UPR CRETACEOUS FIELD TRIP
(KANSAS PORTION)

compiled by

Lynn Watney
Larry Skelton

Kansas Geological Survey
Open-file Report 98-38

UPR Cretaceous Field Trip (Kansas Portion)

June 9-11, 1998

Supplement to Kansas Geological Survey Bulletin 225 (Hattin, 1982) & Kansas Geological Survey Guidebook Series 3 (Hattin and Siemers, 1987)

Compiled by

Lynn Watney and Larry Skelton
Kansas Geological Survey

List of Attachments

1. Field trip maps

2. Stratigraphy

   a. Stratigraphic nomenclature (from Zeller, 1968),
   b. Type log near Monument Rocks (Section 27-13s-30w)
   c. Cretaceous chronostratigraphic and eustatic-cycle chart (Haq, Hardenbol, and Vail, 1988)
   d. Excerpts from Gardner, 1995, "Tectonic and eustatic controls on the stratal architecture of Mid-Cretaceous stratigraphic sequences, central western interior foreland basin of North America"
   e. Index map and black and white versions of color gamma ray cross section (Smoky Hill Chalk to Stone Corral Formation) along township 16 South adjacent to Niobrara exposures seen on trip. Using ColorLith software developed by David Collins, Kansas Geological Survey

3. Physiographic map of Kansas and geologic timetable

4. Kansas shaded relief maps for counties visited on Niobrara portion of trip

5. Structure and sedimentation

   a. Basement structure
   b. Residual aeromagnetic map of Kansas
   c. Combined gravity and magnetics maps with overlays of structure, oil field outlines, and only county overlay for area in western Kansas (black and white version, see color)
   d. Selected regional isopach maps from Merriam (1963), The Geologic History of Kansas, Kansas Geological Survey, Bulletin 162
   e. Regional maps (western Kansas) of Dakota Sandstone
   f. Excerpts from Holdaway (1978), "Deposition of evaporites and red beds of Nippewalla Group, Permian, Western Kansas," Kansas Geological Survey Bulletin 215
   g. Accommodation realms (sediment accommodation regions) – paper by Watney et al., 1997, Modeling of sediment accommodation realms by regionalized classification

6. Dakota Aquifer Program

   a. Program description
   b. Regional Dakota aquifer hydrostratigraphy
   c. Geophysical log analysis of the Dakota aquifer
   d. Seismic records and the synthetic seismogram

List of Attachments

1. Field trip maps

2. Stratigraphy

   a. Stratigraphic nomenclature (from Zeller, 1968),
   b. Type log near Monument Rocks (Section 27-13s-30w)
   c. Cretaceous chronostratigraphic and eustatic-cycle chart (Haq, Hardenbol, and Vail, 1988)
   d. Excerpts from Gardner, 1995, "Tectonic and eustatic controls on the stratal architecture of Mid-Cretaceous stratigraphic sequences, central western interior foreland basin of North America"
   e. Index map and black and white versions of color gamma ray cross section (Smoky Hill Chalk to Stone Corral Formation) along township 16 South adjacent to Niobrara exposures seen on trip.

3. Physiographic map of Kansas and timetable

4. Kansas shaded relief maps for counties visited on Niobrara portion of trip

5. Structure and sedimentation

   a. Basement structure
   b. Residual aeromagnetic map of Kansas
   c. Combined gravity and magnetics maps with overlays of structure, oil field outlines, and only county overlay for area in western Kansas (black and white version, see color)
   d. Selected regional isopach maps from Merriam (1963), The Geologic History of Kansas, Kansas Geological Survey, Bulletin 162
   e. Regional maps (western Kansas) of Dakota Sandstone
   f. Excerpts from Holdaway (1978), "Deposition of evaporites and red beds of Nippewalla Group, Permian, Western Kansas," Kansas Geological Survey Bulletin 215
   g. Accommodation realms (sediment accommodation regions) – paper by Watney et al., 1997, Modeling of sediment accommodation realms by regionalized classification

6. Dakota Aquifer Program

   a. Program description
   b. Regional Dakota aquifer hydrostratigraphy
   c. Geophysical log analysis of the Dakota aquifer
   d. Seismic records and the synthetic seismogram

e. Paper by Macfarlane, Doveton, and Coble (1989), "Interpretation of lithologies and depositional environments of Cretaceous and lower Permian rocks by using a diverse suite of logs from a borehole in central Kansas"

7. Summary of USGS Open-File Report 95-209 by Dean et al., "Core descriptions and preliminary geochemical data for the Amoco Production Company, Rebecca Bounds #1 well, Greeley County, Kansas

8. Figures from "Kansas Oil and Gas Production Trends 1995" by Tim Carr and Doug Beene, Kansas Geological Survey, Open-File Report 95-42

9. Statistics on gas fields in Kansas that produce from the Niobrara Formation

1. Field trip maps

2. Stratigraphy

a. Stratigraphic nomenclature (from Zeller, 1968),

b. Type log near Monument Rocks (Section 27-13s-30w)

c. Cretaceous chronostratigraphic and eustatic-cycle chart (Haq, Hardenbol, and Vail, 1988)

d. Excerpts from Gardner, 1995, "Tectonic and eustatic controls on the stratal architecture of Mid-Cretaceous stratigraphic sequences, central western interior foreland basin of North America"

e. Index map and black and white versions of color gamma ray cross section (Smoky Hill Chalk to Stone Corral Formation) along township 16 South adjacent to Niobrara exposures seen on trip. Using ColorLith software developed by David Collins, Kansas Geological Survey

2.a.

Loess			
Fluvial deposits			
Brady Soil	WISCONSINAN STAGE		
Loess			
Fluvial deposits			
Sangamon Soil	SANGAMONIAN STAGE		
Loess			
Fluvial deposits	ILLINOISAN STAGE		
Yarmouth Soil	YARMOUTHIAN STAGE		
Pearlette ash bed			
Fluvial and eolian deposits	KANSAN STAGE		
Till			
Afton Soil	AFTONIAN STAGE		
Fluvial and eolian deposits	NEBRASKAN STAGE		
Till			
Kimball Member			
Ash Hollow Member	Ogallala Formation		
Valentine Member			
Beecher Island Sh. Mbr.			

WISCONSINAN STAGE
SANGAMONIAN STAGE
ILLINOISAN STAGE
YARMOUTHIAN STAGE
KANSAN STAGE
AFTONIAN STAGE
NEBRASKAN STAGE

PLEISTOCENE SERIES
QUATERNARY SYSTEM

Ogallala Formation

PLIOCENE SERIES
TERTIARY SYSTEM

Beecher Island Sh. Mbr.

Pierre Shale

Salt Grass Shale Mbr.

Lake Creek Shale Mbr.

Weskan Shale Member

Sharon Springs Sh. Mbr.

Montana Group

UPPER CRETACEOUS SERIES

CRETACEOUS SYSTEM

Smoky Hill Chalk Mbr.

Niobrara Chalk

Colorado Group

Fort Hays Ls. Mbr.

Codell Sandstone Mbr.

Blue Hill Shale Mbr.

Carlile Shale

Fairport Chalk Member

Colorado Group

UPPER CRETACEOUS SERIES

Fence-post ls. bed

Pfeifer Shale Member

Jetmore Chalk Member

Greenhorn Limestone

Hartland Shale Member

Lincoln Limestone Mbr.

Graneros Shale

?

Janssen Clay Member

CRETACEOUS SYSTEM

Dakota Formation

Terra Cotta Clay Mbr.

US SERIES

Kiowa Formation

Cheyenne Sandstone

Morrison Formation

Subsurface only

Big Basin Formation

Day Creek Dolomite

Kiger Shale Member

Relay Creek (?) Dol. Mbr.

Whitehorse Formation

Marlow Sandstone Mbr.

Dog Creek Formation

Haskew Gypsum Member

Shimer Gypsum Member

Nescatunga Gyp. Mbr.

Medicine Lodge Gyp. Mbr.

Blaine Formation

Flower-pot Shale

Cedar Hills Sandstone

la Group

LOWER CRETACEO

UPPER JURASSIC SERIES

JURASSIC SYSTEM

CUSTERIAN STAGE

UPPER PERMIAN SERIES

LOWER CRETACEO

IAN SYSTEM

Unit	Member / Bed
Salt Plain Formation	Crisfield ss. bed
	Kingman Sandstone Mbr.
Harper Sandstone	
	Chikaskia Ss. Mbr.
Stone Corral Formation	Runnymede Ss. Mbr.
Ninnescah Shale	

Right-hand column labels:

- Nippewal
- Sumner Group
- CIMARRONIAN STAGE
- LOWER PERMIAN SERIES
- PERM

of
KANSAS
1966

TYPE LOG FOR	GOVE COUNTY

CATALOG NO.	27-13-30 w

Published By

KANSAS GEOLOGICAL SOCIETY

508 East Murdock
Wichita, Kansas 67214
AMherst 5-8677

Compiled & Edited By
KGS TECHNICAL RESEARCH COMMITTEE:

Robert L. Harris, Chmn.
John J. Stone
Charles R. King
Alfred James III
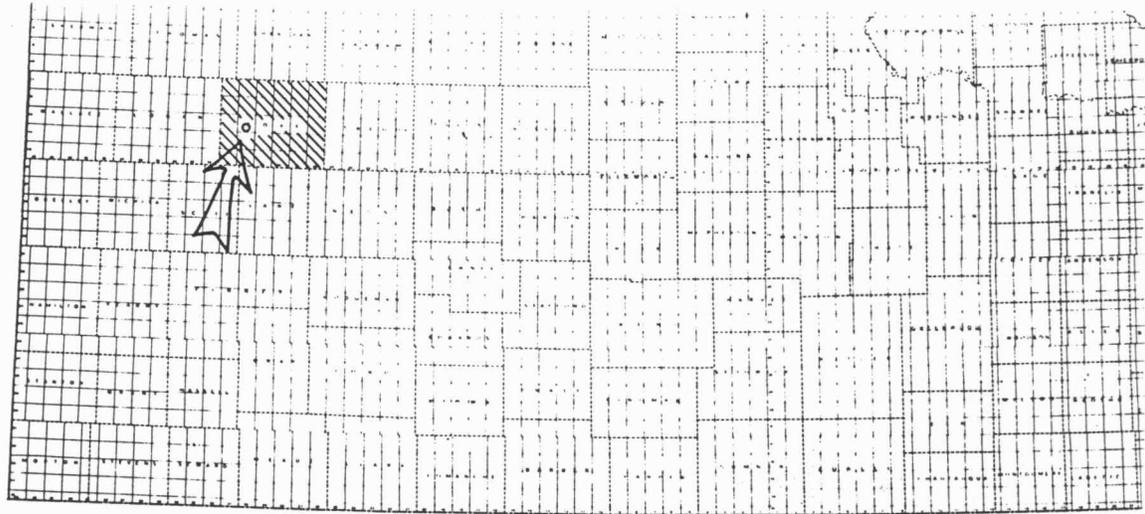Edwin D. Goebel

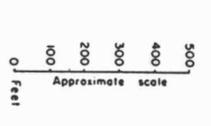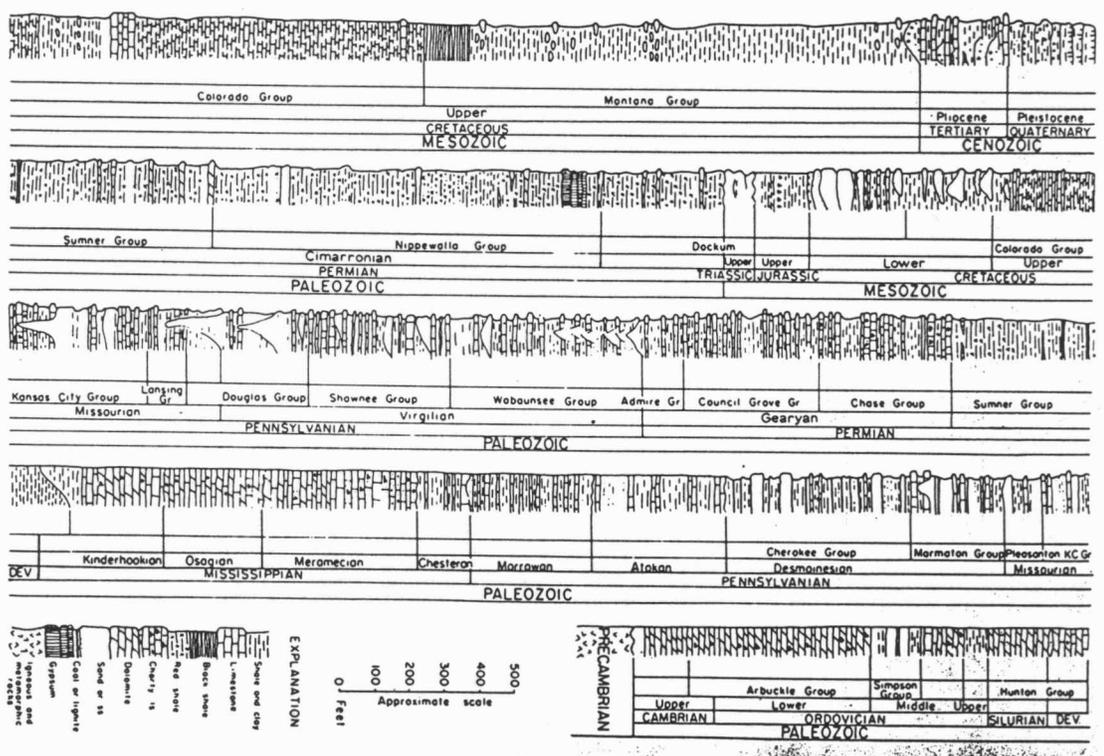Drafted By Harold R. Trapp

FOLD

INDEX

STATE OF KANSAS
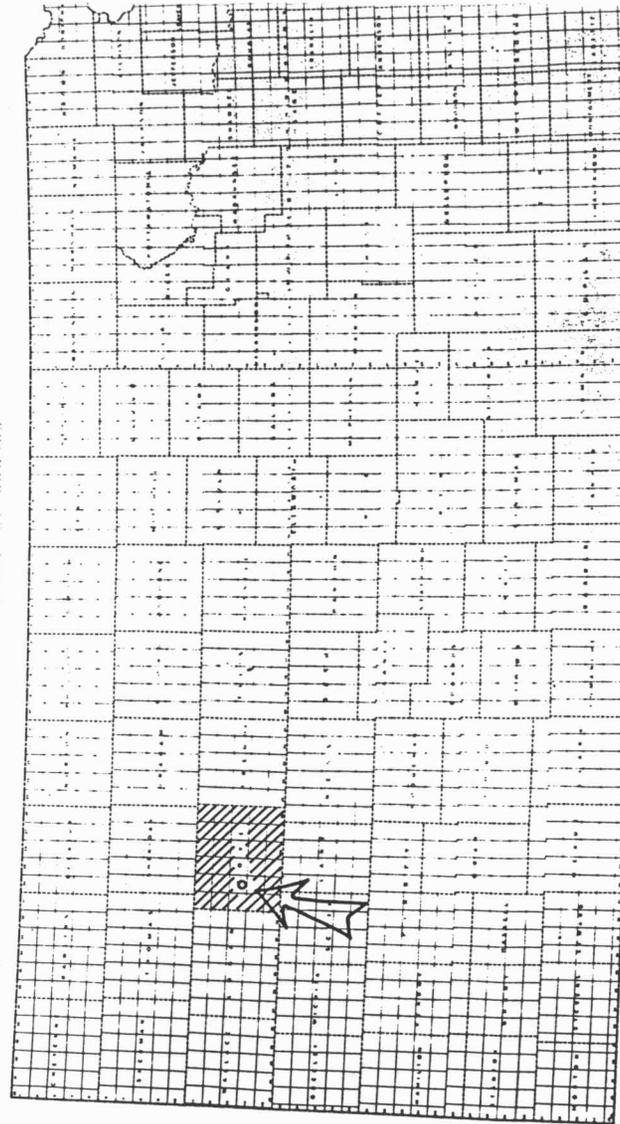
2.b.

Composite stratigraphic section of rocks present in Kansas. Beds older than Mississippian are known only in subsurface (modified from Moore, Frye, Merriam, and others.)
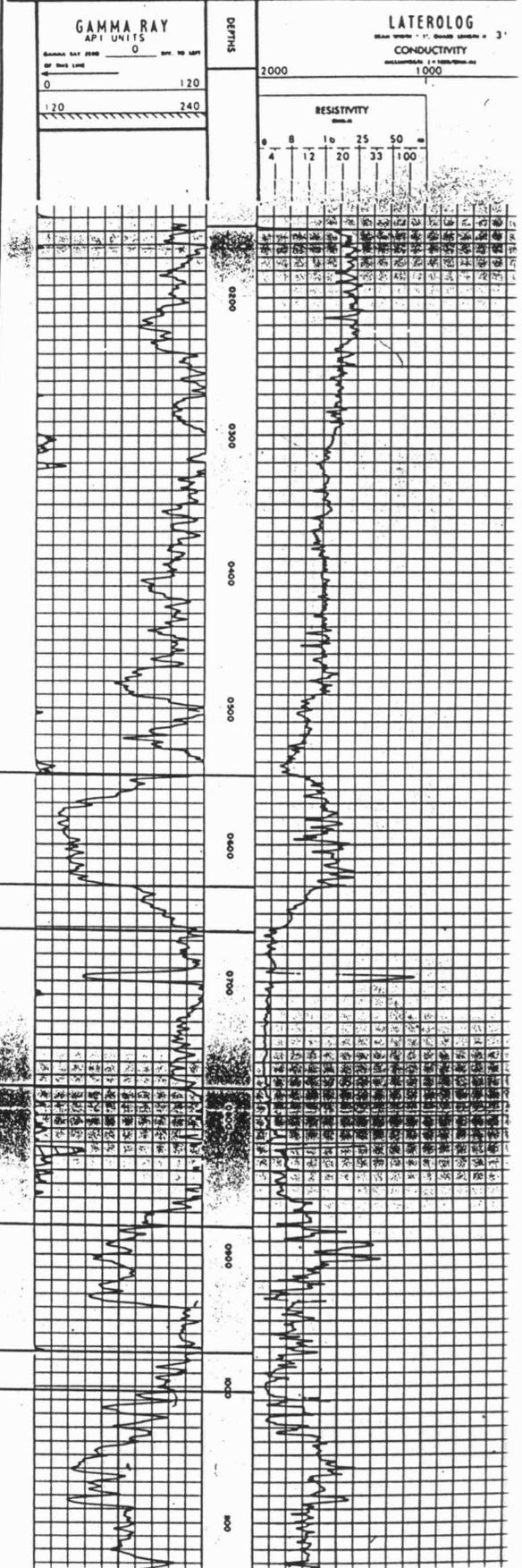
Colorado Group		Upper	Montana Group			Pliocene	Pleistocene
		CRETACEOUS				TERTIARY	QUATERNARY
		MESOZOIC				CENOZOIC	

Sumner Group		Nippewalla Group		Dockum				Colorado Group
	Cimarronian			Upper	Upper	Lower		Upper
	PERMIAN			TRIASSIC	JURASSIC		CRETACEOUS	
PALEOZOIC						MESOZOIC		

Kansas City Group	Lansing Gr	Douglas Group	Shawnee Group	Wabaunsee Group	Admire Gr	Council Grove Gr	Chase Group	Sumner Group
Missourian			Virgilian			Gearyan		PERMIAN
	PENNSYLVANIAN			PALEOZOIC				

DEV	Kinderhookian	Osagian	Meramecian	Chesteran	Morrowan	Atokan	Desmoinesian	Cherokee Group	Marmaton Group	Pleasanton KC Gr
		MISSISSIPPIAN					PENNSYLVANIAN			Missourian
				PALEOZOIC						

EXPLANATION

Coal or lignite • Gypsum • Sand or ss • Dolomite • Chert is • Black shale • Red shale • Shale and clay • Igneous and metamorphic rocks

Approximate scale: 0 100 200 300 400 500 Feet

PRECAMBRIAN		Arbuckle Group		Simpson Group		Hunton Group
	Upper	Lower		Middle	Upper	
	CAMBRIAN	ORDOVICIAN			SILURIAN	DEV
		PALEOZOIC				

CORRELATIONS

USE

☆ Gas
● Oil
★ O&G
▽ Salt water disposal
⚲ Gas storage

TYPE LOG

COMPANY WYCOFF BROTHERS
WELL EKLNA NO. 1
FIELD or WILDCAT
LOCATION SEC. 27-13S-30W
COUNTY GOVE
STATE KANSAS

COUNTY GOVE
FIELD or WILDCAT
LOCATION SEC. 27-13S-30W
WELL EKLNA NO. 1
COMPANY WYCOFF BROTHERS

Recorded by HART-CORNELL

SYSTEM	SERIES	STAGE	GROUP	Formation	Member
CRETACEOUS	UPPER		Colorado	Niobrara Ck.	Smoky Hill Ck.
					Fort Hays Ls.
				Carlile Sh.	Codell Ss.
					Blue Hill Sh.
					Fairport Ck.
				Greenhorn Ls.	
				Graneros Sh.	
				Dakota Ss.	

GAMMA RAY
API UNITS
0
0   120
120   240

DEPTHS

LATEROLOG
CONDUCTIVITY
2000   1000

RESISTIVITY

0 8 16 25 50
4 12 20 33 100

0200
0300
0400
0500
0600
0700
0900

CIMARRONIAN · Nippewalla · Dakota · LOWER

| Dakota Ss. |
| Kiowa Fm. |
| Cheyenne Ss. |
| Whitehorse Fm. |
| ? |
| Dog Creek Fm. |
| Blaine Gyp. |
| Flowerpot Sh. |
| Cedar Hills Ss. |
| Salt Plain Ss. |
| ? |
| Harper Slt. |
| Stone Corral Fm. |
| Ninnescah Sh. |
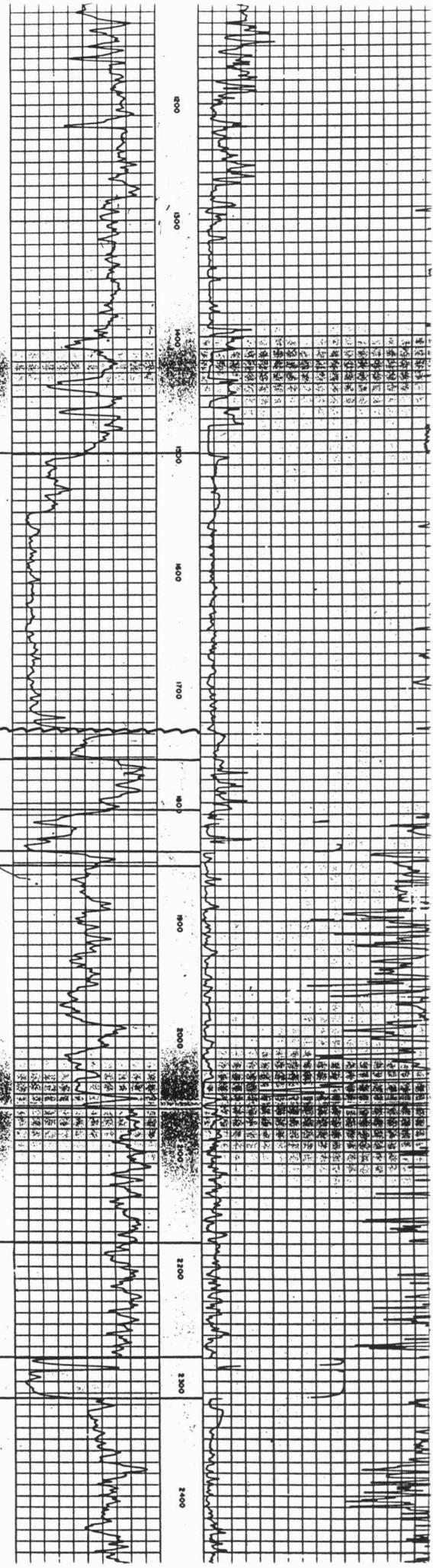
1200 1300 1400 1500 1600 1700 1800 1900 2000 2100 2200 2300 2400

System	Series	Province	Group	Formation	Member
PERMIAN	LOWER	CIM / Sumner		Ninnescah Sh.	
				Wellington Fm.	
		Chase		Nolans Ls.	Herington Ls. / Krider Ls.
				Odell Sh.	
				Winfield Ls.	
				Doyle Sh.	Gage Sh.
					Towanda Ls.
					Holmesville Sh.
				Barneston Ls.	Fort Riley Ls.
					Oketo Sh.
					Florence Ls.
				Matfield Sh.	Blue Springs Sh.
					Wymore Sh.
	GEARYAN			Wreford Ls.	
		Council Grove		Speiser Sh.	
				Funston Ls.	
				Blue Rapids Sh.	
				Crouse Ls.	
				Easly Creek Sh.	
				Bader Ls.	
				Stearns Sh.	
				Beattie Ls.	Cottonwood Ls.
				Eskridge Sh.	
				Grenola Ls.	Neva Ls.
				Roca Sh.	
				Red Eagle Ls.	
				Johnson Sh.	
		Adm		Foraker Ls.	Americus Ls.
				Janesville Sh.	
GILIAN		Wabaunsee		Wood Siding Fm.	
				Root Sh.	
				Stotler Ls.	
				Pillsbury Sh.	
				Zeandale Ls.	Tarkio Ls.
				Willard Sh.	
				Emporia Ls.	
				Auburn Sh.	
				Bern Ls.	Burlingame Ls.
				Scranton Sh.	
				Howard Ls.	
				Severy Sh.	
				Topeka Ls.	

PENNSYLVANIAN

UPPER

VIRGILIAN

Wabaun

Stotler Ls.
Pillsbury Sh.
Zeandale Ls.
Willard Sh.
Emporia Ls.
Auburn Sh.
Bern Ls.

Tarkio Ls.

Burlingame Ls.

Scranton Sh.
Howard Ls.
Severy Sh.

Shawnee

Topeka Ls.

Jones Point Sh.

Calhoun Sh.
Deer Creek Ls.

Larsh-Burroak Sh.

Tecumseh Sh.
Lecompton Ls.

Queen Hill Sh.

Kanwaka Sh.

Oread Ls.

Heebner Sh.

D

Toronto Ls.

MISSOURIAN

Lans.

Stanton Ls.
Vilas Sh.
Plattsburg Ls.

Bonner Springs Sh.

Kansas City

Wyandotte Ls.

Lane Sh.
Iola Ls.
Chanute Sh.
Drum Ls.
Cherryvale Sh.
Dennis Ls.

Stark Sh.

Galesburg Sh.
Swope Ls.

Hush. Sh.

Ladore Sh.
Hertha Ls.

Pleasanton

MIDDLE

DESMOINESIAN

Marmaton

Lenapah Ls.
Nowata Sh.
Altamont Ls.
Bandera Sh.

Pawnee Ls.

Labette Sh.
Fort Scott Ls.

Cherokee

MISS.

UPR.

M.

Warsaw Ls.

LOWER

KIND.

OSAGIAN

Gilmore City Ls.

ORD.

MIDDLE

Viola Ls.?
(Kimmswick)

3600
3700
3800
3900
4000
4100
4200
4300
4400
4500
4600
4700

2.c.

FIG. 15.—Cretaceous chronostrati-
graphic- and eustatic-cycle chart. (See Fig.
14 caption and text for explanation.)

Haq, Hardenbol, Vail (1988)
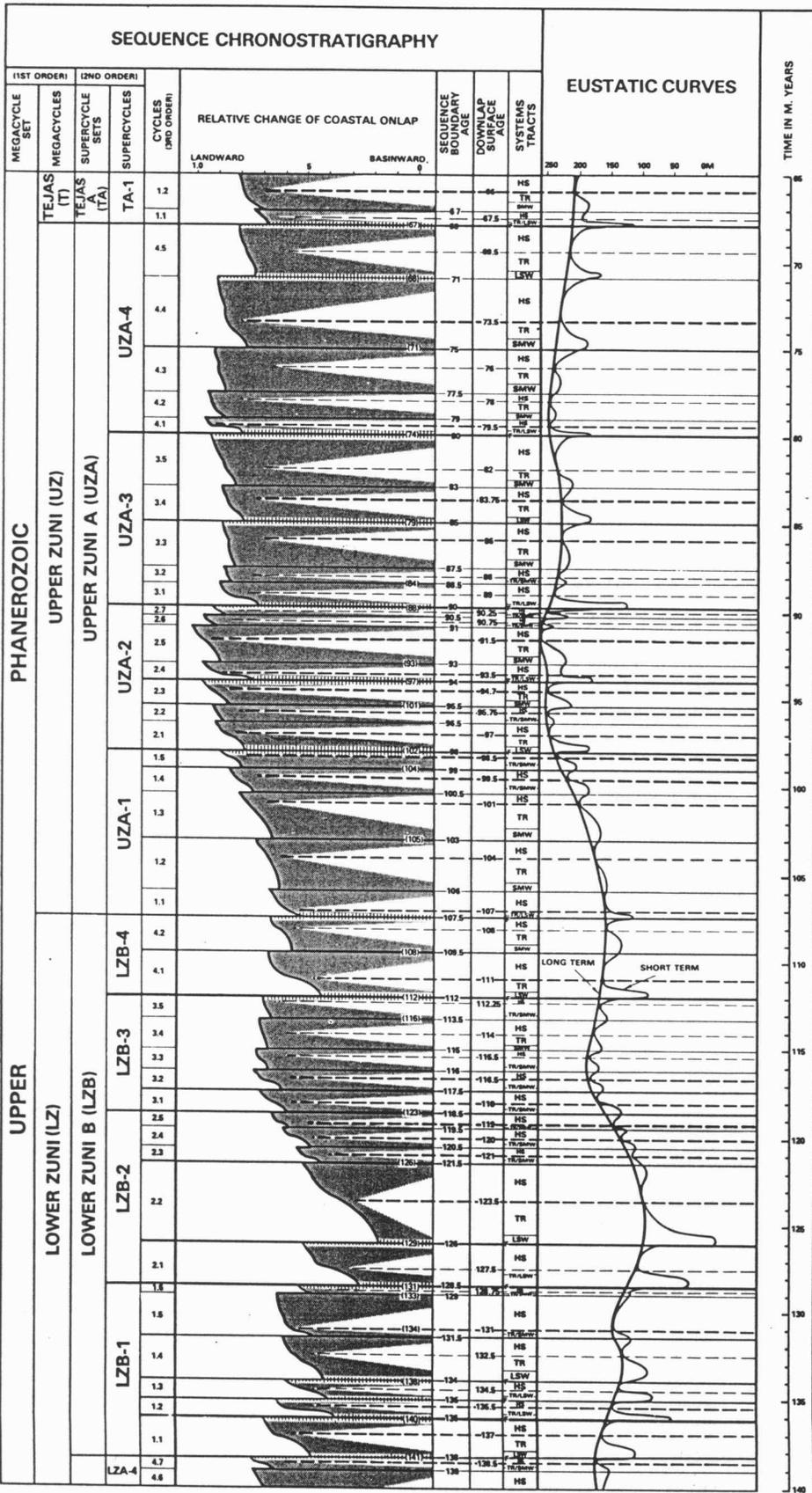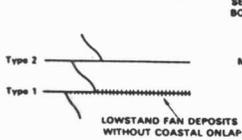
B.U. HAQ, J. HARDENBOL, P.R. VAIL,
L.E. STOVER, R.C. WRIGHT, R. JAN DU CHÊNE

2.d.

TECTONIC AND EUSTATIC CONTROLS ON THE STRATAL ARCHITECTURE OF MID-CRETACEOUS STRATIGRAPHIC SEQUENCES, CENTRAL WESTERN INTERIOR FORELAND BASIN OF NORTH AMERICA

MICHAEL H. GARDNER

Bureau of Economic Geology, The University of Texas at Austin, Austin, TX 78713-7508

ABSTRACT: Changes in stratal architecture defining a hierarchy of time-stratigraphic units record eustatic and tectonic controls on deposition in the central Western Interior foreland basin. Three temporal and spatial scales of stratigraphic cyclicity are recognized, each recording base-level changes of different periodicity. One long-term base-level cycle (600 m thick, 4.5 my) contains four intermediate-term base-level cycles (termed stratigraphic sequences, up to 300 m thick, 1 to 2 my). Each stratigraphic sequence consists of two to eight short-term cycles (up to 40 m thick, 0.3 my). A long-term stratigraphic cycle spanning Turonian through middle Coniacian stages consists of an upward-coarsening succession of marine and nonmarine deposits bounded by deposits formed during eustatic transgressions. Long-term base-level fall is recorded by the episodic eastward progradation of shoreface sandstones into the basin. The regressive maximum of the youngest stratigraphic sequence corresponds to a well-documented eustatic drop in the late Turonian.

Stratigraphic sequences of the Western Interior change as a function of local rates of sediment accommodation relative to supply in foreland subbasins comprising the western margin of the central Western Interior seaway. Turonian–Coniacian stratigraphic sequences were deposited under low accommodation and sediment supply conditions across Wyoming, Colorado, northeastern Utah, and northern New Mexico, and in high sediment accommodation to supply settings in western Wyoming, central Utah, and in northwestern New Mexico (upper part of the youngest sequence). Where sediment accommodation relative to supply rates are lower, stratigraphic sequences show: (1) more unconformities, (2) higher magnitude facies offsets across cycle boundaries, (3) seaward-stepping cycle stacking patterns, (4) vertically truncated facies tracts, (5) lower proportions of nonmarine strata, and (6) higher sandstone- to mudstone-ratios.

Along strike changes in sediment supply and accommodation are superimposed on a long-term pattern of westward-thickening and eastward-prograding basin fill. Regional variations in stratal architecture within stratigraphic sequences are related to southward migration of depocenters in successive foreland subbasins, and southward increases in accommodation recorded by more conformable stratal successions and higher proportions of deep-water carbonates and mudstones. Basinwide variations documented here show that a hierarchy of Turonian–Coniacian chronostratigraphic units may be resolved where stratal patterns are not consistent. Correlating base-level rise-to-fall turnarounds across foreland subbasins links dissimilar stratal patterns within chronostratigraphic units recording the same record of base-level change, but of varying magnitude and with changing contributions from primary controls (i.e., subsidence, sediment supply, and eustasy). For example, northward movement of subtropical (Atlantic-Tethyan) water masses and southward migration of depocenters appear to have locally combined in the late Turonian to produce high accommodation and sediment-supply conditions in the central Utah foreland basin. Here, short-term cycle stacking patterns closely resemble parasequence sets of a third-order depositional sequence. This suggests that this particular cycle stacking pattern and sequence model is most applicable to settings where accommodation and sediment supply are high.

approximate correlation

Smoky Hill Chalk

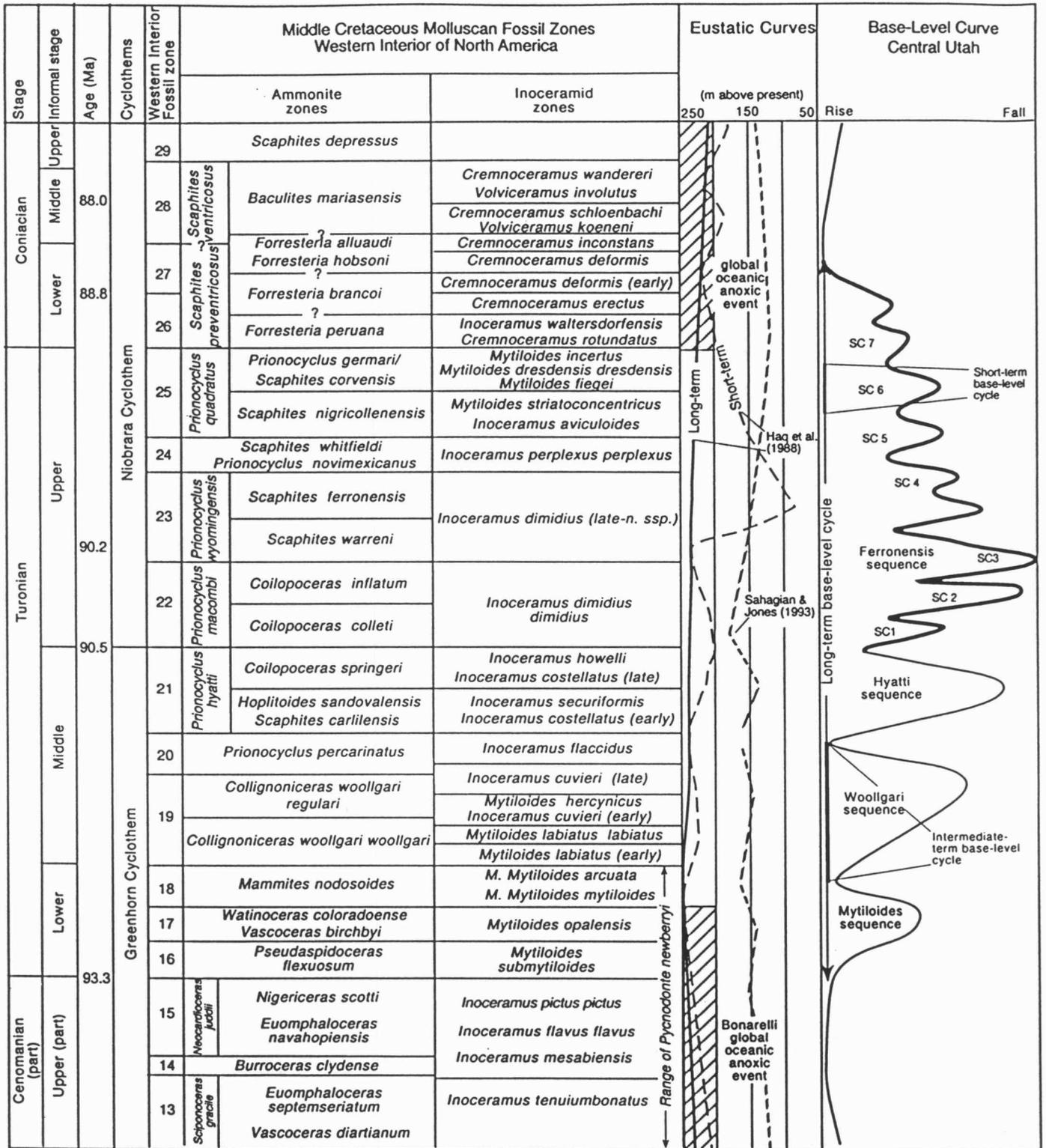*F.T. Hays*

Codell

Carlisle

Greenhorn Ls.

Stage	Informal stage (Upper)	Age (Ma)	Cyclothems	Western Interior Fossil zone	Middle Cretaceous Molluscan Fossil Zones — Western Interior of North America — Ammonite zones	Inoceramid zones	Eustatic Curves (m above present) 250 150 50	Base-Level Curve Central Utah — Rise ... Fall
Coniacian	Upper			29	Scaphites depressus			
	Middle	88.0		28	Baculites mariasensis	Cremnoceramus wandereri / Volviceramus involutus		
						Cremnoceramus schloenbachi / Volviceramus koeneni		SC 7
	Lower			27	Forresteria alluaudi ? / Forresteria hobsoni	Cremnoceramus inconstans		
		88.8				Cremnoceramus deformis	global oceanic anoxic event	
					? / Forresteria brancoi	Cremnoceramus deformis (early)		
				26	? / Forresteria peruana	Cremnoceramus erectus		
						Inoceramus waltersdorfensis / Cremnoceramus rotundatus		
Turonian	Upper		Niobrara Cyclothem	25	Prionocyclus germari / Scaphites corvensis	Mytiloides incertus / Mytiloides dresdensis dresdensis / Mytiloides fiegei		SC 6
					Scaphites nigricollenensis	Mytiloides striatoconcentricus / Inoceramus aviculoides		SC 5
				24	Scaphites whitfieldi / Prionocyclus novimexicanus	Inoceramus perplexus perplexus		SC 4
		90.2		23	Scaphites ferronensis	Inoceramus dimidius (late-n. ssp.)		SC 3 Ferronensis sequence
					Scaphites warreni			
				22	Coilopoceras inflatum	Inoceramus dimidius dimidius		SC 2
		90.5			Coilopoceras colleti			SC 1
	Middle		Greenhorn Cyclothem	21	Coilopoceras springeri	Inoceramus howelli / Inoceramus costellatus (late)		Hyatti sequence
					Hoplitoides sandovalensis / Scaphites carlilensis	Inoceramus securiformis / Inoceramus costellatus (early)		
				20	Prionocyclus percarinatus	Inoceramus flaccidus		
				19	Collignoniceras woollgari regulari	Inoceramus cuvieri (late)		Woollgari sequence
						Mytiloides hercynicus / Inoceramus cuvieri (early)		
					Collignoniceras woollgari woollgari	Mytiloides labiatus labiatus		
						Mytiloides labiatus (early)		
	Lower			18	Mammites nodosoides	M. Mytiloides arcuata / M. Mytiloides mytiloides		Mytiloides sequence
				17	Watinoceras coloradoense / Vascoceras birchbyi	Mytiloides opalensis		
				16	Pseudaspidoceras flexuosum	Mytiloides submytiloides		
Cenomanian (part)	Upper (part)	93.3		15	Nigericeras scotti	Inoceramus pictus pictus		
					Euomphaloceras navahopiensis	Inoceramus flavus flavus	Bonarelli global oceanic anoxic event	
				14	Burroceras clydense	Inoceramus mesabiensis		
				13	Euomphaloceras septemseriatum	Inoceramus tenuiumbonatus		
					Vascoceras diartianum			

(Western Interior Fossil zone additional labels: *Scaphites ventricosus*, *Scaphites preventricosus*, *Prionocyclus quadratus*, *Prionocyclus wyomingensis*, *Prionocyclus macombi*, *Prionocyclus hyatti*, *Neocardioceras juddii*, *Sciponoceras gracile*)

(Eustatic Curves labels: Long-term, Short-term, Haq et al. (1988), Sahagian & Jones (1993))

(Base-Level Curve labels: Short-term base-level cycle, Long-term base-level cycle, Intermediate-term base-level cycle)

(Range of *Pycnodonte newberryi*)

FIG. 2.—Biostratigraphic chart showing ammonite and inoceramid fossil zones for late Cenomanian through middle Coniacian Stages from the Western Interior of North America. Because of potential discrepancies associated with different absolute dates for stage boundaries, eustatic curves from Haq and others (1987) and Sahagian and Jones (1993) are calibrated to biozones. Base-level curves are based on stratigraphic relations in central Utah. Sources of data: Western Interior index fossils from Molenaar and Cobban (1991), upper Cenomanian and lower Turonian Substage biozones from Elder (1985); middle and upper Turonian Substage biozones from Kauffman and Collom (pers. commun., 1990), lower and middle Coniacian zones from Collom, (1991), argon-argon isotopic ages from Obradovich (pers. commun., 1991), and Obradovich (1991).

Gardner, M.H., 1995
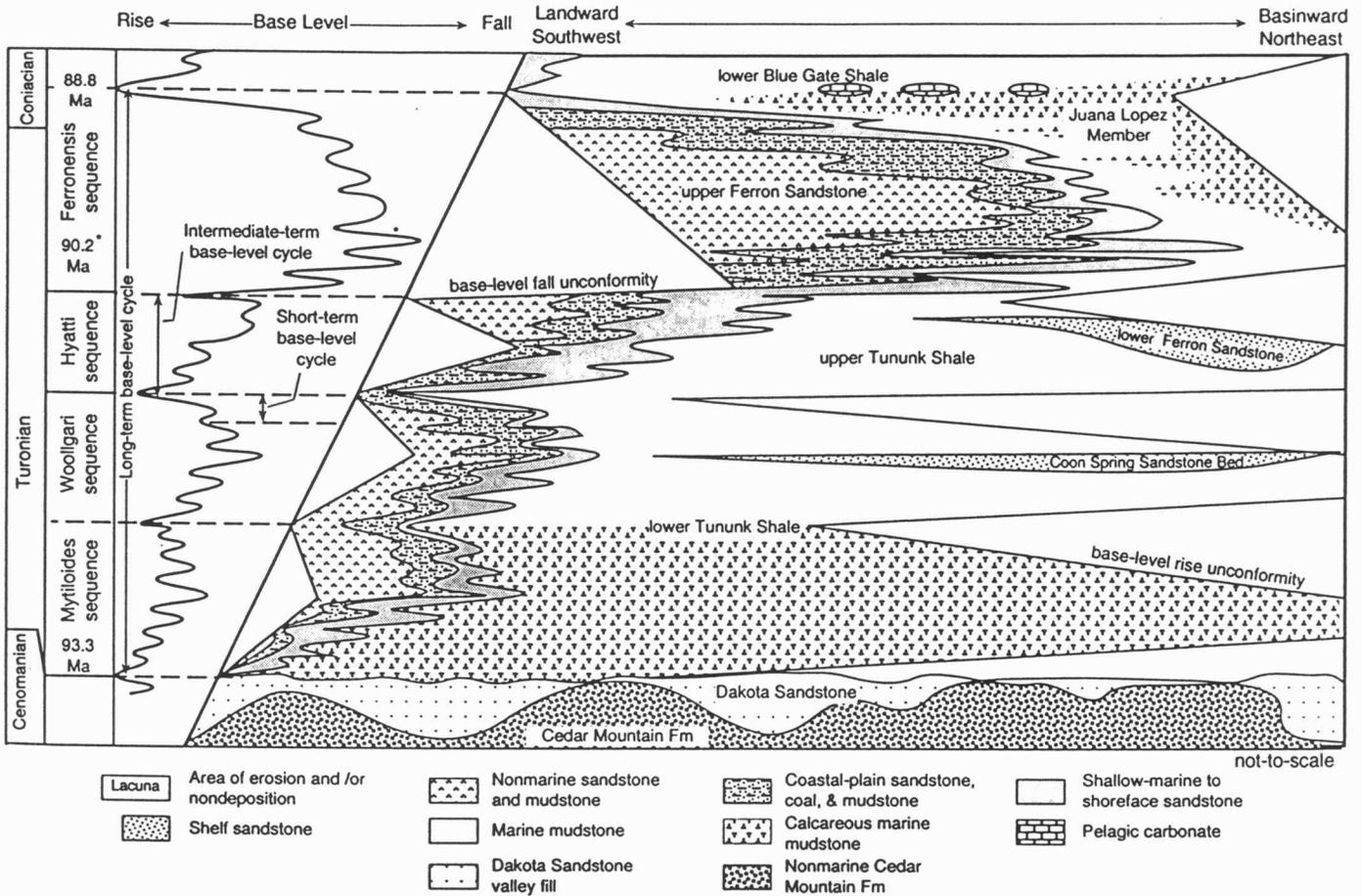
Fig. 4.—Schematic diagram showing stacking patterns of mid-Cretaceous strata in central Utah. Three temporal and spatial scales of stratigraphic cyclicity, each recording a base-level cycle of different periodicity, are recognized. Stratigraphic sequences show a step-wise progradation of more proximal deposits and a basinward migration of base-level fall unconformities in response to base-level fall of the long-term base-level cycle. Unconformities in the basin center are regionally expressed during intermediate-term base-level rise, when sediment starvation and nondeposition promoted hiatal surface development. Argon-argon isotopic data (Obradovich, pers. commun., 1993) are indicated by (*).

Turonian Paleogeography
of North America

Western Interior Seaway

Modified from Williams and Stelck (1975)

Central Western Interior
Study Area

Upper Cenomanian
Lower Turonian depocenter

WYOMING

Lower and Middle
Turonian depocenter

NEBRASKA

UTAH

Fig. 10

Middle & Upper
Turonian depocenter

Fig. 11

Fig. 12

Fig. 19

Fig. 13

Fig. 5

KANSAS

Fig. 14
& 15

Fig.21

Upper Turonian
depocenter

Fig.17

COLORADO

Fig.16

—— Cross-section line

- - - Chronostratigraphic
chart

Upper Turonian to Middle
Coniacian depocenter

Fig. 22

NEW MEXICO

ARIZONA

Northward movement of
Tethyan-Atlantic water mass

FIG. 1.—Map of central portion of U.S. Western Interior Cretaceous Seaway showing paleogeography and Utah study area. Note north-south migration of mid-Cretaceous depocenters across Utah and migration of Ferronensis sequence from southern to central Utah. Lines of cross sections and locations of major study areas discussed in text are shown.
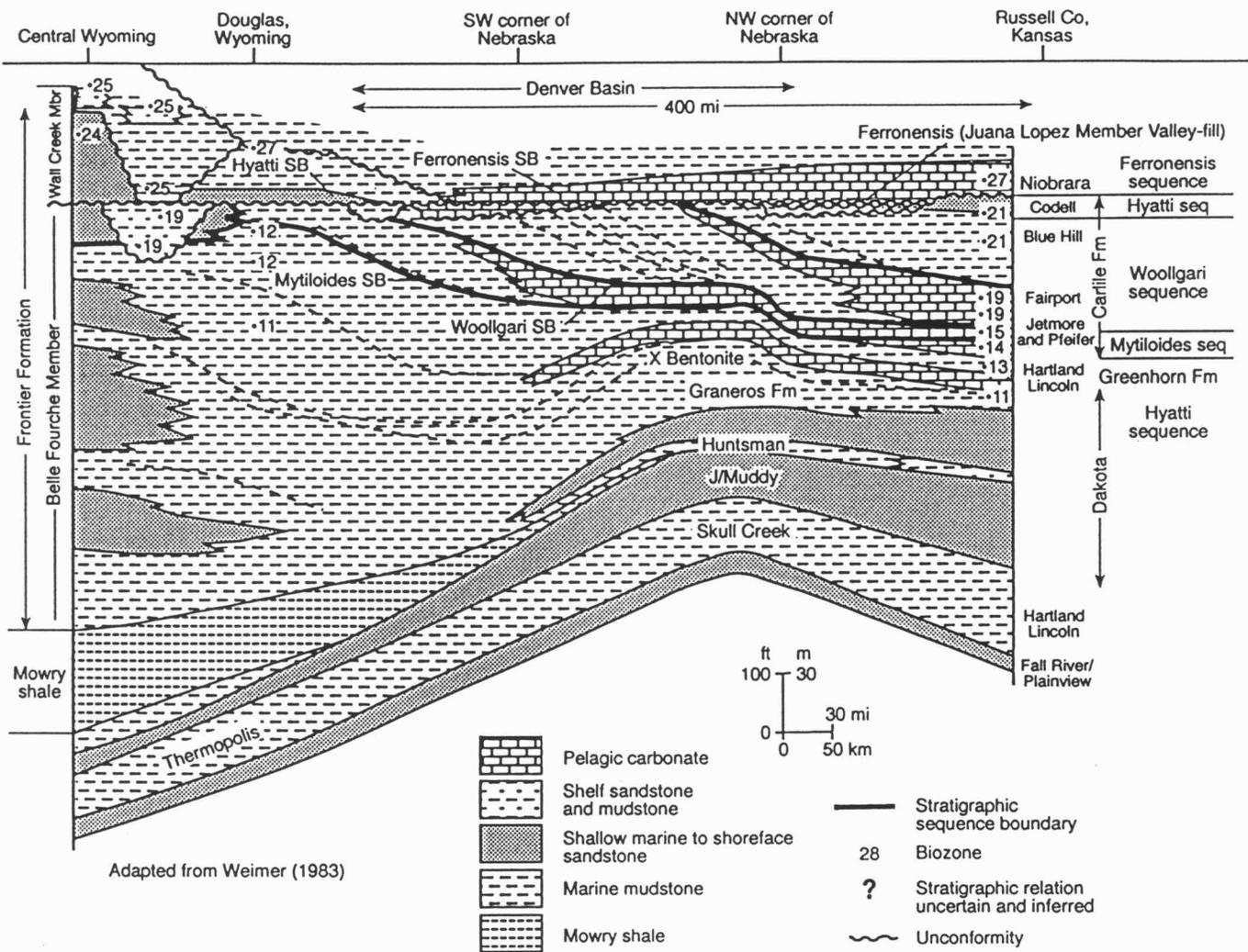
FIG. 19.—Stratigraphic cross section (northwest-southeast) showing correlation and facies relations in mid-Cretaceous stratigraphic sequences from central Wyoming to western Kansas. Cross section adapted from Weimer (1983).
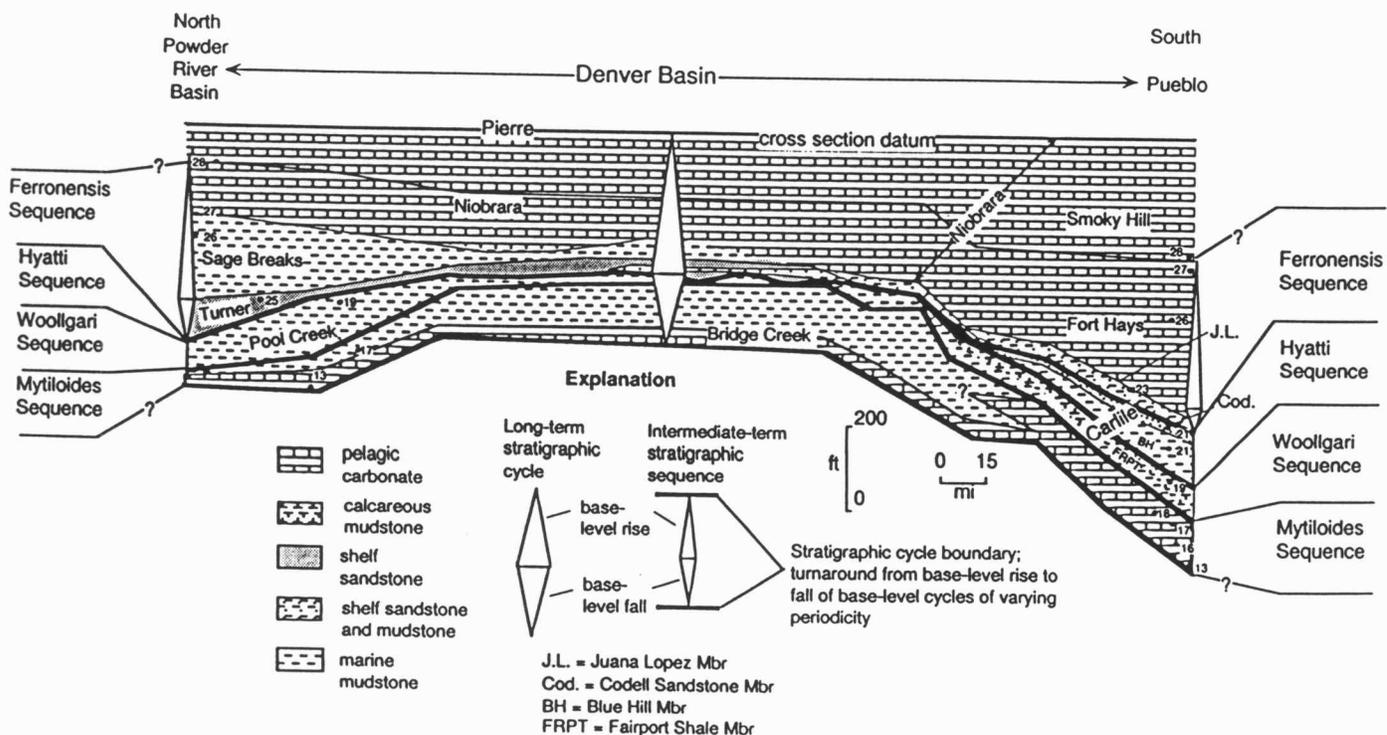
FIG. 21.—Stratigraphic cross section (north-south) along the seaway axis showing correlation and facies relations in mid-Cretaceous stratigraphic sequences from north-central Wyoming to Pueblo, Colorado. Cross section adapted from Weimer (1978).

FIG. 23.—Map showing the distribution of facies and unconformities in the Hyatti sequence of the central Western Interior of North America.

~ Codell Ss.

(a) upper Turonian

Ferronensis sequence
(beginning base-level rise)

Ammonoidea Biozones
Scaphites whitfieldi
Prionocyclus novimexicanus

Inoceramidea Biozones
Inoceramus perplexus perplexus

(c) middle Coniacian

Ferronensis sequence
(maximum base-level rise)

Ammonoidea Biozones
Forresteria peruana

Inoceramidea Biozones
Inoceramus erectus

(b) upper Turonian

Ferronensis sequence
(base-level rise)

Ammonoidea Biozones
Prionocyclus quadratus
Scaphites corvensis
Scaphites nigricolensis
Inoceramidea Biozones
Mytiloides fiegei fiegei
Mytiloides dresdensis dresdensis
Mytiloides aviculoides
Mytiloides striatoconcentricus

Lacuna — Area of erosion or nondeposition

Coastal plain mudstone and sandstone

Shallow marine to shoreface sandstone

Shelf sandstone

Shelf sandstone and mudstone

Marine mudstone

Pelagic carbonate

N

0   100   200 mi
0 100 200 300 km

Adapted from Merewether and Cobban (1986); Additional data from Peterson and Kirk (1977); Molenaar (1983); Cobban and Hook (1979, 1984, 1989)

QAa2283c

FIG. 25.—Maps showing the distribution of facies and unconformities in the Ferronensis sequence of the central Western Interior of North America. This map shows only base-level rise for an intermediate-term base-level cycle about 1 to 2 my in duration.

~ Base FT. Hays – Lower Smoky Hill Chalk

Index map for COLOR GR cross section
prepared by Dave Collins, Kansas Geological Survey
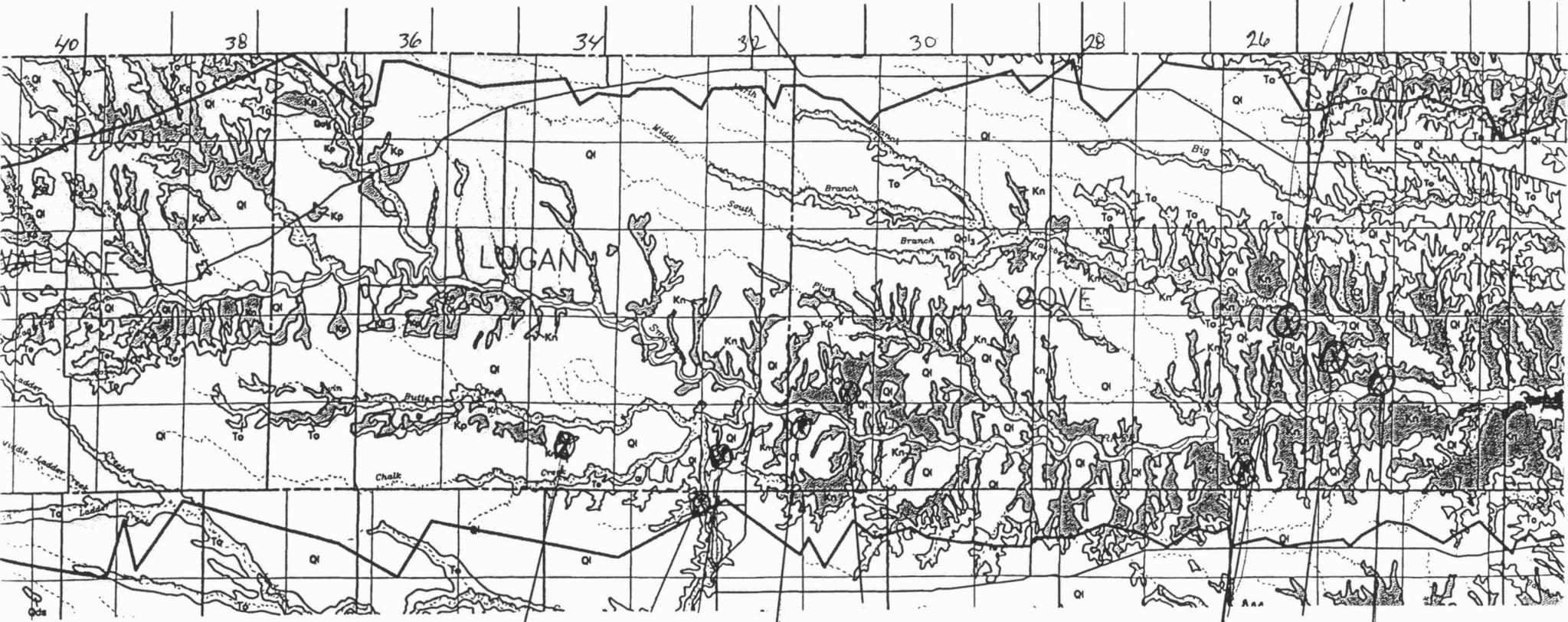
Smokey Hill Chalk

FT. Hays

Greenhorn

base Cretaceous

Blaine
Flowerpot

Cedar Hills

| Kansas Geological Survey | Education 🍎🍎🍎 | Physiographic Map of Kansas |

3.
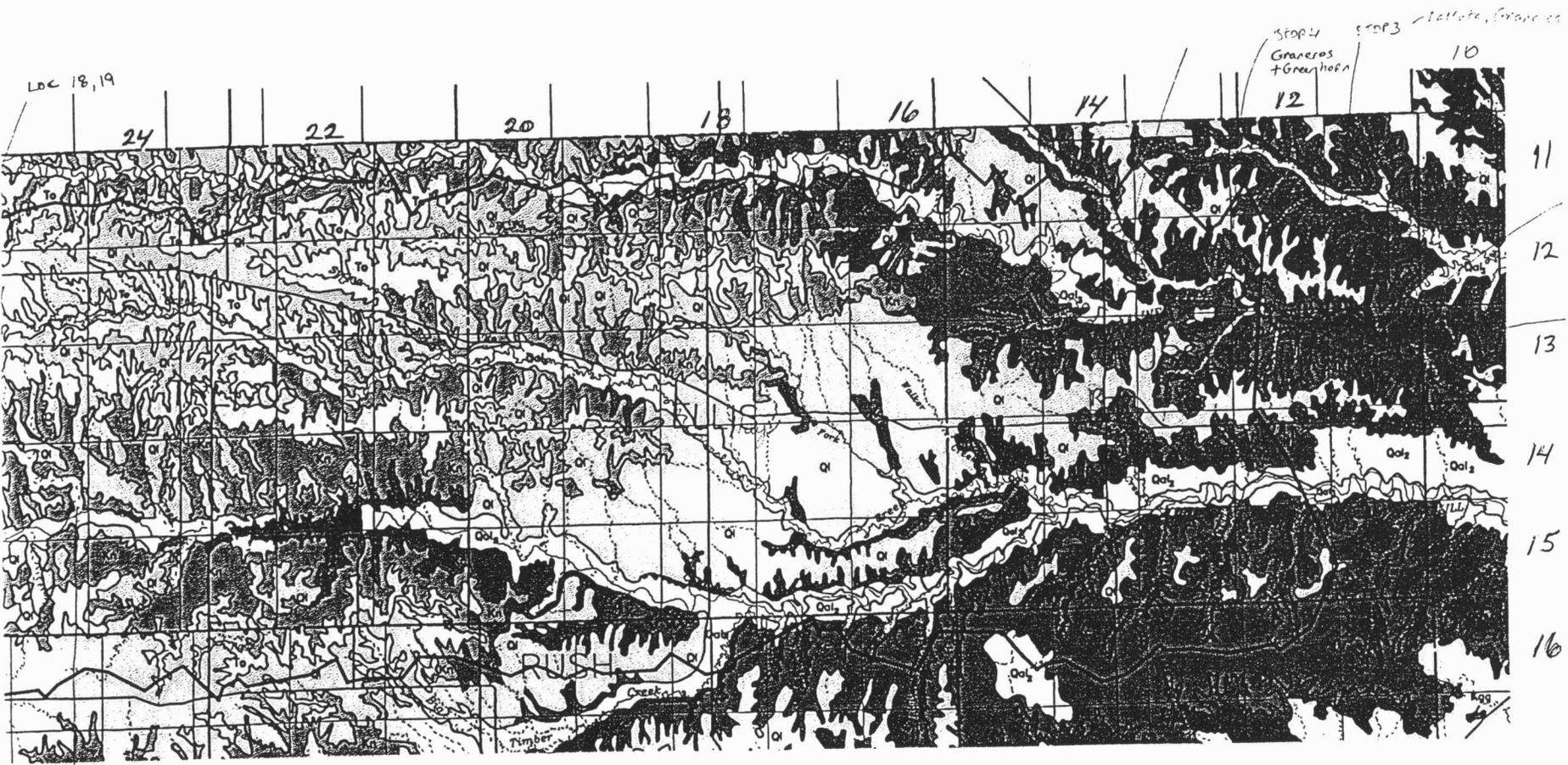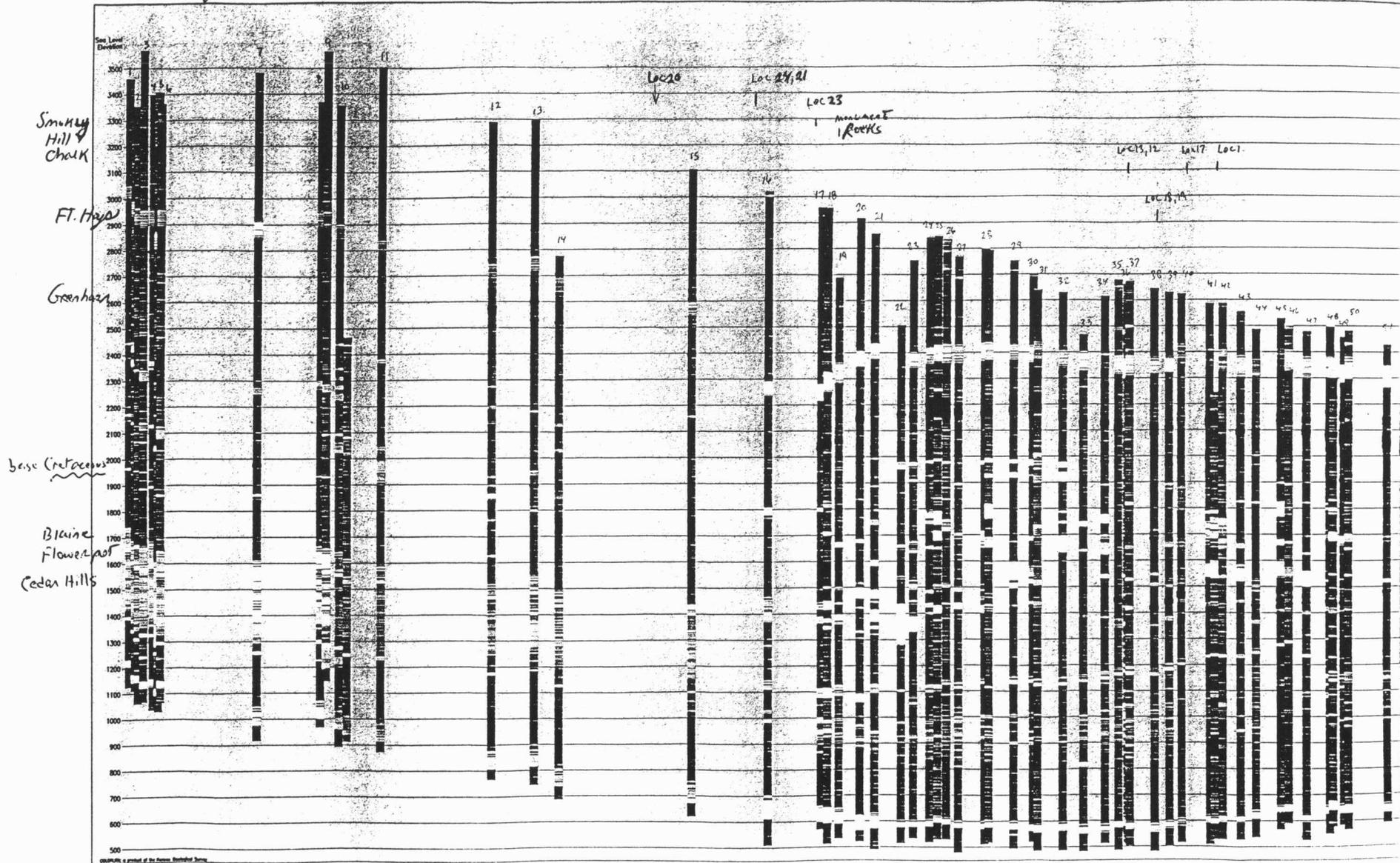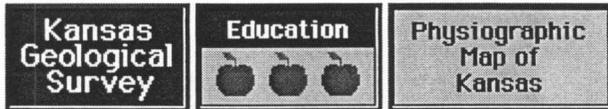
Physiographic Map of Kansas

The Kansas landscape was formed by alternating periods of deposition and erosion. This landscape divides regions of Kansas according to physical geology, or physiography. Each region is different, and that difference is determined largely by geology, along with other factors such as climate.

The Ozark Plateau in extreme southeastern Kansas is made up of rocks deposited during the Mississippian Period of geologic history, about 350 million years ago. Landforms in the Cherokee Lowlands, Osage Cuestas and the Chautauqua Hills are all Pennslyvanian in age, deposited about 300 million years ago. The Flint Hills of east-central Kansas and the Red Hills in the south-central part of the state are both Permian in age, roughly 250 million years old.

Cretaceous-age rocks, deposited about 100 million years ago during the time of the dinosaurs, form the landscape in the Smoky Hills. The High Plains of western Kansas are composed of rock debris washed off the face of the Rocky Mountains over the past few million years. The Arkansas River Lowlands and the Wellington-McPherson Lowlands are areas of recent deposition that border rivers. Glaciers moved into Kansas about 750,000 years ago and sculpted the northeastern corner of the state.

Click on one of the physiographic regions to display typical landscapes which characterize the selected region.

Generalized Physiographic Map of Kansas
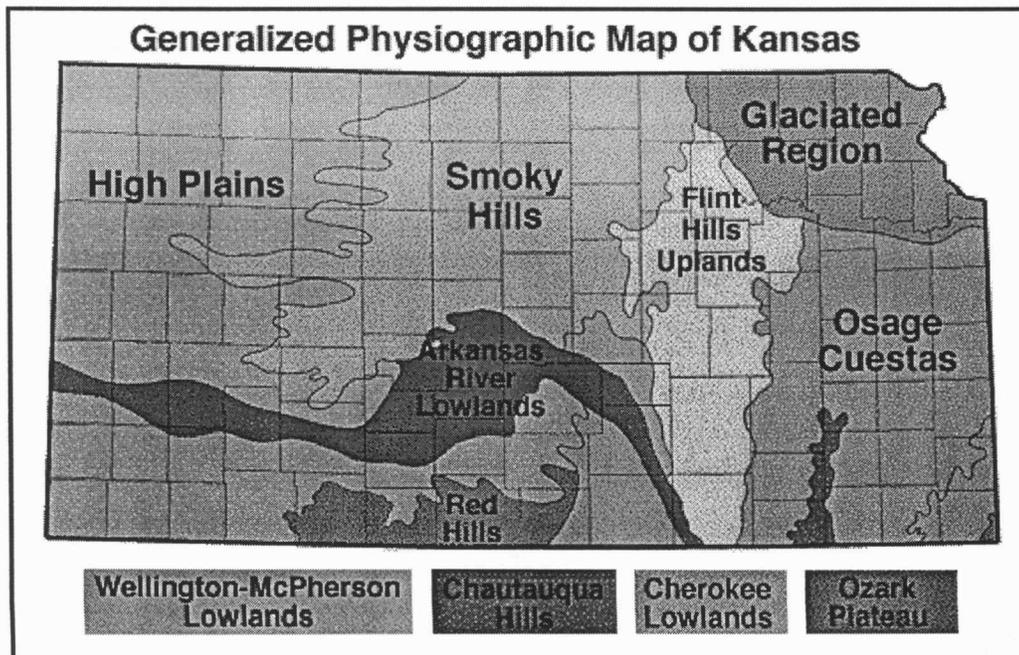
For more information about the state's geology, see the educational publications listed in the KGS Publications and Sales Catalog or the Kansas Geology Page.

Kansas Geological Survey | Education | Geology
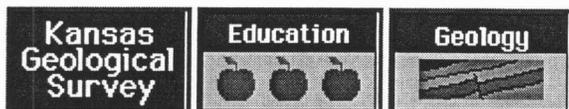
KGS Special Map 10--Geologic Timetable

This map is available as an 8 1/2 by 11 inch sheet (Special Map 10). Single copies sheet are free; multiple copies are 10 cents each. Contact the Publications Sales Office for more information.

Kansas Geologic Timetable
(Not scaled for geologic time or thickness of deposits)

Eras	Periods	Epochs	Est. Length (Years)*	Description	Million Years Past
Cenozoic	Quaternary	Holocene	10,000+	Early, the land was stable with some erosion. Glaciers moved into the northeast at least twice. Later the climate was dry. Sand dunes were formed by wind in the west. Volcanic ash was blown in from California, New Mexico, and Wyoming.	
		Pleistocene	1,590,000		1.6
	Tertiary	Pliocene	3,700,000	Rocks found are part of the Ogallala Formation (sand, gravel, and porous rock), which contains a large quantity of ground water and occurs only in the western third of the state. No rocks were formed in eastern Kansas.	
		Miocene	18,400,000		
		Oligocene	12,900,000		
		Eocene	21,200,000		
		Paleocene	8,600,000		66.4
Mesozoic	Cretaceous		77,600,000	Much of the western half was covered by seas. Limestone, sandstone, and chalk formed from sea deposits. Fossils can be found in these rocks, which crop out in central and western Kansas.	144
	Jurassic		64,000,000	Most rock in Kansas is underground in the west. A few small outcrops are found in the southwest corner.	208
	Triassic		37,000,000	No rocks have been found in Kansas.	245
Paleozoic	Permian		41,000,000	Much of Kansas was covered by several seas. As they rose and fell, limestone, shale, and chert were deposited. The Flint Hills were formed. When the seas dried up, salt and gypsum were left behind. Salt, now underground, is mined in central Kansas. The Red Hills were formed from deposits of shale, siltstone, gypsum, and dolomite.	286
	Pennsylvanian		34,000,000	For much of the period the land was flat. Seas and swamps came and went; coal formed in swamps from dead plants. Shale, limestone, sandstone, chert, and conglomerates were deposited. Two ridges of hills, the Nemaha uplift and the Central Kansas uplift, appeared; both are now burried. Pennsylvanian rocks are found at the surface in eastern Kansas.	320
	Mississippian		40,000,000	Repeated layers of limestone, shale, and sandstone indicate that seas rose and fell. Mississippian rocks are the oldest found at the surface and are in the southeast corner; elsewhere these rocks are only underground.	360
	Devonian		48,000,000	Seas covered Kansas during much of the the period. Limestone, shale, and sandstone deposits are only underground.	408
	Silurian		30,000,000	Land was uplifted and seas disappeared. Limestone deposits are found only underground.	438
	Ordovician		67,000,000	Seas covered Kansas during much of the period. Limestone, shale, and sandstone deposits are only underground.	505
	Cambrian		65,000,000	Early, the climate was dry and many rocks eroded. Later, parts of Kansas were covered by seas. Dolomite, sandstone, limestone, and shale are now underground.	570
	Precambrian		3,930,000,000	These rocks are the oldest on earth. In Kansas, they are only found deep below the surface and not much is known about	

4. Kansas shaded relief maps for counties
    visited on Niobrara portion of trip

Kansas Shaded Relief

4.
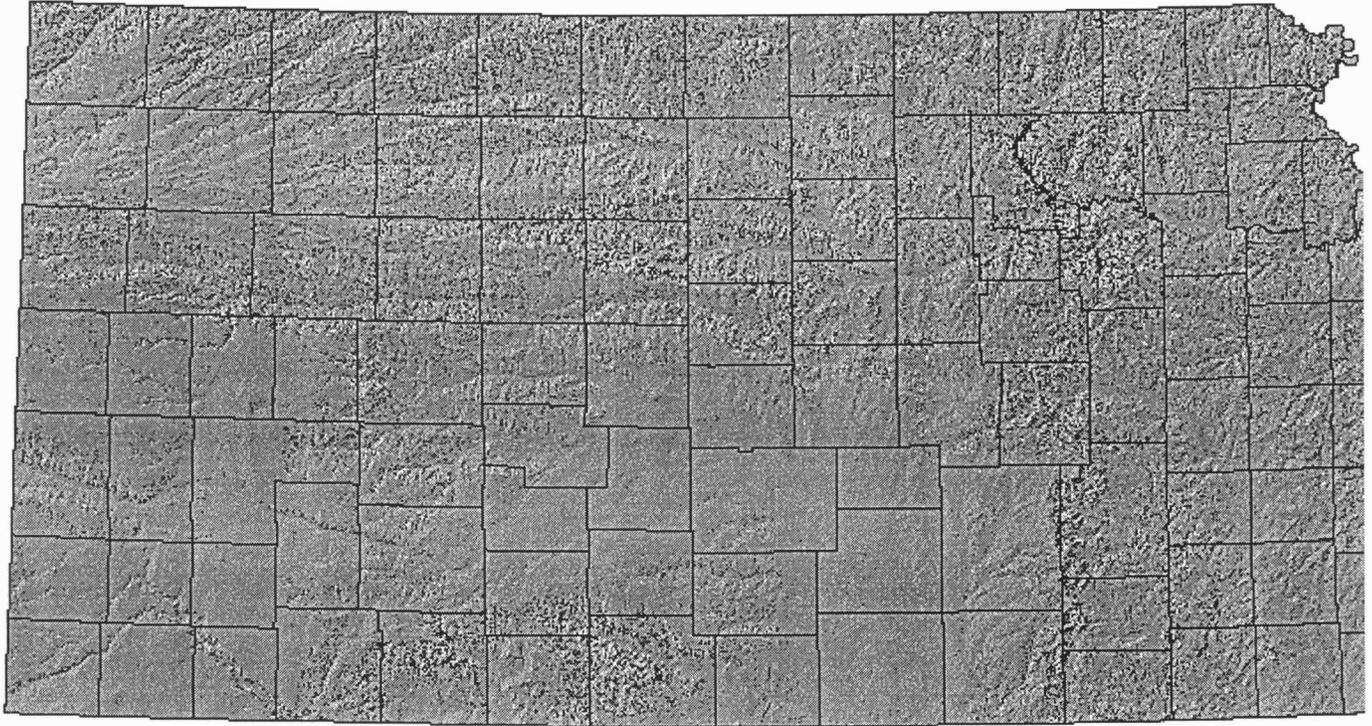
Illumination angle = 315 degrees; Angle from horizon = 40 degrees; Topographic exaggeration = 15 times
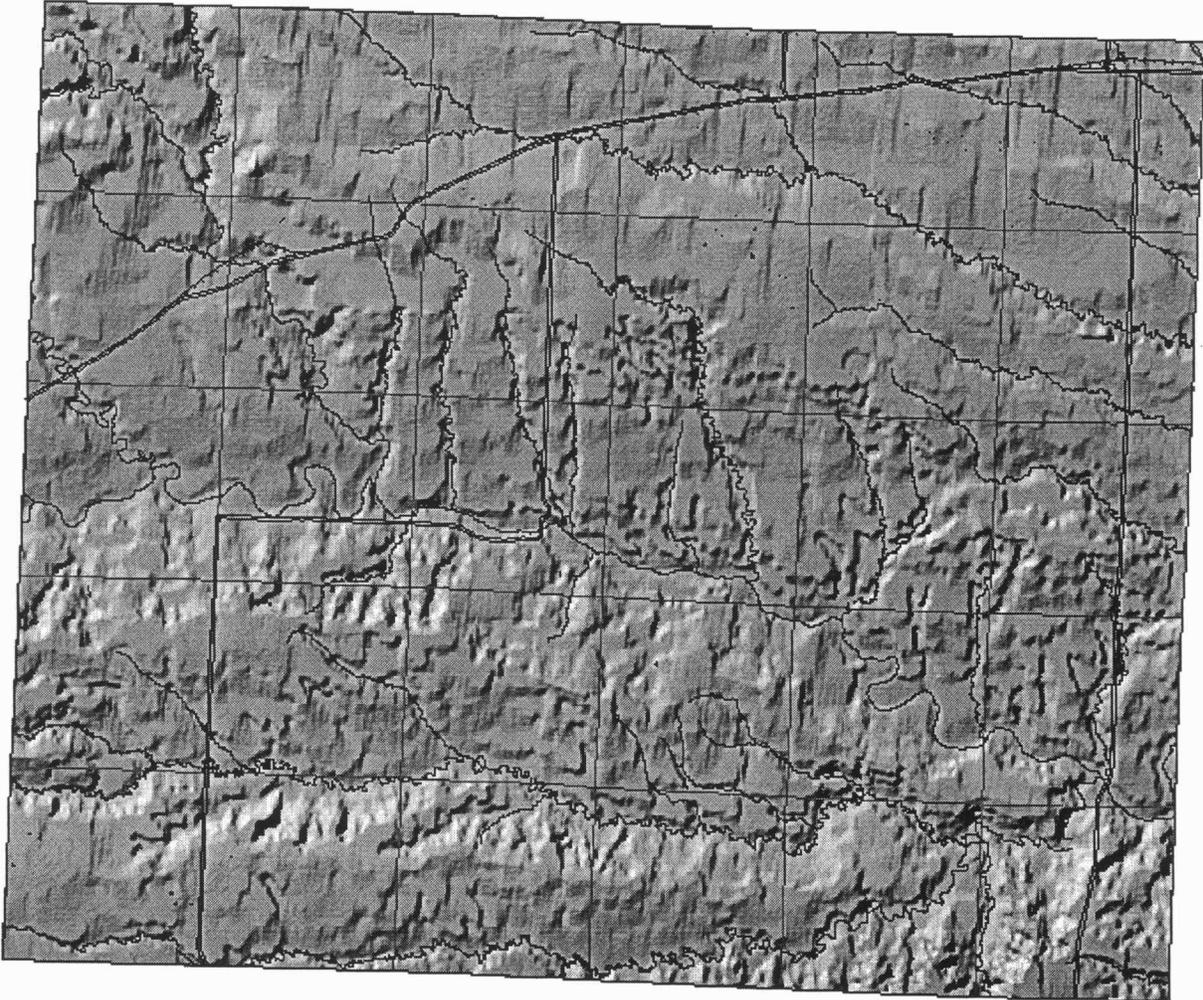
Select by Name

Allen I Anderson I Atchison I Barber I Barton I Bourbon I Brown I Butler I Chase I Chautauqua I Cherokee I Cheyenne I Clark I Clay I Cloud I Coffey I Comanche I Cowley I Crawford I Decatur I Dickinson I Doniphan I Douglas I Edwards I Elk I Ellis I Ellsworth I Finney I Ford I Franklin I Geary I Gove I Graham I Grant I Gray I Greeley I Greenwood I Hamilton I Harper I Harvey I Haskell I Hodgeman I Jackson I Jefferson I Jewell I Johnson I Kearny I Kingman I Kiowa I Labette I Lane I Leavenworth I Lincoln I Linn I Logan I Lyon I McPherson I Marion I Marshall I Meade I Miami I Mitchell I Montgomery I Morris I Morton I Nemaha I Neosho I Ness I Norton I Osage I Osborne I Ottawa I Pawnee I Phillips I Pottawatomie I Pratt I Rawlins I Reno I Republic I Rice I Riley I Rooks I Rush I Russell I Saline I Scott I Sedgwick I Seward I Shawnee I Sheridan I Sherman I Smith I Stafford I Stanton I Stevens I Sumner I Thomas I Trego I Wabaunsee I Wallace I Washington I Wichita I Wilson I Woodson I Wyandotte I

Return to KanView homepage

Logan County Shaded Relief

Click image to FTP 1:250K DEM Quadrangle data

Illumination angle (azimuth) = 315 degrees
Angle from horizon (altitude) = 40 degrees
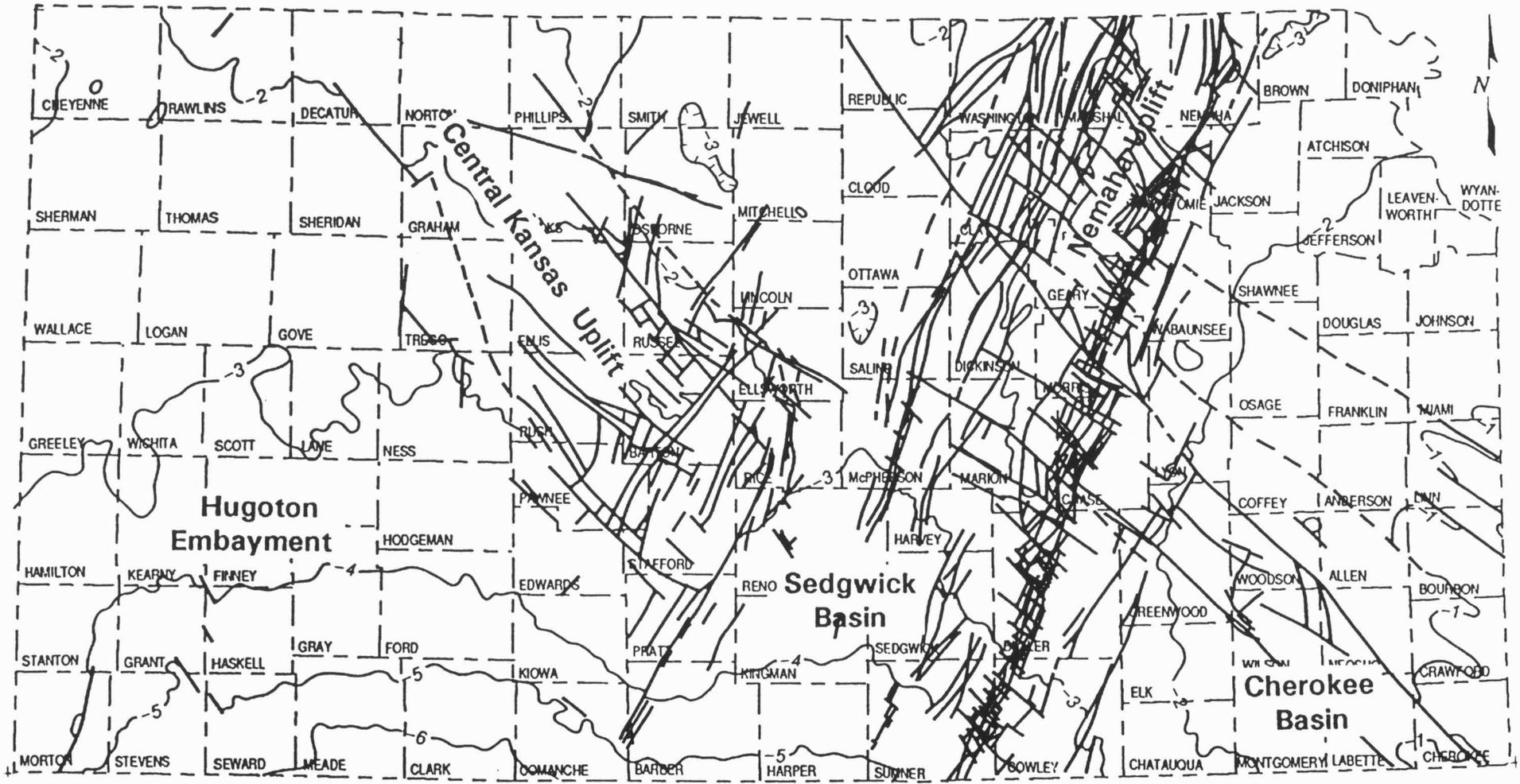Topographic exaggeration (z-factor) = 15 times

Other Logan County Maps:
Color Elevation I Geology I Contours I Land Cover I Hydrology I Environmental Monitoring Sites I Aquifers I
Demographics I

Back to Kansas Shaded Relief Base Map

Gove County Shaded Relief
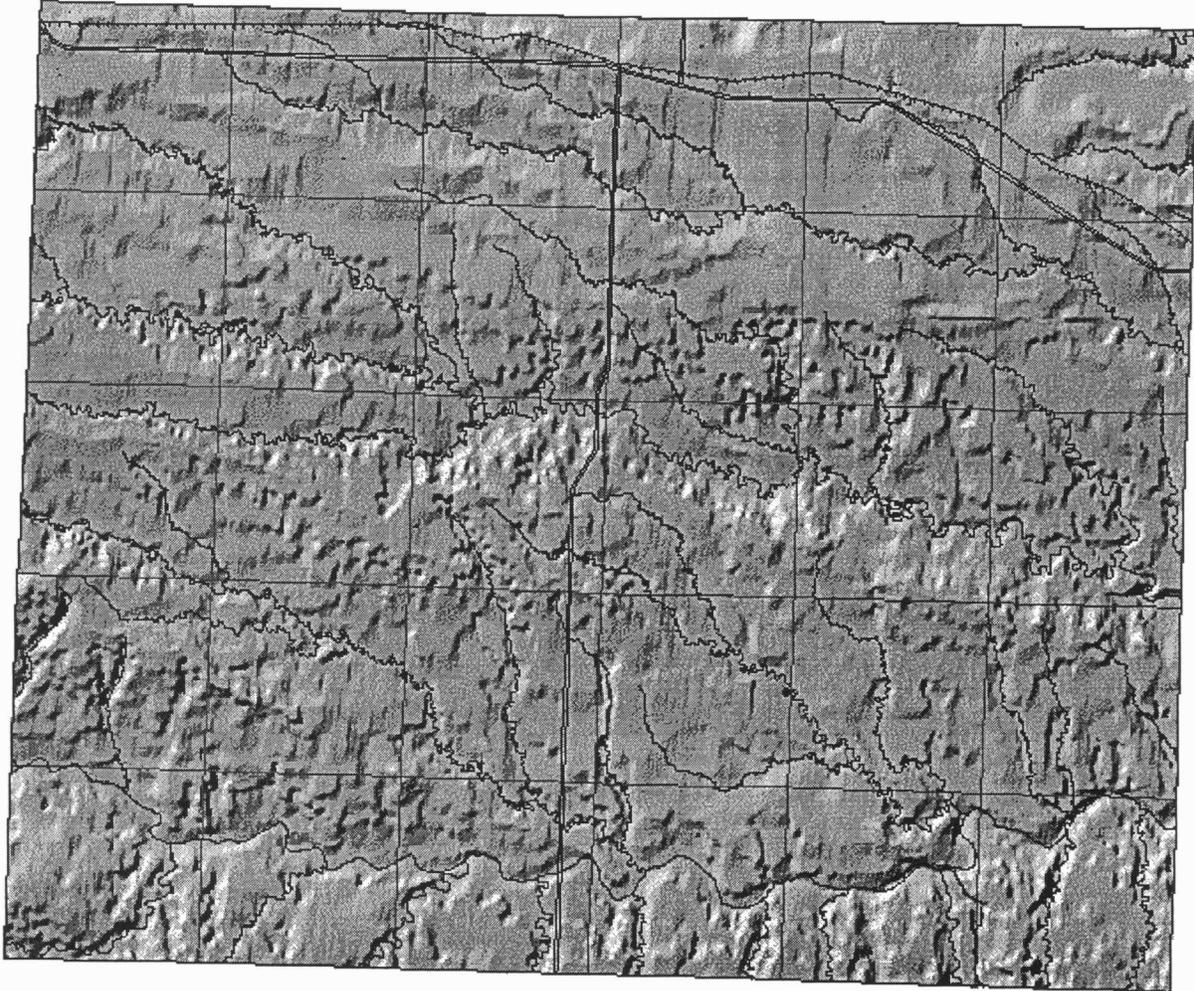
Click image to FTP 1:250K DEM Quadrangle data

Illumination angle (azimuth) = 315 degrees
Angle from horizon (altitude) = 40 degrees
Topographic exaggeration (z-factor) = 15 times

Other Gove County Maps:
Color Elevation I Geology I Contours I Land Cover I Hydrology I Environmental Monitoring Sites I Aquifers I Demographics I

Back to Kansas Shaded Relief Base Map

Trego County Shaded Relief
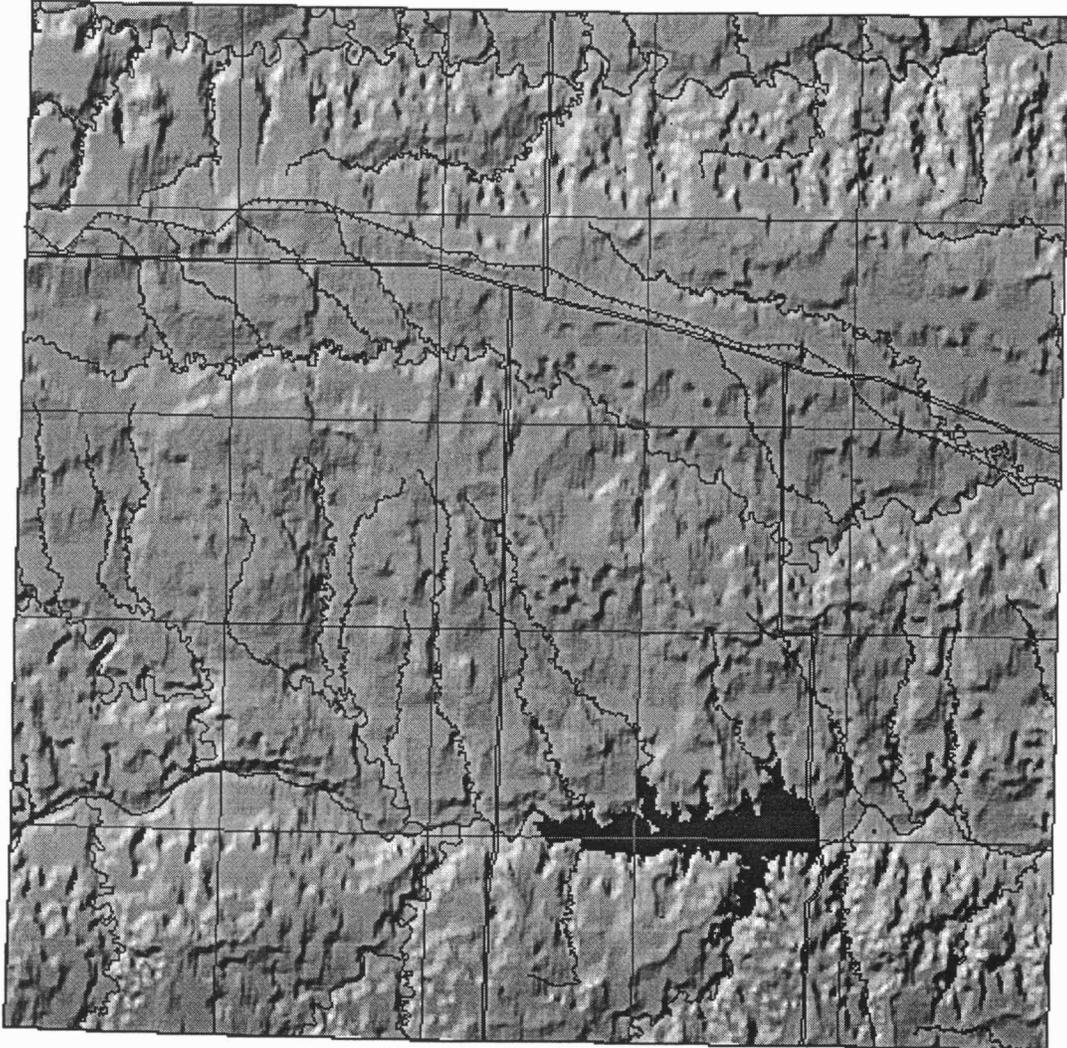
Click image to FTP 1:250K DEM Quadrangle data

Illumination angle (azimuth) = 315 degrees
Angle from horizon (altitude) = 40 degrees
Topographic exaggeration (z-factor) = 15 times

Other Trego County Maps:

Color Elevation | Geology | Contours | Land Cover | Hydrology | Environmental Monitoring Sites | Aquifers | Demographics |

Back to Kansas Shaded Relief Base Map

Ellis County Shaded Relief
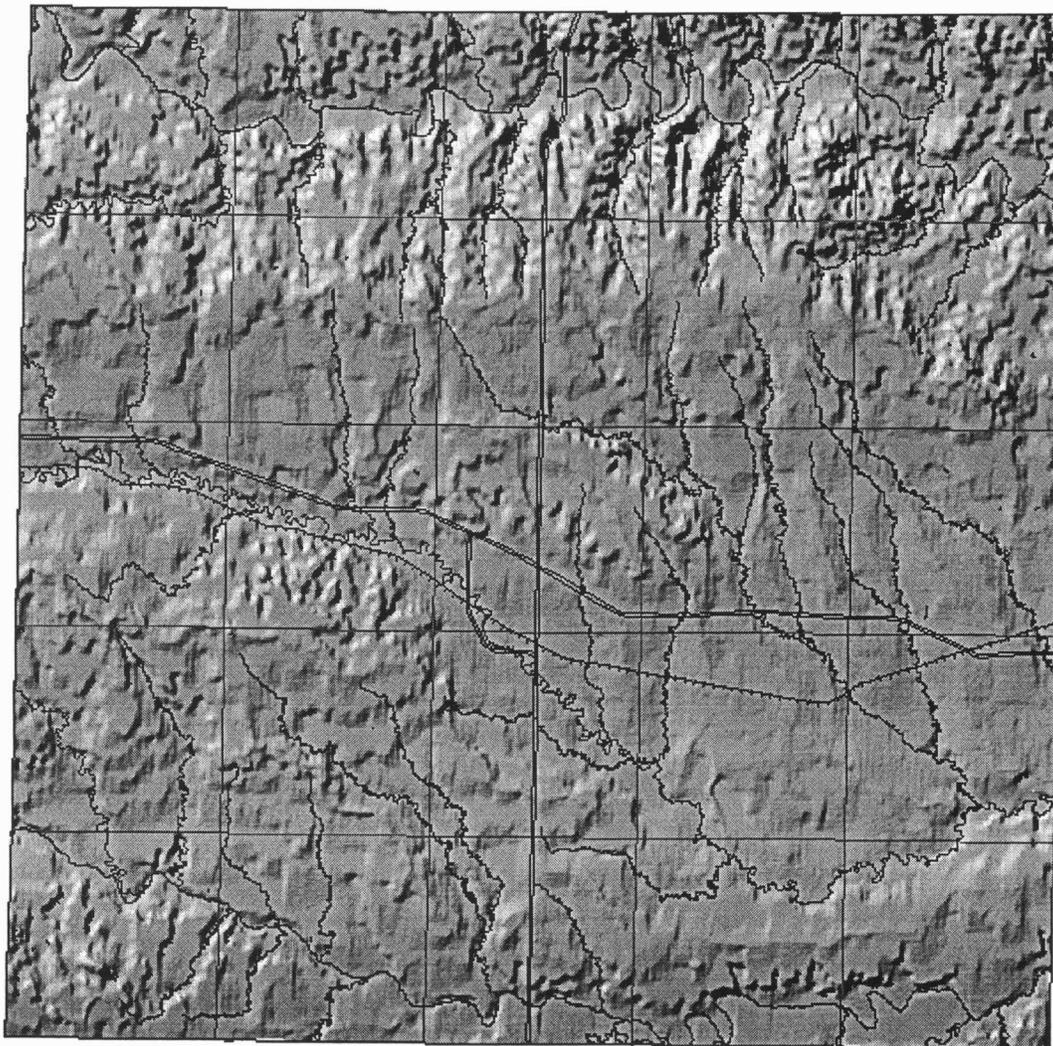
Click image to FTP 1:250K DEM Quadrangle data

Illumination angle (azimuth) = 315 degrees
Angle from horizon (altitude) = 40 degrees
Topographic exaggeration (z-factor) = 15 times

Other Ellis County Maps:
Color Elevation | Geology | Contours | Land Cover | Hydrology | Environmental Monitoring Sites | Aquifers |
Demographics |

Back to Kansas Shaded Relief Base Map

5. Structure and sedimentation

    a. Basement structure
    b. Residual aeromagnetic map of Kansas
    c. Combined gravity and magnetics maps with overlays of structure, oil field outlines, and only county overlay for area in western Kansas (black and white version, see color)
    d. Selected regional isopach maps from Merriam (1963), The Geologic History of Kansas, Kansas Geological Survey, Bulletin 162
    e. Regional maps (western Kansas) of Dakota Sandstone
    f. Excerpts from Holdaway (1978), "Deposition of evaporites and red beds of Nippewalla Group, Permian, Western Kansas," Kansas Geological Survey Bulletin 215
    g. Accommodation realms (sediment accommodation regions) – paper by Watney et al., 1997, Modeling of sediment accommodation realms by regionalized classification

Basement structure

Hugoton Embayment

Central Kansas Uplift

Nemaha Uplift

Sedgwick Basin

Cherokee Basin

CHEYENNE RAWLINS DECATUR NORTON PHILLIPS SMITH JEWELL REPUBLIC WASHINGTON MARSHALL NEMAHA BROWN DONIPHAN ATCHISON

SHERMAN THOMAS SHERIDAN GRAHAM CLOUD MITCHELL OTTAWA LEAVEN-WORTH WYAN-DOTTE JEFFERSON

WALLACE LOGAN GOVE TREGO ELLIS RUSSELL LINCOLN SALINE GEARY DICKINSON WABAUNSEE SHAWNEE DOUGLAS JOHNSON

GREELEY WICHITA SCOTT LANE NESS RUSH BARTON ELLSWORTH RICE McPHERSON MARION MORRIS LYON OSAGE FRANKLIN MIAMI

HAMILTON KEARNY FINNEY HODGEMAN PAWNEE STAFFORD RENO HARVEY CHASE COFFEY ANDERSON LINN

STANTON GRANT HASKELL GRAY FORD EDWARDS PRATT KINGMAN SEDGWICK BUTLER GREENWOOD WOODSON ALLEN BOURBON

MORTON STEVENS SEWARD MEADE CLARK COMANCHE BARBER HARPER SUMNER COWLEY ELK WILSON NEOSHO CRAWFORD

KIOWA CHATAUQUA MONTGOMERY LABETTE CHEROKEE

5.a.

5. d.

The Geologic History of Kansas

By Daniel F. Merriam
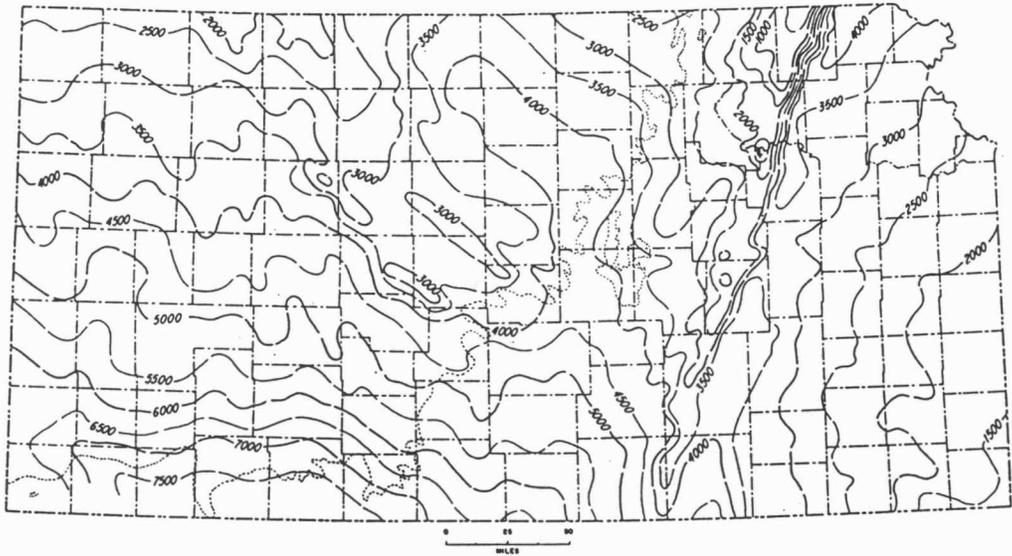
FIGURE 31.—Map showing thickness of Paleozoic rocks in Kansas. Area northwest of dashed line is buried beneath Mesozoic deposits. Contour interval 500 feet.
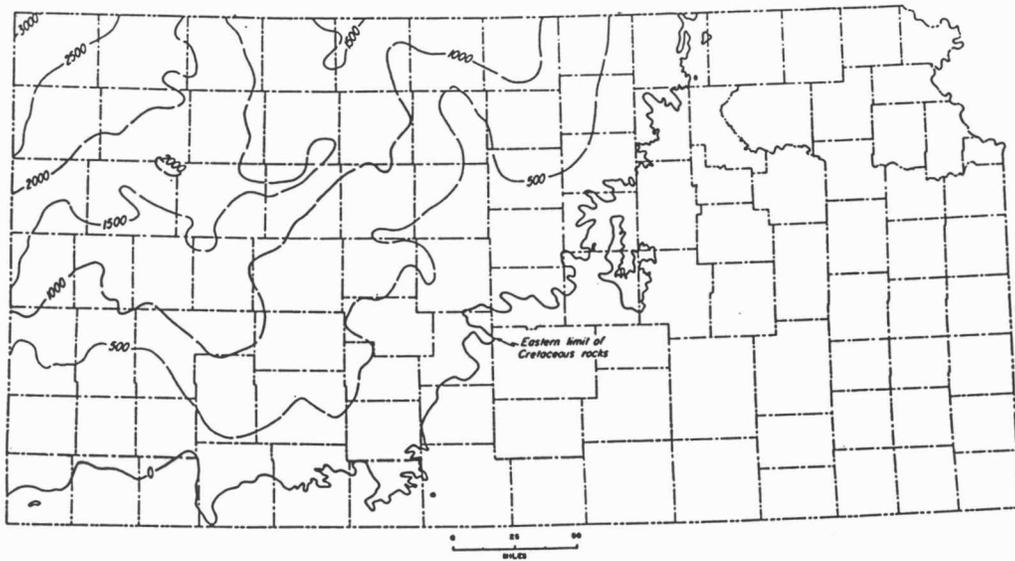
FIGURE 16.—Map of Kansas showing thickness of Cretaceous deposits, a wedge-shaped mass of material between Permian, Triassic, or Jurassic units beneath and Tertiary beds above. Contour interval 500 feet.
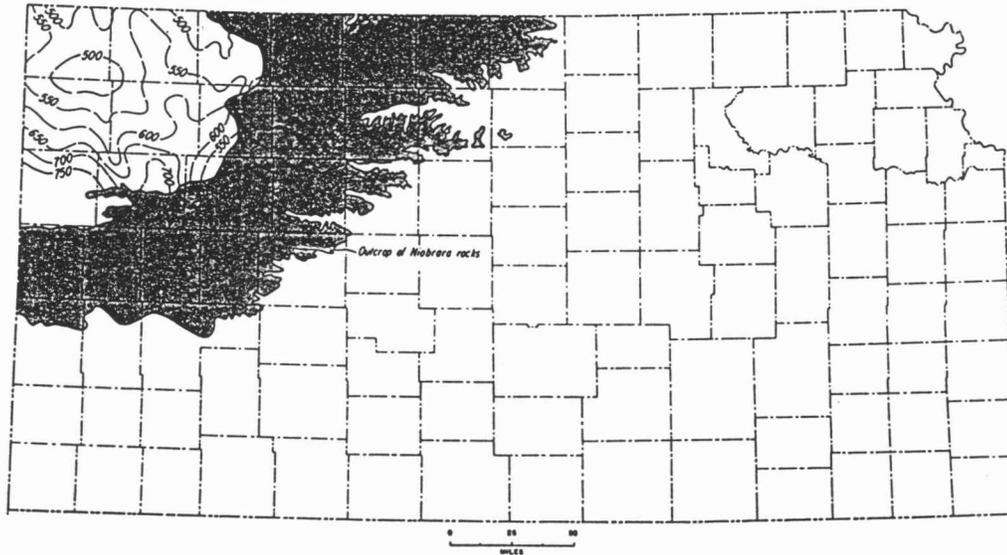
FIGURE 19.—Isopachous map of Niobrara Formation in Kansas. Contour interval 50 feet.
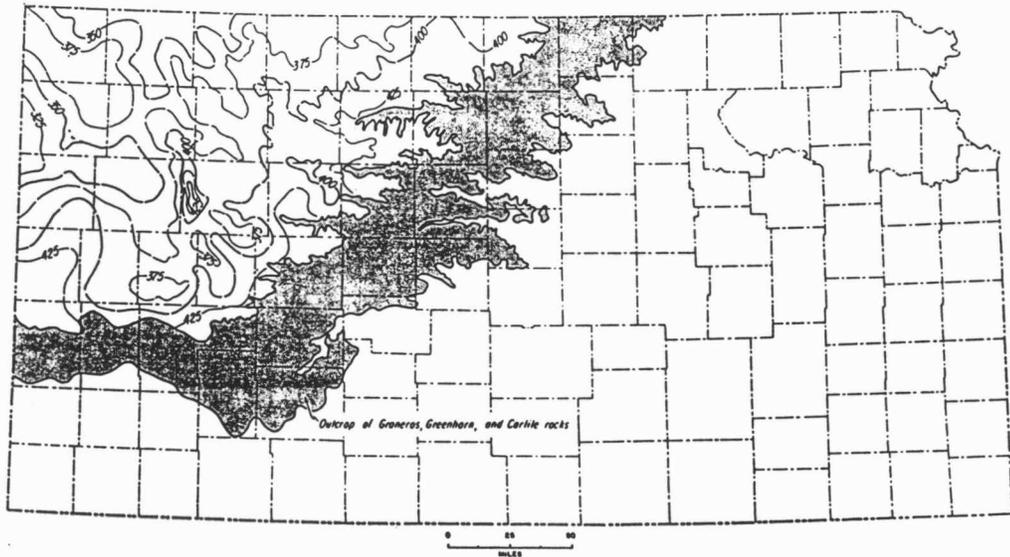
FIGURE 21.—Isopachous map from base of Fort Hays Limestone to top of Dakota; interval includes Carlile, Greenhorn, and Graneros Formations. Maximum thickness is in western Gove County. Contour interval 25 feet.
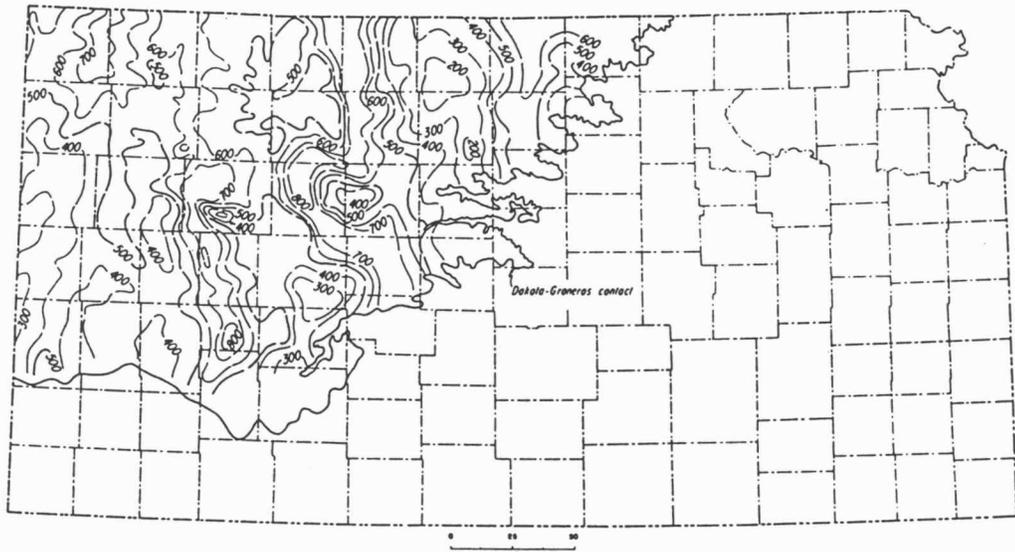
FIGURE 23.—Isopachous map of beds between top of Dakota and base of Cretaceous. Inasmuch as the upper surface was essentially flat and horizontal and the lower surface is erosional, contours show position and shape of pre-Cretaceous topographic features. Contour interval 100 feet.
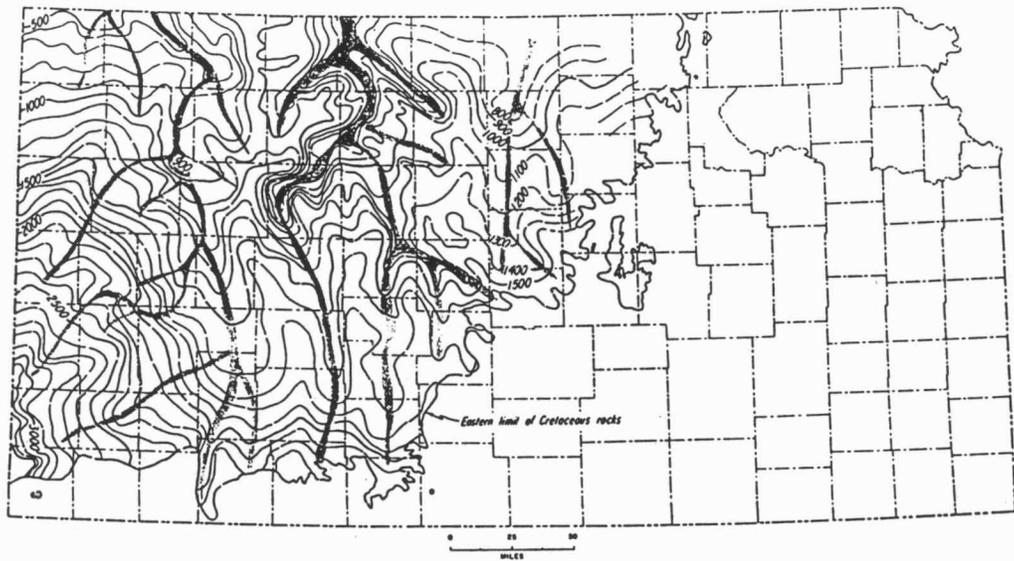
FIGURE 25.—Map of Kansas showing present configuration of surface at base of Cretaceous beds, i.e., topographic features that were developed on pre-Cretaceous surface. Three major northward-trending valleys and their tributaries are shaded. Contour interval 100 feet. Additional detailed work was done on this surface by Schuman (1963); Jesse McNellis (personal communication, August 13, 1963) believes the valley as shown in Rush County is due to a miscorrelation of placing the Cretaceous-Permian contact too low.
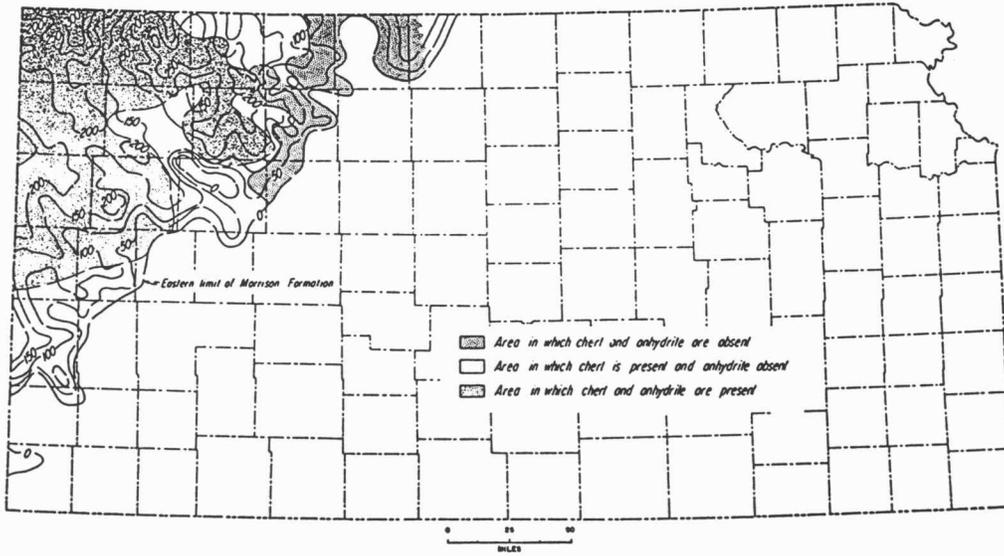
FIGURE 27.—Isopachous map of Morrison Formation (Jurassic) in western Kansas (adapted from Merriam, 1955a). Contour interval 50 feet.
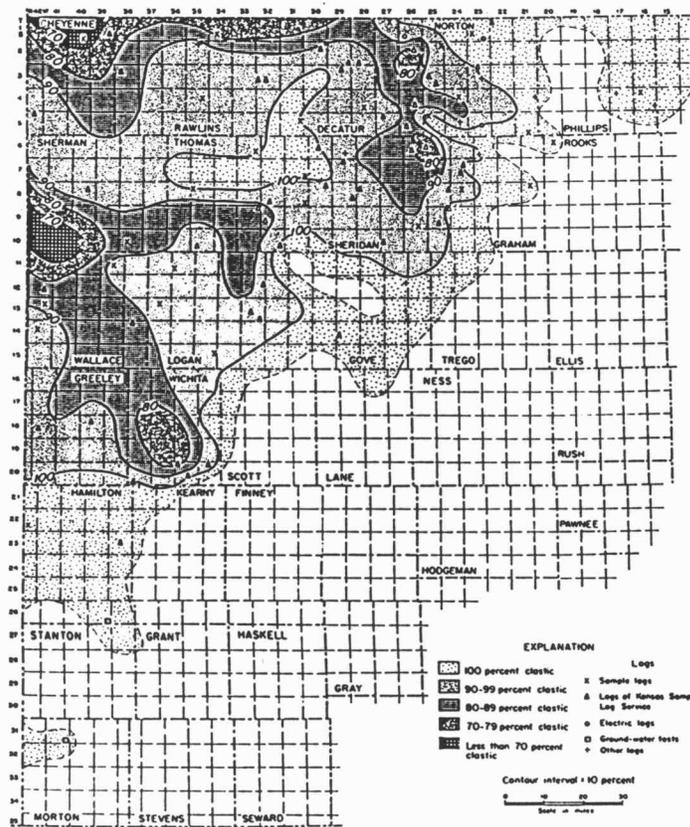
FIGURE 29.—Clastic-percentage map of Morrison Formation (Jurassic) in western Kansas. Distribution of clastics suggests that beds were deposited by northwestward-flowing streams and that source of sediments was southeast (from Merriam, 1955a).
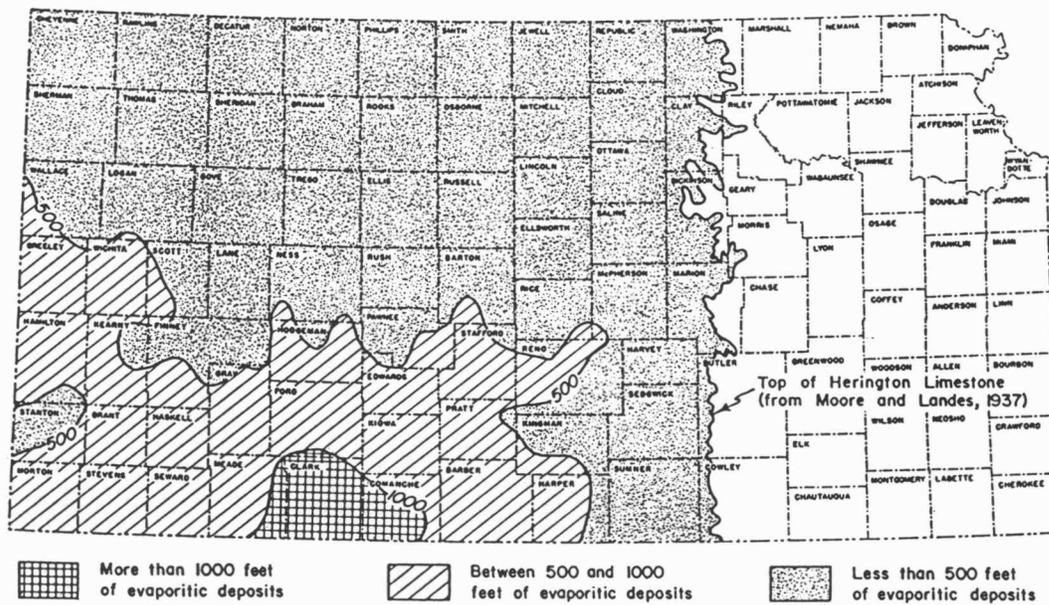
FIGURE 35.—Map of Kansas showing total thickness of evaporitic deposits in Permian redbed sequence. Maximum thickness is about 1,400 feet in Clark County. Contour interval 500 feet.
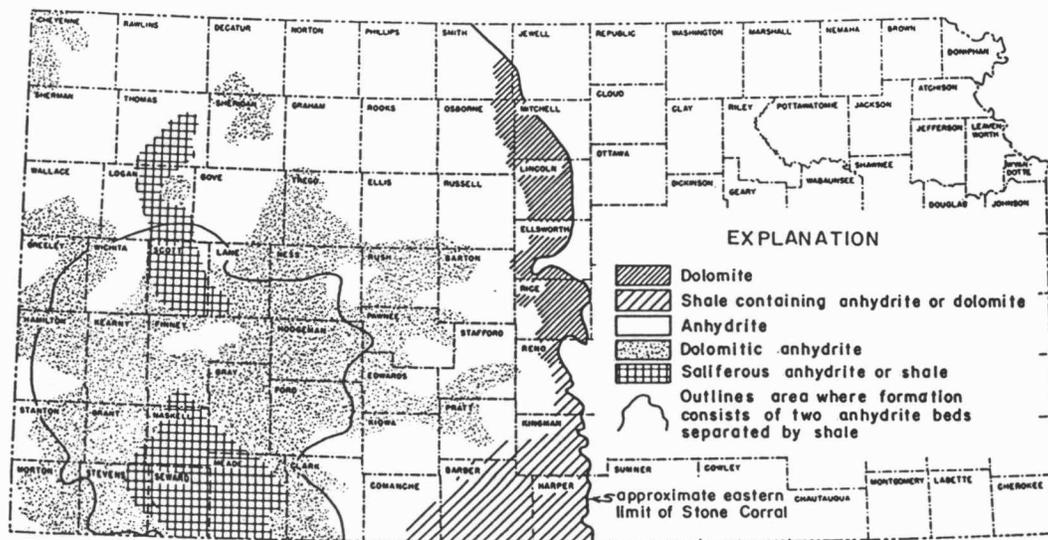
FIGURE 40.—Generalized surface and subsurface distribution of lithologic types in Stone Corral Formation. North of Rice County, eastern limit of formation is covered by later deposits, whereas formation crops out discontinuously south of east-central Rice County (from Merriam, 1957a).

TOP CONFIGURATIC
OF THE
DAKOTA AQUIFEF

Kansas Geological Surve
1995

P. Allen Macfarlane

Harsha Jayadilake

Steve Yoder

Outcrop/subcrop of the stratigraphic units
that comprise the Dakota aquifer (Dakota For
Kiowa Formation, and Cheyenne Sandstone)

Region of the Dakota aquifer confined
by younger Cretaceous strata

Line of equal elevation, above mean sea level
(Contour interval = 100 feet)

Fault zone

Extent of the outcrop/subcrop
(dashed where inferred)

Lambert Conformal Conic Projection
with standard parallels at 37°15 and 39°15

Miles

Scale 1:1,000,000
1 inch equals 15.78 miles

The Kansas Geological Survey does not guarantee this map to be
free from errors or inaccuracies and disclaims any responsibility
or liability for interpretations from the map and decisions
based thereon.

Extent of Study Area

5.e.(1)

BOTTOM CONFIGURA
OF THE
DAKOTA AQUIFEI

Kansas Geological Surve
1995

P. Allen Macfarlane

Harsha Jayatilake

Steve Yoder

Outcrop/subcrop of the stratigraphic units
that comprise the Dakota aquifer (Dakota Fo
Kiowa Formation, and Cheyenne Sandstone

Region of the Dakota aquifer confined
by younger Cretaceous strata

Line of equal elevation, above mean sea lev
(Contour interval = 100 feet)

Fault zone

Extent of the outcrop/subcrop
(dashed where inferred)

Lambert Conformal Conic Projection
with standard parallels at 37°15' and 39°15'

Miles
Scale 1:1,000,000
1 inch equals 15.75 miles

The Kansas Geological Survey does not guarantee this map to be
free from errors or inaccuracies and disclaims any responsibility
or liability for misprediction from the map and decisions
based thereon

Extent of Study Area

5.e.(2)

POTENTIOMETRIC SU

OF THE

DAKOTA AQUIFE

Kansas Geological Sur

1995

R Allen Macfarlane

Harsha Jayatilake

Steve Yoder

Outcrop/subcrop of the stratigraphic units
that comprise the Dakota aquifer (Dakota Fo
Kiowa Formation, and Cheyenne Sandstone

Region of the Dakota aquifer confined
by younger Cretaceous strata

Line of equal elevation, above mean sea lev
(Contour interval = 100 feet)

Fault zone

Extent of the outcrop/subcrop
(dashed where inferred)

Lambert Conformal Conic Projection
with standard parallels at 37°15 and 39°15

Miles

Scale 1:1,000,000

The Kansas Geological Survey does not guarantee this map to be
free from errors or inaccuracies and disclaims any responsibility
or liability for interpretations from the map and decisions
based thereon

Extent of Study Area

5.e.(3)

5. f.

KATRINE A. HOLDOWAY[1]

Deposition of Evaporites and Red Beds of the Nippewalla Group, Permian, Western Kansas

ABSTRACT

An unusual red bed-evaporite sequence of Permian Age was cored in western Kansas for the Atomic Energy Commission in 1972. The core extends upwards from the Harper and Salt Plain formations, through the Cedar Hills Sandstone, Flower-pot Shale and the Blaine Formation. In the core, the Harper and Salt Plain formations and the Cedar Hills Sandstone are red bed deposits, commonly cemented by halite. Overlying the Cedar Hills, the sediments corresponding to the Flower-pot Shale and the Blaine Formation are composed predominantly of fine to coarsely crystalline halite which is intimately associated with varying amounts of red silty mudstone.

The bromine concentration of the halite is very low, commonly less than 5 ppm, throughout the section. The textural and stratigraphic relationships of the sediments suggest that this is the result of repeated solution and reprecipitation of the halite *in situ* during deposition, and was not caused by widespread post-depositional recrystallization. The low bromine concentration of the halite, minor amount of carbonate in the sequence, and the intimate association of evaporites with red beds suggest that the deposition of these sediments took place in a shallow, continental basin, which was subject to occasional flooding by the sea.

INTRODUCTION

The existence of complex red bed-evaporite sequences in the Nippewalla Group, upper Leonardian, Permian, in the subsurface of western Kansas, has been known since the late 1800s. Much progress was made in the identification of the individual units during the 1920s and 1930s as a result of numerous wells drilled in exploration for oil and gas. Correlation and distribution of the evaporite units, mainly halite and anhydrite, have previously been established only on the basis of geophysical and sample logs. In 1972, a core was taken of the evaporite sequences in Wichita County, Kansas (Fig. 1), for the Atomic Energy Commission (A.E.C. Test Hole 5) to determine whether the thick halite beds were suitable for the storage of high-level radioactive wastes. The site was chosen in order to penetrate the salt beds in the area where they are thickest, as indicated by geophysical logs, and is located 150 ft. north and 150 ft. east of the center of sec. 22, T.19S., R.37W. Fresh water mud was used for drilling between 0-1159 ft. (0-353 m), and salt-saturated mud between 1159-2450 ft. (353-747 m). The total depth drilled was 2450 ft. (747 m). The top of the Permian was reached at 1185 ft. (361 m), and a 3.5 in. (89 mm) diameter core was drilled from 1540 to 2058 ft. (470-627 m). Only when the core had been drilled was it found that the salt is intimately associated with variable amounts of red anhydritic clay, and is quite unsuitable for the disposal of waste. The core penetrated 510 ft. (155 m) of sediments, extending upwards from the Harper and Salt Plain formations through the Cedar Hills Sandstone, Flower-pot Shale, and the Blaine Formation. Photographs of rocks illustrated here, Figs. 6-50, are all from sections of core from this well, A.E.C. Test Hole 5.

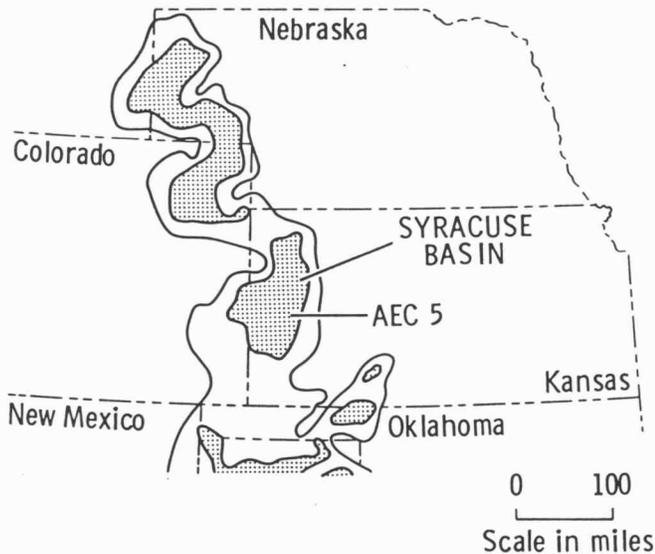[1] *Present address:* MOBIL NORTH SEA LIMITED, LONDON, U.K.

FIGURE 1. Occurrence of evaporite facies in the Nippewalla Group of the Midcontinent (after Rascoe, 1972) and location of drilling site for AEC Test Hole 5 in the Syracuse Basin.

Evaporites of equivalent age occur in the subsurface of southwestern Nebraska, and western Oklahoma and, as in Kansas, correlation of the deposits and interpretation of the environments in which they were deposited has been based upon studies of well logs and samples. The A.E.C. core appears to be the only core of the Nippewalla Group evaporite deposits in the western Midcontinent. Previously, no detailed petrographic study of the evaporites in the subsurface has been possible, because of the lack of cored material. Such a study is essential in order to interpret the depositional environment of the evaporitic sediments. This extremely valuable core serves as the basis for the present study.

PREVIOUS WORK

The Permian System in Kansas was originally defined by Cragin in 1896. Later, Norton (1939) studied the Permian red beds in Kansas and Oklahoma, and made further stratigraphic subdivisions which, for the most part, are still in use today.

The stratigraphy of the Nippewalla Group in the subsurface in Kansas was studied by Merriam (1958), Malone (1962), Campbell (1963), and Schumaker (1966). More recently, regional stratigraphic correlations and lithofacies maps for the Permian of the Midcontinent were compiled by Rascoe (1968) and Rascoe and Baars (1972), and for the United States as a whole by McKee *et al.* (1967a; 1967b).

Several studies have been conducted on the Blaine in outcrop and subsurface in Kansas and Oklahoma, including those by Kulstad *et al.* (1956), Ham (1960), Fay, (1964), and Johnson (1967). Jordan and Vos-

burg (1963) described units equivalent in age to the Nippewalla Group of Kansas from Oklahoma and the Texas Panhandle.

Swineford (1955) apparently made the only study of the petrography of the sediments of the Nippewalla Group in Kansas, and her study was confined to exposures in south-central Kansas. Spores from the Flower-pot Formation in Oklahoma were described by Wilson (1962).

A report on the suitability of the salt section cored in western Kansas for radioactive waste disposal was prepared for the Atomic Energy Commission by the staff of the Kansas Geological Survey and consultants (Bayne and Brinkley, 1972).

PALEOGEOGRAPHY

Permian red beds and evaporites occur throughout the western Midcontinent. They are thought to have been deposited in extensive shallow brackish-saline seas subject to periodic influxes of marine water from the south (Hills, 1942).

Sediments were deposited throughout the region in southwestern Nebraska, western Kansas, western Oklahoma, western Texas, and eastern Colorado and New Mexico, in an area referred to in general terms as the Permian Salt Basin (Bachman and Johnson, 1973). The sediments were shed from the surrounding land masses, the coarse-grained debris being derived from the east and south (Swineford, 1955) and the fine-grained material from the low-lying area to the north (Mudge, 1967). The seas were confined by the Front Range to the west, and the Ozarks, Arbuckles, and Wichitas to the east and south. A low-lying land mass was located to the north and northeast in Nebraska (Fig. 2) (Mudge, 1967). Low-lying positive elements[*] within the major depositional basin of the Midcontinent led to further restrictions of the sea, resulting in the deposition of halite.

In Kansas, evaporites of the Nippewalla Group were deposited in the Hugoton Embayment of the Anadarko Basin (Maher and Collins, 1948), in a saline arm of the sea extending from the south (Hills, 1942) (Fig. 2). Halite was deposited in the Syracuse Basin of the Hugoton Embayment, which was bounded to the west by the Las Animas Arch (Mudge, 1967) and to the east by the Oakley Anticline (Fig. 2) (Merriam, 1963). Halite was also deposited in south-central Kansas in a basin which may have been connected with the Syracuse Basin (Malone, 1962; Campbell, 1963).

Evaporite deposits equivalent in age to those of the Nippewalla Group in Kansas occur in Nebraska,
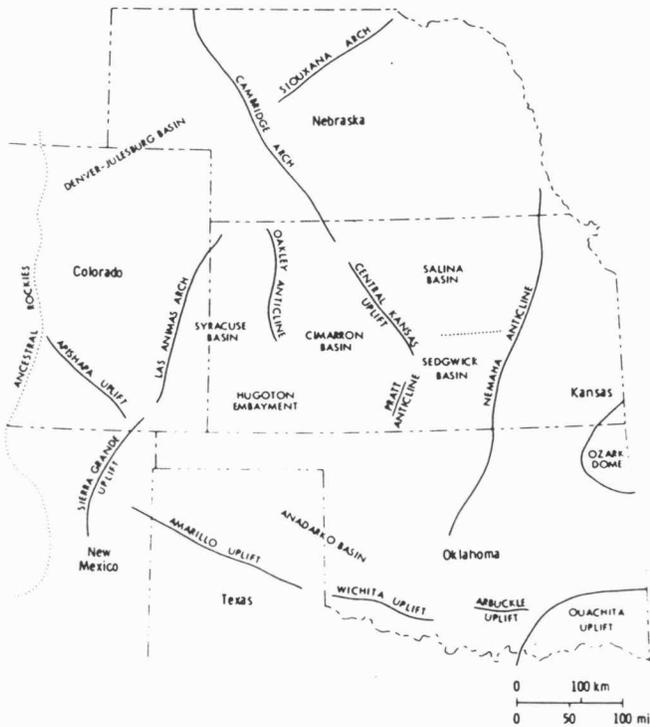
---

[*] McKee *et al.*, 1967a, p. 16.

FIGURE 2. Structural elements controlling Leonardian deposition in the Midcontinent (after McKee *et al.*, 1967).

in the Julesburg Basin (Fig. 2), and in Wyoming, as well as farther south in Oklahoma and Texas. A western connection to the sea was postulated for the basins in Nebraska and Wyoming (Maughan, 1966) and a southern connection for those in Oklahoma and Texas (Hills, 1942). Previous investigations have linked Kansas to the sea via the Hugoton Embayment and Anadarko Basin (Hills, 1942; Malone, 1962; Campbell, 1963; Schumaker, 1966).

CORRELATION OF UPPER LEONARDIAN-LOWER GUADALUPIAN SEDIMENTS IN THE MIDCONTINENT

Correlation of upper Leonardian-lower Guadalupian sediments of the western Midcontinent is problematical, and at the present time has not been satisfactorily resolved. Continental red bed evaporite facies occur in western Nebraska, Kansas, and Oklahoma, and in each state a different classification is used. In Kansas, the Leonardian-Guadalupian boundary is apparently not a well-marked hiatus; thus, the Cimarronian Stage was introduced to include all deposits from the Wellington Formation to the base of the Whitehorse Formation (O'Connor, 1963).

The sediments forming the basis of the present study fall within the Nippewalla Group of Cimarronian age. The formations included in the Nippewalla Group by the Kansas Geological Survey are the Harper Sandstone, Salt Plain Formation, Cedar Hills Sandstone, Flower-pot Shale, Blaine Formation, and the Dog Creek Formation (Fig. 3). These units crop out in south-central Kansas, with a total thickness of about 930 ft. (284 m). The sediments are typically unfossiliferous, and consist of conformable red beds and gypsum beds (O'Connor *et al.*, 1968). Correlation and nomenclature are made difficult by the fact that evaporites, including thick salt beds, generally occur in the subsurface, where they are protected from solution, and the formations with which they are associated are described and classified in outcrop. In the subsurface of western Kansas, unnamed salt and anhydrite beds occur in most of the formations of the Nippewalla Group.

Due to the unfossiliferous nature of the sequence, correlation of the sediments of the Nippewalla Group in Kansas with similar deposits in Nebraska and Oklahoma is based upon tracing unconformities, and anhydrite and dolomite marker beds, such as the Blaine and Stone Corral formations (Rascoe, 1968; Johnson *et al.*, 1975). Many of the thin marker beds do not extend into Kansas, and the time-stratigraphic position of the beds within the Nippewalla Group is difficult to ascertain. As Swineford (1955) remarked, "The problem of correlation of non-fossiliferous red clastics with a type marine section in West Texas seems almost insurmountable ...."
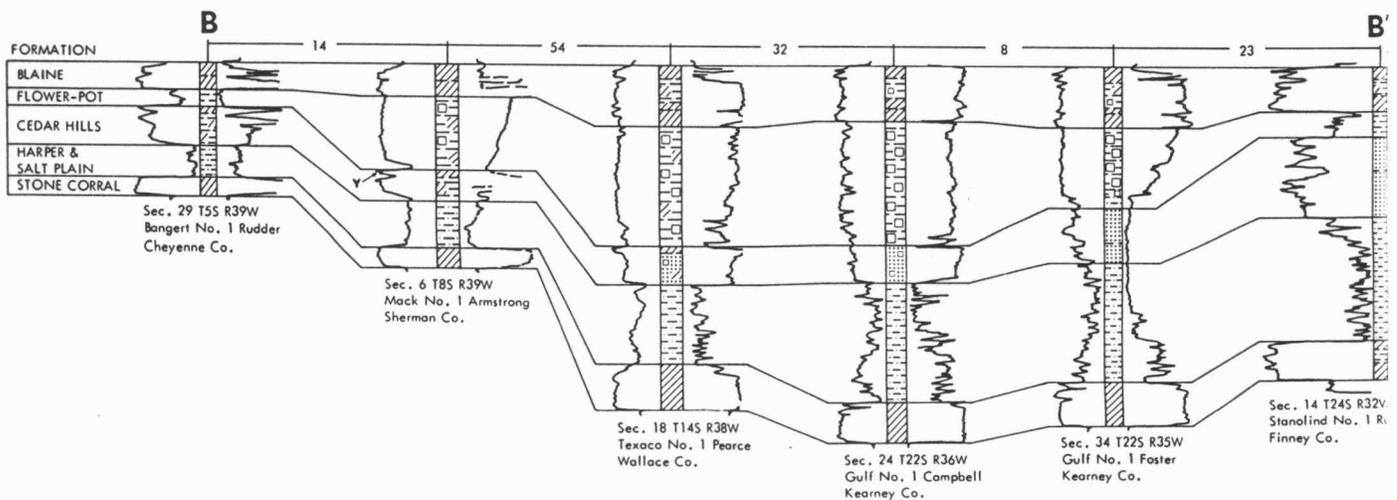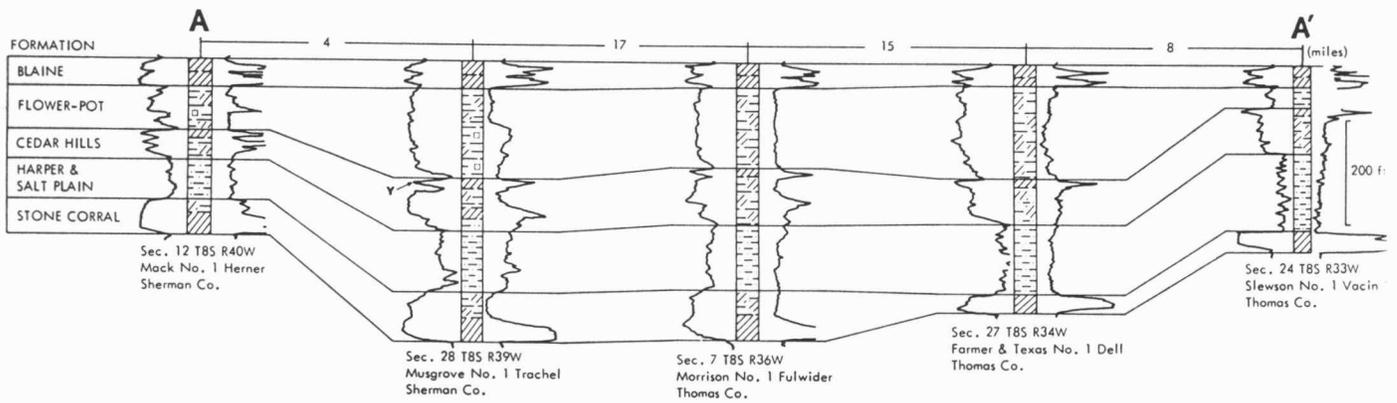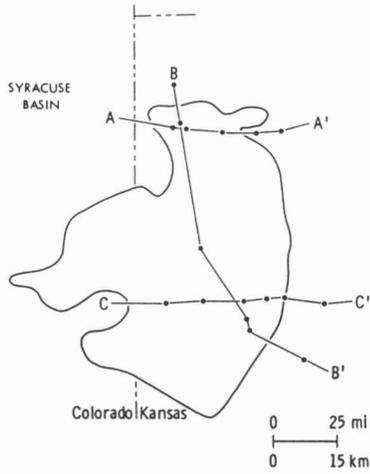
THE NIPPEWALLA GROUP IN KANSAS

The units present in the core from A.E.C. Test Hole 5 are the Harper and Salt Plain formations, Cedar Hills Sandstone, Flower-pot Shale, and Blaine Formation (Fig. 3). Descriptions of these units in outcrop were given by Swineford (1955), Kulstad *et al.* (1956), Fay (1964), Schumaker (1966), and Zeller (1968). A summary of the main features of the units in outcrop, taken from these reports, is included below for completeness and to permit comparison with the textures and lithologies of the same units in the subsurface. The Stone Corral Formation and Dog Creek Formation were not cored, and are therefore not included in the present discussion.

The dominant sediments of the cored section are red clay, silt and sand, associated with varying amounts of halite and anhydrite (Fig. 4). Minor amounts of dolomite, magnesite and quartz, and traces of the iron oxides geothite and/or hematite also occur. No potassium or magnesium salts, other than magnesite, have been found in this evaporite sequence. The cored sediments form a conformable sequence (Swineford, 1955; Rascoe, 1968) and, in most cases, the formation boundaries are clearly gradational. The boundaries are placed according to changes in lith-

Plate III
1978

THICKNESS OF FLOWER - POT SHALE
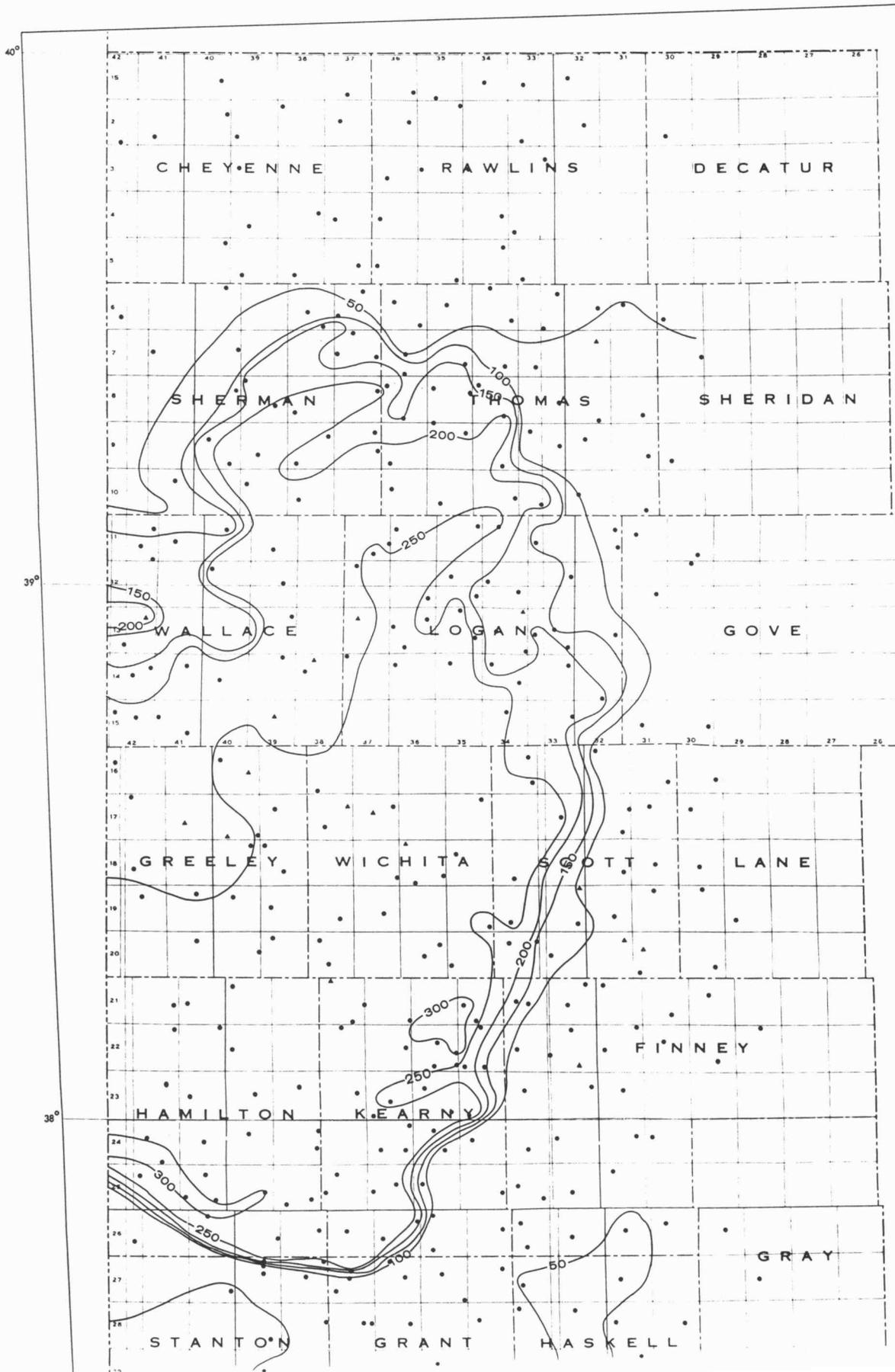
SYRACUSE BASIN CROSS SECTIONS

SYRACUSE
BASIN

B

A ———————— A'

C ———— C'

B'

Colorado | Kansas

| 0 | 25 mi |
| 0 | 15 km |

A ———— 4 ———— 17 ———— 15 ———— 8 ———— **A'** (miles)

FORMATION

BLAINE

FLOWER-POT

CEDAR HILLS

HARPER &
SALT PLAIN

STONE CORRAL

200 ft

Sec. 12 T8S R40W
Mack No. 1 Herner
Sherman Co.

Sec. 28 T8S R39W
Musgrove No. 1 Trachel
Sherman Co.

Sec. 7 T8S R36W
Morrison No. 1 Fulwider
Thomas Co.

Sec. 27 T8S R34W
Farmer & Texas No. 1 Dell
Thomas Co.

Sec. 24 T8S R33W
Slewson No. 1 Vacin
Thomas Co.

B ———— 14 ———— 54 ———— 32 ———— 8 ———— 23 ———— **B'**

FORMATION

BLAINE

FLOWER-POT

CEDAR HILLS

HARPER &
SALT PLAIN

STONE CORRAL

Sec. 29 T5S R39W
Bangert No. 1 Rudder
Cheyenne Co.

Sec. 6 T8S R39W
Mack No. 1 Armstrong
Sherman Co.

Sec. 18 T14S R38W
Texaco No. 1 Pearce
Wallace Co.

Sec. 24 T22S R36W
Gulf No. 1 Campbell
Kearney Co.

Sec. 34 T22S R35W
Gulf No. 1 Foster
Kearney Co.

Sec. 14 T24S R32W
Stanolind No. 1 R
Finney Co.

W. Lynn Watney
John C. Davis
Ricardo A. Olea
Jan Harff
Geoff C. Bohling

Modeling of Sediment Accommodation Realms by Regionalized Classification

An application to Upper Pennsylvanian Genetic Stratigraphic Units and Genetic Sets in Kansas

Zusammenfassung

Sechs aufeinanderfolgende stratigraphische Einheiten des Oberen Pennsylvanian eines Gebietes von annähernd 116 000 km² in Kansas wurden hinsichtlich der Mächtigkeitsentwicklung mit der Methode der regionalisierten Klassifizierung untersucht. Es handelt sich dabei um genetisch-stratigraphische Einheiten (GSU) und Folgen von GSU (Genetic Sets), die Proxies für bildungszeitlich differenzierte Ablagerungssequenzen darstellen. Mit der regionalisierten Klassifizierung wurden Gebiete identifiziert, in denen die genetischen Einheiten relativ gleichförmig ausgebildet sind und deren Grenzen die Blockstruktur des Fundaments nachzeichnen. Es ist daher anzunehmen, daß die Reaktivierung von älteren Störungssystemen die Hauptursache für regionale Differenzierungen der Sedimentationsbedingungen auf dem Pennsylvanian-Schelf von Kansas bilden. Die für die einzelnen Regionen spezifischen Entwicklungen des Sedimentationsraumes werden durch jeweils typische Absenkungskurven beschrieben. Übergangszonen zwischen diesen Regionen, die durch strukturelle Diskontinuitäten gekennzeichnet sind, können bedeutsame Migrationswege für Kohlenwasserstoffe oder mineralisierte Lösungen bilden.

1 Introduction

The geographic location of Kansas (Figure 1), in the center of the conterminous United States, coincides with the shelf margin of the Anadarko and Arkoma basins and the northern extension of the shelf. These basins were actively subsiding as the Gondwana-Larentia continental plate collision occurred during Pennsylvanian (Late Carboniferous) time. Episodic subsidence of the basins led to flexing of the adjoining shelf which was expressed as differential subsidence. This subsidence diminished gradually toward the north away from the basins. The position of the shelf margin in southern Kansas shifted repeatedly and abruptly northward as the lower shelf was exposed to episodes of sediment starvation; these episodes significantly changed local sedimentation patterns and affected sediment accommodation space. The resulting pattern of subsidence is recorded in the thicknesses of stratigraphic intervals that responded to changes in sediment accommodation space.

In this study, we examine a shelf-to-basin setting which is sufficiently large, both geographically and stratigraphically, to address the question of controls on sediment accommodation space. A high resolution stratigraphic data set derived fom petrophysical logs was used to better characterize sediment accomodation space.

Regionalized classification introduced by Harff and Davis [1] based on thicknesses of stratigraphic units provides a consistent way to resolve time and can provide an empirical model that is sufficiently detailed to permit inferences about relationships with dominant spatial trends and patterns in the basement.

2 Regionalized Classification Procedure

The concept of multivariate classification of "geological objects" developed by Voronin [2] and extended by Rodionov [3] has been combined with elements of regionalized variable theory by Harff and Davis [1] to produce what is called "regionalized classification."

The objective of regionalized classification is – based on observations at distinct sampling points – to subdivide a two- or three-dimensional portion of the earth's crust into contiguous portions called regions that are as internally homogeneous as possible and as distinct as possible from adjacent regions.

The initial step in regionalized classification is typification, in which the observations are subdivided into groups based on their mutual similarities. An unsupervised hierarchical clustering procedure such as Ward's algorithm, which uses a within-cluster minimum variance criterion, can be used to produce candidate groups (Bock [4]).

At the highest level of clustering, all observations belong to a single cluster and of necessity form a contiguous region. As the number of clusters increases, however, the spatial organization breaks down and the resulting map is a chaotic mixture of individual points. The level in the hierarchy at which this occurs provides a clue to the appropriate number of regions.

For each cluster at each sampling location, the posterior probabilities that the observation belongs to each respective group is calculated. Probabilities are interpolated to a grid covering the area of investigation using the kriging procedure (Davis [5]).

The final phase in regionalization is to produce a grid showing the maximum probability of assignment to any group; this distinguishes those locations that can be assigned to a region with reasonable certainty from locations whose classification is unclear. The latter mostly form boundaries between regions but may also delineate areas which do not fit well into the system of classes that has been specified. A map
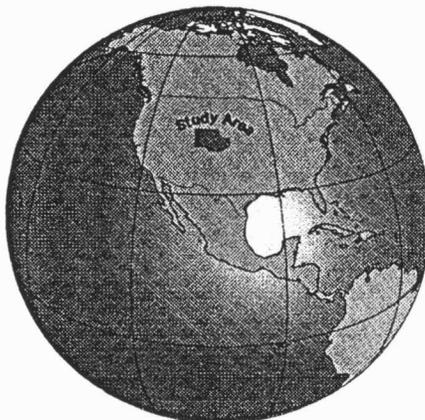

Fig. 1. Study Area.

showing the membership assignment at each grid node is the final expression of the regionalization. The regionalization map should be accompanied by a contour map of the maximum probability of assignment, because this expresses the reliability of the regions.

3 Structural Geology and Precambrian Provinces in Kansas

Within the study area there are several major structural provinces (Baars and Watney [6]), including the Central Kansas and Nemaha uplifts and the Hugoton embayment, and the Sedgwick, southern Salina, and northern Cherokee basins (Figure 2). Prominent fault zones are associated with the Central Kansas and Nemaha uplifts and the Pratt Anticline. The Humboldt Fault Zone clearly defines the Nemaha uplift. The Central Kansas Uplift includes two conjugate sets of faults, one trending northwest and the other northeast.

Assessing the possibility that Pennsylvanian depositional patterns on the Kansas shelf reflect the reactivation of preexisting basement structures requires information about the nature of the Precambrian basement. The basement supports the relatively thin veneer of sedimentary rocks in Kansas and provides the crust with most of its strength. Three of five major Precambrian provinces recognized in the western Midcontinent are present in Kansas. The provinces are distinguished by their geologic histories and the resulting differences in composition and structure. The three provinces are shown in Figure 3 and include the southern Central Plains orogen (sCP), the southern granite-rhyolite province (SGR), and the Midcontinent Rift (MCR) (Van Schmus and others [7]).

4 Stratigraphy/Genetic Stratigraphic Units/Genetic Sets

Stratigraphic units used in this study include in the Upper Pennsylvanian Series, Missourian to early Virgilian Stages, Kansas City, Lansing, Douglas, and Shawnee groups (Figure 4). In Kansas, these units are from 10 to more than 150 ft (3 to 50 m) thick successions (cyclothems) of alternating marine carbonates and nonmarine to shallow marine siliciclastics.

Genetic stratigraphic units (GSU) represent distinct, mappable sedimentary intervals delimited by thin, prominent flooding and condensed sections
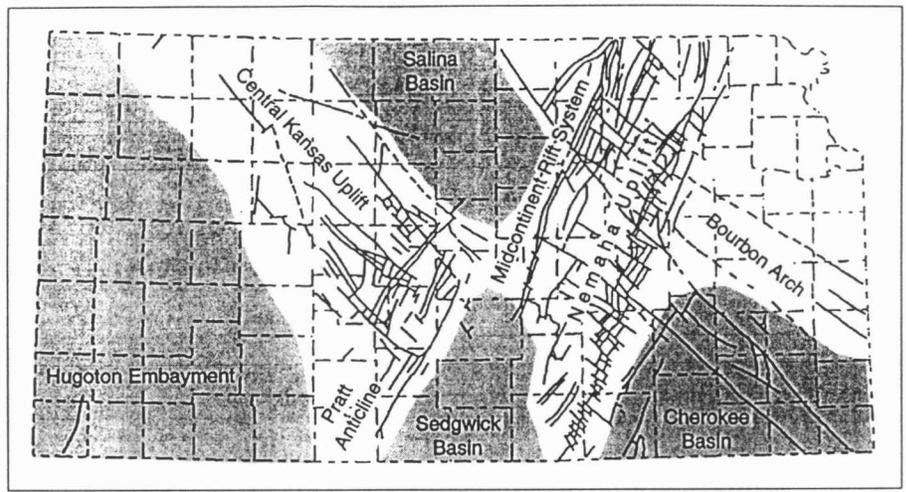
Fig. 2. Major structural elements and Basins in Kansas.

that can be regionally correlated (Galloway [8]). Flooding units are thin limestones or more rarely thin, widespread coals, both with sharp basal contacts. The Upper Pennsylvanian condensed sections are thin, usually distinctive radioactive black marine shales. Each GSU consists of a thin flooding unit overlain by a condensed section, followed by a shallowing-up-ward carbonate or siliciclastic unit that is capped by a paleosol which represents a subaerial unconformity. These unconformities delimit time-distinct stratigraphic packages some which are regionally extensive and meet all of the characteristics of depositional sequences (Vail and others [9]; Youle, Watney and Lambert [10]). GSUs serve as proxies for time-distinct depositional se-
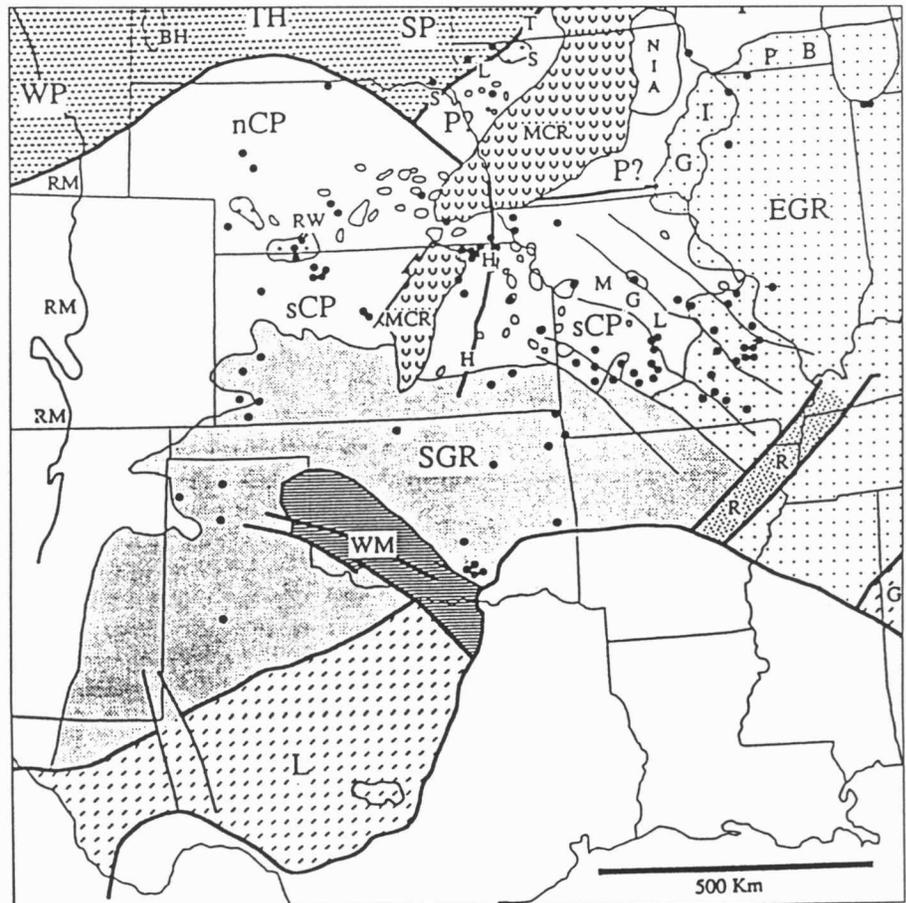

Fig. 3. Major Precambrian geologic features of the western Midcontinent region. Provinces in study area include sCP, southern Central Plains orogen, MR, Midcontinent Rift, and SGR, southern granite-rhyolite province. From Van Schmus and others, 1993.

Table 1. Isopach intervals used for regionalized classification of the Pennsylvanian Kansas Shelf.

Upper Datum	Lower Datum
1) Base Heebner Shale (Virgilian Shawnee Group) (*upper Muncie Creek genetic set*)	Top Stanton Limestone (Missourian Lansing Group)
2) Top Stanton Limestone (*lower Muncie Creek genetic set*)	Base Iola Limestone (Missourian Kansas City Group)
3) Base Iola Limestone Base (*Quivira GSU*)	Dewey Limestone
4) Base Dewey Limestone (*Wea GSU*)	Base Cherryvale Shale
5) Base Cherryvale Shale (*Stark GSU*)	Base Dennis Limestone
6) Base Dennis Limestone (*Hushpuckney GSU*)	Base Swope Limestone

quences because of the proximity of their boundaries over much of the shelf (Watney and others [11]). Thicknesses of the GSUs vary regionally, presumably in response to processes that affected sediment accommodation space such as subsidence, shelf elevation, sea-level history, and sediment supply.

This study considers the Hushpuckney GSU, Stark GSU, Wea GSU, and Quivira GSU (Table 1) presented in Watney and others [11].

Sets of genetic stratigraphic units are recognized in the Pennsylvanian of the U.S. Midcontinent. Genetic sets are defined as a succession of related GSUs that have similar regional patterns of lithology and thickness that are distinct from the characteristics of stratigraphic intervals above and below (Watney and others [11]). Genetic sets are well developed along the northern shelf margin bordering the Anadarko and Arkoma basins in southern Kansas

and northern Oklahoma (Figure 5). Each is approximately 330 ft (100 m) thick and contains from 5 to 7 GSUs. Genetic sets may have different characteristics, and may include progradational, aggradational, or retrogradational stacking patterns (Youle, Watney and Lambert [10]). Like GSUs, genetic sets are time-distinct but provide temporal views of changes on the shelf over a longer time and introduce additional influences into the mix of processes that are reflected in a regionalized classification.

5 Data Collection

3096 wells are included in this study, collected from an area that includes approximately 70 % of the state of Kansas, extending from its western and southern borders into the central and eastern portions of the state.

The regionalized classification of Pennsylvanian sedimentary intervals on the Kansas shelf found in this study is based on thicknesses of the six stratigraphic intervals listed in Table 1 and identified in Figure 4. Thicknesses of the intervals were measured on well logs from over 3000 wells in the study area. The initial GSU correlations were made using information from rocks obtained as well cores scattered throughout the mapped area and from outcrops. Gamma ray/neutron-density and other gamma ray/porosity well log combinations were used for measurements because condensed sections (usually radioactive shales) are clearly discernible on the gamma ray logs and lithologies are relatively easy to discriminate using these log combinations.

6 Regionalization of the Kansas Shelf

The clustering phase of regionalization is illustrated in Figure 6 which shows the partial dendrogram produced using Ward's clustering algorithm applied to interval thicknesses from the 3096 wells used in the study. Clustering indicates that 15 clusters are appropriate so only the final stages of 15 and fewer clusters are shown. The dendrogram indicates the relative similarities between clusters, and the approximate affinities between individual clusters and the larger groupings from which they emerged. At the lowest level of the dendrogram, the numbers correspond to those assigned to regions in the following discussion, and the colors on the diagram correspond to those
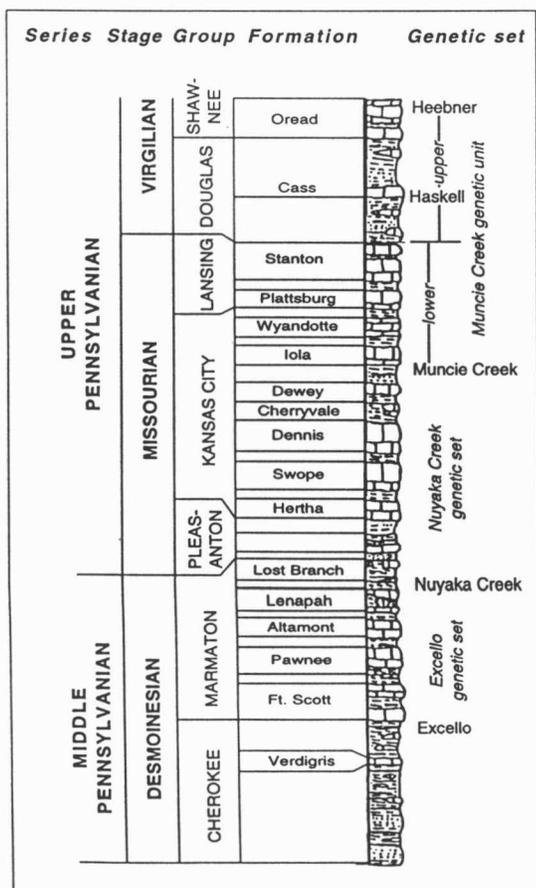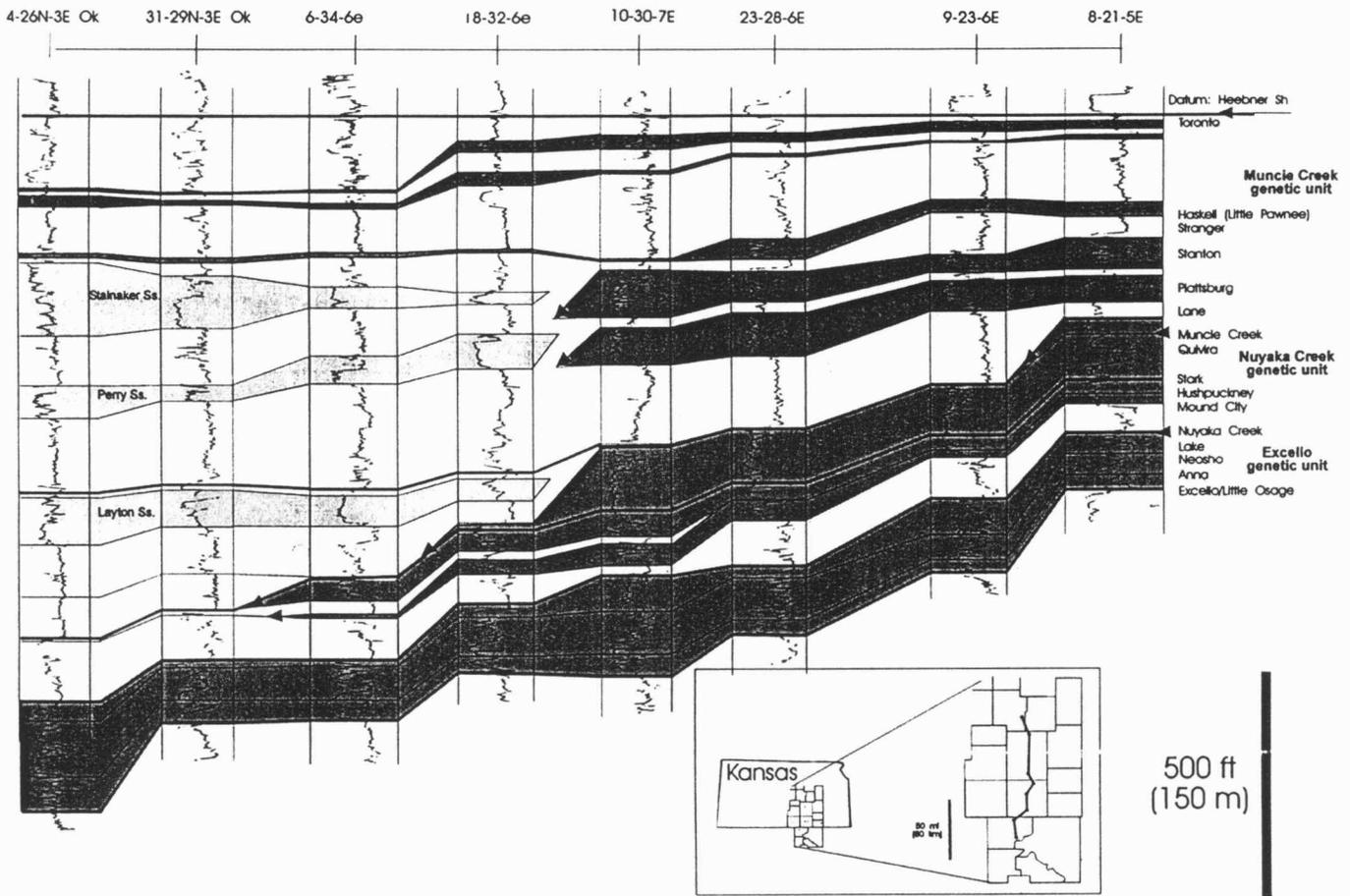

Fig. 4. Generalized stratigraphic column showing Pennsylvanian interval used in this study.

Fig. 5. North-south cross section from central Kansas to northern Oklahoma showing stratigraphic and structural relations in genetic stratigraphic units used in this study. From Watney and others [11].

Fig. 6. Dendrogram showing order of clustering and approximate relationship between regions. Clusters are identified by numbers from 1 to 15; colors correspond to those on regionalized map shown in Fig. 9.
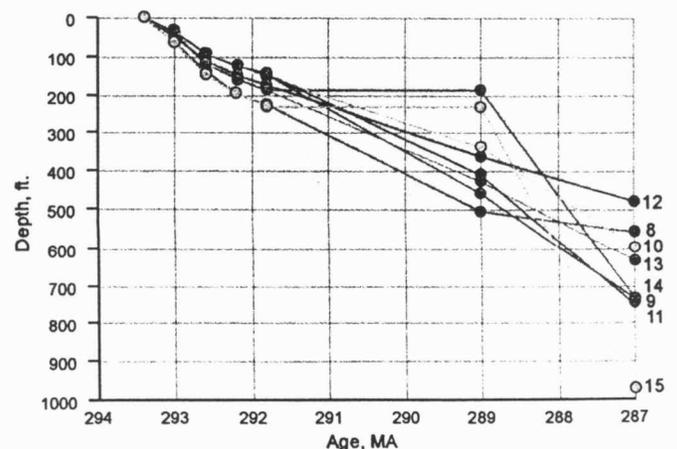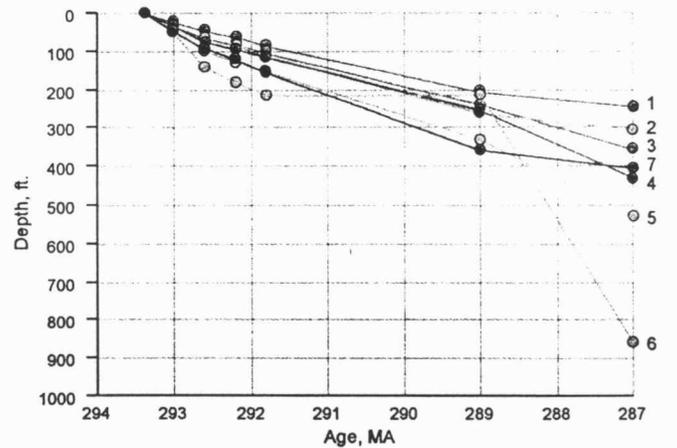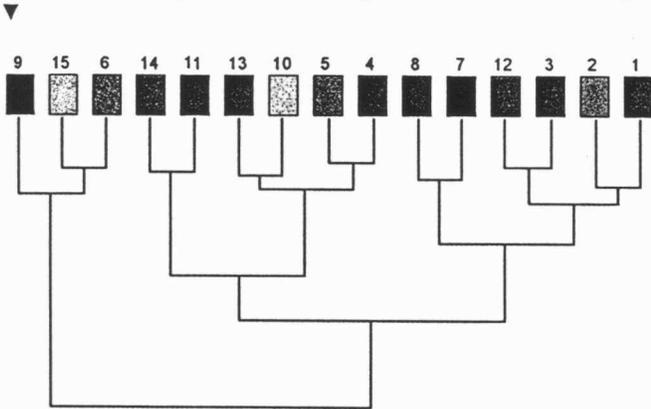
Fig. 7. Subsidence curves for regions on the Central Kansas Shelf. Numbers and colors correspond to regions shown on regionalization map (Fig. 9).
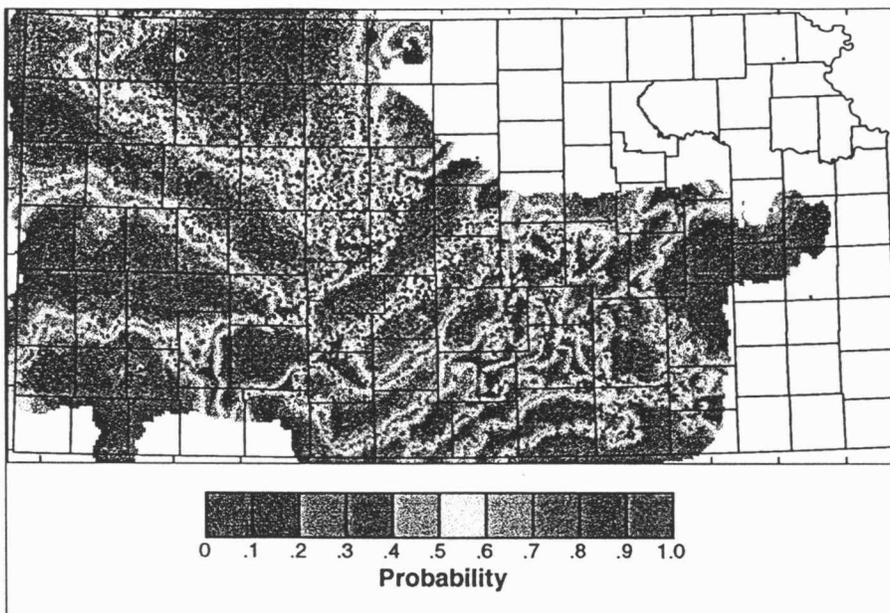
Fig. 8. Maximum probability of correct classification in the assigned group, for a regionalization of the Upper Pennsylvanian of Kansas into 15 regions. Contour interval is p=0.10.

used on the regionalization map. Each cluster can be described by a "mean" conventional subsidence curve (Figure 7) constructed from averaged thicknesses of stratigraphic units of cluster members and an estimated age of this units.

The next step in the regionalization process is to map the probability of class membership at every location in the study area into each of the 15 classes. The map of maximum probability of correct membership in some class is shown in Figure 8.

Figure 9 is the final regionalization, based on the probabilities of correct assignment to membership in one of the 15 clusters. The 15 regions form four distinctive mapped areas (Figure 10) which will be described below.

6.1 Western Area
Regions 1 and 2 in the western area correspond with the northwest Kansas shelf, the northern reaches of the Hugoton Embayment, and the northwestern part of the Central Kansas Uplift (Figure 2). Regions 1 and 2 also are part of the sCP Precambrian province (Figure 3). The location of region 2 closely corresponds to the position of the boundary between Precambrian provinces sCP and SGR.

Subsidence is very low in these regions relative to other regions. The area is highest on the shelf and most distant from the foreland basins and may have undergone less subsidence than regions farther south. Subsidence in region 2 is greater than in region 1 probably because region 2 is farther south and closer to the directed stresses of the active foreland basin.

Regions 7 and 8 lie closer to the Anadarko Basin than do the more northern regions of the western area and are characterized by greater subsidence. Region 8 is thicker than region 7, particularly in the Nuyaka Creek genetic set, probably because region 8 is closer to the center of tectonism. There is an indication that region 8 also is distinguished from region 7 by deformation .

6.2 Central Area
The central area of regions coincides with the Midcontinent Rift (MCR) Precambrian province (Figure 3).

Subsidence plots of regions 4, 5, 10, and 13 (Figure 7) show progressive increases in subsidence rates toward what were foreland basins in the southeast. Apparently, the directed stress of the foreland basins propagated northward, but with decreasing intensities leading to reactivation of preexisting structures.

Region 13 is a southerly extension that split off from region 10 late in the classification procedure. The two regions exhibit very similar subsidence values, although those of region 13 are somewhat greater. Region 13 is a rhombic-shaped block that appears to be an extension of MCR trends, but lies south of the boundary between Precambrian provinces sCP and SGR (Figure 3). Its greater rates of subsidence may be attributable to being part of the southern SGR province in closer proximity to the foreland basin. The intersecting Precambrian province boundaries appear to control the character of reactivated blocks of overlying sediment, judging from the distribution and associations of the regions. An analogous relationship between basement province boundaries probably has led to the shapes of region 5 and region 4 (Figure 9).

6.3 South-Central Area
Regions 6, 9, and 15 are characterized by the most subsidence of any region (Figure 7). Within these regions, the early Muncie Creek genetic unit apparently accumulated during a period of
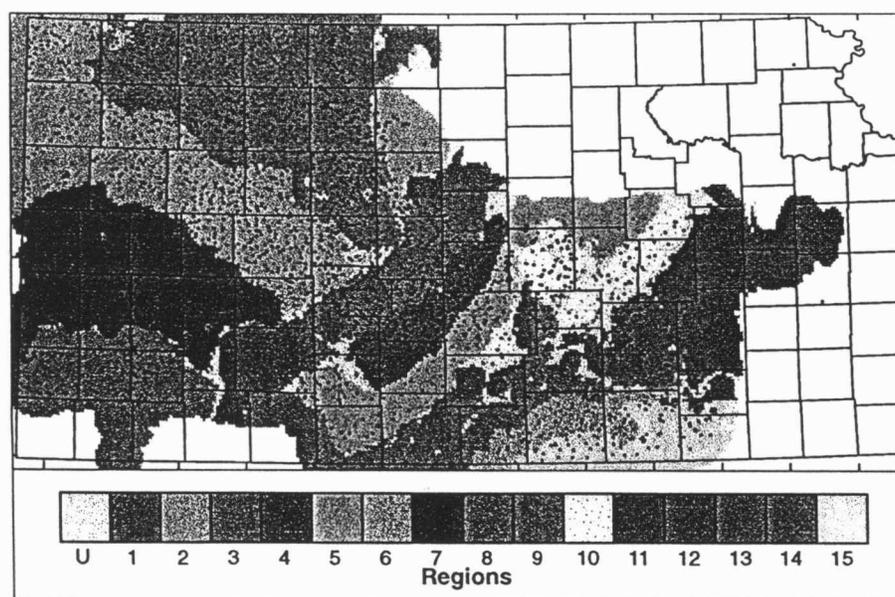

Fig. 9. Regionalization map based on Upper Pennsyslvanian genetic stratigraphic units and genetic sets in Kansas. Regions are identified by number from 1 to 15. and are shown in colors. Areas in grey (identified as U) are unclassified because the probability of correct classification is less than p=0.5.
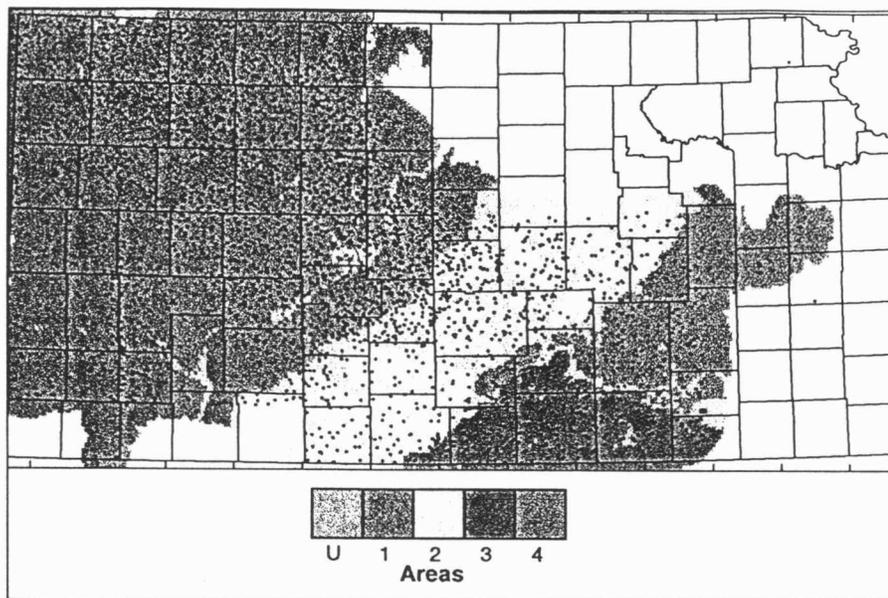
32

Fig. 10. Regions defined by regionalization and shown in Fig. 9 combined into four areas on the Kansas Shelf. Western area (1) is composed of regions 1, 2, 3, 7, 8, and 12. Central area (2) is composed of regions 4, 5, 10, and 13. South-central area (3) is composed of regions 6, 9, and 15. Eastern area (4) is composed of regions 11 and 14. Areas in gray (identified as U) are unclassified because the probability of correct classification is less than p=0.5.

sediment starvation. A pronounced carbonate shelf margin developed to the immediate west and north where carbonate sedimentation kept pace with subsidence, leading to the accumulation of thick carbonate intervals (Watney and others [11]). This was the site of increased early subsidence during the time of deposition of the Nuyaka Creek genetic set. During the time of the upper Muncie Creek genetic set, sedimentation filled in the space created by earlier sediment starvation. This area has the shape of a rhombic block whose outline is closely related to basement heterogeneities, further evidence for reactivation.

6.4 Eastern Area

Region 14 is situated at the southern edge of the sCP basement province and borders the Nemaha Uplift to the east and the MCR on the west; there is a strong correlation between basement features and the region. A large carbonate bank developed in the lower Muncie Creek genetic set. A line of apparent structural flexure borders this region on the south, beyond which the carbonate bank is lost because of sediment starvation (Watney and others [11]). There is an apparent cause-and-effect relationship between the location of the carbonate bank and the structurally-controlled hinge line.

Region 11 is a large broad area residing on the east flank of the Nemaha Uplift. It overlies part of the sCP Precambrian basement province and is characterized by greater thicknesses of strata than immediately to the west.

7 Summary

Basement reactivation along structural and compositional weaknesses is clearly defined by regionalized classification. The key factors in deformation of the Kansas shelf are proximity to active foreland basins with generally greater deformation closer to the Anadarko and Arkoma Basins; position within the three basement provinces sCP, SGR, and MCR; and compositional and structural differences within the Precambrian provinces as expressed in gravity and magnetic derivative maps and reflected to some extent in present-day structures. Quantitative information supplied by regionalized classification provides useful perspectives that facilitate geologic interpretation. Although the number of classes for regionalization are chosen, once this is specified the boundaries between regions are determined automatically by the statistical model, using only information in the data.

Further characterization of the regions that have emerged from regionalized classification is warranted. It may be especially valuable to assess the development of stratigraphic traps along region boundaries and to test if regional boundaries coincide with conduits for fluid migration along unhealed fractures and possible fault systems.

References

[1] J. Harff, J. C. Davis: Regionalization in geology by multivariate classificatio; Mathematical Geology, v. 22, no. 5, (1990), p. 573 588.
[2] Ju. A.Voronin: Geologija i Matematika; Novosibirsk: Izd. Nauka, 1967, 253 p.
[3] D. A. Rodionov: Statisticeskie Resenija v Geologii; Moscow: Izd. Nedra, 1981, 231 p.
[4] H. H. Bock: Automatische Klassifikation; Gottingen: Vandenhoeck & Rupprecht, 1974, 480 p.
[5] J. C. Davis: Statistics and Data Analysis in Geology; New York: John Wiley and Sons, Inc., 1986 ,646 p.
[6] D. L. Baars, W. L. Watney: Paleotectonic control of reservoir facies; in: Franseen, E. K., and others, eds.: Sedimentary Modeling: Computer Simulations and Methods for Improved Parameter Definition; Kansas Geological Survey, Bull. 233, 1991, p. 253-262.
[7] W. R. Van Schmus and others: Proterozoic geology of the western Midcontinent basement; in: J. C., Reed, Jr. and others, eds., Precambrian of: Conterminous U.S., The Geology of the North America: v. C-2, 1993, p. 239-334.
[8] W. E. Galloway: Genetic stratigraphic sequences in basin analysis: I, Architecture and genesis of flooding surface bounded depositional units; American Association Petroleum Geologists, Bull. v. 73, , 1989, p. 125– 142.
[9] P. Vail and others: Seismic stratigraphy and global changes in sea level; in: Payton, C. E., ed.: Seismic Stratigraphy - Applications to Hydrocarbon Exploration; American Association Petroleum Geologists, Mem. 26, 1977, p. 49-212.
[10] J. C. Youle, W. L. Watney, L. L. Lambert: Stratal hierarchy and sequence stratigraphy – Middle Pennsylvanian, Southwestern Kansas, U.S.A.; in: Klein, G. D., ed.: Pangea: Paleoclimate, Tectonics, and Sedimentation During Accretion, Zenith, and Breakup of a Supercontinent; Boulder, CO, Geological Society America, Special Paper 288, 1994, p. 267-285.
[11] W. L. Watney and others, in press: Cycle hierarchy and genetic stratigraphy of Middle and Upper Pennsylvanian strat in the upper Mid-Continent; Tulsa Geological Society, Special Publication No. 3.

Author's addresses:

Dr. W. L. Watney, Prof. Dr. J. C. Davis, Dr. R. A. Olea, G. C. Bohling, Kansas Geological Survey, 1930 Constant Ave, Lawrence, KS 66047, USA.

Prof. Dr. J. Harff, Institut für Ostseeforschung, Sektion Marine Geologie, Seestraße 15, D-18119 Rostock-Warnemünde.

Dakota Aquifer Program

6. a.

Dakota Aquifer Program--Introduction

The Dakota Aquifer Program

More than eight years ago, state and local agencies recognized the localized depletion of near-surface sources of water in western and central Kansas and the need to identify other sources that might replenish available supplies. This focused the attention of the water agencies on the Dakota, a deeper and more complex sandstone aquifer system.

Even though the Dakota has been used as a source of water for more than a century, its hydrologic character has been poorly understood and the issues surrounding its use have been inadequately addressed. Little was known about either the quantity or the quality of ground water or the impact of regional or local development on the Dakota that could be used to guide regional or local planning until recently. There were also concerns related to human activity, such as the potential hazards of disposing oil-brine in shallow zones beneath the Dakota in central Kansas and the protection of usable ground-water resources in the Dakota.

In response, the Kansas Geological Survey began an eight-year investigation into the hydrogeology and water quality of the Dakota in 1988. The goal of the Program is to provide information to state and local agencies and users, and to assist the agencies in the development of appropriate management plans and policies. This program is unique because it is designed for proactive rather than reactive water-resources management of a regional aquifer system. The broad objectives of the program are to: (1) characterize the geologic framework of the Dakota aquifer; (2) define the ground-water flow system within the aquifer to identify sources of recharge, discharge, flow path, and areas of interaction with other aquifer systems; (3) assess the impact of development in the Dakota and interacting aquifer systems, including the impact of oil-field brine disposal in the underlying Permian on the Dakota aquifer in the areas of aquifer interaction.

During the planning stage it was recognized that a multidisciplinary effort was needed to understand the influence of the aquifer framework geology on the subsurface hydrologic system and water quality. As a result the backbone of the program is an integrated, interdisciplinary research strategy that incorporates elements of stratigraphy and sedimentology, petrophysics, subsurface hydrology, and water quality. Furthermore, the wide extent of Dakota in Kansas mandated a phased approach to the research to keep the size and scope of the investigations manageable. Thus the focus of the research has shifted with time from where the aquifer is shallow and currently under development (State FY90 94) to the deeper, undeveloped regions in northwest Kansas (State FY95 96). Each subregional project began with data-base development, progressed to the formulation of conceptual and mathematical models, and finally, applied the models to management issues with state and local agency input. Data-base development, mapping, data analysis, and mathematical modeling of the system were facilitated using state-of-the-art software packages.

Dakota Home || Next Page--Dakota Aquifer Extent

Dakota Aquifer Program

Dakota Aquifer Program--Introduction
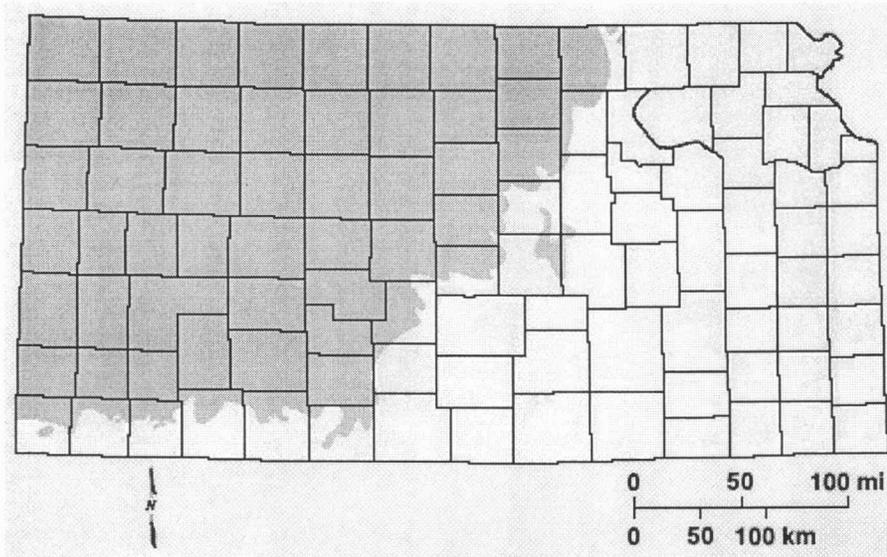
Extent of the Dakota Aquifer

The Dakota aquifer system and its equivalents extend across much of the central North American continent. Figure 1 is a map showing the Dakota extent in North America. The contiguous aquifer system extends northward from Kansas approximately to the Arctic Circle in Canada, southward into northeastern New Mexico and the Oklahoma panhandle, westward to the Rocky Mountain front, and eastward to western Iowa and Minnesota.

Figure 1
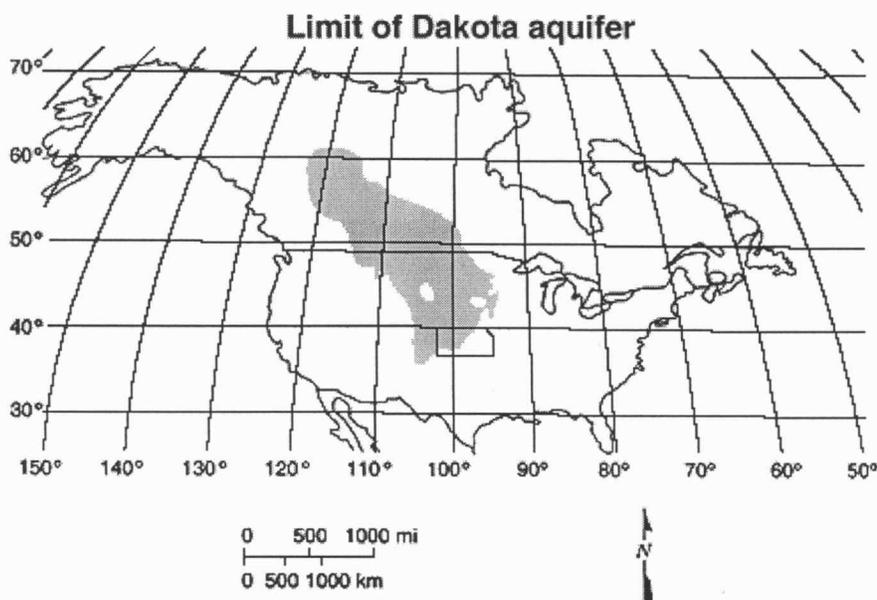
Across the Continental Divide, the Dakota aquifer is present in many of the intermontane basins. In Kansas, the Dakota is present in most of the western two-thirds of the state. Figure 2 shows that the aquifer extends westward from Washington County in the north-central part of the state and northward from Morton County in southwestern Kansas. In all the Dakota is present in 59 of the 105 counties in the state.

Figure 2

Dakota Home ‖ Previous Page--Description of the Dakota Aquifer Program

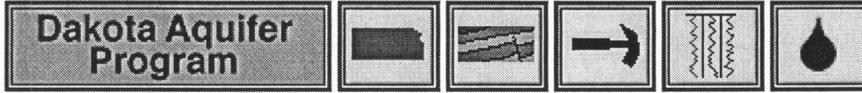Kansas Geological Survey, Dakota Aquifer Program
Updated April 8, 1996.
Scientific comments to P. Allen Macfarlane
Web comments to webadmin@crude2.kgs.ukans.edu
The URL for this page is HTTP://www.kgs.ukans.edu/Dakota/vol1/intro/extent.html

Dakota Aquifer Program

6.b.

Dakota Aquifer Program--Subsurface Hydrology

Regional Dakota aquifer hydrostratigraphy

The geologic units that form the Dakota aquifer in Kansas are the Dakota Formation, the Kiowa Formation, and the Cheyenne Sandstone (Table 1). These geologic units were deposited during the Cretaceous Period in alluvial valleys and in the coastal plain adjacent to the developing Western Interior seaway (Hamilton, 1994).

Table 1 also shows the equivalent stratigraphic units in eastern Colorado. The combined thickness of these units can range up to more than 700 ft in west-central parts of the state. However, not all of the units that constitute the Dakota contain aquifer-grade material that can yield water to wells.

The amount of sandstone, considered to be the aquifer material, varies from less than 5% to more than 50% of the total thickness, even over distances of less than a mile. More information on the stratigraphy of these deposits can be found on this volume of the CD set in the Geologic Framework directory.

Table 1

ERA	SYSTEM	ROCK STRATIGRAPHIC UNITS	HYDROSTRATIGRAPHIC UNITS
Cenozoic	Quaternary	Unconsolidated Sediments	High Plains & Alluvial Valley aquifers
	Tertiary	Ogallala Fm.	
Mesozoic	Cretaceous	Colorado Group	Upper Cretaceous aquitard
		Dakota Ss./Dakota Fm.	Upper Dakota aquifer
		Purgatoire Fm./ Kiowa Fm.	Kiowa Shale aquitard
			Lower Dakota aquifer
	Jurassic/Triassic	Morrison Fm. Dockum Group	Morrison-Dockum aquifer[1]
Paleozoic	Permian/ Pennsylvanian	Permian Undiff.	Permian-Pennsylvanian aquitard
		Cedar Hills Ss.	Cedar Hills Sandstone aquifer
		Permian/Pennsylvanian Undiff.	Permian-Pennsylvanian aquitard

1. The Morrison-Dockum is considered an aquifer only in southeastern Colorado and adjacent southwestern Kansas. Elsewhere in Kansas it is included in the Permian-Pennsylvanian aquitard.

At the regional scale, the Dakota aquifer system consists of upper and lower units (Table 1; Figure 1). The

upper aquifer unit consists entirely of the Dakota Formation and the shoreline deposits at the top of the Kiowa Formation and is approximately 300 ft thick. The lower aquifer unit consists of the Longford Member of the Kiowa Formation and the Cheyenne Sandstone and varies considerably in thickness up to 200 ft. These upper and lower regional aquifers are separated in western and parts of central Kansas by thick, marine shale in the Kiowa Formation, referred to as the Kiowa shale aquitard (Table 1). The thickness of the aquitard ranges up to more than 300 ft in parts of west-central and southwestern Kansas. The Kiowa shale aquitard is not present in much of central Kansas where it has been removed by erosion or was not deposited. Where it is not present the potential exists for direct hydraulic connection between the upper and lower Dakota aquifer. Figure 2 shows the extent of the Kiowa shale aquitard in Kansas.
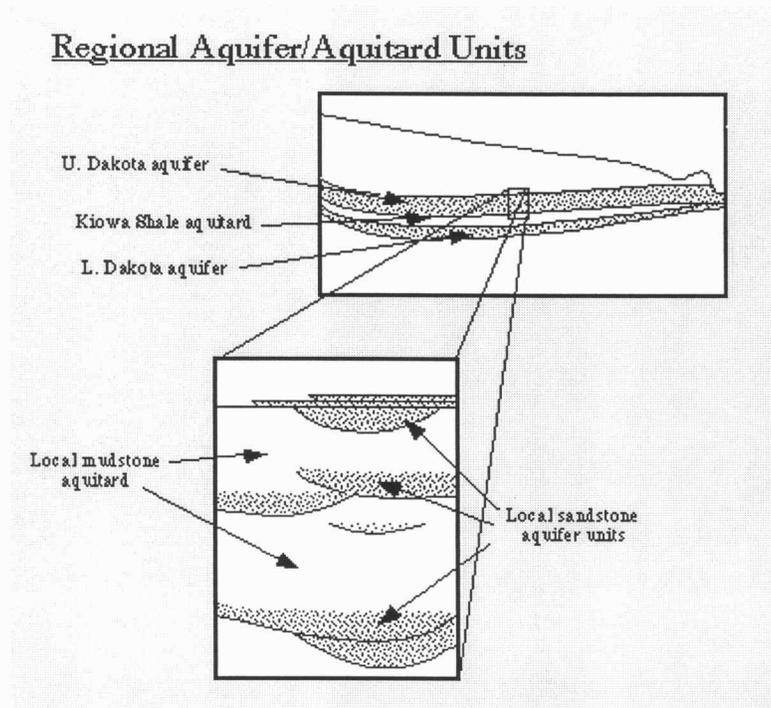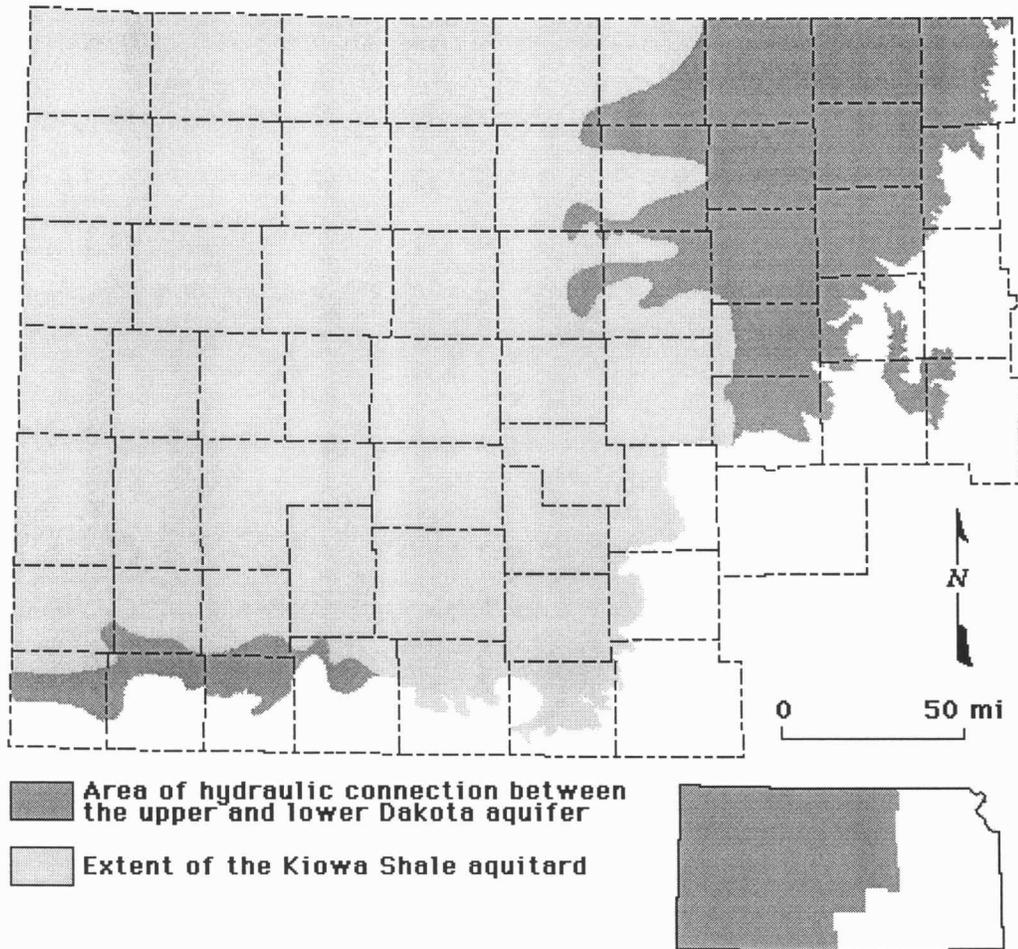
Figure 1

**Figure 2**--Extent of the Kiowa shale aquitard in Kansas.

HYDROLOGIC PROPERTIES

In most hydrogeologic investigations, the permeable nature of a natural porous medium to the flow of water is indicated by its hydraulic conductivity, expressed in L/T units. Sandstone hydraulic conductivities are derived from the results field tests involving either single or multiple wells and laboratory measurements of small samples from the outcrop or coring. Because of the variability of natural porous media, the hydraulic conductivity is a log-normally distributed parameter in most instances (Freeze and Cherry, 1979). The "average" value for the log-normal distribution is the geometric mean of the distribution.

Twenty-two reliable values of hydraulic conductivity from field hydraulic tests of wells in the Dakota aquifer of Kansas were found in the literature or were derived from field tests conducted for the Dakota Aquifer Program. Most of the values come from pumping tests where the Dakota aquifer is shallow in central and southwestern Kansas. The hydraulic conductivity data from the field hydraulic testing range from 3.6-88 ft./day with a geometric mean value of 12.5 ft/day (Figure 3A). The highest hydraulic conductivities are generally found in the outcrop or near the outcrop areas of the Dakota aquifer in central Kansas and the lowest values in southwestern Kansas.

Figure 3. Distribution of hydraulic conductivity (A) and specific storage (B) values from 22 pumping tests of the Dakota Aquifer in Kansas.

A

B
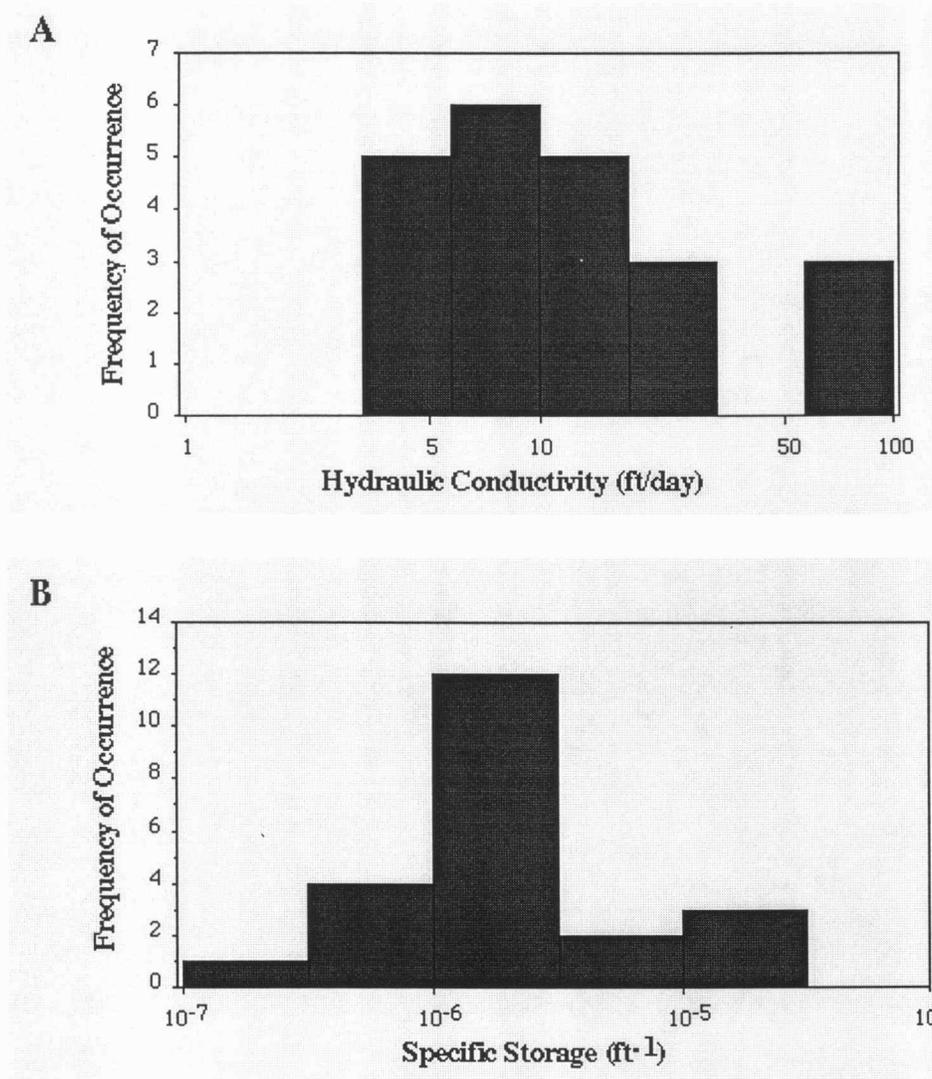
In Figure 4 similar trends can be observed in the results from lab tests on core samples of the sandstones from the Dakota aquifer in central and northwest Kansas. Core samples of sandstone from central Kansas appear to be more permeable than core samples of sandstone from northwest Kansas. The test results suggest that hydraulic conductivity is generally highest in the better sorted and coarser sandstones. These sandstones are most common in the lower sections of thick, amalgamated, multi-story fluvial- and distributary-channel sandstone bodies found in central Kansas.

Figure 4. Histograms of horizontal hydraulic conductivity of fluvial and shoreface sandstones from the Dakota and Kiowa Formations in the KGS #1 Jones (central Kansas) and the #1 Beaumeister (northwestern Kansas).
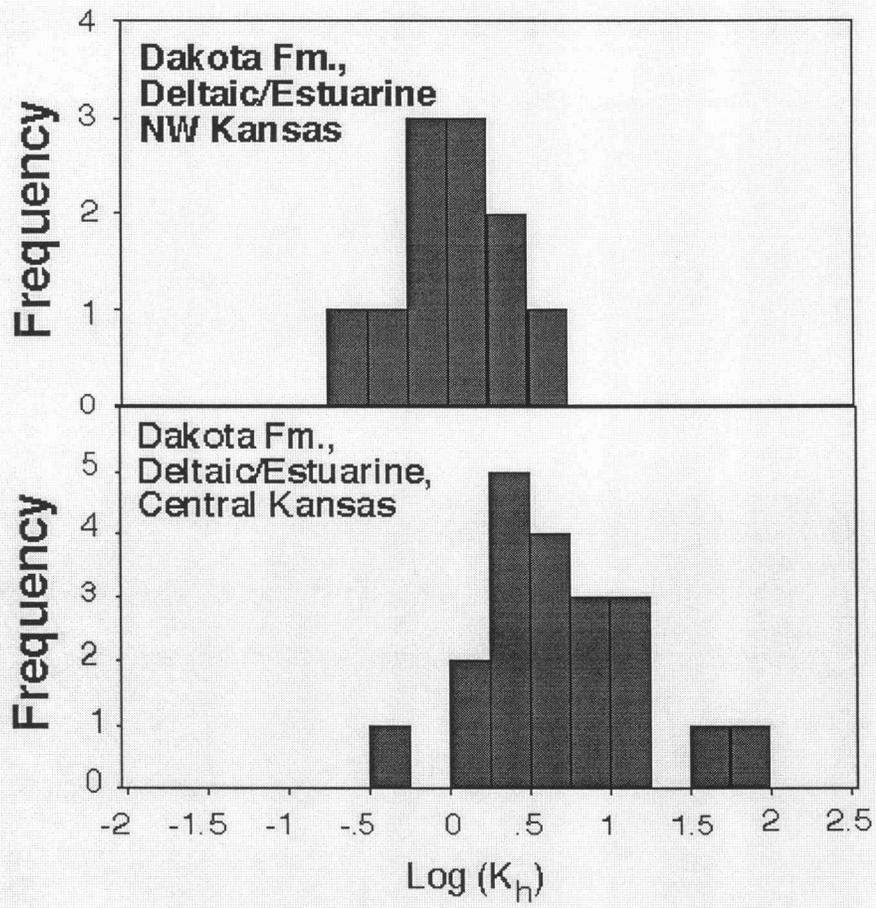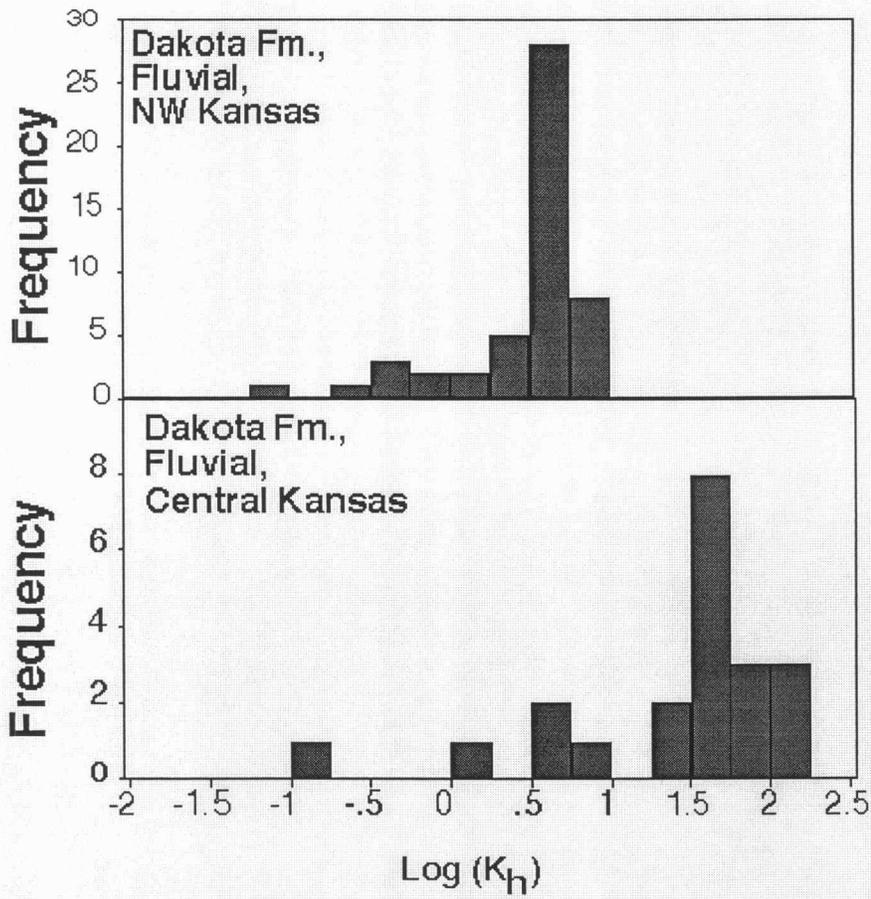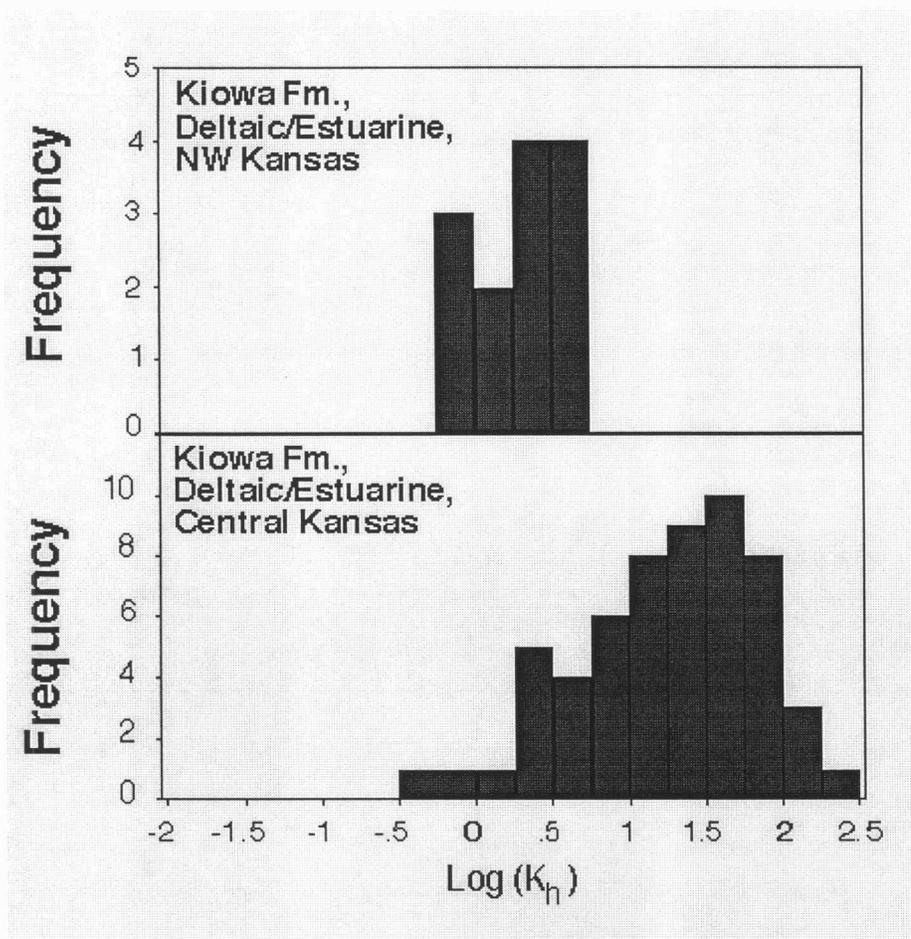
Direct field or laboratory tests on the mudstone matrix were not conducted in the Dakota Aquifer Program. However, Wade (1991, 1992) reported a mudstone vertical hydraulic conductivity of $2.2 \pm 0.6 \times 10\text{-}3$ ft./day from a pumping test of a thick sandstone aquifer in Washington County. Macfarlane et al. (1994) concluded from analysis of a pumping test near the outcrop in central Kansas, that the vertical hydraulic conductivity of the mudstone is considerably less than 0.001 ft/day, perhaps by several orders of magnitude. These results suggest that processes associated with erosion and unloading of the Dakota aquifer sediments may significantly increase the bulk vertical hydraulic conductivity of the mudstone matrix that surrounds the sandstone bodies of the Dakota aquifer.

The release of water from storage in confined aquifers is analogous to the process of consolidation in soil mechanics. Water is released from storage by (1) the expansion of water under confinement due to the decrease in fluid pressure to atmospheric, and (2) the consolidation of the confined aquifer framework due to the release of water. These two phenomena are expressed jointly in the specific storage term:

$$S_s = \rho g (\alpha + n\beta)$$ (eqn. 1)

Where ρ is the water density (mass per cubic liter), g is the acceleration of gravity (length per square of time), and α and β are the compressibilities of the aquifer framework and the water, respectively (length multiplied by time squared divided by mass). In eqn. 3 the expansion of the framework is reflected in α and that of the water is reflected in the $n\beta$ term. In most cases the consolidation of the aquifer framework is most important influence on the specific storage. The storativity is the product of the specific storage and the thickness of the sandstone aquifer.

Twenty-two reliable values of specific storage from field hydraulic tests of wells in the Dakota aquifer of Kansas were found in the literature or were derived from field tests conducted for the Dakota Aquifer Program. Most of the values come from pumping tests where the Dakota aquifer is shallow in central and southwestern Kansas. Values of specific storage range from 1.5 x 10-7 (inverse feet) up to 2.9 x 10-5 (inverse feet), which is within the expected range of values for confined sandstone aquifers. In Figure 2B the data appear to be log normally distributed with a geometric mean of 2.1 x 10-6 (inverse feet).

REFERENCES CITED

Freeze, R.A., and Cherry, J.A., 1979, Ground Water: Englewood Cliffs, N.J., Prentice Hall Inc., 604 p.

Hamilton, V.J., 1994, Sequence stratigraphy of Cretaceous Albian and Cenomanian strata in Kansas, in Shurr, G. W., Ludvigsen, G. A., and Hammond, R. H., eds., Perspectives on the Eastern Margin of the Cretaceous Western Interior Basin: Geological Society of America Special Paper 287, p. 79-96.

Macfarlane, P.A., Doveton, J.H., Feldman, H.R., Butler, J.J., Jr., Combes, J.M., and Collins, D.R., 1994, Aquifer/aquitard units of the Dakota aquifer system in Kansas: methods of delineation and sedimentary architecture effects on ground-water flow and flow properties: Journal of Sedimentary Research, v. B64, no. 4, pp. 464-480.

Wade, A. 1991, Determination of aquifer properties of the Dakota aquifer in Washington County, Kansas from a pumping test: Kansas Geological Survey Open-File Report 91-1c, 62 p.

Wade, A., 1992, Ground-water flow systems and the water-resources potential of the Dakota aquifer in a two-county area in north-central Kansas: MS thesis, University of Kansas, Lawrence, 158 p.

6. c.

Dakota Aquifer Program--Petrophysics

Geophysical Log Analysis of the Dakota Aquifer

The Gamma-ray Log

The gamma-ray log is widely used as a record to locate the depth of key stratigraphic formations (Figure 2) and to subdivide the Dakota into units of sandstone and shale (Figure 3). The gamma-ray tool measures natural radioactivity of rocks in a similar way to a geiger counter. The sources of radiation are almost entirely from isotopes of thorium, uranium, and potassium. Although the radioactivity of most rocks is fairly low, it is sufficient to make a clear distinction between sandstones (low radioactivity) and shales (higher radioactivity) (Figure 3). Older gamma-ray logs are recorded in "counts" whose numbers vary according to the tool design. Almost all modern gamma-ray logs are recorded in API (American Petroleum Institute) units, which makes a common standard for log comparison. The scale was chosen so that a value of zero would mean no radioactivity and a value of 100 would match a typical Mid-continent shale. In practice, shales can be somewhat variable in their radioactivity according to their silt content, types of clay mineral, and the occurrence of small amounts of uranium.

Figure 2. Use of gamma-ray log for stratigraphic subdivision of Dakota Aquifer in KGS Jones #1 NENENE 2-10S-8W, Lincoln County, Kansas.
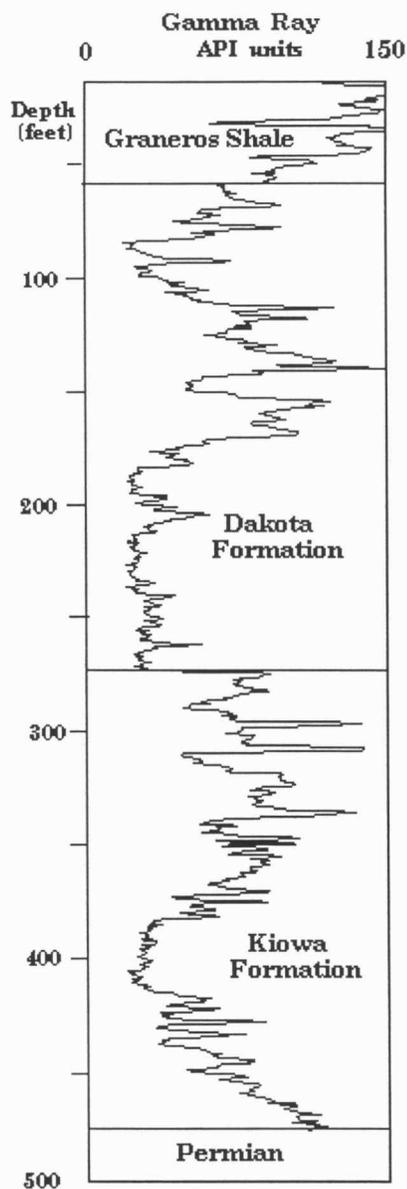
Once the stratigraphic boundaries of the Dakota Aquifer are located (Figure 2), the gamma-ray log can be used to mark off depth intervals of sandstones and shales. As a general rule-of-thumb, experience has shown that a value of 60 API units is a satisfactory boundary to differentiate sandstones (below 60) and shales (above 60). An example of using this procedure is shown in Figure 3. The subdivision of a Dakota Aquifer section into sandstones and shales reveals the structure of aquifer and aquitard layers.

Figure 3. Use of gamma-ray log to subdivide the Dakota Aquifer in KGS Jones #1 between sandstone aquifer zones and shale aquitard zones theough the use of a gamma-ray cut-off value.
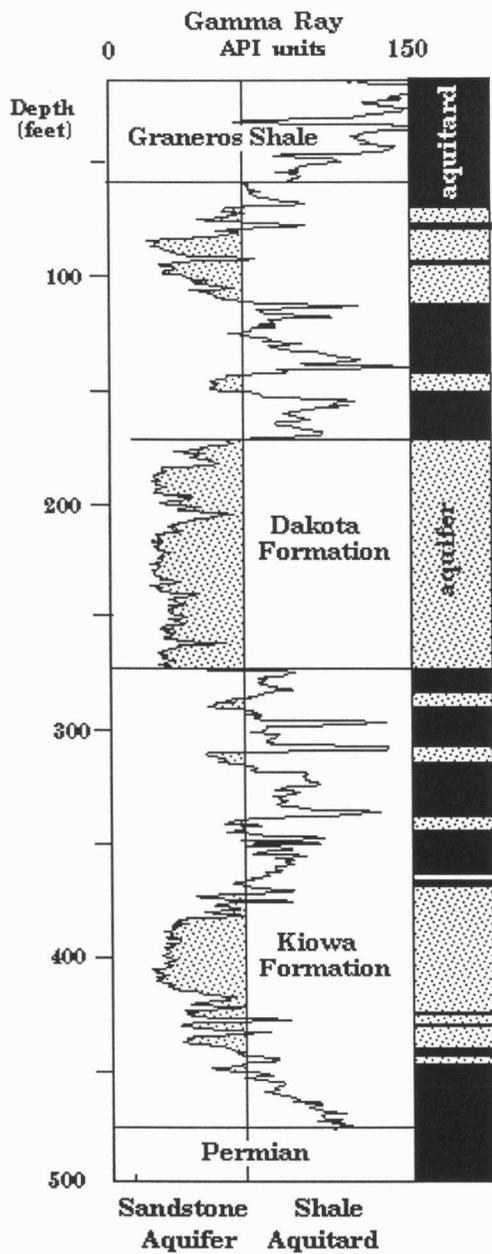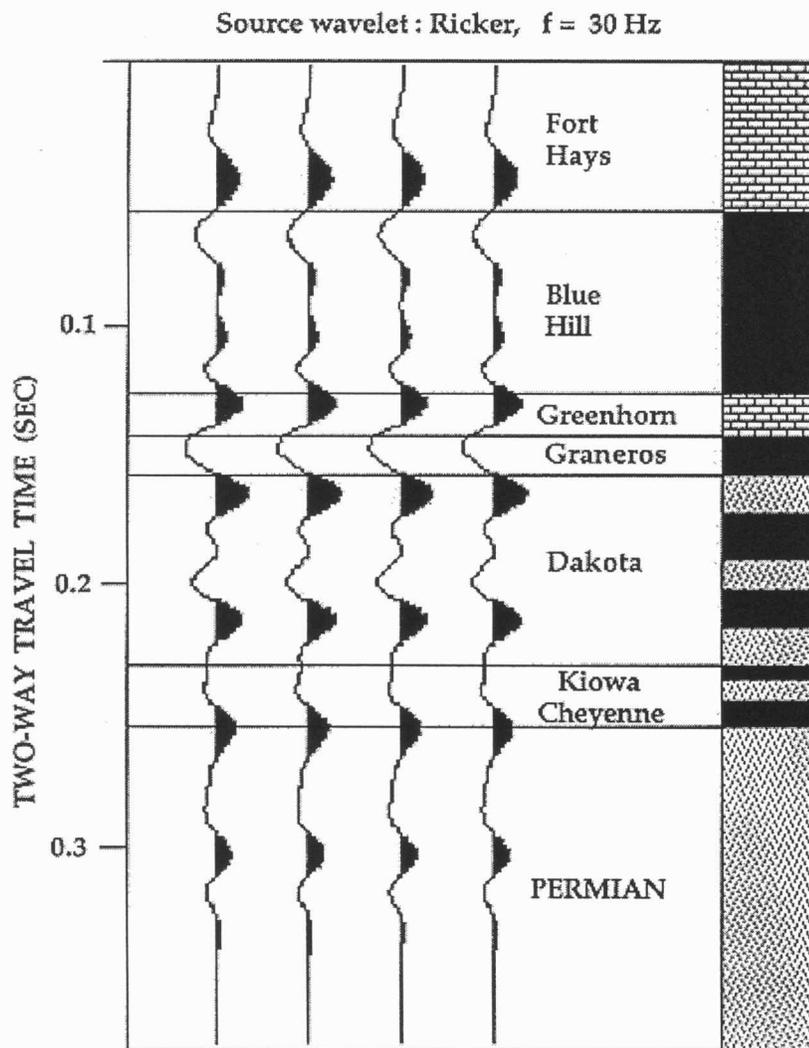
Dakota Aquifer Program
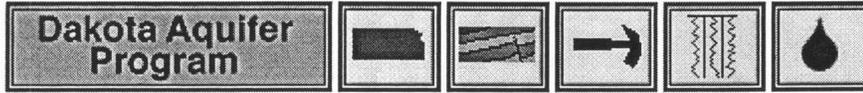
6, d.

Dakota Aquifer Program--Geologic Framework

Seismic records and the synthetic seismogram

Seismic shooting is widely practiced by the energy industry as an exploration method in the search for oil and gas fields. A high energy source at the ground surface is used to generate acoustic waves which radiate down through the earth. The waves are refracted and reflected by the stratigraphic layers in the subsurface. Particularly strong reflections occur at boundaries between rock layers that have a marked difference in impedance caused by an abrupt change in velocity and density. The acoustic reflections are detected and timed by a line of geophones at ground level and their measurements collated in a cross-section of reflection events at various depths. In general, acoustic velocities are slower in less competent rocks such as shales, but faster in more rigid rocks such as sandstones or limestones. The reflections of the seismic record therefore correspond to layers of differing rock types that can be used for stratigraphic work or the search for specific rock bodies such as channel sandstones.

Seismic energy sources used by the energy industry are required to generate reflections from rock units several thousand feet below the surface, and so typically have frequencies of the order of 30 Hz. A simulation of a field record of this type is shown in Figure 1. This synthetic seismogram was computed using a sonic log recorded in a Dakota Aquifer program observation well in Ellis County. Notice that the depth scale is not measured in feet but in units of two-way travel time in seconds that record the time that elapsed between the triggering of the energy source and the arrival of the reflection at the geophone. Because the sound velocity changes continuously with depth the time record is not a simple transformation of depth. The reflection peaks (black) pick up rock boundaries where the acoustic velocity increased downwards going from a "slow" shale to a "faster" limestone or sandstone, while the reflection troughs (white) match the reverse situation. The 30 Hz frequency of the energy source results in a fairly coarse resolution, so that only fairly thick rock units with strong impedance contrasts can be distinguished. This characteristic can be seen in Figure 1, where the stratigraphic units are resolved easily, but reflections generated by the sandstones within the Dakota Aquifer tend to overlap and merge.

Figure 1. Synthetic seismogram for the Dakota aquifer and adjacent stratigraphic units, calculated from geophysical logs in the observation well KGS Braun #1 (NENENE 30-12S-18W), Ellis County, Kansas.

Better precision can be obtained by high-frequency seismic shooting of Dakota Aquifer sections where they are fairly close to the surface. Coyle (1990) made several field studies in the vicinity of Dakota Aquifer program observation wells to evaluate the feasibility of seismic methods in the location of channel sandstones. Sonic logs at the wells could be used to create synthetic seismograms, so that interpretations of field records could be correlated with geology.

Gamma-ray and sonic logs are shown from a second observation well in Ellis County (Figure 2). The sonic log was converted to a two-way reflection time record of velocity, which was then transformed to a train of reflection coefficients and convolved with a 100 Hz Ricker wavelet (Figure 3). By superimposing the synthetic seismogram at the observation well location on the East-West seismic line (Figure 4), the field reflections can be related to specific geological features. The Stone Corral provides a strong reflector that is easily recognized on seismic records from the entire region The contact between the Dakota Formation and the underlying Kiowa Shale can be seen , and is caused by the sharp change in velocity at the contact (see Figure 2). Reflections from the Greenhorn Limestone, Graneros Shale, and the top of the Dakota Formation can also be identified on the field record from their signatures on the synthetic seismogram. The distinctive and laterally continuous reflection at 0.26 seconds was interpreted to coincide with the top of the Permian.

Figure 2. Gamma-ray and sonic logs from observation well KGS Brungardt #1 (SESESE 25-12S-17W), Ellis Co., Kansas.

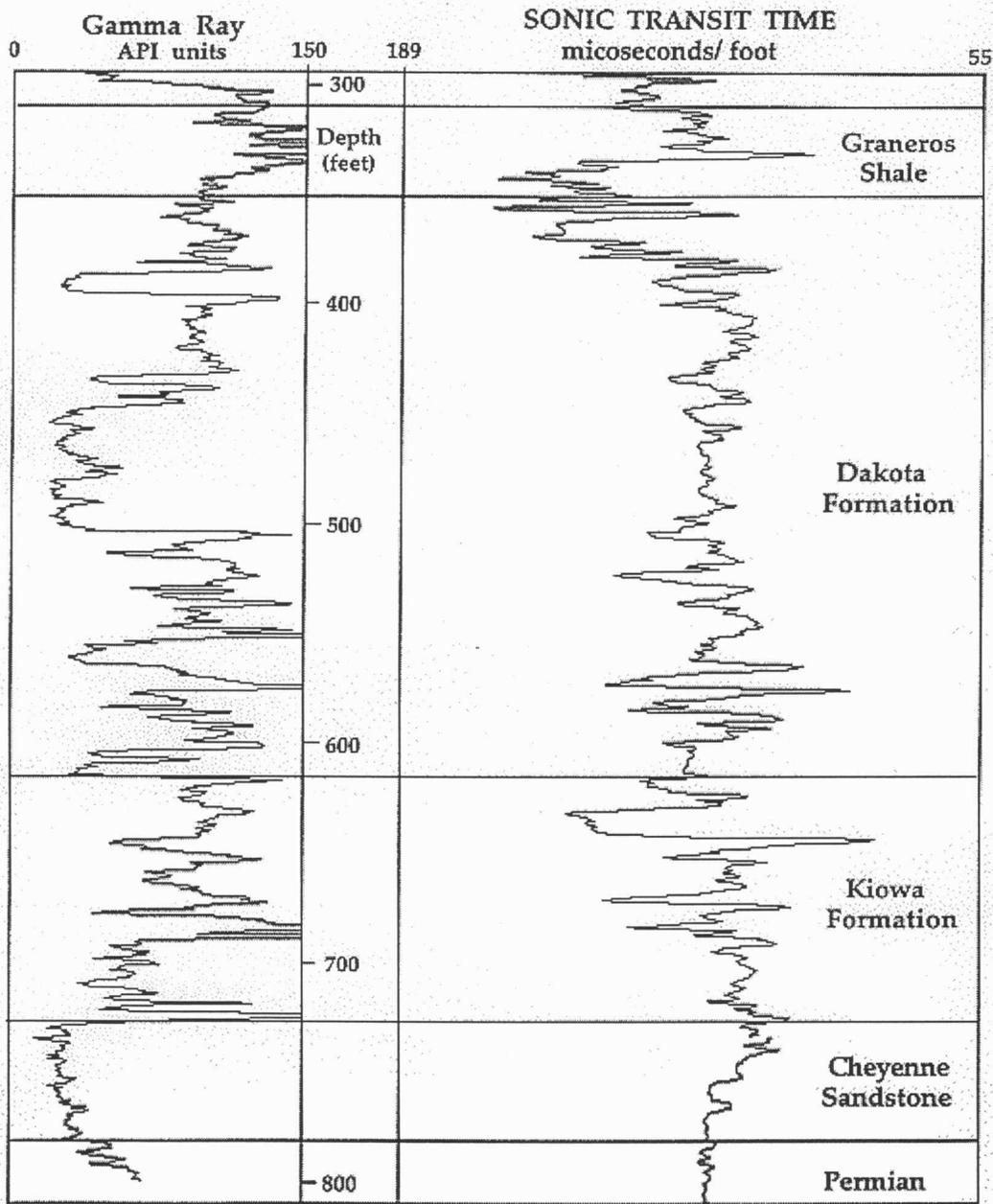**Figure 3.** Computation of synthetic seismogram from the sonic log of the Brungardt well (see Figure 2) by the conversion from depth to a scale of acoustic travel time and convolution with a Ricker wavelet of frequency 100 Hz (from Coyle, 1990).
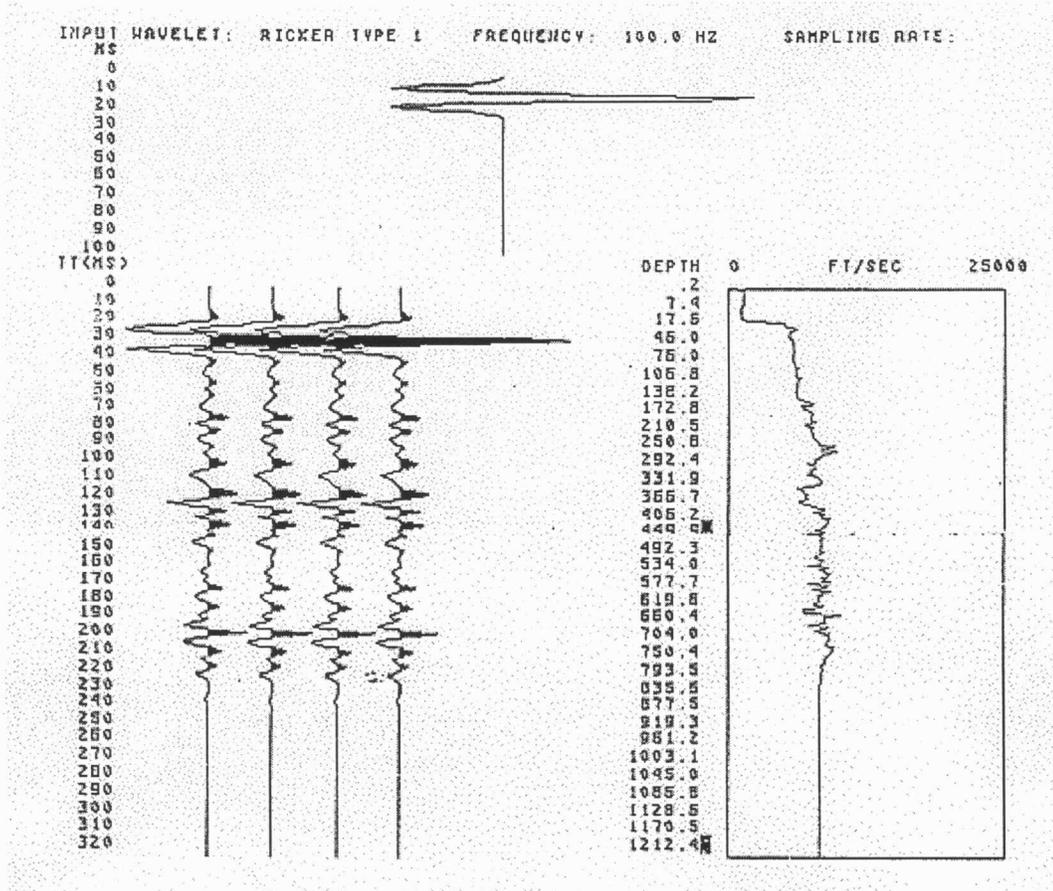
Figure 4. Comparison between the synthetic seismogram computed from the Brungardt well sonic log (see Figure 3) and a field seismic line shot at the well site (from Coyle, 1990).

Figure 5. CDP seismoc section tied to Dakota Aquifer program observation well KGS Haberer #1 (NESENE 14-12S-15W), Russell County, Kansas. Note channel sandstone. From Coyle, 1990.
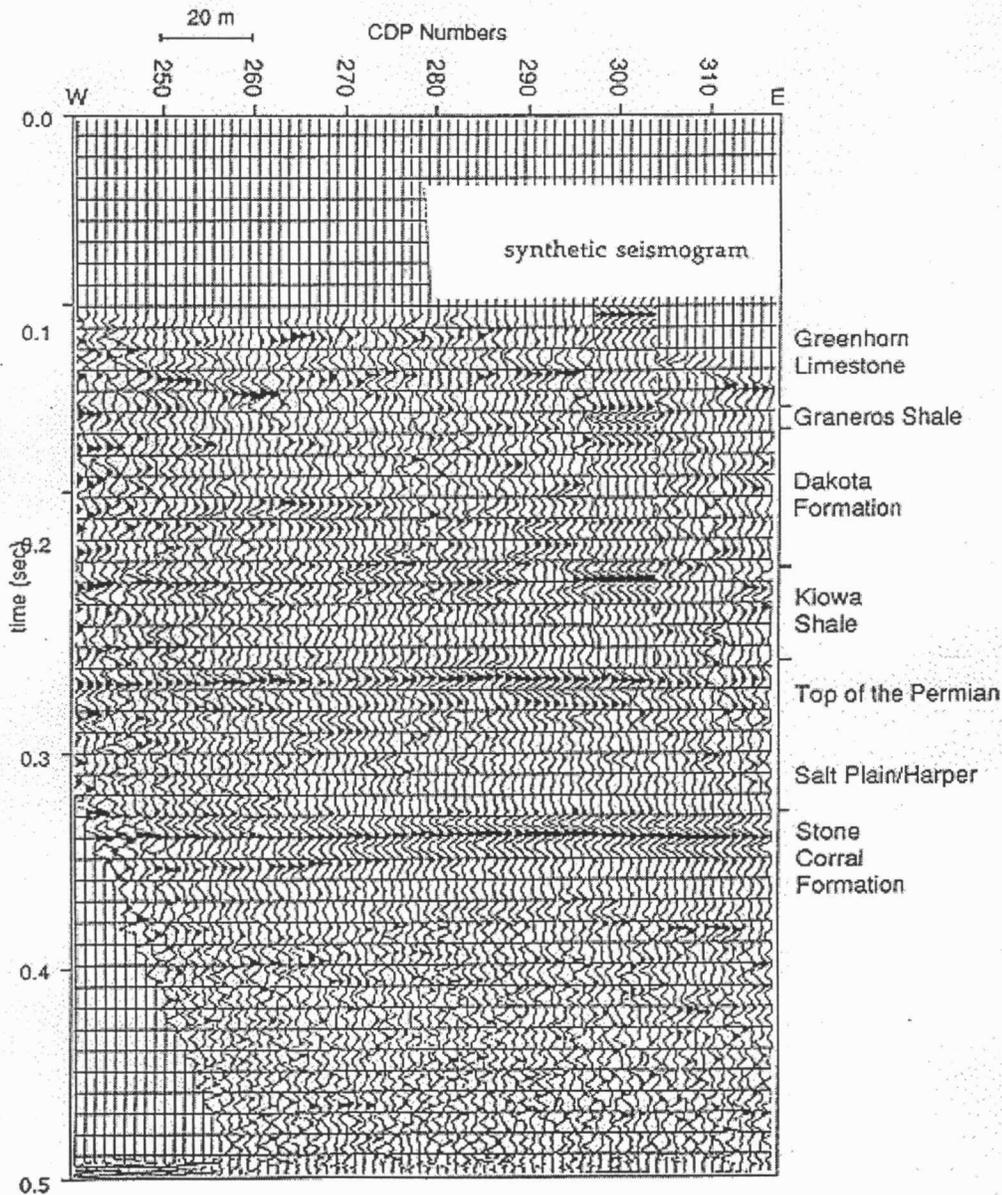
Coyle (1990) concluded that while thin sandstone lenses within the Dakota would not be detectable at this frequency (100 Hz), modeling suggested that sandstones thicker than 30 feet would be resolvable. A field seismic line shot over a Dakota channel sandstone at another site gave some support to his conclusion (Figure 5). Thinner sandstones could be identified where reflections were recorded with frequencies higher than 180 Hz. The resolution and quality of seismic records were also found to be site dependent. The best sites were located on fresh exposures of Graneros Shale, where reflections of 200 Hz and higher were recorded. The worst sites occurred on the Greenhorn Limestone outcrop, while low frequencies were recorded at levels higher than the Greenhorn.

Reference:

Coyle, W.G., III, 1990, Feasibility of detecting sandstone lenses in the Dakota Formation by seismic reflection, Russell and Ellis Counties, Kansas: Unpubl. MS thesis, Univ. Kansas, 59 pp.

Dakota Home ‖ Geologic Framework Index

Kansas Geological Survey, Dakota Aquifer Program
Updated July 5, 1996.
Scientific comments to P. Allen Macfarlane
Web comments to webadmin@crude2.kgs.ukans.edu
The URL for this page is HTTP://www.kgs.ukans.edu/Dakota/vol1/geo/seismic.html

6.e.

Interpretation of lithologies and depositional environments of Cretaceous and Lower Permian rocks by using a diverse suite of logs from a borehole in central Kansas

P. A. Macfarlane, J. H. Doveton, G. Coble
Kansas Geological Survey, University of Kansas, Lawrence, Kansas 66046

ABSTRACT

As part of an extensive research program, a borehole was drilled to extend sedimentary facies models of the Cretaceous into the subsurface on the eastern side of the western interior Cretaceous basin in Kansas. Lithodensity-neutron and spectral gamma-ray logging runs were completed to facilitate interpretation of rocks penetrated by the borehole. Th/K, Th/U, and composition profile logs based on apparent grain density and photoelectric absorption index were prepared and used to show vertical changes in geochemical facies and clay mineralogy. These logs were compared with the gamma-ray log and drill cuttings to interpret depositional environments. The Th/K log sharply defines the Cretaceous/Permian boundary and, together with the Th/U log, emphasizes the contrast between marine Upper Cretaceous rocks of the Greenhorn depositional cycle and nonmarine to transitional rocks of the Lower Cretaceous. The long-term cyclic pattern of the Th/U log is an excellent indicator of a broad transgression/regression during the Greenhorn cycle on an open marine shelf, whereas extreme fluctuations of Th/U in the Lower Cretaceous rocks suggest a high degree of short-term environmental variability. Interpretation of the RHOMAA-UMAA compositional profile in the Dakota Formation indicates several pulses of marine transgression and regression prior to the initiation of the Greenhorn cycle in central Kansas.

INTRODUCTION

Sedimentary rocks of Cretaceous age are present in much of central and western Kansas. Upper and Lower Cretaceous units have been described extensively along the outcrop belt (e.g., see Hattin and Siemers, 1987; Latta, 1946; Franks, 1980). These rocks record several transgressive/regressive cycles that occurred during deposition of the western interior Cretaceous section. Hattin and Siemers (1987) have recognized cycles of transgression and regression in the Upper Cretaceous rocks beginning with the upper part of the Dakota Formation. Franks (1980) has described cyclical patterns of deposition in the Lower Cretaceous Kiowa Formation of central Kansas.

Although these rocks have been studied in detail where they crop out, very little work has been done to trace depositional environments and lithofacies into the subsurface. This is particularly true of the Lower Cretaceous rocks, which are relatively unknown where they are covered. Franks (1979, 1980) and Scott (1970) have noted problems regarding nomenclature and correlation between surface and subsurface sections of Lower Cretaceous rocks in the western interior. Recently, as part of an extensive research program on the Kansas Lower Cretaceous, a borehole was drilled that penetrated part of the Upper Cretaceous, all of the Lower Cretaceous, and part of the Lower Permian (Fig. 1). The purpose of drilling this hole was to extend knowledge of Lower Cretaceous sedimentary facies into the subsurface toward the axis of the western interior Cretaceous basin.

To accomplish this task, lithodensity-neutron and spectral gamma-ray logging runs of the borehole were completed to supplement information from drill cuttings. The logs were processed by using techniques described by McCall and Gardner (1982) and Schlumberger (1988) in order to graph vertical changes in mineralogy and geochemical fluctuations as indicators of depositional environments in these rocks.

SPECTRAL GAMMA-RAY LOG ANALYSIS

Natural gamma radiation in rocks is almost entirely attributable to potassium-40 and radioactive isotopes of the uranium and thorium families. A conventional gamma-ray log records the total intensity of gamma radiation from a broad range of sources. In the design of the spectral tool, "windows" are set to count gamma radiation within specific energy ranges. The spectral measurements are processed by computer to convert the raw count rates to concentration of the three major radioactive sources. The gamma-ray spectral log records curves of thorium and uranium which are both scaled in parts per million, together with potassium in percent.

In sedimentary rocks, thorium is almost exclusively restricted to aluminosilicate minerals. Consequently, the thorium curve is a good indicator of the bulk proportion of clay minerals within logged formations. The thorium/potassium ratio (Th/K) provides a generalized index of potassium richness related to thorium, and so is useful for broad discrimination between radioactive minerals. Relatively low-ratio (high-K) feldspars and micas are distinguished from higher ratio clay minerals, which range from illite through smectite to kaolinite and chlorite in decreasing potassium content (Hassan et al., 1976).

The thorium/uranium ratio (Th/U) has also proved to be useful in the recognition of "geochemical facies" (Adams and Weaver, 1958). The Th/U ratio is an indicator of redox potential. Uranium has an insoluble tetravalent state that is fixed under reducing conditions, but is transformed to the soluble hexavalent state that may be mobilized into solution. In
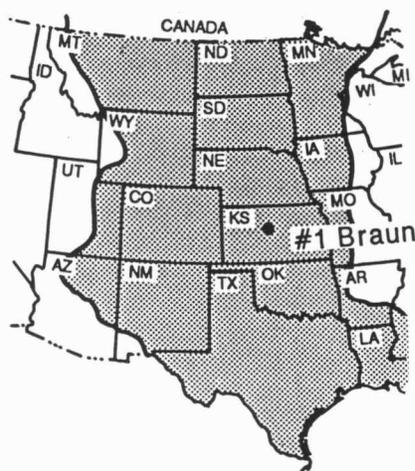

Figure 1. Location of #1 Braun borehole relative to Cretaceous western interior seaway (Early Turonian).

contrast, thorium has a single insoluble tetravalent state that is geochemically associated with uranium and is therefore a useful standard for comparison purposes. On the basis of outcrop measurements, Zelt (1985) showed close relations between Th/U and transgressive/regressive cycles in the Upper Cretaceous rocks of Colorado, Utah, and New Mexico.

The Th/K and Th/U ratios were plotted as logs together with the gamma-ray trace and compared with a graphic lithology log (Fig. 2). The simultaneous consideration of these data throughout the sequence reveals striking and readily interpretable patterns. The Th/K log shows fluctuations in value that reflect changes in the volumetric proportions and types of clay minerals, micas, and feldspars. An abrupt shift occurs at the Cretaceous-Permian contact (top of the Cedar Hills Sandstone) and highlights clearly a major unconformity at the base of the Cretaceous. Petrographic descriptions based on outcrop samples (Swineford, 1955) and cores (James, 1972; Holdoway, 1978) have characterized the Cedar Hills Sandstone as a quartz-feldspar-illite assemblage. The Th/K log within this unit is restricted to the theoretical range of ratio values between 0.5 and 3.5 suggested for a feldspar-illite mixture by Schlumberger (1988). In contrast, the shift to higher Th/K values in the Lower Cretaceous is caused by the change in mineralogy to illite-smectite-kaolinite, reported from

petrographic studies of these units in outcrop (Franks, 1979). Schlumberger (1988) gave the generalized ranges for these minerals as 2–3.5 (illite), 3.5–12 (smectite), and 12–28 (kaolinite). These data collectively explain the reason for the abrupt discontinuity in the Th/K log at the unconformity at the base of the Cretaceous. They also suggest that the oscillations of the Th/K log within the Lower Cretaceous formations may reflect volumetric variations of illite and kaolinite that are possibly linked with marine and deltaic fresh-water environments, respectively. The Th/K ratio trace in the Graneros Shale overlaps the range of the Lower Cretaceous curve. However, there is a distinctive bias toward higher Th/K ratios in the Graneros that probably reflects the increased importance of smectite as a significant component. Th/K fluctuations in the Upper Cretaceous units appear to be caused by changes in illite, smectite, and mixed-layer clays as products of predominantly marine environments; these are the clay mineral components reported in X-ray diffraction analyses of insoluble residues (Arthur et al., 1985). High-amplitude Th/K variations in the Graneros Shale and the Greenhorn Limestone may reflect the occurrence of bentonites (observed in the drill cuttings) interbedded with normal illitic marine shales. These bentonites represent altered ash deposits generated from volcanic events in the Idaho-Montana and New Mexico–Arizona regions.

The Th/U ratio log was indexed with the diagnostic values of 2 and 7 suggested by Adams and Weaver (1958) to facilitate interpretation of depositional environment through its use as an oxidation-potential indicator. The ratio indicates an oxidizing environment for much of the Cedar Hills Sandstone, which was interpreted by Holdoway (1978) to have been deposited in an eolian setting. The occurrence of glauconite in drill cuttings from the upper part of the formation is a strong indicator of marine origin and is matched by decline of Th/U to a neutral range. This section may reflect deposition in shallow bodies of water that were linked to an ephemeral sea, as suggested by Holdoway (1978) for the overlying Flower-pot Shale.

Above the Cretaceous/Permian boundary, the Th/U log exhibits a high-frequency character in the Cheyenne, but is consistently greater than 7. This is compatible with an oxidizing terrestrial environment of deposition by alluvial processes. The overlying Kiowa Shale marks a transgressive phase and is generally considered to represent a transitional to shallow-marine environment in Kansas (Franks, 1980). The average Th/U ratio in the Kiowa is lower than in the Cheyenne, but shows only a weak trend in the intermediate range. This feature is a pale shadow of strong signals recorded in the spectral ratio of Upper Cretaceous transgressive strata in this well. However, the subdued character of the Kiowa section is in accordance with a peak-transgression paleogeographic map, on which the well site would be located close to the shoreline (Vuke, 1981). Stacked repetitions of high and medium Th/U ratios characterize the overlying Dakota Formation. These probably reflect the high lateral variability of environments expected in nonmarine settings as well as the interplay between mostly brackish and fresh-water regimes of deltaic environments.

In contrast to the Dakota trace, relatively smooth, long-term cyclic pattern of the Th/U log characterizes the Upper Cretaceous marine sequence and is an excellent indicator of a broad transgressive/regressive couplet on an open marine shelf. In fact, the broad sine-wave feature conforms precisely with the outcrop interpretation of the Greenhorn cycle as a classic example of a symmetric, third-order tectonoeustatic cycle (Glenister and Kauffman, 1985). Hattin (1985) was able to correlate demonstrably time-parallel beds in the Greenhorn from outcrops in Kansas to locations in Colorado and New Mexico. He concluded that the exceedingly widespread deposition of relatively thin units implied a regionally flat, gently sloping sea floor. This interpretation would account for the strong simple transgressive/regressive signal that appears in the ratio
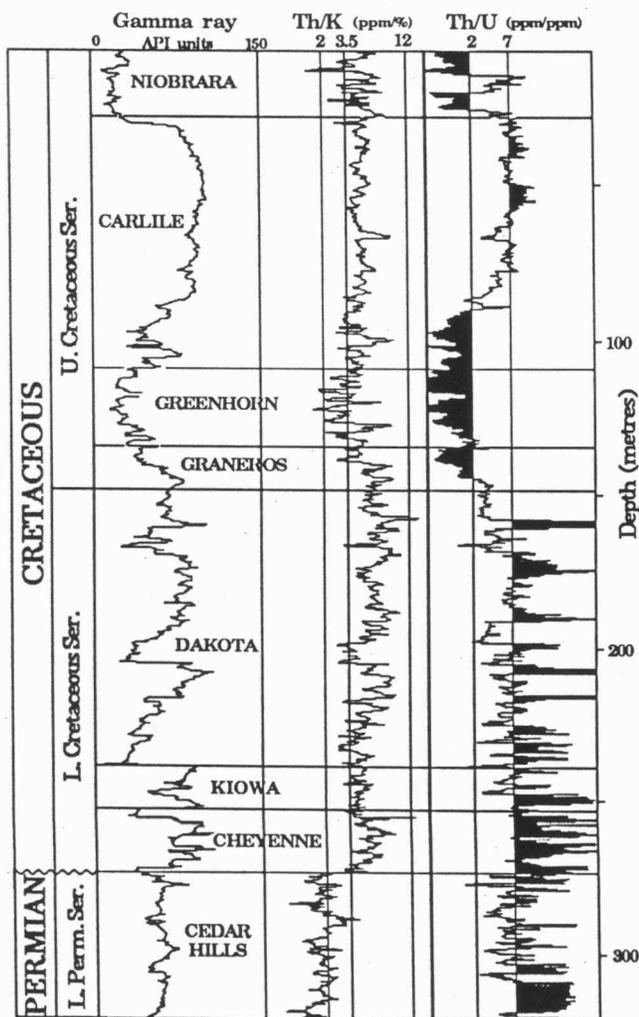

Figure 2. Computed gamma-ray, Th/U, and Th/K logs from borehole KGS Braun #1 30-12S-18W, Ellis County, Kansas.

log from the top of the Dakota Formation to the base of the Niobrara Formation. The transgressive phase of the cycle started during the deposition of the uppermost part of the Dakota, continued through the Graneros Shale, and reached maximum development in the Greenhorn Limestone. The regressive hemicyclotherm began near the end of Greenhorn deposition and continued through the Carlile Shale to terminate in the Codell Sandstone Member.

An abrupt break occurs in the Th/U log at the boundary between the Codell Sandstone Member and the overlying Niobrara Chalk. This contact is thought to represent a long period of nondeposition followed by a major transgression (Hattin and Siemers, 1987). The Th/U log shows this second transgression clearly, but also indicates a distinctive regressive event within the Fort Hays Member. The regional extent of this anomaly is indicated by the occurrence of a similar peak on the Th/U log from a well in the Denver Basin of Colorado (Zelt, 1985).

ANALYSIS AND INTERPRETATION OF THE LITHODENSITY-NEUTRON AND PHOTOELECTRIC ABSORPTION INDEX LOGS

The spectral gamma-ray log analysis gives good indications of generalized clay-mineral associations. However, the similarity of the potassium and thorium levels of some clay minerals and the mixture of clay minerals that characterizes most shales cause ambiguities of interpretation. Consequently, additional diagnostic information from other logs is useful, particularly for detailed work on clay-mineral identification and facies recognition within the Lower Cretaceous units.

The recent introduction of the photoelectric cross section as a supplementary curve to the conventional neutron and density logs has substantially improved the log recognition of mineralogy. The photoelectric cross section is a measure of the absorption of low-energy gamma rays by the formation in the borehole wall, and is measured in units of barns per electron. More important, the measurement is a direct function of the aggregate atomic number (Z) of elements within the formation, and thus is a sensitive indicator of mineralogy. The display of lithodensity-neutron data on a RHOMAA-UMAA crossplot is the most direct means to ascertain rock compositions from this log combination (McCall and Gardner, 1982). RHOMAA is the hypothetical density of the rock matrix computed as a mathematical projection of the rock's bulk density, which eliminates the effect of the fluids in the pore space. UMAA is the theoretical volumetric photoelectric absorption index of the matrix, calculated from the photoelectric factor by using similar considerations.

A RHOMAA-UMAA crossplot of digitized data from the Lower Cretaceous formations is shown in Figure 3. This plot is indexed with the approximate locations of standard clay minerals (Schlumberger, 1988) which, in reality, show ranges of variability as a consequence of differing compositions and morphologies from their ideal. The data cloud shows a wedge pattern whose upper vertex is sited at the coordinates of quartz. The range in UMAA values of the clay minerals is an expression of their differences in elemental composition and aggregate atomic number (Z). The data range between values for low-Z clays (kaolinite, smectite, and muscovite) and high-Z clays (illite and chlorite) and can be represented reasonably by a composition triangle. Any single point on the plot may then be recast as proportions of the three end members. The RHOMAA-UMAA data for the Lower Cretaceous rocks were transformed to a proportional log of these three components by a matrix algebra computer algorithm described by Doveton (1986). The result is shown in Figure 4, together with the Th/U ratio logs.

The RHOMAA-UMAA log of the Lower Cretaceous shows the progressively increasing effects of marine transgression at the beginning of the Greenhorn cycle within the Dakota Formation. The proportion of high-Z clays increases significantly near the middle of the formation and
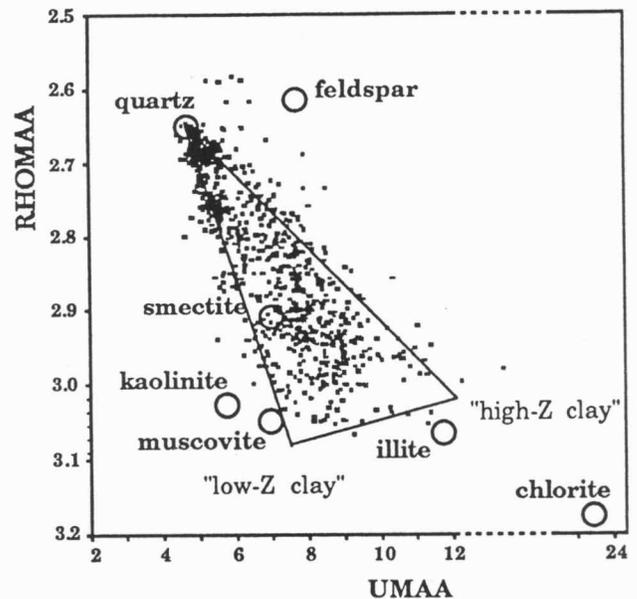

Figure 3. RHOMAA-UMAA crossplot of digitized data from Lower Cretaceous rocks in #1 Braun borehole indexed with approximate locations of clay minerals (Schlumberger, 1988).
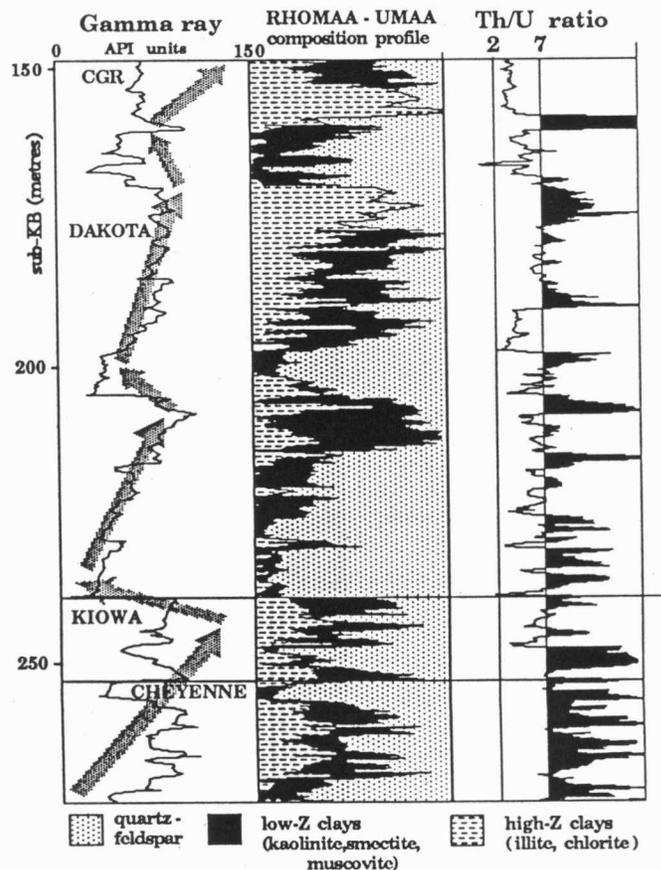

Figure 4. RHOMAA-UMAA proportional lithology log of Lower Cretaceous rocks in #1 Braun borehole. Arrows mark interpreted transgressive (to right) and regressive (to left) trends.

composes most of the clay fraction in the upper half. Franks (1979) noted increases in the illite and chlorite fraction of the clays in the upper part of the Dakota along the outcrop in central Kansas. Nearer the Denver Basin in northwest Kansas, Merriam et al. (1959) found that the majority of the clays in the Dakota are illite and chlorite.

Using RHOMAA-UMAA, gamma ray, and Th/U logs of the Dakota, it is possible to delineate several pulses of marine transgression and progradation by streams. In the lower part, a stacked sequence of channel sandstones indicates progradation by streams during retreat of the Kiowa seas. Rapid alternations of the Th/U ratios in this interval suggest varying depositional environments ranging from channel to backswamp. Fining upward of these channel deposits and the predominance of low-Z clays in the clay- and silt-size fractions of the rocks indicate a renewed phase of marine transgression. Above this sequence, deposition of more high-Z clay-rich, less well developed channel sandstones signals a progradation of terrigenous deposits across the Lower Cretaceous shoreline. Low Th/U ratios in the upper part of this channel sandstone suggest an extended period during which the environment of deposition was not well oxygenated. The clastics above these channel sandstones are predominantly fine grained, the proportion of high-Z clays increasing upward until only these clays make up the fine fraction of the Dakota sediments. These fine-grained deposits appear to be more marinelike and indicate another transgressive pulse by the Lower Cretaceous seas. Renewed progradation is indicated by a unit consisting of interbedded sandstones and low-Z clays. This signifies possibly the last progradational episode prior to inundation by the Upper Cretaceous seas at this location. The fluctuations of the gamma-ray curve, the presence of glauconite from the driller's log, and the predominance of illite in the sediments above and below this unit suggest that these coarser sediments were deposited just offshore in a marine environment as a delta-front sheet sand similar to the tabular flat-bedded sandstones described by Siemers (1976). Above these coarser delta-front sandstones are the rocks with low and relatively stable Th/U, together with high proportions of illite, indicating an offshore marine environment with higher water salinities similar to that described by Hattin and Siemers (1987).

In the Kiowa Formation and the Cheyenne Sandstone, the RHOMAA-UMAA log shows that these units consist of interbedded high- and low-Z clays and sandstones. Overall, the appearance of this log, together with the total gamma-ray and the Th/U and Th/K logs, indicates that there is very little difference in the depositional environment between time of formation of the Kiowa Formation and the Cheyenne Sandstone. This supports the observations of Franks (1980) that the Cheyenne of southern Kansas is very similar to the Kiowa of central Kansas.

CONCLUSIONS

These results show that much useful information on lithologies and environments of deposition can be gained through an analysis of the spectral gamma-ray, lithodensity-neutron, and photoelectric absorption index logs of rock sequences. In this study, contrasts between marine and nonmarine Cretaceous environments in the central Kansas borehole are strongly indicated by the nature of the fluctuations in the Th/U log. This reflects the mobility of these elements under varying oxidation-reduction conditions, as well as sources for these elements. Variations in the concentrations of Th, U, and K also reflect environmental changes that occurred during the Greehhorn cycle. Comparison of Th/U ratio logs from the borehole in central Kansas with the ratio logs of outcrops and boreholes in Colorado and Utah show marked similarities. In the Lower Cretaceous Dakota Formation, several distinct sedimentary depositional packages have been delineated using the RHOMAA-UMAA and Th/U ratio logs. These packages appear to be related to periods of marine transgression and progradation by streams during the early development of the western interior Cretaceous basin.

REFERENCES CITED

Adams, J.A.S., and Weaver, C.E., 1958, Thorium to uranium ratios as indications of sedimentary processes: Example of concept of geochemical facies: American Association of Petroleum Geologists Bulletin, v. 42, p. 387–430.

Arthur, M.A., Dean, W.E., Pallastro, R.M., Claypool, G.E., and Scholle, P.A., 1985, Comparative geochemical and mineralogic studies of two cyclic and transgressive pelagic limestone units, Cretaceous Western Interior Basin, U.S.: Society of Economic Paleontologists and Mineralogists Field Trip Guidebook No. 4, p. 16–27.

Doveton, J.H., 1986, Log analysis of subsurface geology—Concepts and computer methods: New York, Wiley Interscience, 273 p.

Franks, P.C., 1979, Record of early marine transgression—Longford Member, Kiowa Formation: Kansas Geological Survey Bulletin 219, 55 p.

——1980, Models of marine transgression—Example from Lower Cretaceous fluvial and paralic deposits, north-central Kansas: Geology, v. 8, p. 55–61.

Glenister, L.M., and Kauffman, E.G., 1985, High-resolution stratigraphy and depositional history of the Greenhorn regressive hemicyclothem, Rock Canyon anticline, Pueblo, Colorado: Society of Economic Paleontologists and Mineralogists Field Trip Guidebook No. 4, p. 170–183.

Hassan, M., Hossin, A., and Combaz, A., 1976, Fundamentals of the differential gamma-ray log: Society of Professional Well Log Analysts Transactions, 17th Annual Logging Symposium, Paper H, 18 p.

Hattin, D.E., 1985, Distribution and significance of widespread, time-parallel pelagic limestone beds of the Greenhorn Limestone (Upper Cretacous) of the central Great Plains and southern Rocky Mountains: Society of Economic Paleontologists and Mineralogists Field Trip Guidebook No. 4, p. 28–37.

Hattin, D.E., and Siemers, C.T., 1987, Guidebook, Upper Cretaceous stratigraphy and depositional environments of western Kansas: Kansas Geological Survey Guidebook Series 3, 55 p. (reprinted with modifications).

Holdoway, K., 1978, Deposition of evaporites and red beds of the Nippewalla Group, Permian, western Kansas: Kansas Geological Survey Bulletin 215, 43 p.

James, G.W., 1972, Mineralogy and distribution of water-insoluble residues from AEC Test Hole 5 in Bayne, C.K., and Brinkley, D., eds., Geology, hydrology, thickness and quality of salt at three alternative sites for disposal of radioactive wastes in Kansas: University of Kansas Center for Research, Inc., p. 50–57.

Latta, B.F., 1946, Cretaceous stratigraphy of the Belvidere area, Kiowa County, Kansas: Kansas Geological Survey Bulletin 64, Part 6, p. 217–260.

McCall, D.C., and Gardner, J.S., 1982, Lithodensity log applications in the Michigan and Illinois basins: Society of Professional Well Log Analysts Transactions, Paper C, 21 p.

Merriam, D.F., Atkinson, W.R., Franks, P.C., Plummer, N., and Preston, F.W., 1959, Description of a Dakota (Cretaceous) core from Cheyenne County, Kansas: Kansas Geological Survey Bulletin 134, Part 1, 104 p.

Schlumberger, 1988, Log interpretation charts: New York, Schlumberger Limited, 150 p.

Scott, R.W., 1970, Stratigraphy and sedimentary environments of Lower Cretaceous rocks, southern western interior: American Association of Petroleum Geologists Bulletin 54, p. 1225–1244.

Siemers, C.T., 1976, Sedimentology of the Rocktown Channel sandstone, upper part of the Dakota Formation (Cretaceous), central Kansas: Journal of Sedimentary Petrology, v. 20, p. 97–123.

Swineford, A., 1955, Petrography of Upper Permian rocks in south-central Kansas: Kansas Geological Survey Bulletin 111, 179 p.

Vuke, S., 1981, Depositional environments of the Early Cretaceous seaway, northwestern United States: Northwestern Geology, v. 10, p. 1–112.

Zelt, F.B., 1985, Paleoceanographic events and lithologic/geochemical facies of the Greenhorn marine cycle (Upper Cretaceous) examined using natural gamma-ray spectrometry: Society of Economic Paleontologists and Mineralogists Field Trip Guidebook No. 4, p. 49–59.

7. Summary of USGS Open-File Report 95-209 by Dean et al., "Core descriptions and preliminary geochemical data for the Amoco Production Company, Rebecca Bounds #1 well, Greeley County, Kansas

U.S. DEPARTMENT OF THE INTERIOR

U.S. GEOLOGICAL SURVEY

CORE DESCRIPTIONS AND PRLIMINARY GEOCHEMICAL DATA FOR THE AMOCO PRODUCTION COMPANY
REBECCA K. BOUNDS #1 WELL, GREELEY COUNTY, KANSAS.

by

Walter E. Dean[1], Michael A. Arthur[2], Bradley B. Sageman[3], and Michael D. Lewan[4]

Open-File Report 95-209

[1] MS 939 Federal Center, Denver, CO 80225
[2] Department of Geosciences, Pennsylvania State University, University Park, PA 16802
[3] Department of Geological Sciences, Northwestern University, Evanston, IL 60201
[4] MS 977 Federal Center, Denver, CO 80225

1995

TABLE OF CONTENTS

ILLUSTRATIONS

INTRODUCTION

Background

The Cretaceous Western Interior Seaway Continental Scientific Drilling Project (WISK-DP) began in 1991 as a collaborative, multidisciplinary study of middle to Upper Cretaceous marine strata in the Utah-Colorado-Kansas corridor of the Western Interior Seaway. The project presently involves about two dozen researchers from the USGS, Amoco Production Company, and seven academic institutions. Objectives of the first phase of WISK-DP were to drill three holes or groups of holes, one in western Kansas, one in eastern Colorado, and one in eastern Utah. These states span the Cretaceous Western Interior Seaway that extended from the Gulf of Mexico north to the Arctic Ocean during maximum marine transgressions. (Figure 1). The first phase of the project was to focus on the two most extensive transgressive episodes in the seaway during the middle Cretaceous that resulted in deposition of two important organic-carbon-rich pelagic limestone units, the Cenomanian-Turonian Greenhorn Formation and Santonian-Campanian Niobrara Formation. An interdisciplinary team of researchers from government, academia, and industry would conduct biostratigraphic studies, paleoecologic studies, inorganic, organic and stable isotopic geochemical studies, mineralogical investigations, and high-resolution geophysical logging. Cores would provide the unweathered samples and continuous smooth exposures required for these studies.

Information for the eastern end of the transect was obtained from a hole that was drilled in 1988 and continuously cored (with better than 90% recovery) by Amoco Production Company in western Kansas (Amoco Rebecca K. Bounds #1, Greeley County, Kansas; Figure 2). Cores for the western end of the transect were obtained in 1991 when the USGS drilled and continuously cored (with better than 98% recovery) three holes in the Kaiparowits Basin of south central Utah (Fig. 2). These three cores, USGS CT-1-91, USGS SMP-1-91 , and USGS Escalante #1 (Figure 2) are presently archived in the USGS Core Research Center (USGS-CRC) in Denver. The third hole (USGS Portland #1; Fig. 2), was drilled by the USGS with DOE funding and continuously cored (with essentially 100% recovery) in Cretaceous strata in the Cañon City Basin near Florence, Colorado. The Portland core is also archived in the USGS-CRC, Denver. The purpose of this report is to present core descriptions and some preliminary geochemical data for the Amoco Bounds core.

Amoco Bounds Core

The Amoco Production Company, Rebecca K. Bounds #1 well was drilled in March of 1988 in Section 17, T18S, R4 2W, Greeley County, Kansas, to a total depth (TD) of 2645 feet (806 meters). Ground level elevation was 3824 feet (1166 meters). The hole was continuously cored from a depth of 522 feet (159 meters) to TD using Amoco's slim-hole high-speed advanced drilling system (SHADS) also known as stratigraphic high-speed advanced drilling system (Walker and Millheim, 1989; Randolph and Jourdan, 1991; Scott and others, 1993). Coring began in the middle of the Smoky Hill Member (Santonian) of the Niobrara Formation (Figures 3 and 4) and bottomed in the Mississippian. In January, 1992, the Cretaceous part of the Bounds core (522 -1495 feet; 159-456 meters) was released by Amoco and shipped to the USGS-CRC in Denver. The core was slabbed at the USGS-CRC, and a 2-cm-thick slab of the core is archived there. The archived slabs are stored in 1-m-long boxes, 3 m per box. This report contains visual core descriptions (Appendix I) of the core slabs from the Niobrara Formation to the top of the Dakota Sandstone (522-1115 feet; 159-340 meters; Figures 3 and 4).
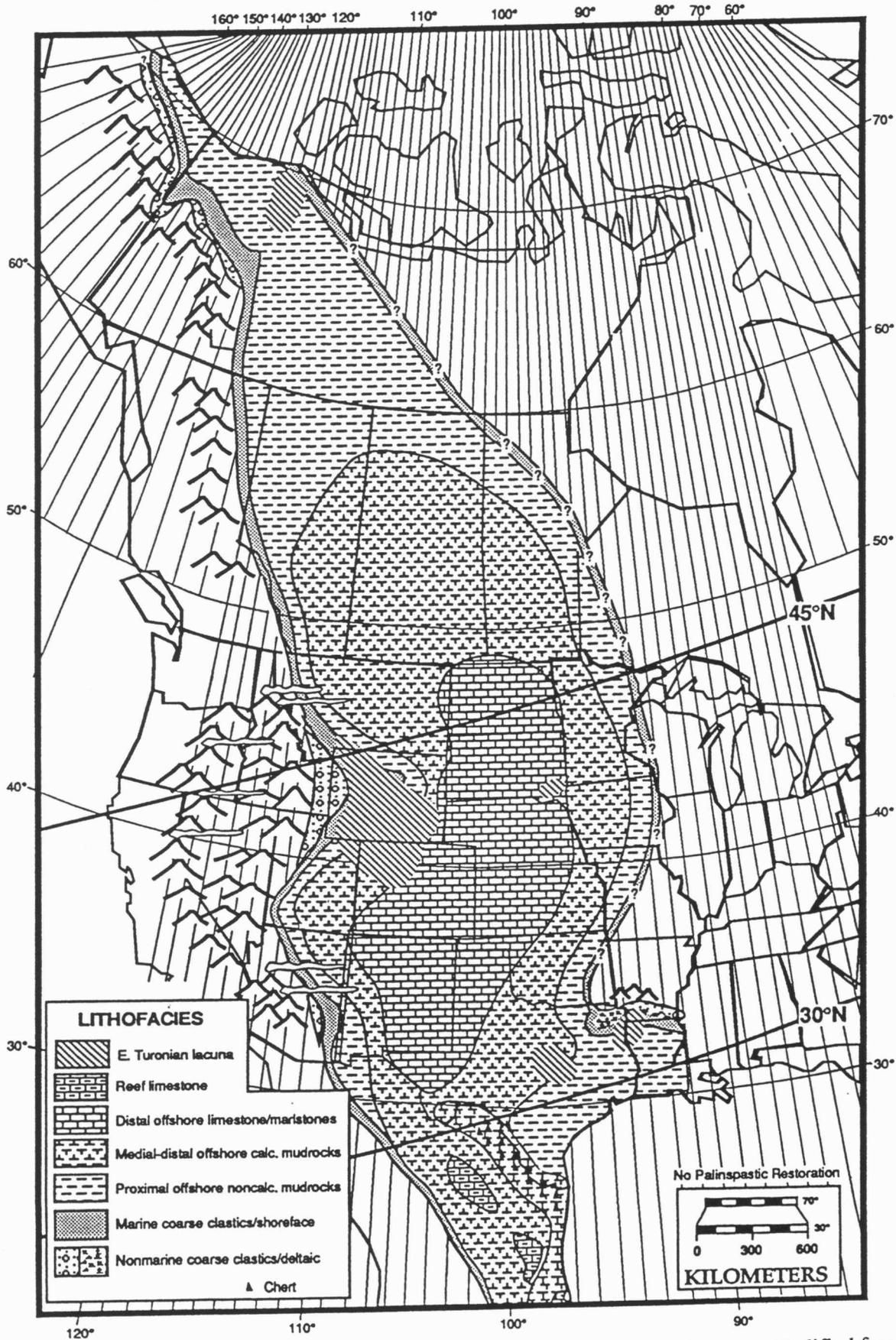
Figure 1. Lithofacies map for the early Turonian of the Western Interior Seaway. Modified from Arthur and Sageman, 1994.
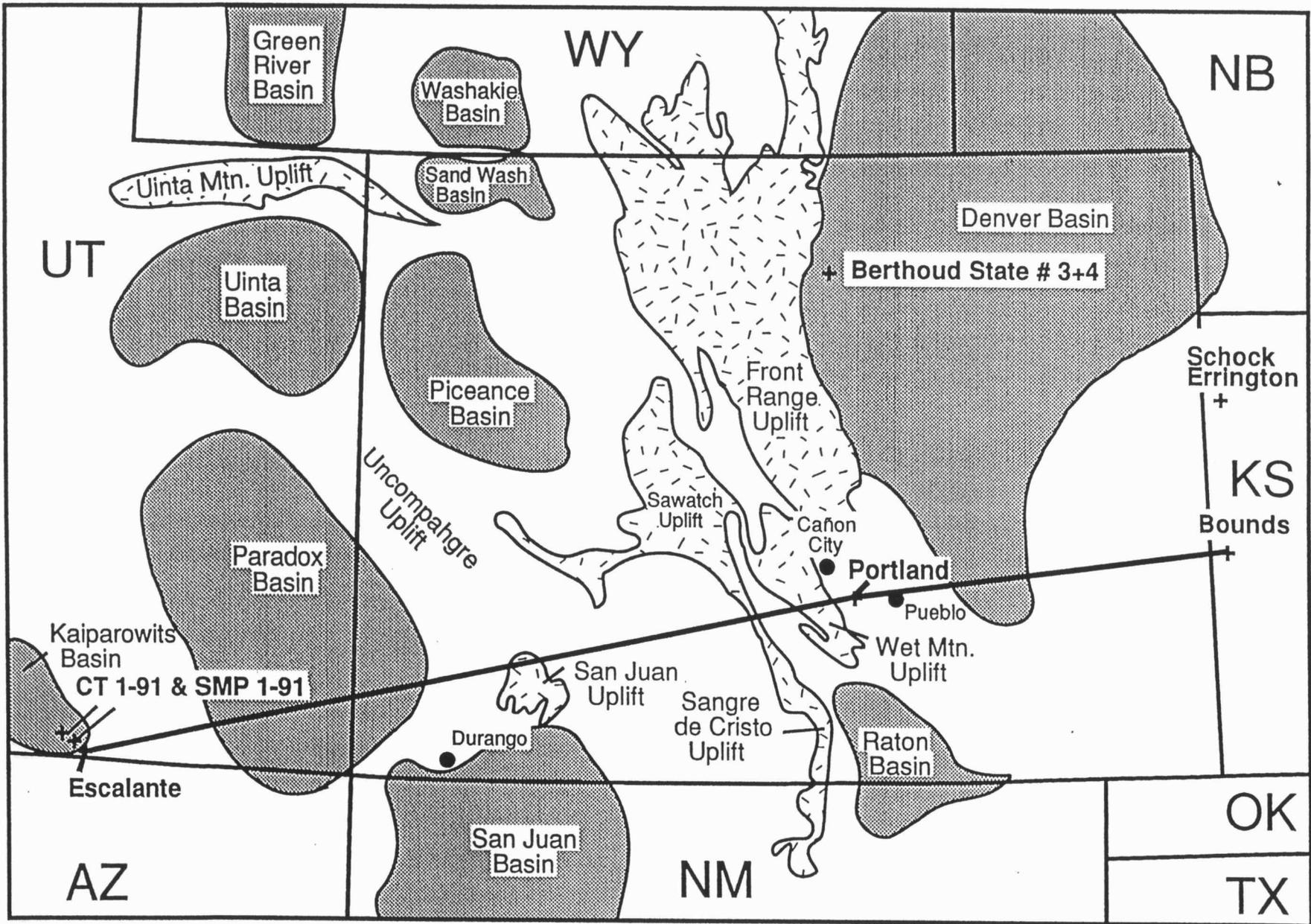
Figure 2. Map showing locations of major basins and uplifts in Colorado and adjacent states, and locations of existing cores that have been analyzed as part of the Cretaceous Western Interior Seaway Continental Scientific Drilling Project.

Amoco Rebecca K. Bounds #1 S17, T18S, R 42W, 38.1°N, 101.15°W
elev. 3824' (1166 m, relative to ground level)

Depth (feet)

Members

Formations

500

begin coring (522'; 159 m)

522

Smoky Hill
Chalk

Niobrara
Formation

600

593'
(180.7 m)

Fort Hays Limestone

675'
(205.7 m)

700

Codell Sandstone

755'
(230.1 m)

Blue Hill Shale

784'
(239 m)

800

Fairport
Chalky Shale

Carlile
Shale

900

905'
(275.8 m)

Bridge Creek Limestone

Greenhorn
Formation

1000

991'
(302 m)

Hartland Shale

1027'
(313 m)

Lincoln Limestone

1046'
(318.8 m)

XXXXXXXXXX   "X" Bentonite

Graneros Shale

1100

1115'
(339.8 m)

Dakota Sandstone

1200

Top Jurassic Morrison Formation @ 1495' (455.7 m)

Figure 3. Tops of formations and members from the Niobrara Formation to the top of the Dakota Sandstone in the Bounds core.

CRETACEOUS WESTERN INTERIOR SEAWAY TRANSECT
Amoco #1 Rebecca K. Bounds

							gamma-ray (API)

0 gamma-ray (API) 160

56 deep-laterolog (ohm-m) 0

Depth (m) (ft)	Stage	Formation	Member	Box no.	Lithology	Summary Description

Smoky Hill Chalk Member of the Niobrara Formation:

Interbedded MARLSTONE and MARLY LIMESTONE; beds mostly several tens of cm thick; marlstone; marly limestone more common below about 174 meters; occasional thin beds of bentonite (1-6 cm); common shell debris of *Inoceramus* and oysters; shell and fish debris increases below about 174 meters.

MARLSTONE: laminated to slightly bioturbated; olive gray to olive black.

MARLY LIMESTONE: slightly to moderately bioturbated with *Planolites*, *Chondrites*, and *Teichichnus* burrows; light olive gray to light gray.

Fort Hays Limestone Member of Niobrara Formation:

Interbedded LIMESTONE beds several tens of centimeters to over one meter thick and thin (several centimeters to, rarely, several tens of centimeters) MARLSTONE beds; occasional thin (1-2 cm) beds of bentonite.

LIMESTONE: very bioturbated with *Planolites*, *Teichichnus*, *Thalassinoides*, and *Zoophycos* burrows; very light gray to white.

MARLSTONE: slightly bioturbated; olive gray to light olive gray.

Codell Sandstone Member of Carlile Shale:

SANDSTONE (lithic arenite): medium grained; well sorted; very bioturbated with *Planolites*, *Chondrites*, and *Teichichnus* burrows; light olive gray to yellow gray; common dark flaser solution seams.

Stage column: SANTONIAN, CONIACIAN, MIDDLE TURONIAN, UPPER TURONIAN

Formation: Niobrara Formation, Carlile Sh

Member: Smoky Hill Chalk, Fort Hays Limestone, Codell Ss

Figure 4. Lithologic log of the Bounds core (modified from Scott and others, 1993) with descriptions for each member or formation summarized from the 100-cm descriptions in Appendix I..

7

CRETACEOUS WESTERN INTERIOR SEAWAY TRANSECT
Amoco #1 Rebecca K. Bounds

Codell Sandstone Member of Carlile Shale:

SANDSTONE (lithic arenite): medium grained; well sorted; very bioturbated with *Planolites, Chondrites,* and *Teichichnus* burrows; light olive gray to yellow gray; common dark flaser solution seams.

Blue Hill Shale Member of Carlile Shale:

MUDSTONE: fissile; moderately to poorly laminated with some recognizable burrows; olive gray to olive black; occasional thin (mostly <10 cm) beds of bioturbated siltstone.

Fairport Chalky Shale Member of Carlile Formation:

MARLSTONE: moderately to well laminated; no recognizable trace fossils; olive black; fecal pellets in discrete zones increase downward; occasional thin (several centimeters) beds of bentonite; several thin (<10 cm) calcarenite layers composed mostly of *Inoceramus* and oyster debris.

Figure 4 (cont.)

CRETACEOUS WESTERN INTERIOR SEAWAY TRANSECT
Amoco #1 Rebecca K. Bounds

Depth (m)	(ft)	Stage	Formation	Member	Box no.	Lithology	Summary Description

0   gamma-ray (API)   160

56 deep-laterolog (ohm-m) 0

Fairport Chalky Shale Member of Carlile Formation:

MARLSTONE: moderately to well laminated; no recognizable trace fossils; olive black; fecal pellets in discrete zones increase downward; occasional thin (several centimeters) beds of bentonite; several thin (<10 cm) calcarenite layers composed mostly of *Inoceramus* and oyster debris.

Bridge Creek Limestone Mbr. of Greenhorn Formation:

Dominant lithology is MARLSTONE with interbedded MARLY LIMESTONE and CALCARENITE (275.8 to 289.6 m) with well-developed cycles of MARLSTONE and LIMESTONE below 289.6 m.

MARLSTONE: moderately to well laminated; no apparent burrows; olive gray.

MARLY LIMESTONE: faintly laminated; no apparent burrows; light olive gray.

LIMESTONE: very bioturbated with small to large burrows, mostly *Planolites* and *Chondrites*; very light gray to white with darker burrow fill

CALCARENITES: several cm to several 10's of cm thick; mostly homogeneous with no apparent burrows; composed of fecal pellets, *Inoceramus* fragments, and unrecognizable calcareous fragments; light olive gray.

Hartland Shale Member of Greenhorn Formation:

MARLSTONE to CALCAREOUS CLAYSTONE: well laminated with no recognizable burrows; olive gray to olive black; common fragments of *Inoceramus*; occasional layers of bentonite; Marlstone/claystone is interbedded with thin beds of CALCARENITE composed predominantly of fecal pellets, shell fragments, and forams; homogeneous to poorly laminated; no recognizable burrows; very light gray.

Stage column: MIDDLE TURONIAN / LOWER TURONIAN / UPPER CENOMANIAN

Formation column: Carlile Shale / Greenhorn Formation

Member column: Fairport Chalky Shale / Bridge Creek Limestone / Hartland Shale

Box no.: 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48

Depth markers: 260, 270, 900, 280, 290, 950, 300, 1000, 310

Figure 4 (cont.)

9

CRETACEOUS WESTERN INTERIOR SEAWAY TRANSECT
Amoco #1 Rebecca K. Bounds

0   gamma-ray (API)   160

56   deep-laterolog (ohm-m)   0

Depth (m)	Depth (ft)	Stage	Formation	Member	Box no.	Lithology	Summary Description

Depth (m): 310, 320, 330, 340, 350, 360
Depth (ft): 1050, 1100, 1150

Stage: UPPER CEN. / MIDDLE CENOMANIAN

Formation: Greenhorn Fm. / Graneros Shale / Dakota ("Muddy") Sandstone

Member: Hartland Sh. / Lincoln Ls.

Box no.: 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64

Hartland Shale Member of Greenhorn Formation

Lincoln Limestone Member of Greenhorn Formation:

CALCAREOUS MUDSTONE: upper (1 meter) well laminated with concentrations of fecal pellets and forams in laminae and in thin beds of CALCARENITE; both lithologies are olive black to olive gray; below (314 meters) CALCAREOUS MUDSTONE; mostly homogeneous with much fewer laminae; no recognizable burrows; olive black to olive gray; occasional layers of bentonite.

Graneros Shale:

Dominant lithology from 318.8 to 330 meters is CALCAREOUS MUDSTONE; homogeneous to poorly laminated; no visible burrows; olive black; 330 to 331 meters is the THATCHER LIMESTONE MBR.; irregularly laminated to banded; small horizontal burrows but most with no burrows; light gray; 330.7 to 331.0 m is CALCAREOUS CLAYSTONE like lithology above Thatcher, (331 to 339.8 m) is MUDSTONE; noncalcareous; homogeneous to poorly laminated; no visible burrows; olive black; 7-cm-thick sandstone bed at 333.1 m and 9-cm-thick sandstone bed at 339.2 m; occasional layers of bentonite.

Dakota Sandstone:

(description only to 343.2 m)

"Muddy" or "J" SANDSTONE in the Denver Basin; very fine grained with a few muddy stringers; homogeneous to moderately bioturbated with small burrows; very light gray to yellowish gray.

Figure 4 (cont.)

CRETACEOUS WESTERN INTERIOR SEAWAY TRANSECT
Amoco #1 Rebecca K. Bounds

Depth (m) / Depth (ft) | Stage | Formation | Member | Box no. | Lithology | Summary Description

0   gamma-ray (API)   160

56 deep-laterolog (ohm-m) 0

Dakota Sandstone:

(description only to 343.2 m)

"Muddy" or "J" SANDSTONE in the Denver Basin; very fine grained with a few muddy stringers; homogeneous to moderately bioturbated with small burrows; very light gray to yellowish gray.

Glencairn Shale Member of Purgatoire Formation

LATE ALBIAN

Dakota ("Muddy") Sandstone

Purgatoire Formation — Glencairn Shale

Figure 4 (cont.)

11

CRETACEOUS WESTERN INTERIOR SEAWAY TRANSECT
Amoco #1 Rebecca K. Bounds

Figure 4 (cont.)

EXPLANATION
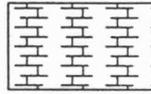
	Limestone
	Marly Limestone
	Marlstone
	Calcareous Mudstone
	Shale or Mudstone
	Sandstone
	Bentonite
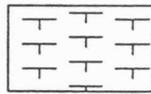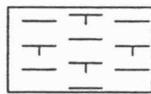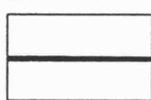
Figure 4 (cont.)

8. Figures from "Kansas Oil and Gas Production Trends 1995" by Tim Carr and Doug Beene, Kansas Geological Survey, Open-File Report 95-42

Kansas Oil and Gas Production Trends 1995   8.

Kansas Geological Survey Open-File Report 95-42

Tim Carr and Doug Beene

This report serves as a continuation of earlier reports on production trends in the Kansas oil and gas industry (Carr, 1994a &b). Data are derived from the files of the Kansas Geological Survey, which are maintained by Doug Beene, from the publications and on-line data of the Energy Information Agency, and from various published sources. This report updates and supplements information provided in previous reports.

These questions will be addressed in the report.
> What is the value of oil and gas production to Kansas?
> How important is oil versus gas production in Kansas?
> How important are oil and gas production to state and county tax revenues?
> What are the important stratigraphic horizons that produce oil and gas in Kansas?
> What is the geographic distribution of oil and gas production in Kansas?
> What is happening in Kansas oil and gas production?

Figure 1

Kansas Production--Value of crops vs. value of oil and gas

KANSAS PRODUCTION
Crops and Oil & Gas
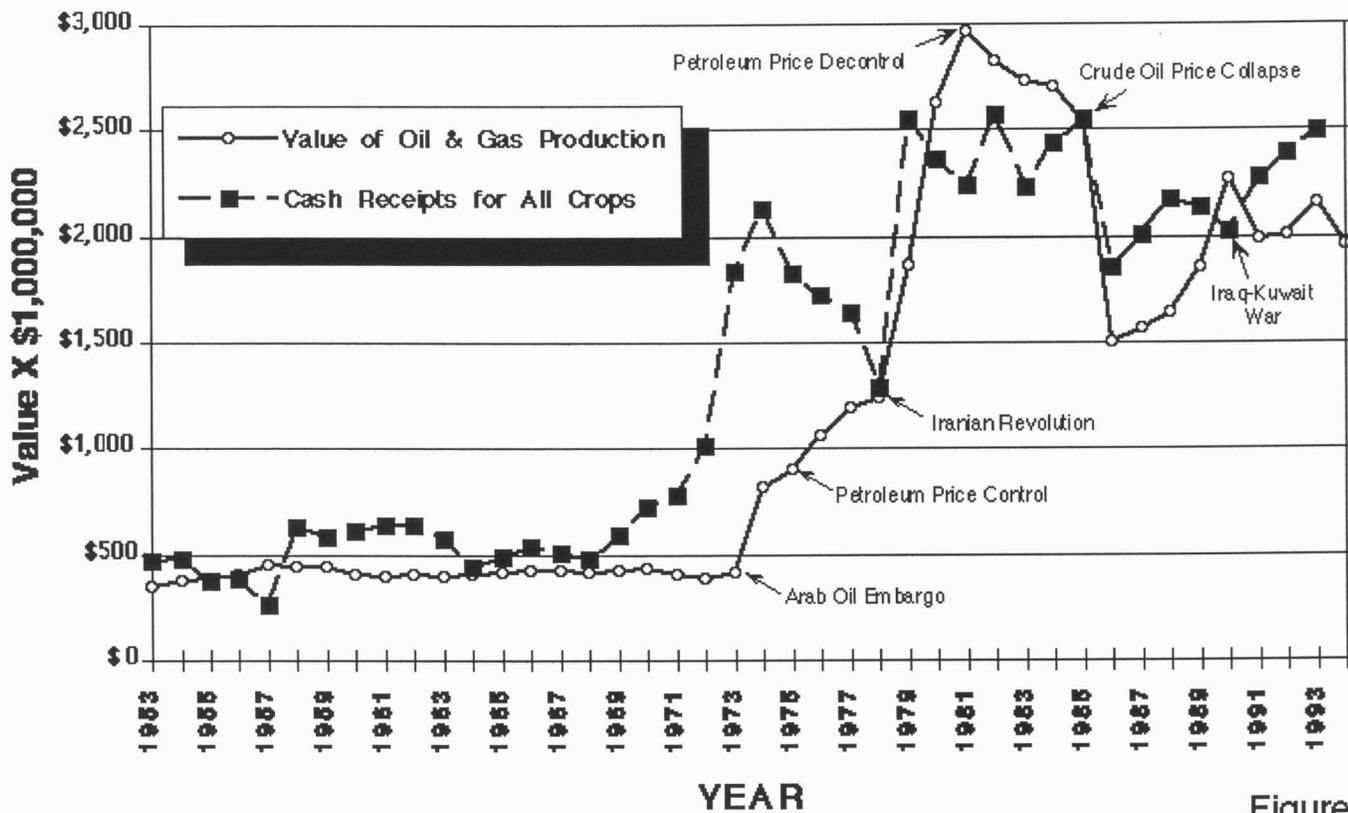
Figure 1

Figure 2

Value of Kansas oil and gas
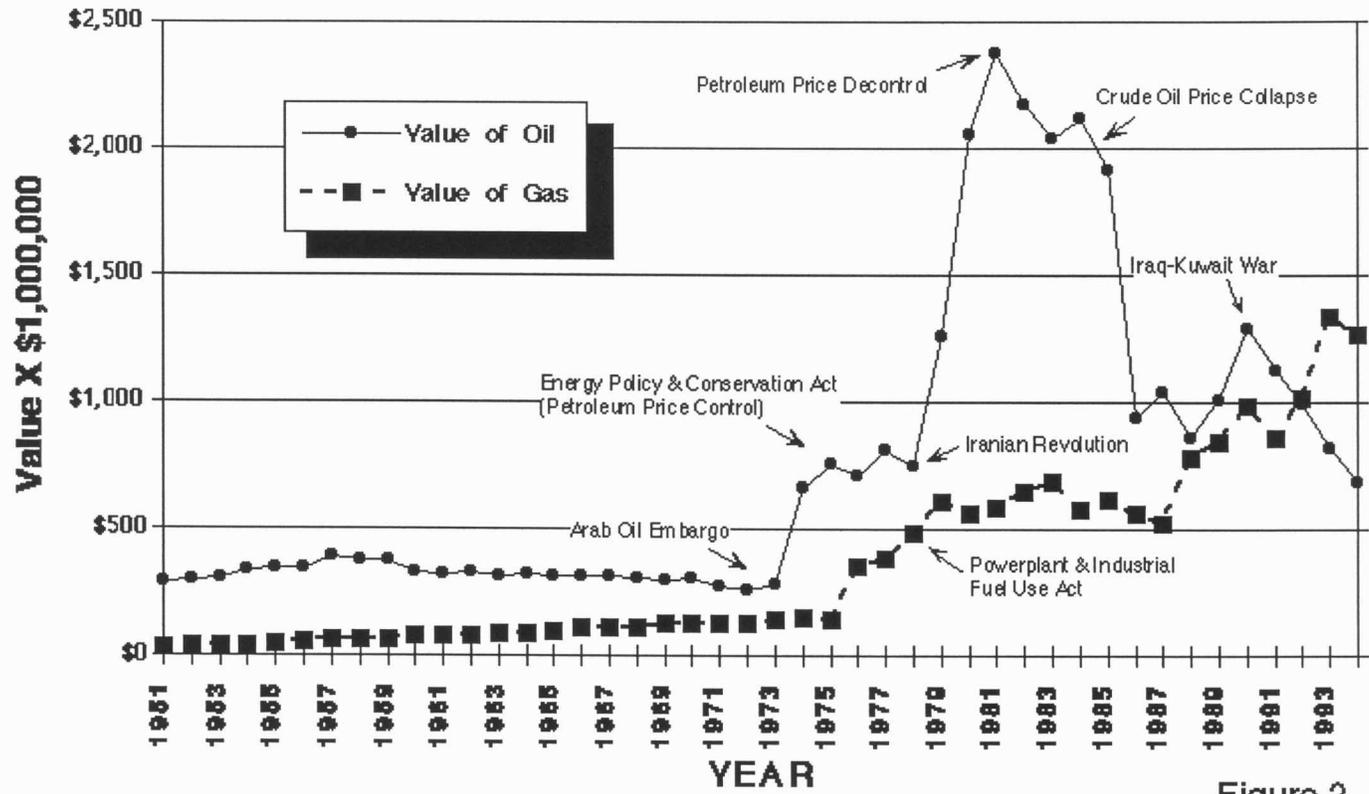

KANSAS PRODUCTION
Oil & Gas

Figure 2

Figure 3

Amount of production of Kansas oil (millions of barrels) and gas (billions of cubic feet).
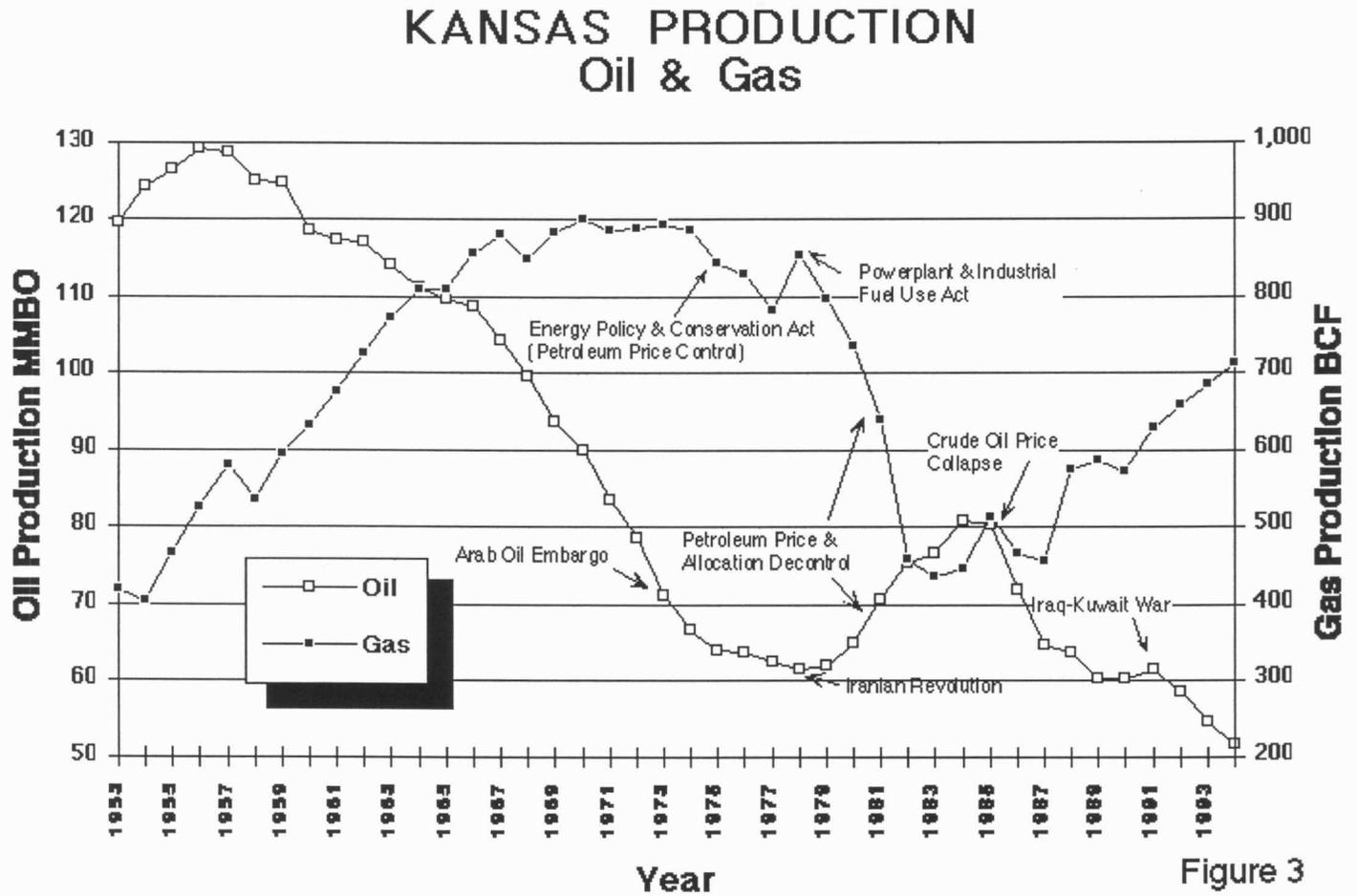

KANSAS PRODUCTION
Oil & Gas

Figure 3

Figure 4

Gas production (billions of cubic feet) and number of wells in the Hugoton Gas Field.
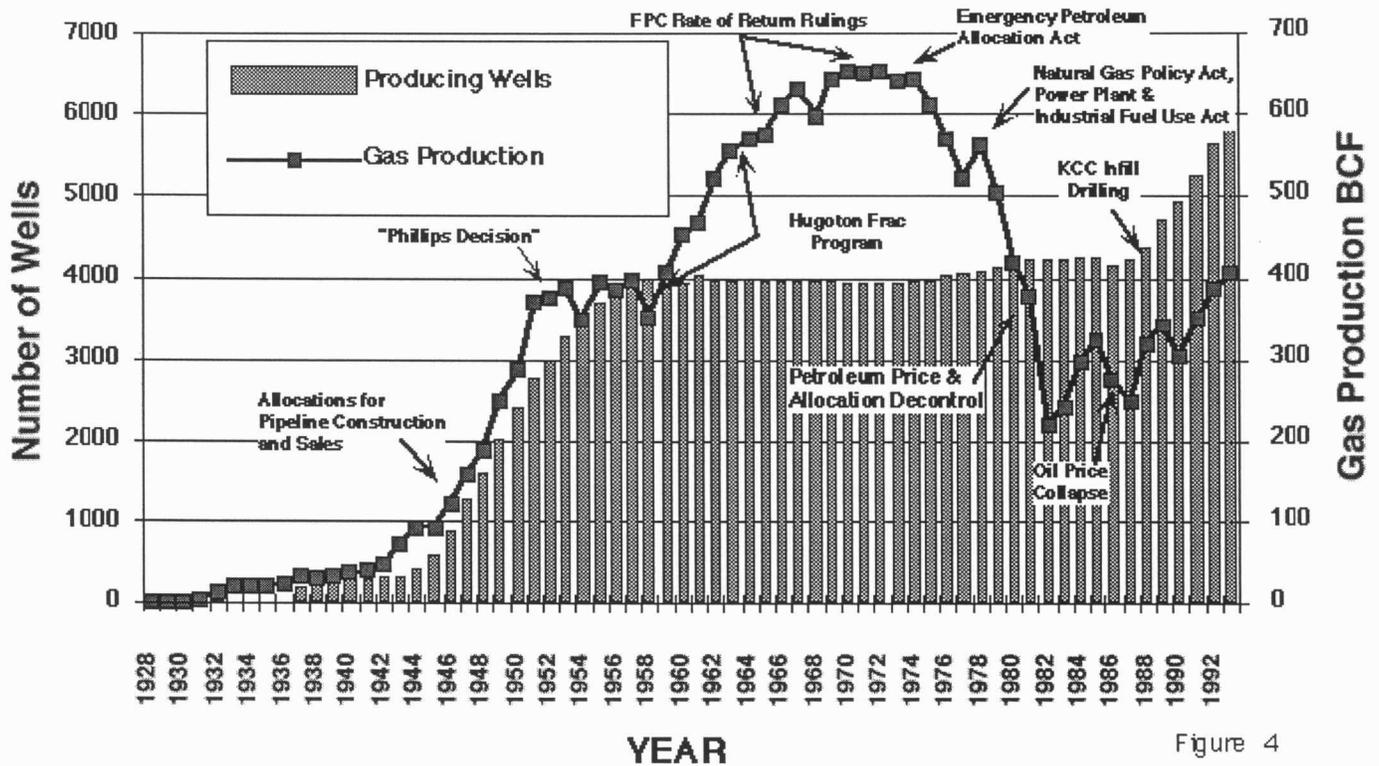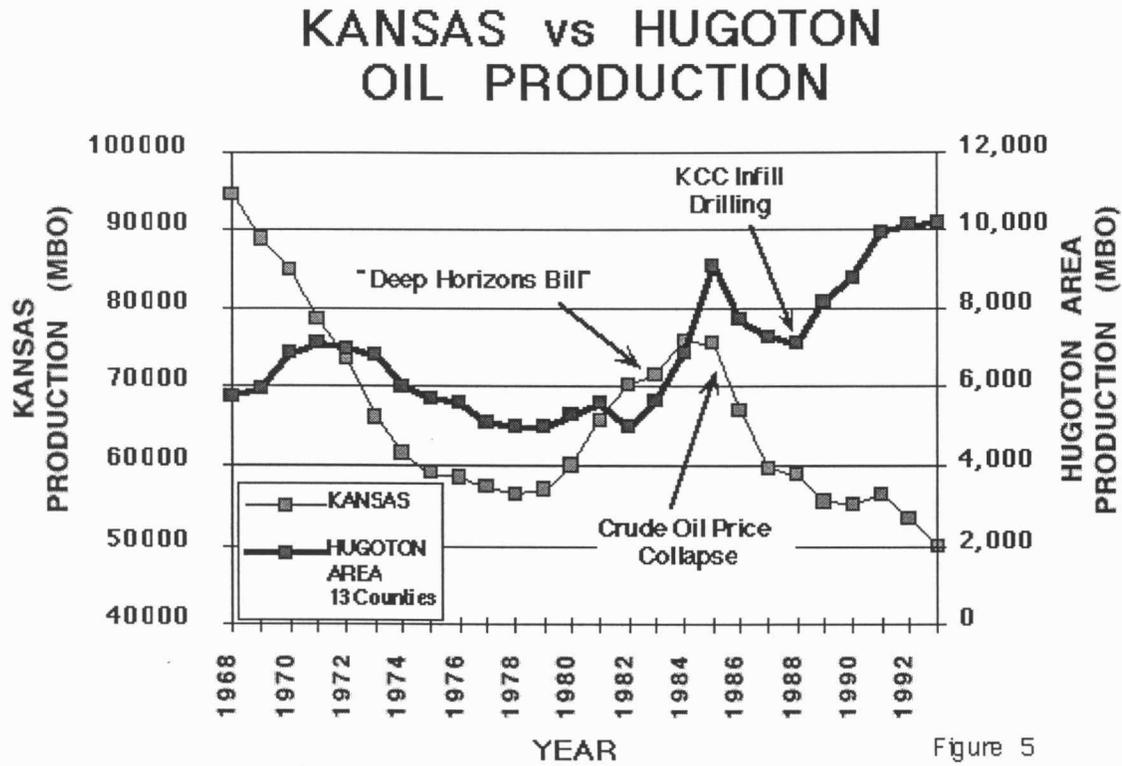
Figure 5

Kansas vs. Hugoton oil production.
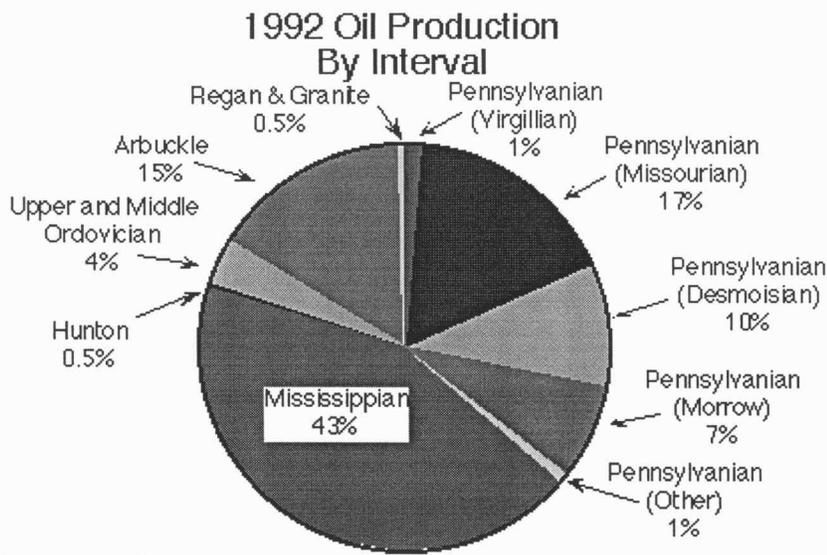

Figure 5

Figure 6

Oil production by stratigraphic interval.

Figure 6

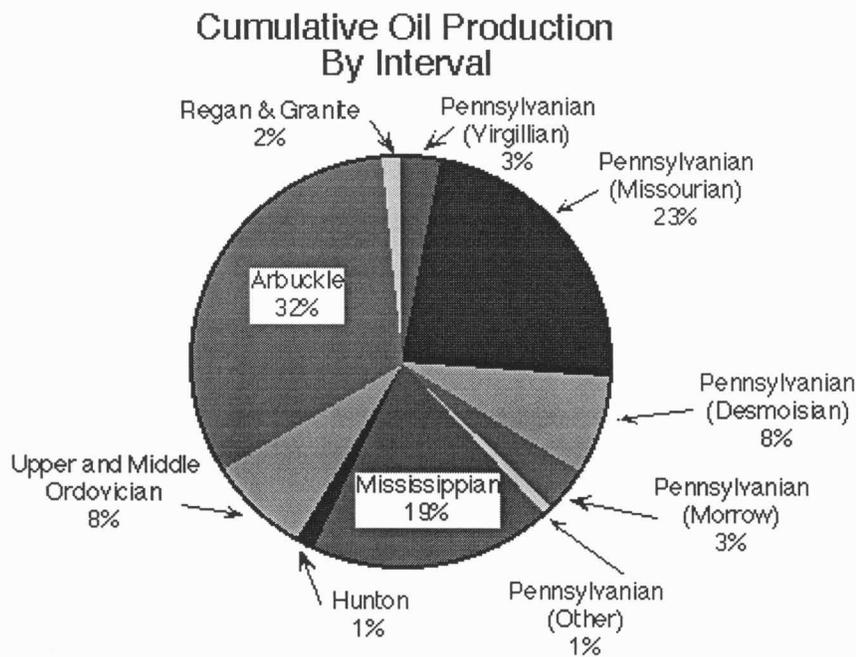# Figure 7

Gas production by stratigraphic interval.

1992 Annual Gas Production By Interval

Pennsylvanian (Morrow) 9%

Mississippian 6%

Pennsylvanian (Missourian) 1%

Pennsylvanian (Desmoisian) 1%

Pennsylvanian (Virgillian) 2%

Permian 79%

Figure 7

1992 Production 649 BCF

Cumulative Gas Production By Interval

Pennsylvanian (Morrow) 9%

Pennsylvanian (Desmoisian) 1%

Mississippian 2%

Pennsylvanian (Missourian) 1%

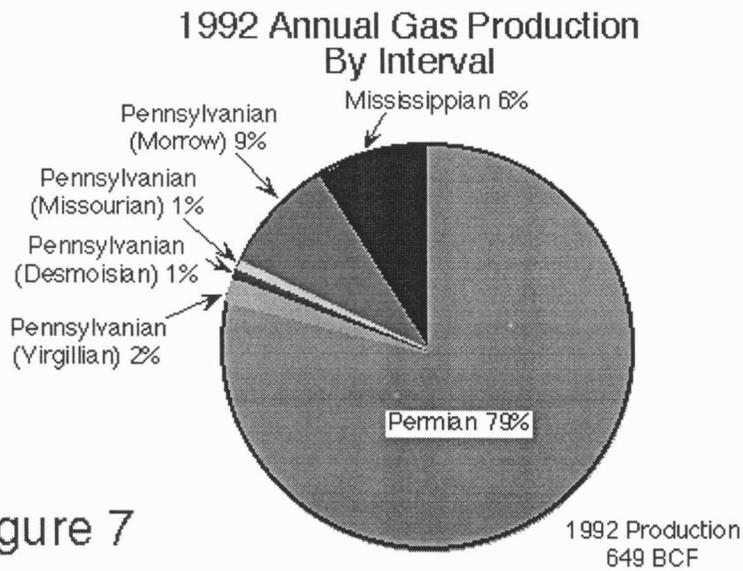Pennsylvanian (Virgillian) 2%

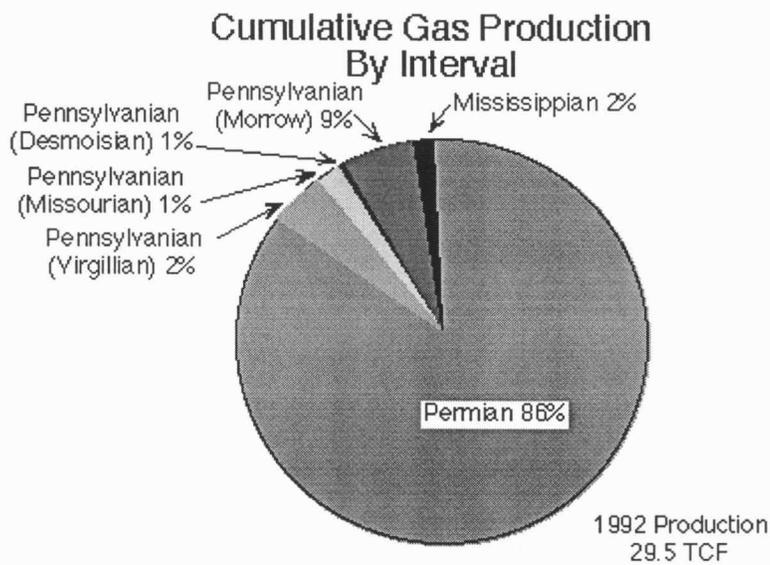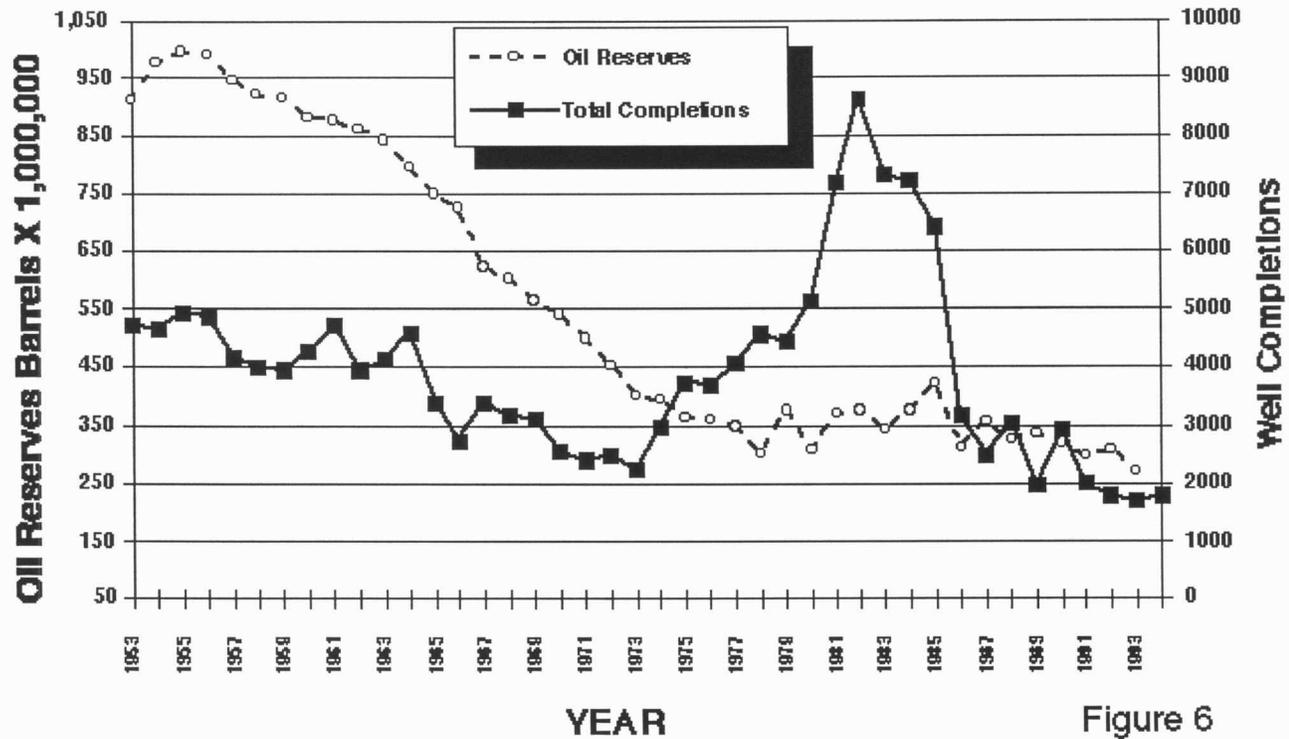Permian 86%

1992 Production 29.5 TCF

Figure 8

Kansas Reserves and Well Completions

KANSAS Reserves and Completions

9. Statistics on gas fields in Kansas that produce from the Niobrara Formation

Field(s) Found

9.

Your request has been processed:

3 hits have(has) been found!

Start a New Search

Field[1]:**CHERRY CREEK**

- **Cum. Oil**:199663 **Cum. Gas**:2279015 **Total Active Well**:UNKNOWN
- **Trap Type**:UNKNOWN **Field Acres**:UNKNOWN
- **RTD**:4460 **Disc. Date**:1976
- **Township:** (1)2S(2)3S(3)4S(4)5S
- **Range:** (1)40W(2)41W(3)42W
- **Reservoir:** (1)NIOBRARA
- **Lithology:** (1)CARBONATE
- **Geology Age:** (1)CRETACEOUS(2)PENNSYLVANIAN
- **County:** (1)CHEYENNE

Field[2]:**CHERRY CREEK NIOBRAR**

- **Cum. Oil**:0 **Cum. Gas**:3028874 **Total Active Well**:UNKNOWN
- **Trap Type**:UNKNOWN **Field Acres**:UNKNOWN
- **RTD**:UNKNOWN **Disc. Date**:UNKNOWN
- **Township:** (1)2S(2)3S(3)4S(4)5S
- **Range:** (1)39W(2)40W(3)41W(4)42W
- **Reservoir:** (1)NIOBRARA
- **Lithology:** (1)UNKNOWN(2)CARBONATE
- **Geology Age:** (1)UNKNOWN(2)CRETACEOUS
- **County:** (1)CHEYENNE

Field[3]:**GOODLAND NIOBRARA GA**

- **Cum. Oil**:0 **Cum. Gas**:4426842 **Total Active Well**:UNKNOWN
- **Trap Type**:UNKNOWN **Field Acres**:UNKNOWN
- **RTD**:UNKNOWN **Disc. Date**:UNKNOWN
- **Township:** (1)7S(2)8S
- **Range:** (1)38W(2)39W(3)40W
- **Reservoir:** (1)NIOBRARA
- **Lithology:** (1)CARBONATE
- **Geology Age:** (1)CRETACEOUS
- **County:** (1)SHERMAN