud
30 50 100
GR (API)
c
Cities Service E-2 Thompson
Sec. 31-30S-33W, Haskell Co.
OIL & GAS Victory Field
(LKC, MARM, CHER, MOR, MISS)
Resistivity
Deep Induction
0 50
VR SR SM
NM R 0
4550
K
K
Sol'n channels
dolospar
sparsely fossil.,
fractured
inc. qtz silt
inc. fossilif.
20 15 10 8
LS ϕ(sonic)
DST 4534-55
F/ 2318 MCFPD/80"
R 25' O&GCM
FP 370-370#
ϕUPPER 28% SW
ϕLOWER 37% SW
Rw=0.05, m=2


d
Texaco 4 Litsey
Sec. 25-31S-6W, Harper Co.
Runnymede Field (KC, MISS, SP)
LS ϕ(r)
20 15 10 8 0
3750
base CO3
black shale
K
VR SR SM
NM R O
fen. lam.lithocl. Root casts corroded oolite surface,sol'n cavities, fractures dolospar
Anastomosing fractures mudstone
Pf up section in LKC 41 BOPD, 48% WTR
0 150
GR(API)


e
LSϕ (Density)
20 10 0
KRM #6 LEMON
SESE Sec 14-34S-20W
4750
4800
FR
NM VR R SR O SM
K
0 GR 120
120 (API) 360
1 10 100
R_T, guard

CLINTON 2-D STEGMAN



Description

J-Zone

3425-26 (K-zone regressive shale) Carbonate clasts in green shale, dark brown colored grainstone with well rounded bioclasts including fusulinids, crinoids, tubular forams, bivalves; cut by solution enhanced, reticulate intergranular pores lines by brown micritic calcite, cut by sheet cracks; clasts fit together suggesting an insitu origin; shale sits on laminated carbonate crust that is developed in multiple layers; crust consists of dark brown, microcrystalline calcite

3426-33 (K-zone regressive carbonate) Coated, peloid packstone to grainstone with diverse fossils including large crinoids and brachiopods; upper portion of unit contains abundant root tubes lined with dark brown micritic calcite; upper portion strongly overprinted with brown dense carbonate; faint cross stratification and sharp base with wackestone; complex spar cement evolution in thin section with low Fe calcite to medium Fe dolomite to Fe calcite in same zoned crystal; initial cement irregularly distributed, blocky followed by coarser calcspar

3433-35 Wackestone with diverse fossils burrowed with scattered coated grains

3435-37.5 Wackestone as above with increasing wispy shale laminations

3437.5-39.5 Coarse grained osagia-coated packstone with diverse fauna

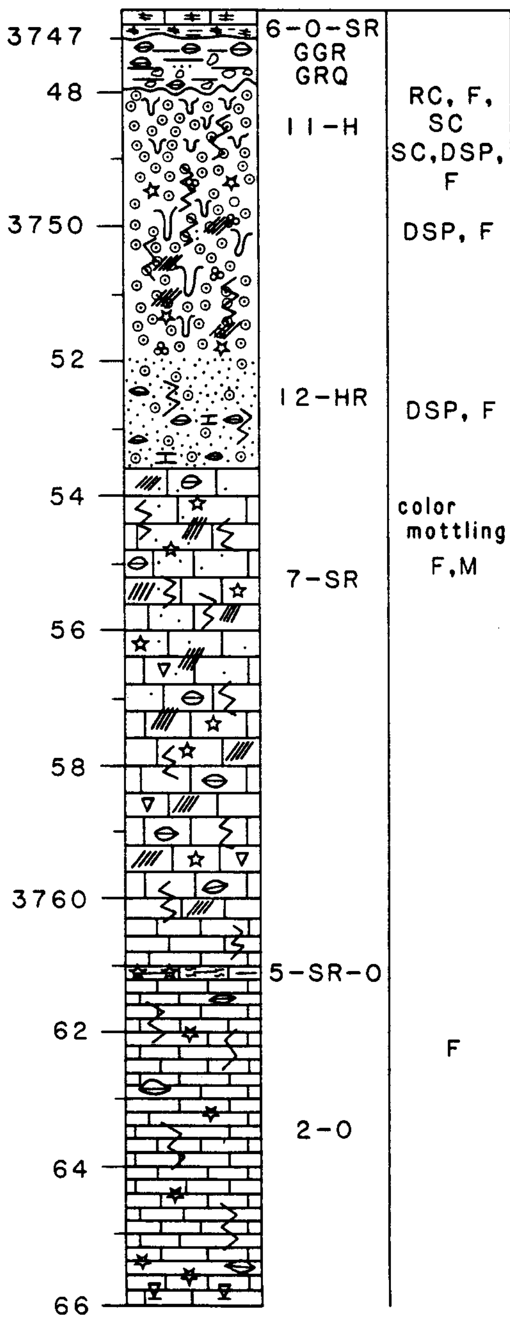
3439.5-42 Wackestone with diverse fauna

3442-43 (base of K-zone regressive carbonate) Green crinoid, brachiopod-rich shale sharply in contact below with carbonate underlain by "salt and pepper" colored packstone containing diverse fossil fragments, corroded clasts of mm-sized carbonate mud, and possible phosphate pellets

3443-43.2 (regressive shale of underlying L-zone) Blocky green unfossiliferous shale underlain by subaerial crust (well developed on solution etched carbonate)

transgressive K-Zone

TEXACO 4 Litsey Ne Ne Nw 25-31S-6W



Description

3744.2-47 (J-zone, transgressive) Dark grey to dark brown argillaceous micrite with wispy shale laminations and phylloid algal-rich wackestone with rugose coral, crinoids, brachiopods, sponge, tubular forams, scattered organic flecks, shale layer rich in fenestrate bryozoa with laminations of quartz silt

3747-48 (top K-zone, regressive shale) Sharp upper contact; soft dark grey blocky shale, slightly silty with abrupt decrease in fossils with depth; fossils include large casts of Myalina, small bivalves with fragments rimmed by pyrite lenses; also contains lenses of dark grey micrite, intraclasts of micrite, lime mud lithoclasts consisting of dark grey micrite with fenestral fabric

3748-49 (top of K-zone regressive carbonate) Very sharp upper contact with shale that is wavy, irregular and notched with cm-relief; surface is also corroded and darkened; underlying oolite is heavily micritized and neomorphosed grey to brown, cut by fissures with darkened patches of limestone; intergranular pores are solution enlarged and connected (reticulate) rimmed by dense brown microcrystalline calcite; pores grade to solution cavity or fissure that is coated by brown calcite frequently with clotted texture; also mm-sized round to elongate pores rimmed by dense micritic calcite (root casts) in association with crumbly fractures (Dunham, 1967)

3749-52 Brown to dark grey mottled oolite with occasional crinoids, forams; heavy neomorphism, cm-sized solution fissures lined with dark brown micritic calcite filled by milky dolospar with undulose extinction, clear calcspar, scattered vertical fractures with oil stain, moldic porosity

3752-53.5 Fine-grained pellet oolite grainstone to pellet packstone with abundant small bivalves; patches of mikly dolospar with undulose extinction, heavy recrystallization

3753.5-60.5 Decreasing peloids in micrite (packstone to wackestone), crinoids, bivalves, common cm-sized rounded areas of alteration - dark grey areas in a yellow-brown to tan matrix with more irregular fractures, also with bivalve molds along outside edge of alteration; fine amplitude black stylolites (alteration areas proceed from mold development to microcrystalline calcite cement fill and neomorphism of micrite to give a homogeneous area)

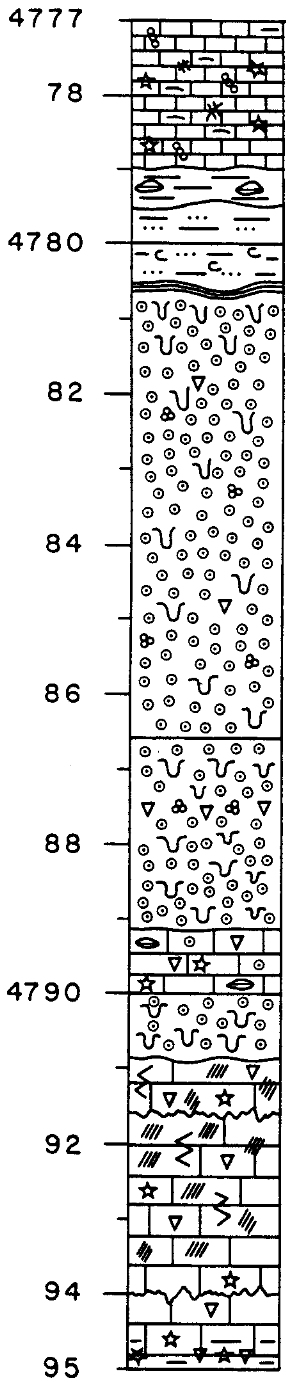
3760.5-60.7 Dark grey micrite, argillaceous with scattered crinoids, occasional tubular forams, scattered flecks of red-brown organic matter and irregular spar filled micro-fractures

3760.7-65 Matrix as above with fractures with thin white chalky outline, fractures anastomosing, radiating from light brown areas of alteration

3765-66 Matrix as above, increasing crinoids and bivalves, dark coating on some fragments, dense mudstone at base with scattered pyrite, scattered flecks of organic matter

K-Zone to 3784

KRM #6 LEMON Se Se Sec 14-34S-20W



Facies	Diag. Overpr.
6-O-SR	
GGR-GRQ	
GRQ 14S	SC,F,CSP
11H	SC
11H+ 12HR	V,M,DSP CSP
2-O	V,DSP
11H	V,M
2-O	color mottling CSP F

Description

4777-79 (J') Dark brown to gray wackestone, slight to moderately argillaceous, scattered gastropods, pelecypods, tubular forams, crinoids, phylloid algae, burrowed with patchy clusters of fossils

4779-80 Gray to brown firm calcareous shale with scattered small brachiopods, pelecypod valves (mm-sized), cm-relief at top, lower portion is burrowed unfossiliferous siltstone, gray to green

4780-80.5 Gray to green very calcareous, argillaceous siltstone with rounded cm-sized micrite nodules (brown to dark brown mottled with small fractures - may be caliche)

at 4780.5 Dark brown to brown, densely cemented oolite, 0.25 to .5 mm diameter, extensive alteration with solution cavities, fissures cm-sized with recrystallized area surrounding voids, vadose quartz silt partly fills some of these voids with coarse calcite spar filling remainder of void, scattered forams including tubular ones attached to grains; top surface of oolite is capped by dark brown 2 to 3 cm thick subaerial crust of micrite with smooth undulating upper surface with 3 to 5 cm relief, immediately above this is the quartz siltstone with scattered dolomitized oolites

4780.5-89 Oolite, brown, highly altered, fine grained with mixed layers of oolite and bioclastic grainstone, scattered molds and vugs, slight oil stain, fair porosity and permeability, occasional brachiopods and forams, patches are silicified; at 4788 scattered patches of coarsely crystalline dolomite spar replacing grains, cm-sized vugs with occasional dogtooth calcite spar, mottled coloration to light brown varying according to crystal size of finely crystalline blocky calcite spar

4789-90 Mixed bioclastic wackestone with brachiopods, pelecypods, crinoids, generally poorly preserved; scattered ooids and peloids, dark brown creamy matrix of micrite with intensely mottled areas of recrystallized micrite producing granular calcite cement with vugs to cm-sized (open), scattered coarse dolomite fill in portions of these vugs

4790-91 Heavy altered oolite (1/16 to 1/4 mm diameter ooids) as above

4791-95 Dark brown wackestone with intense alteration of micrite to patchy light brown granular and cream, dense micrite; scattered brachiopods with broken spines, crinoids; dark gray wispy shale laminations in part stylolitic, scattered discontinuous fractures; at 4795 larger brachiopods, scattered crinoids, wispy but more distinctly bedded dark gray shale, less alteration at the bottom of the core

K-Zone to 4829

a

Clastic facies

B	black shale with conodonts, fish scales, phosphate
DG	dark-gray shale--restricted fauna, orbiculoid brachiopods
GGR	green to gray shale, normal marine fauna including crinoids, brachiopods, bryozoa
GRQ	green quartz siltstone to claystone, lacks normal marine fossils
RB	red-brown, maroon shale or siltstone
CON	mixed pebble carbonate conglomerate

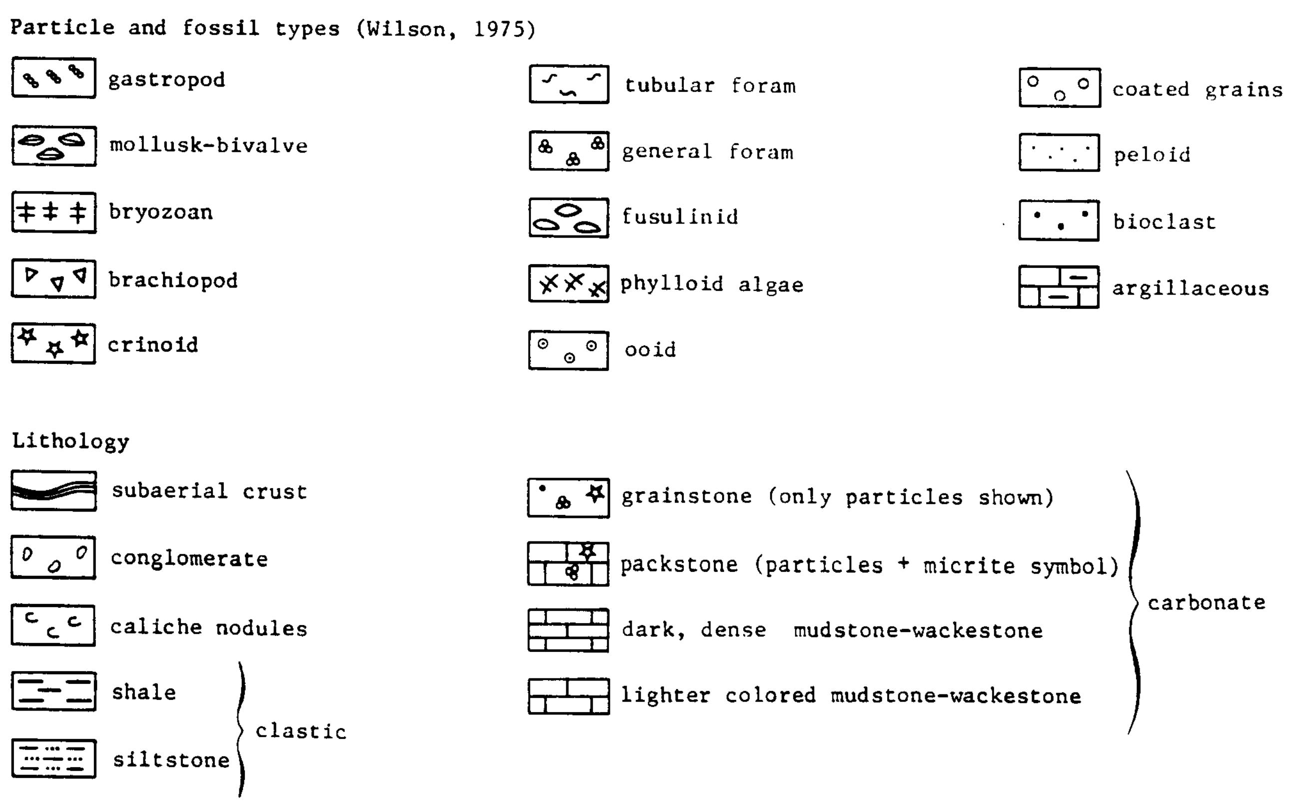
Diagenetic overprinting

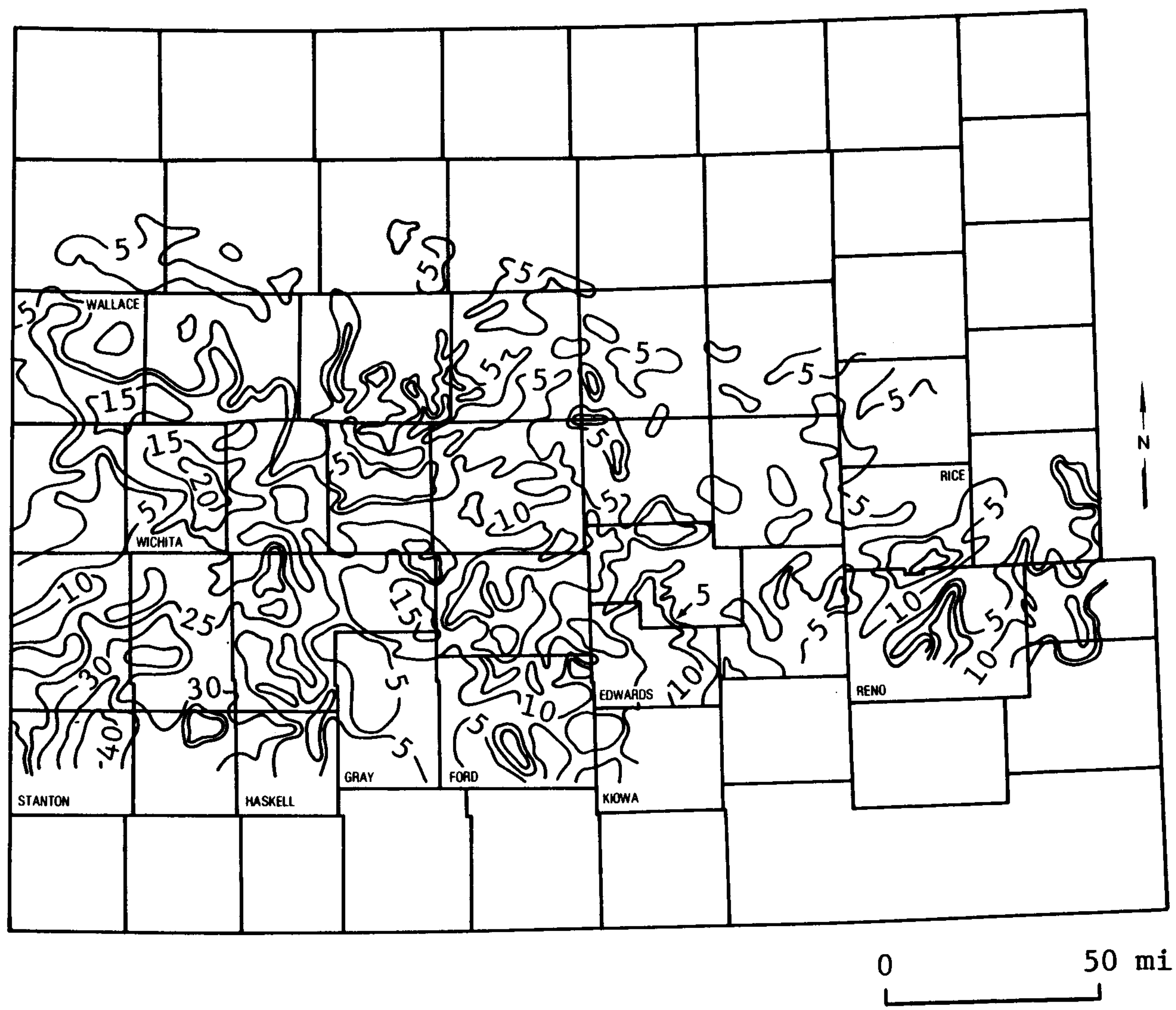
M	molds
V	vugs
CSP	microgranular calcite spar
DSP	dolospar
S	silification
F	fractures
SC	solution channels
IB	in situ breccia
SHC	sheet cracks
CIRC	circumgranular cracks
RC	root casts
///	noticeable recrystallization
~	fissures--solution-enlarged vugs

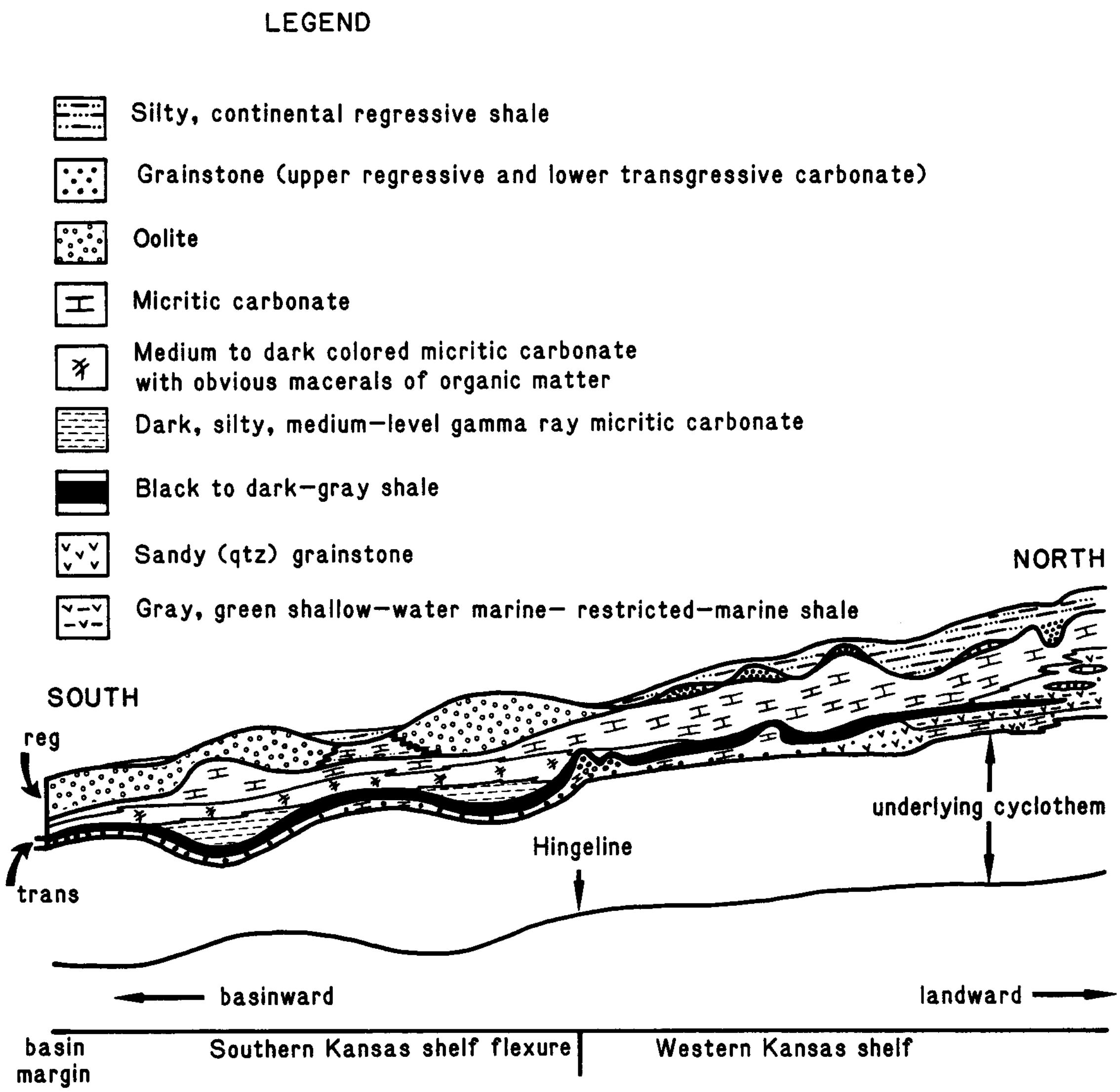
Carbonate facies

1-0	brachiopod
2-0	crinoid-brachiopod
3-0	bryozoan
4-0	fusulinid-crinoid
5-SR	tubular (encrusting) foram + O (Osagia) + B (brach-crinoid) + G (gastropod-bivalve) restricted to slightly restricted marine
6-0-SR	phylloid algal, tubular foram, brachiopod, crinoid
67-SR	gastropod - bivalve (mollusk) - ostracod
8-R	silty, argillaceous micrite (mudstone)
9-VR	peloidal, laminated, fenestral micrite, very restricted
10-H	diverse skeletal packstone-grainstone, open marine
11-H	oolite
12-H	pellet, peloid, restricted skeletal packstone-grainstone, restricted marine
13-H	Osagia grainstone-packstone
14-S	subaerial crust
15-S	caliche
16-0	hardground
STR	stromatolite

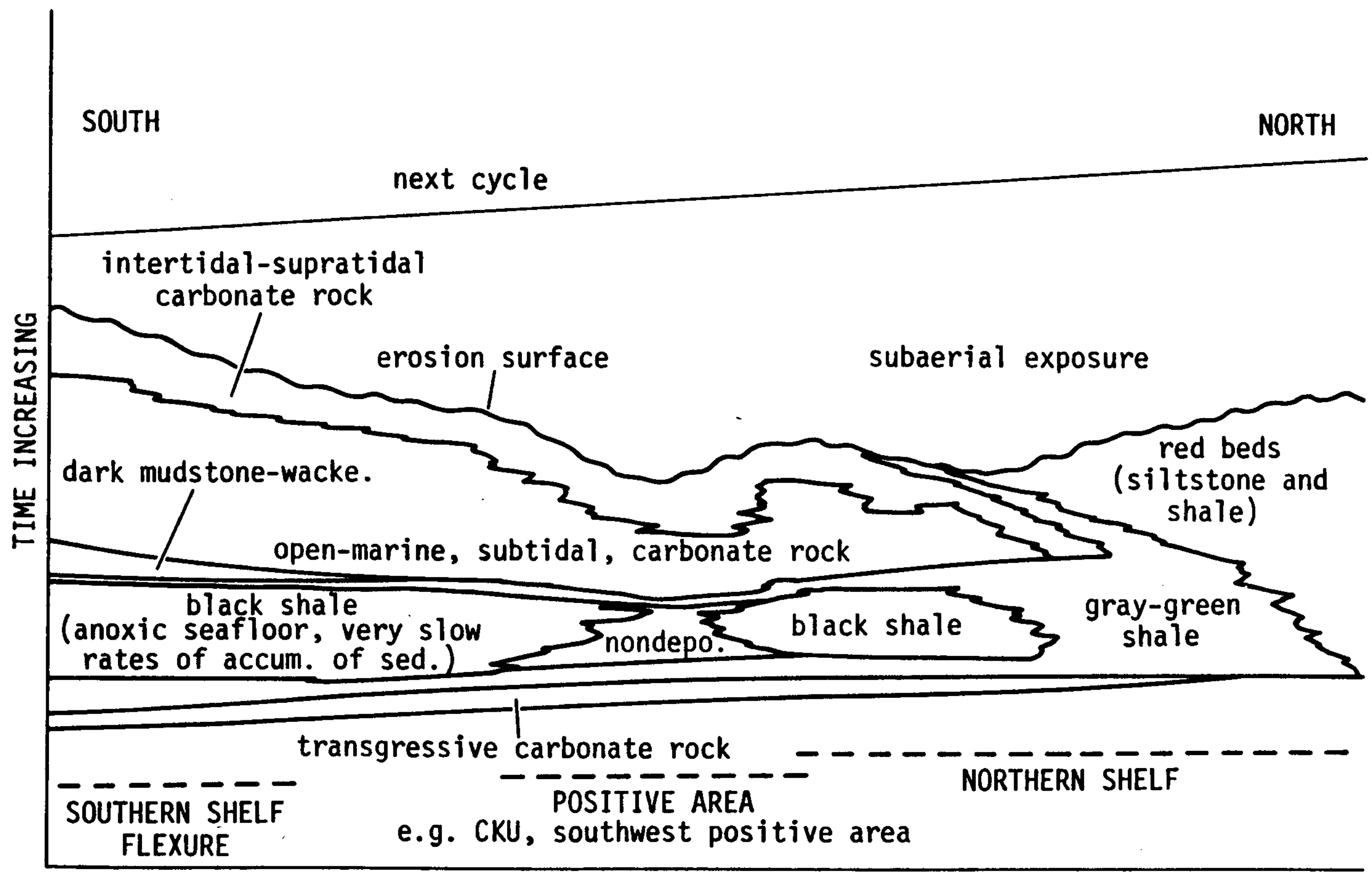
b

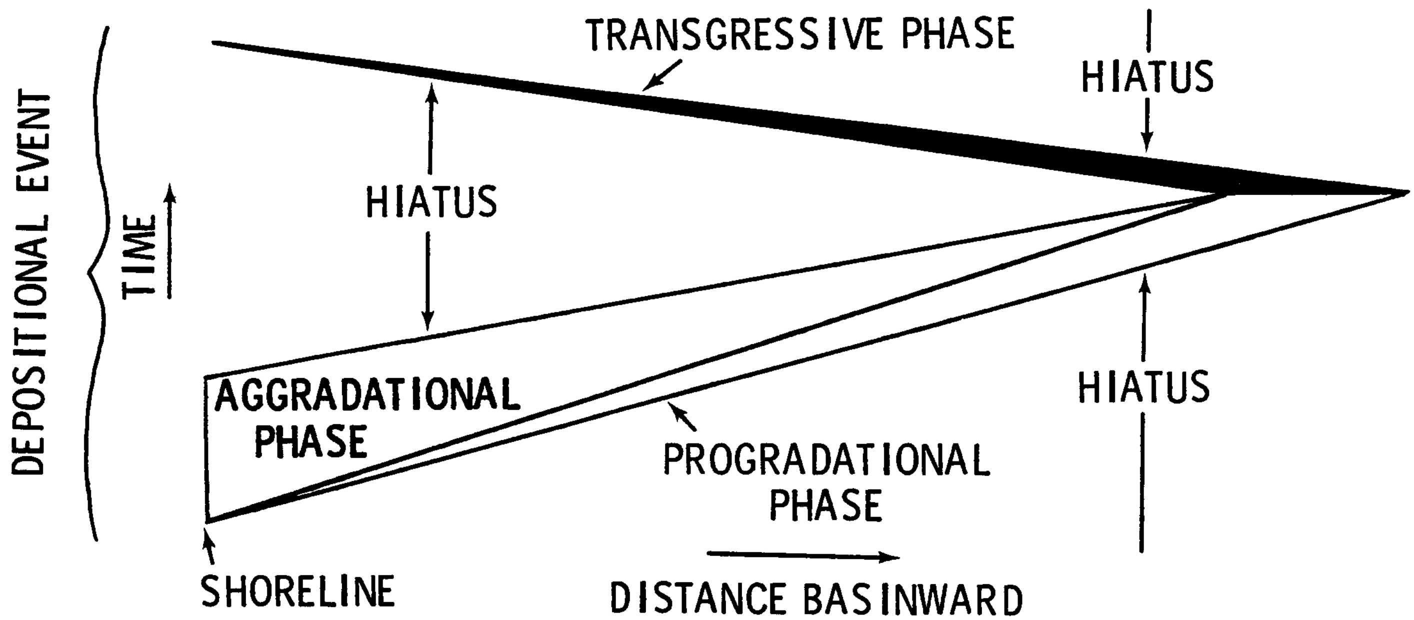



WALLACE
WICHITA
STANTON
HASKELL
GRAY
FORD
EDWARDS
KIOWA
RICE
RENO
N
0
50 mi

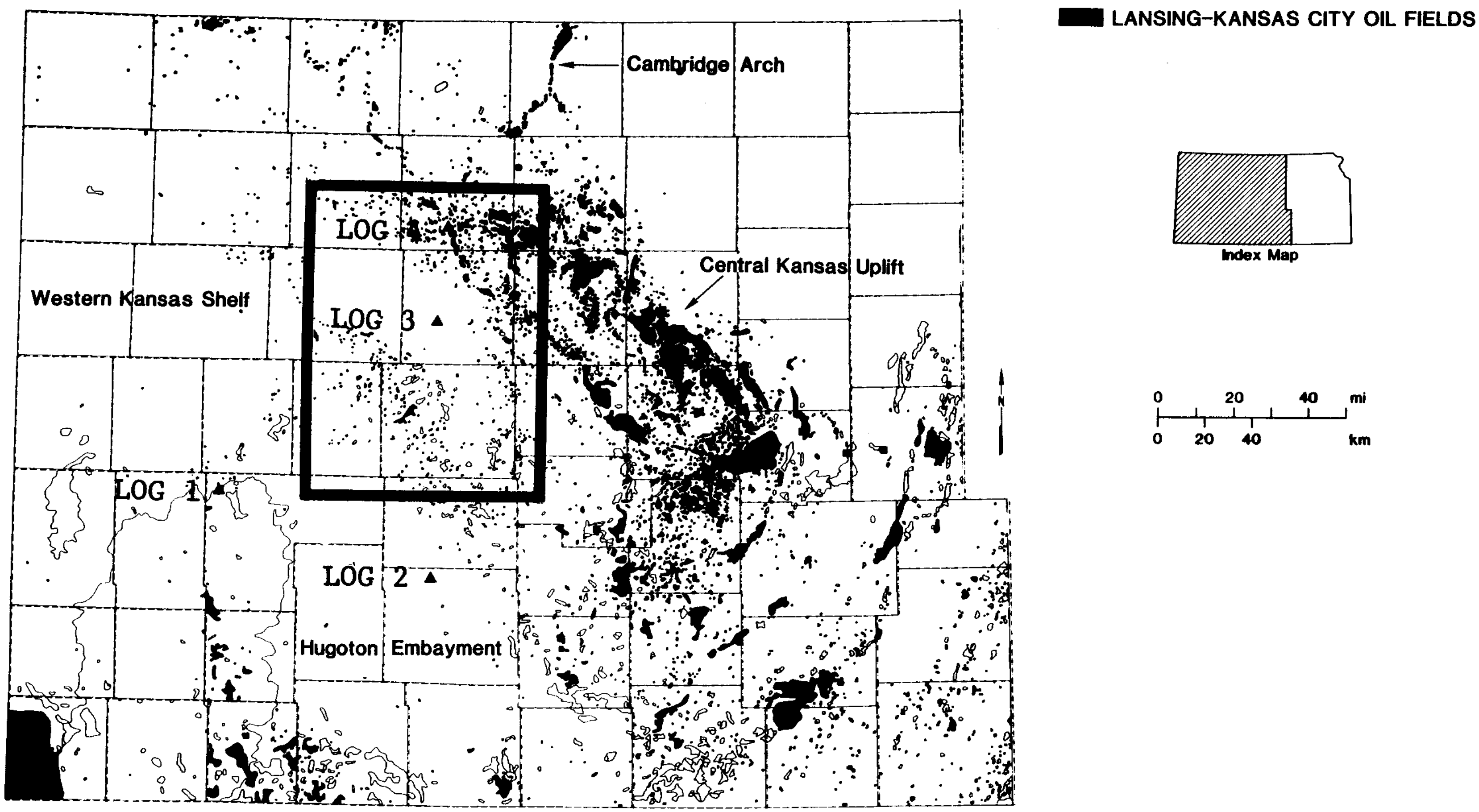


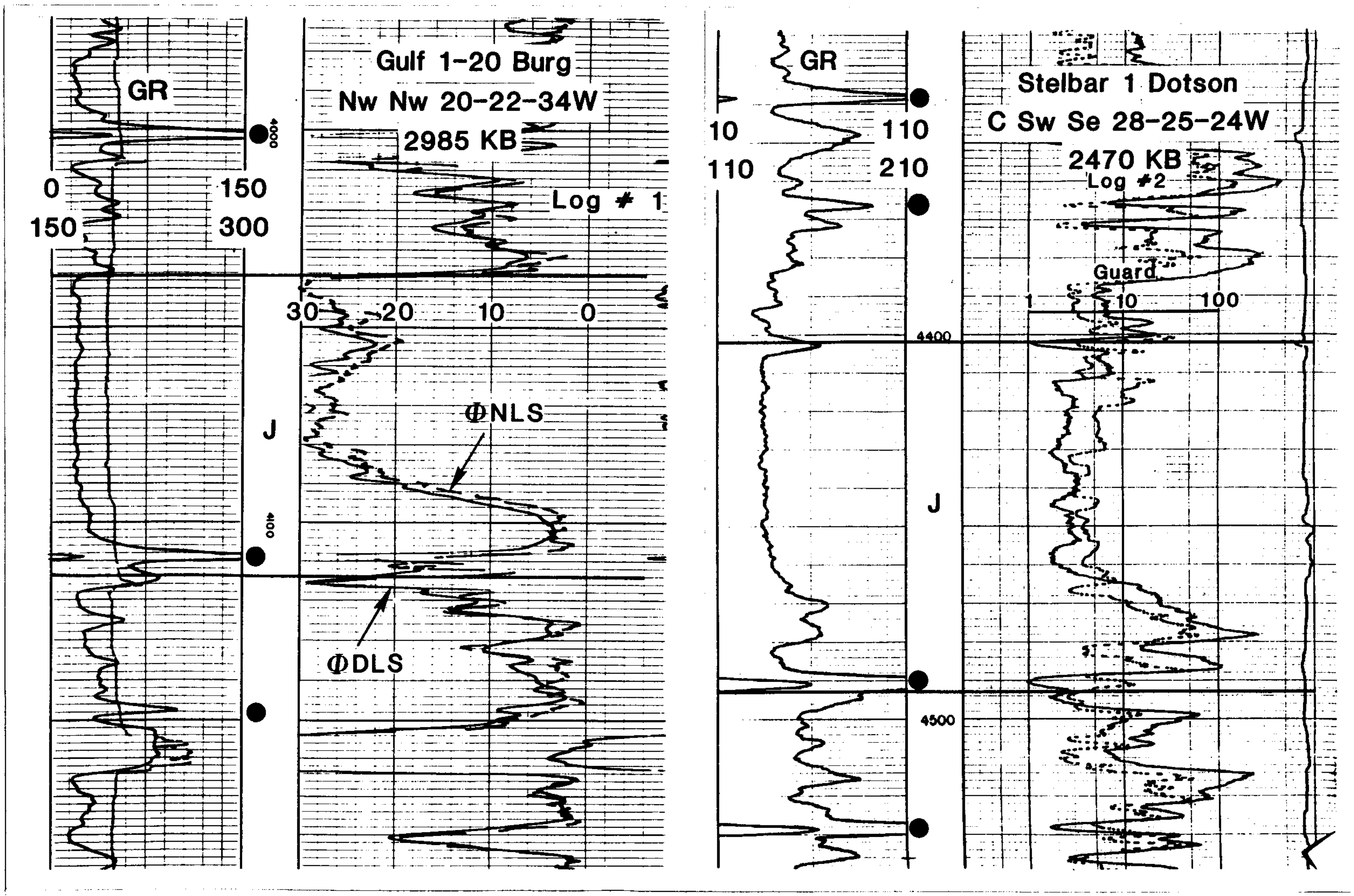
A Model Cross Section of a Missourian Cyclothem on a carbonate-dominated, stable shelf

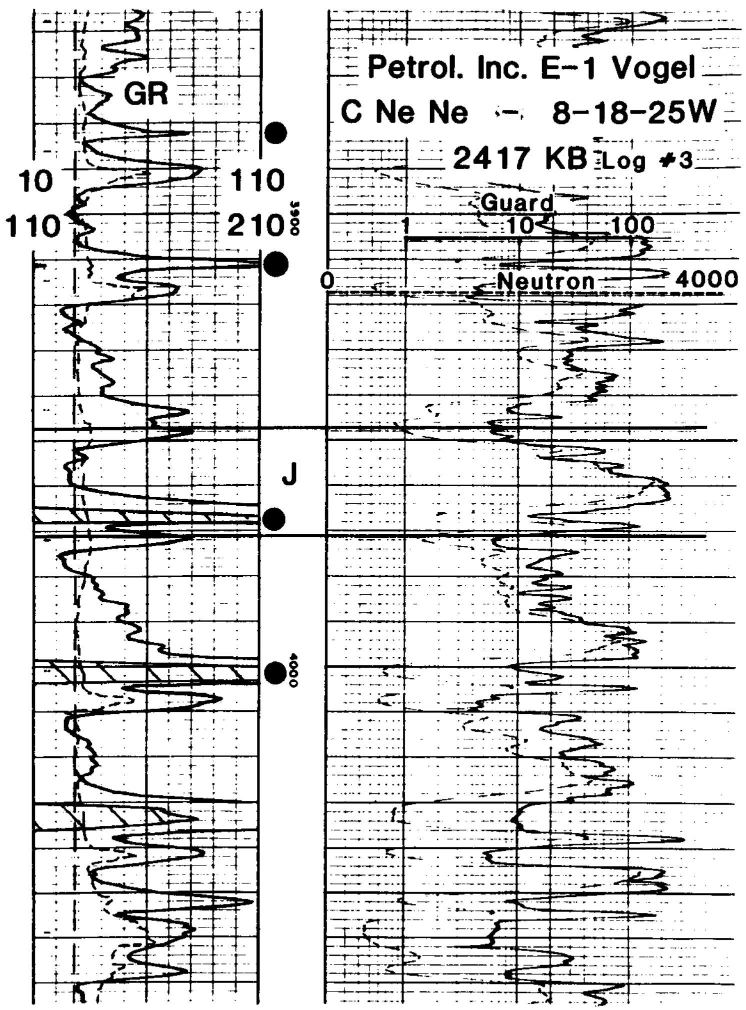

SOUTH
NORTH
next cycle
intertidal-supratidal carbonate rock
erosion surface
subaerial exposure
dark mudstone-wacke.
red beds (siltstone and shale)
open-marine, subtidal, carbonate rock
black shale (anoxic seafloor, very slow rates of accum. of sed.)
nondepo.
black shale
gray-green shale
TIME INCREASING
transgressive carbonate rock
SOUTHERN SHELF FLEXURE
POSITIVE AREA
e.g. CKU, southwest positive area
NORTHERN SHELF

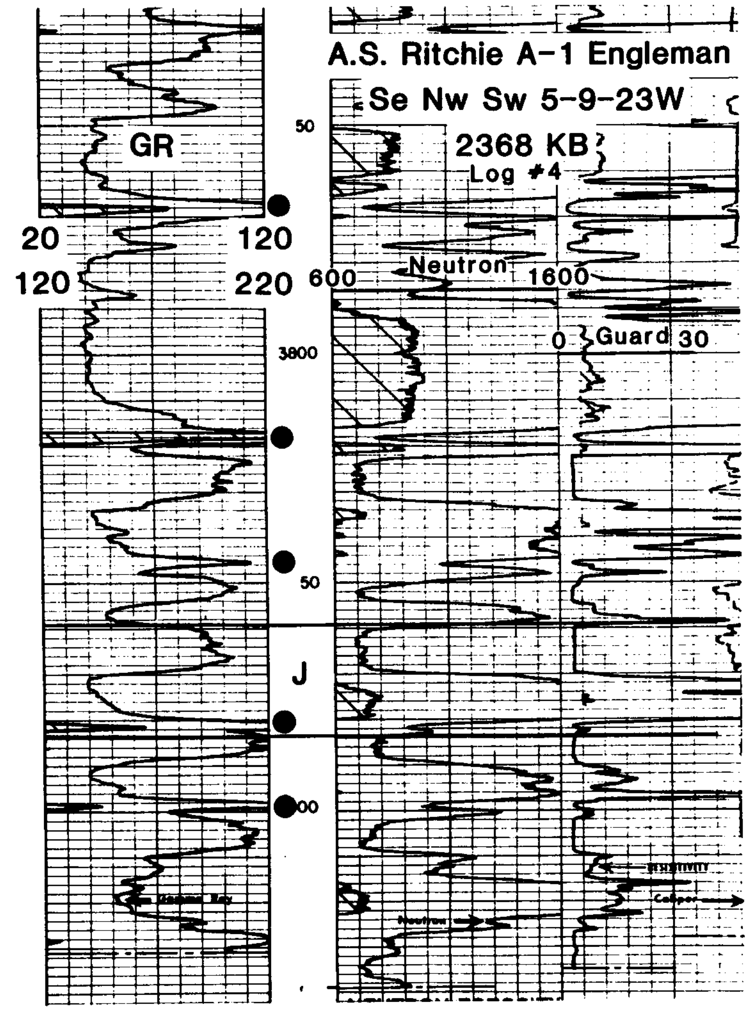


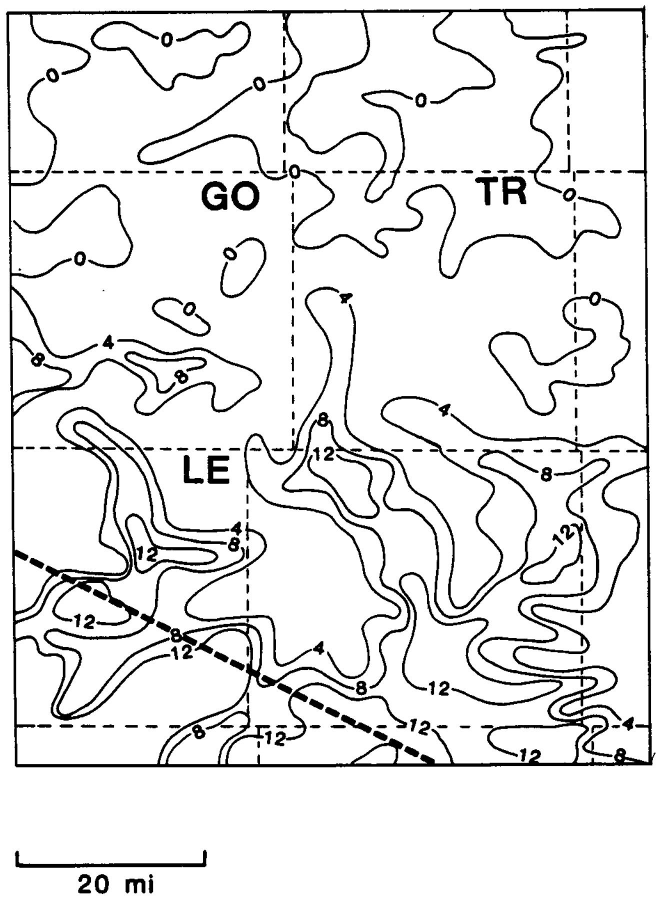
(FRAZIER, 1974)


LANSING-KANSAS CITY OIL FIELDS
Cambridge Arch
Central Kansas Uplift
Western Kansas Shelf
Hugoton Embayment
LOG 1
LOG 2
LOG 3
LOG 4
Index Map
0 20 40 mi
0 20 40 km

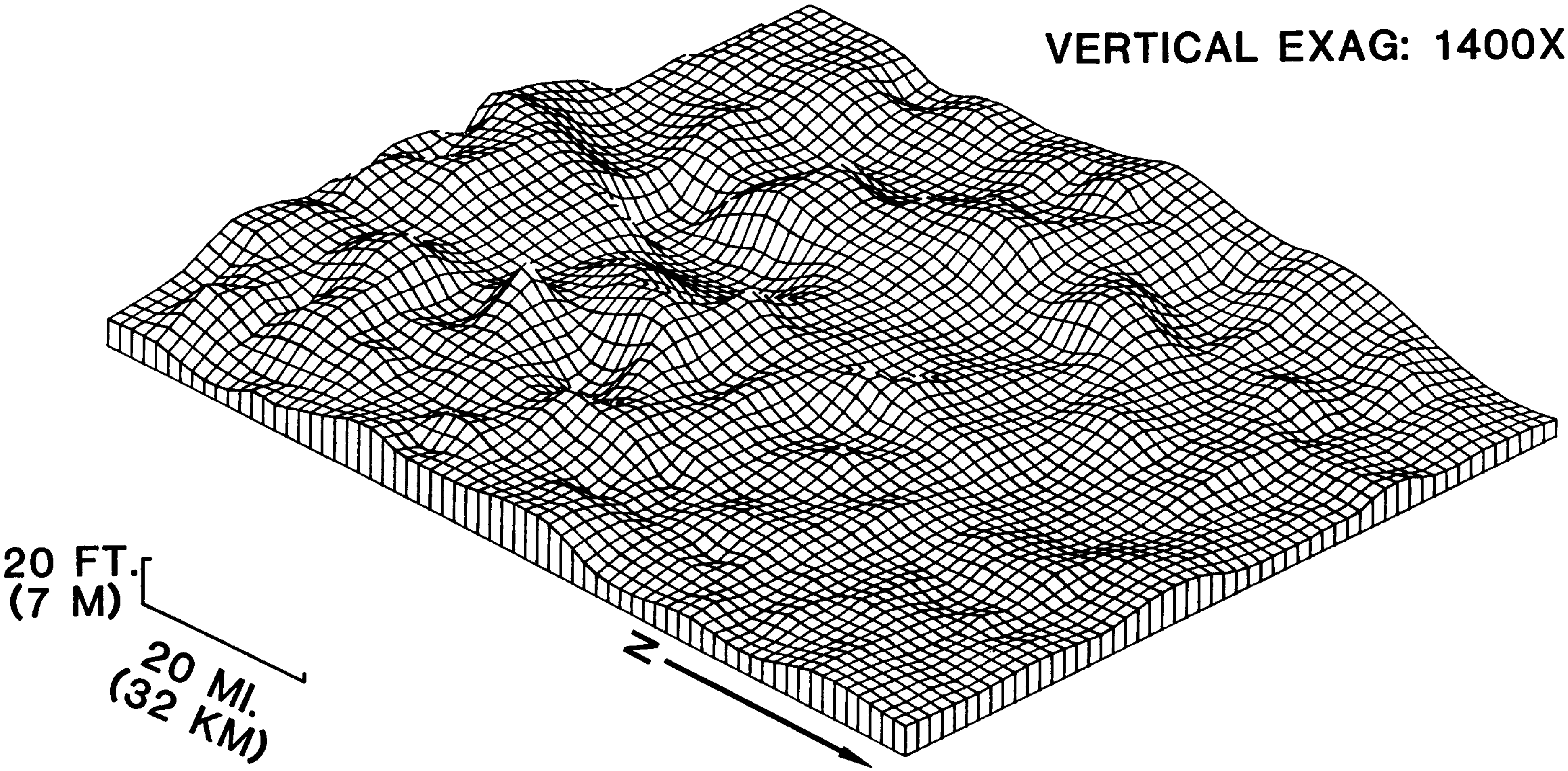

GR
Gulf 1-20 Burg
Nw Nw 20-22-34W
2985 KB
Log # 1
0
150
150
300
4000
4100
30
20
10
0
J
ΦNLS
ΦDLS
GR
Stelbar 1 Dotson
C Sw Se 28-25-24W
2470 KB
Log #2
10
110
110
210
Guard
1
10
100
4400
J
4500

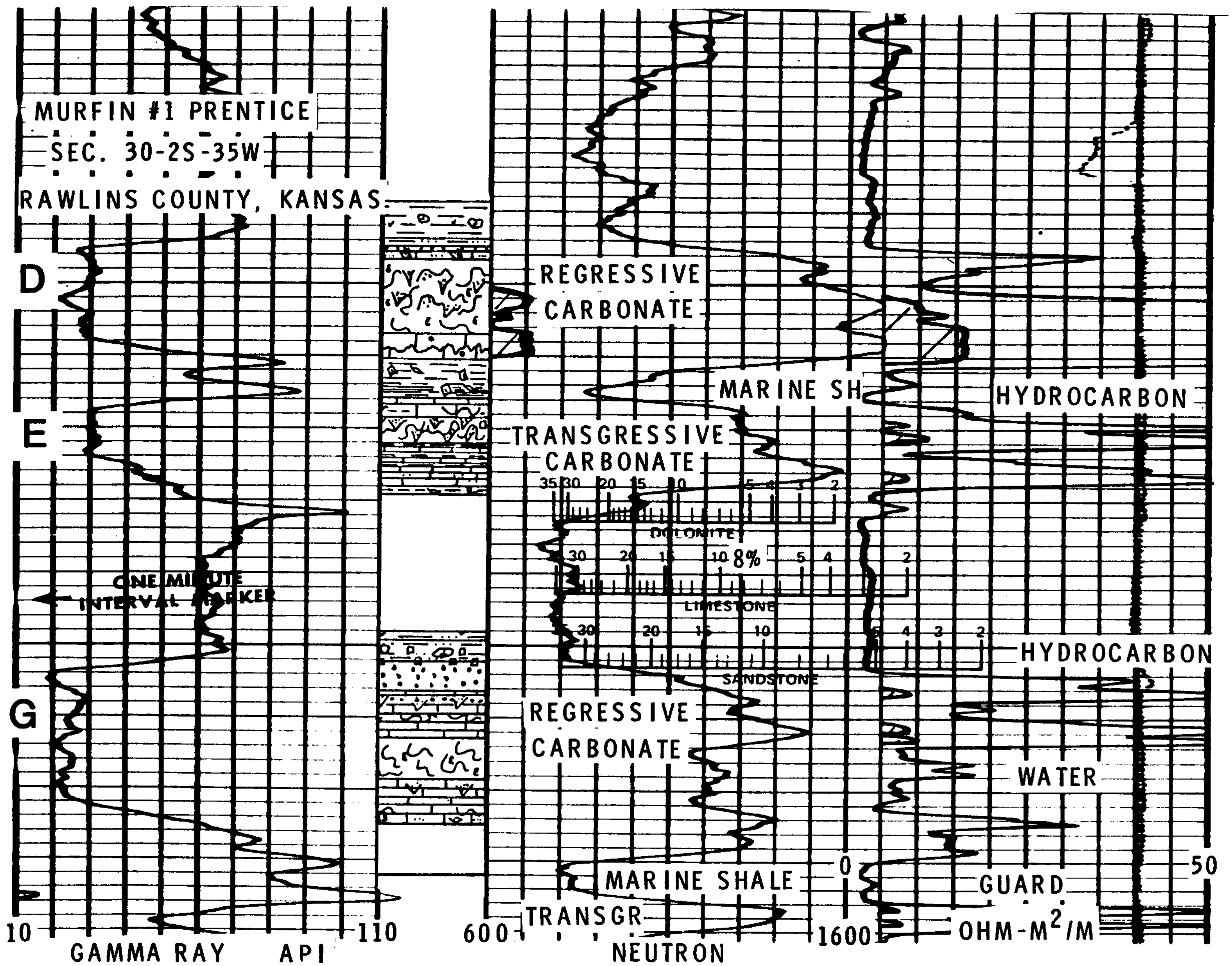

Petrol. Inc. E-1 Vogel
C Ne Ne 8-18-25W
2417 KB Log #3
GR
10 110
110 210
3900
Guard
1 10 100
0 Neutron 4000
J
4000


A.S. Ritchie A-1 Engleman
Se Nw Sw 5-9-23W
2368 KB
Log #4
GR
50
20 120
120 220
600 Neutron 1600
0 Guard 30
3800
50
J


GO
TR
LE
0
4
8
12
20 mi

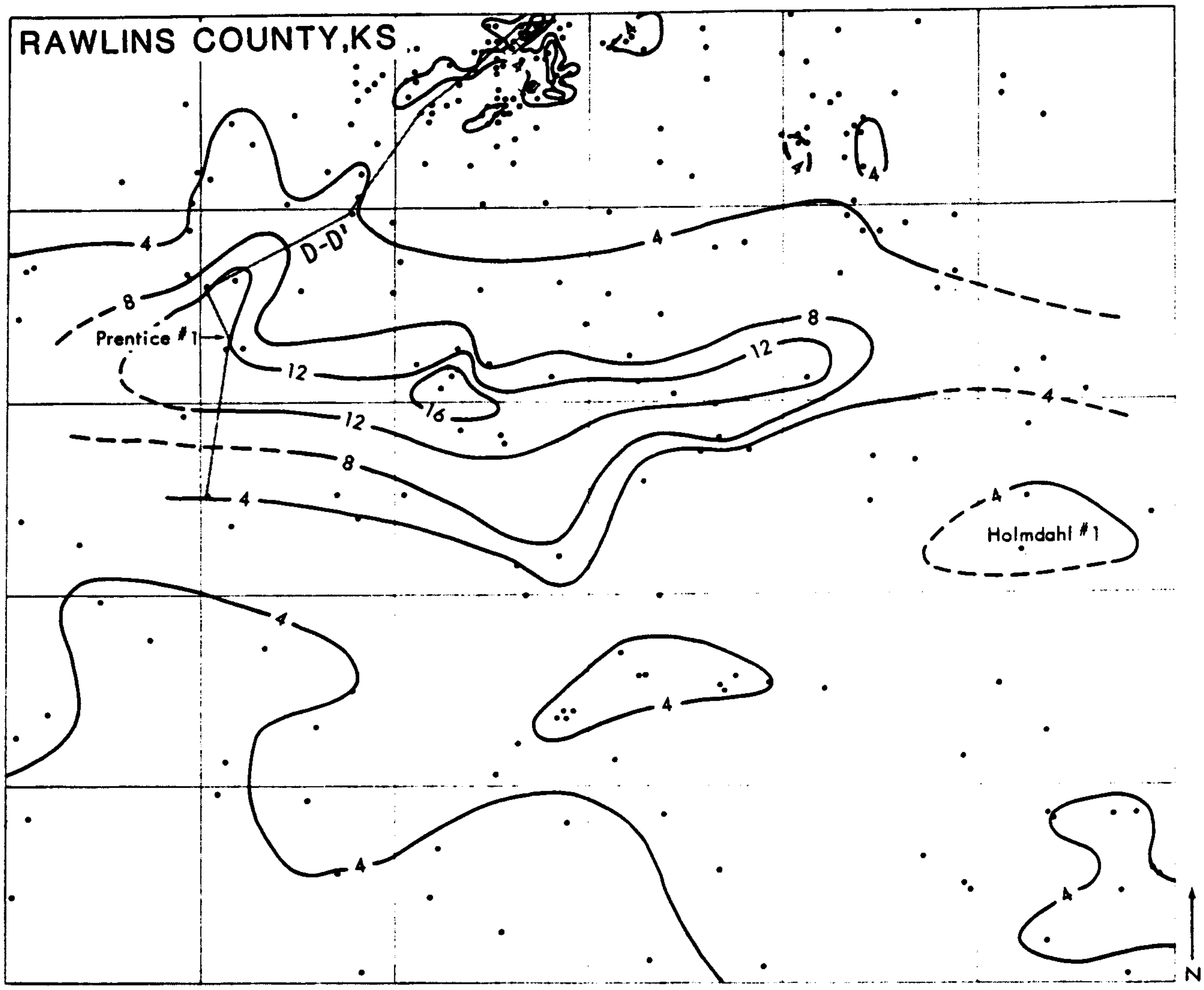
THICKNESS OF POROUS CARBONATE, J-ZONE





MURFIN #1 PRENTICE
SEC. 30-2S-35W
RAWLINS COUNTY, KANSAS
D
E
G
REGRESSIVE CARBONATE
MARINE SH
TRANSGRESSIVE CARBONATE
ONE MINUTE INTERVAL MARKER
DOLOMITE
8%
LIMESTONE
SANDSTONE
REGRESSIVE CARBONATE
MARINE SHALE
TRANSGR
HYDROCARBON
HYDROCARBON
WATER
GUARD
10
GAMMA RAY API
110
600
NEUTRON
1600
0
50
OHM-M²/M

TRANSGRESSIVE E-ZONE CARBONATE ISOPACH



EXPLANATION

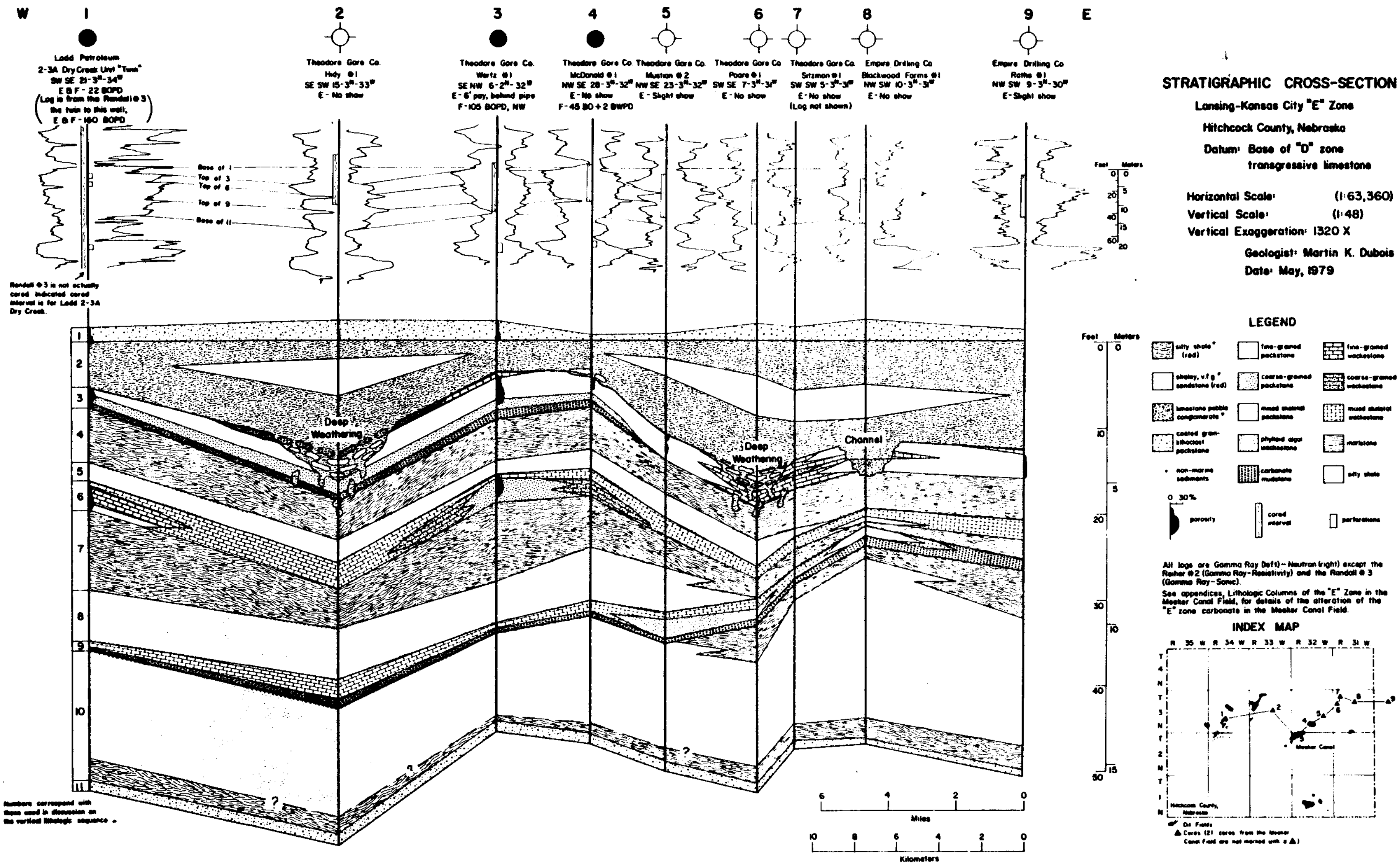
Productive Area of E-Zone

Contour Interval 4 Ft.

0 4 mi

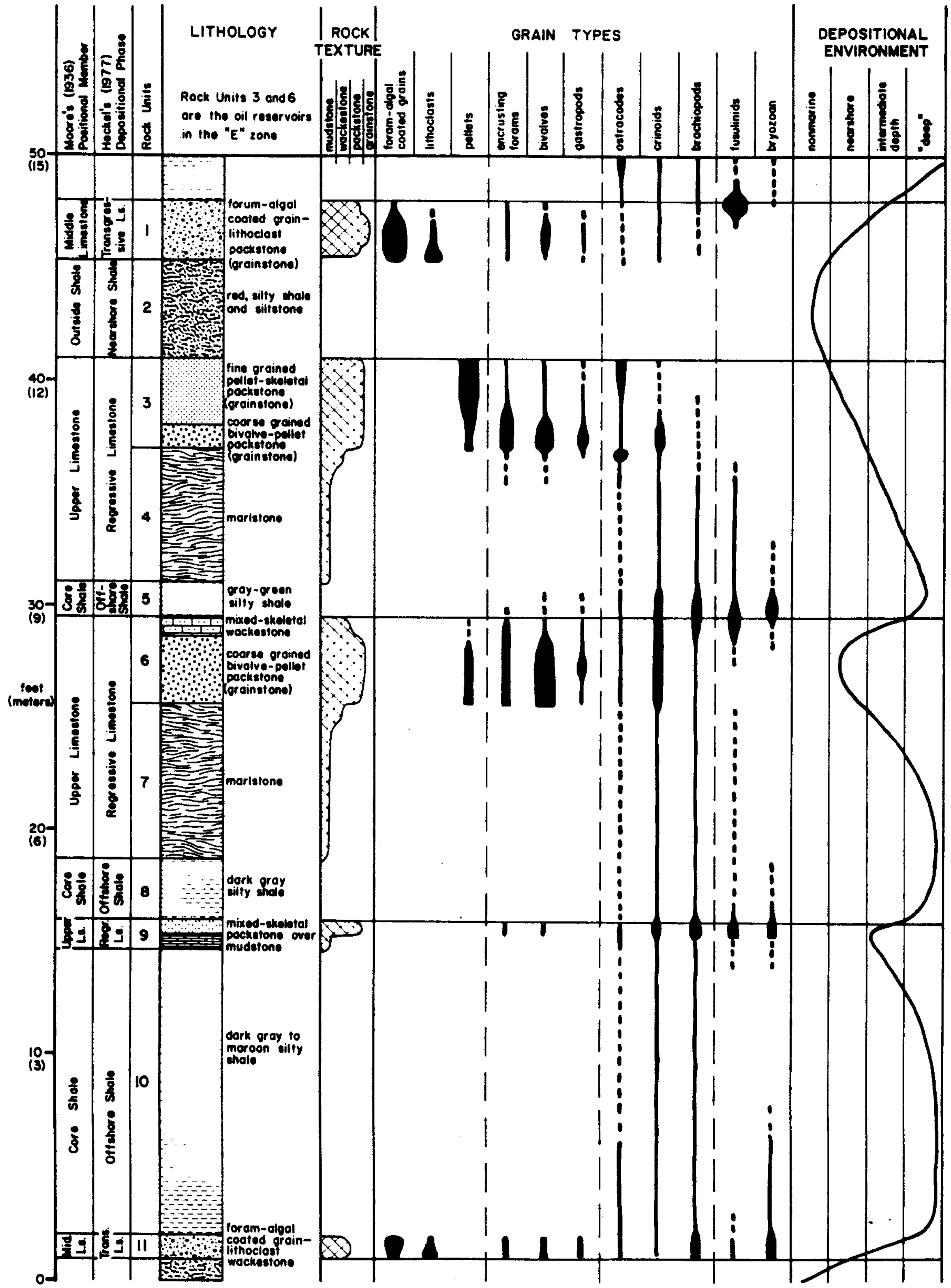
0 5 km

from Watney (1980)



from Dubois (1985)

"E" ZONE CYCLE



from Dubois (1985)