STRATIGRAPHY AND DEPOSITIONAL HISTORY OF THE KEARNY FORMATION (LOWER PENNSYLVANIAN) IN WESTERN KANSAS

by

Dean A. McManus
B.S., Southern Methodist University, 1954
M.S., University of Kansas, 1956

Submitted to the Department of Geology and the Faculty of the Graduate School of the University of Kansas in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

Advisory Committee:

R. C. Moore
Chairman

Edward [illegible]

[illegible]

September 1959

TABLE OF CONTENTS

	Page
ABSTRACT	1
INTRODUCTION	4
Purpose of investigation	4
Location of area	5
Previous work	8
Stratigraphic nomenclature	10
Acknowledgements	14
STRATIGRAPHY	15
Mississippian rocks	15
Kearny Formation	19
Lower member	20
Distribution and thickness	20
Lithology and paleontology	22
Upper contact	35
Upper member	36
Distribution and thickness	36
Lithology and paleontology	37
Upper contact	48
Atokan rocks	49
Regional summary of the Kearny Formation	50
SEDIMENTOLOGIC REFLECTION OF ENVIRONMENTAL PARAMETERS	58
Limestones	60

Biosparite 61
Oösparite. 68
Intrasparite 70
Micrite. 73
Biomicrite 76
Quartzose calcarenite. 76
Sandstones. 77
Subgraywacke 78
Feldspathic sandstone. 82
Argillaceous sandstone 83
Micaceous siltstone. 84
Shales. 85
Unfossiliferous, dark, thinly-laminated shale. 86
Fossiliferous, dark, thinly-laminated shale. 87
Arenaceous shale 89
Reddish-brown, blocky shale. 90
Coal. 90
Summary 91
AGE AND DEPOSITIONAL HISTORY 95
Tectonic framework. 95
Deposition of Mississippian rocks 96
Morrowan-Mississippian boundary 97
Deposition of Kearny Formation. 102
Lower member 103

Upper member 112

Conclusions. 120

Atokan-Morrowan boundary. 129

Deposition of Atokan rocks. 131

CONCLUSIONS. 132

REFERENCES 137

APPENDIX -- TYPICAL SECTIONS OF MEMBERS OF KEARNY FORMATION 144

LIST OF ILLUSTRATIONS

Plate		Page
1.	Structure contour map on top of Mississippian rocks.	pocket
2.	Isopachous map of lower member of Kearny Formation	pocket
3.	Sand-shale ratio map of lower member of Kearny Formation.	pocket
4.	Isopachous map of upper member of Kearny Formation	pocket
5.	Sand-shale ratio map of upper member of Kearny Formation.	pocket
6.	(A) Regional stratigraphic cross section F-D, Sherman County to Thomas County; (B) Regional stratigraphic cross section I-H, Meade County to Gray County	pocket
7.	Sand-shale ratio map of Kearny Formation.	pocket
8.	Isopachous map of Kearny Formation. . .	pocket
9.	Sand-shale ratio map of lower transgressive part of Kearny Formation.	pocket
10.	Lithofacies map of Kearny Formation . .	pocket
11.	Regional stratigraphic cross section A-A', Morton County to Cheyenne County	pocket

12. (A) Regional stratigraphic cross section A-B, Morton County to Clark County; (B) Regional stratigraphic cross section G-H, Hamilton County to Gray County. . . . . pocket

13. Structure contour map on top of Kearny Formation . . . . . pocket

14. (A) Structural cross section C-J, Seward County to Thomas County; (B) Structural cross section A-E, Morton County to Finney County . . pocket

Figure

1. Map of major tectonic features in western Midcontinent 6

2. Index map showing location of cross sections 7

3. Example of diverse nomenclature for pre-Cherokee rocks 12

4. Photomicrograph of crinoidal molluscoid calcarenite. 63

5. Photomicrograph of allochems. 63

6. Photomicrograph of crinoidal calcarenite. 66

7. Biosparite variation. 68

8. Photomicrograph of algal oösparite. . . 71
9. Photomicrograph of microcrystalline limestone. 71
10. Photomicrograph of micrite. 74
11. Photomicrograph of fine-grained sandstone. 74
12. Photomicrograph of coarse-grained sandstone. 81
13. Generalized section with representative genera 99
14. Generalized cross section through Anadarko Basin 102
15. Typical section of lower member 145
16. Typical section of upper member 147

ABSTRACT

Interpretation of subsurface data from over 700 wells in western Kansas forms the basis for a discussion of the stratigraphic composition and depositional history of the Lower Pennsylvanian Kearny Formation. The stratigraphic description includes an expression of the transitional and transgressive nature of the formation which oversteps progressively older Mississippian rocks to the north and contains overlapping units. The Kearny thickens southward to several hundred feet in the Anadarko Basin and thins on the flanks of the Keyes Dome and Central Kansas Uplift.

Two unnamed members are recognized, each composed mainly of shale, but the lower, thinner, and less extensive one contains local thick sandstone bodies and a culminating clastic limestone phase. The thin, overlapping part of the upper member contains similar clastics reflecting a high energy-level, but the thicker development consists mainly of dark shales with some intercalated coal beds and elongate sandstone bodies. The section is poorly fossiliferous, but associated with the limestones is a crinoid-molluscoid element. Contacts of the formation are relatively distinct except along the wedge edge of the eastern margin, and in the deeper part of the Hugoton Embayment where upper Chesteran rocks are present.

Sediments of the formation are placed in five lithologic classes: 1) microcrystalline limestones, 2) allochemical limestones, 3) chemical-matrix sandstones, 4) detrital-matrix sandstones, and 5) clay rocks. Each class reflects levels of energy in the environment and degree of influence by extrabasinal factors. The lower member is characterized by the second and third classes, the upper one by the first and fifth.

The depositional history of the formation indicates that moderate diastrophism in adjacent areas ushered in the Kearny sea with its deltaic, littoral, and sublittoral environments. Channel sandstones and deltaic deposits were formed near the Central Kansas Uplift and Keyes Dome. A clear-water, open environment of extensive limestone formation was followed by continued northward advancement of the sea and increased subsidence of the Anadarko Basin, producing a paralic domain dominated by lagoonal environments with offshore bars and with periodic invasions of restricted marine, euxinic, and paludal deposits. A rhythmic alternation of deposits is suggested, but a cyclic repetition is not demonstrated. Toward the end of Kearny time the northeastern shoreline lay well up on the flank of the land mass formed by the Central Kansas Uplift and extended into Nebraska and eastern Colorado. Final retreat of the sea produced an extensive paralic coal basin. Middle Atokan deposition is marked by little disturbance

of the underlying sediments, although adjacent regions were effected by diastrophism.

Several sand-shale ratio maps are included with isopachous maps, structural contour maps, and regional cross sections. Descriptions of typical sections of the Kearny members are appended.

INTRODUCTION

Purpose of Investigation

Stratigraphic studies of the outcropping Pennsylvanian rocks in eastern Kansas have been carried on for many years, and the westward subsurface continuation of the Cherokee Group and younger Pennsylvanian rocks from the outcrop belts in eastern Kansas has been recognized for some time. The subsurface deposits of the western part of the state, however, have received attention only within the last thirty years, and only recently has emphasis been placed on the lower part of the Pennsylvanian sequence. Also within the past few years the number of deep wells in the area has increased to the point where adequate control is available for a regional study.

The Kearny Formation of Pennsylvanian age represents the lower part of the sequence occupying the stratigraphic interval between the Mississippian rocks and the Cherokee Group in western Kansas. A variety of rock types, ranging from coal to fossiliferous limestone, comprises the formation, and forms a stratigraphically complex succession that ranges in thickness from a featheredge to more than 500 feet. Previous workers have briefly discussed the occurrence and composition of the formation, but have only mentioned the structural relations to bounding unconformities or the

facies changes within the unit. The Kearny Formation serves as an excellent example for the stratigraphic and paleoecologic study of a transitional and transgressive unit.

The purpose of this report is to describe the Kearny Formation on a regional basis with sufficient detail to enable the reconstruction of depositional environments, to recognize any persistent subdivisions within the unit and correlate them throughout the area, to determine the temporal relationship with the superjacent and subjacent deposits, and to interpret the tectonic significance of the unit. It is hoped that this study will represent the beginning of regional interpretation of the Lower and Middle Pennsylvanian rocks in the Hugoton Embayment. Also, this report can serve as a basis for interrelating the isolated sandstone reservoirs of oil and natural gas in the formation.

Location of Area

The report deals with the Kearny Formation in the northeastern part of the Hugoton Embayment of the Anadarko Basin (Fig. 1). To the east of the area are the Pratt Anticline and Central Kansas Uplift, and to the west is the Las Animas Arch. The Keyes Dome is located at the southwest corner of the region, and to the southeast the area adjoins the Northwest Oklahoma Platform. A spur axis from the Anadarko Basin crosses the southwestern part of the region as the axis of the Embayment.

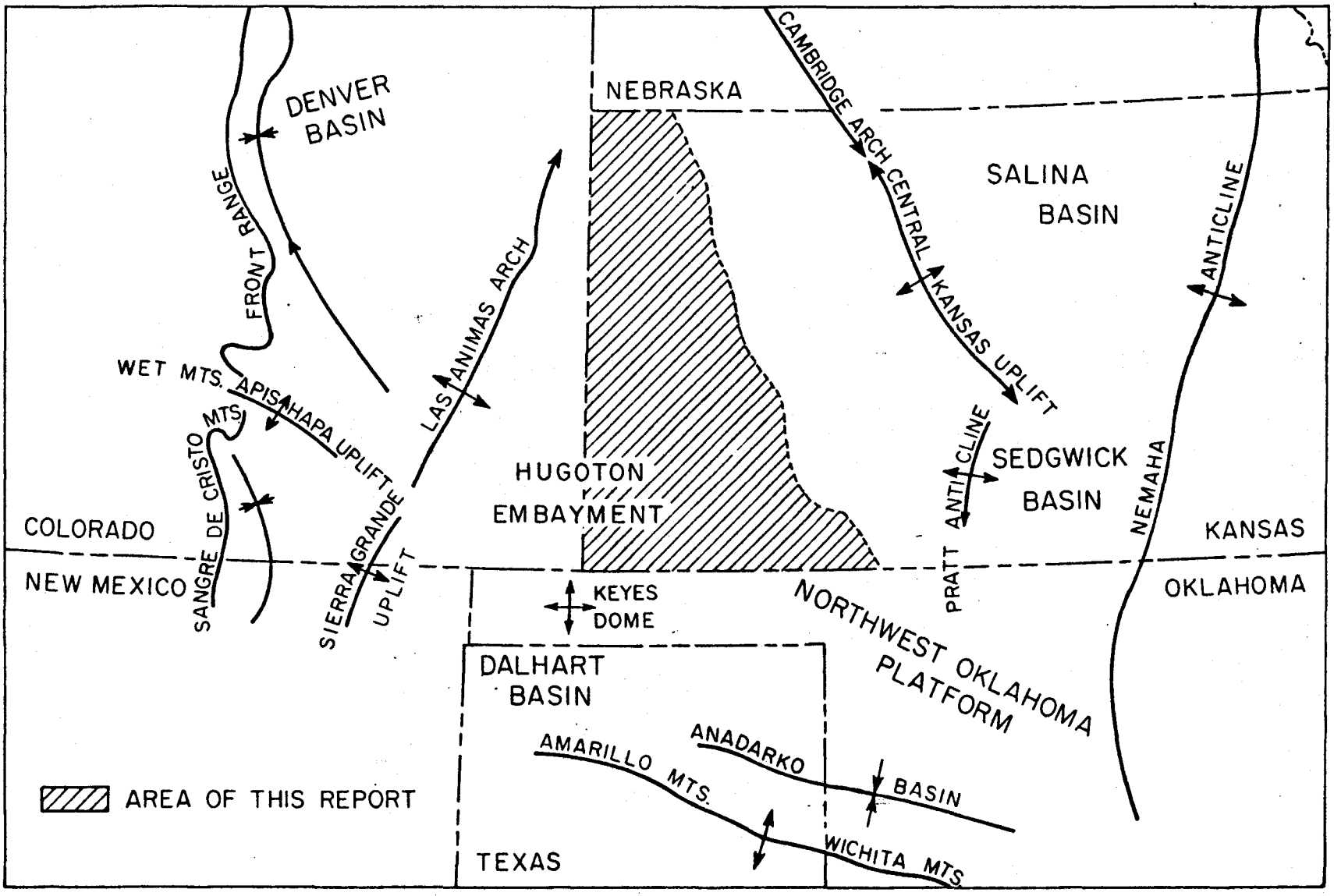


FIG. 1. Relation of area to major tectonic features in western Midcontinent (after Merriam, 1955).

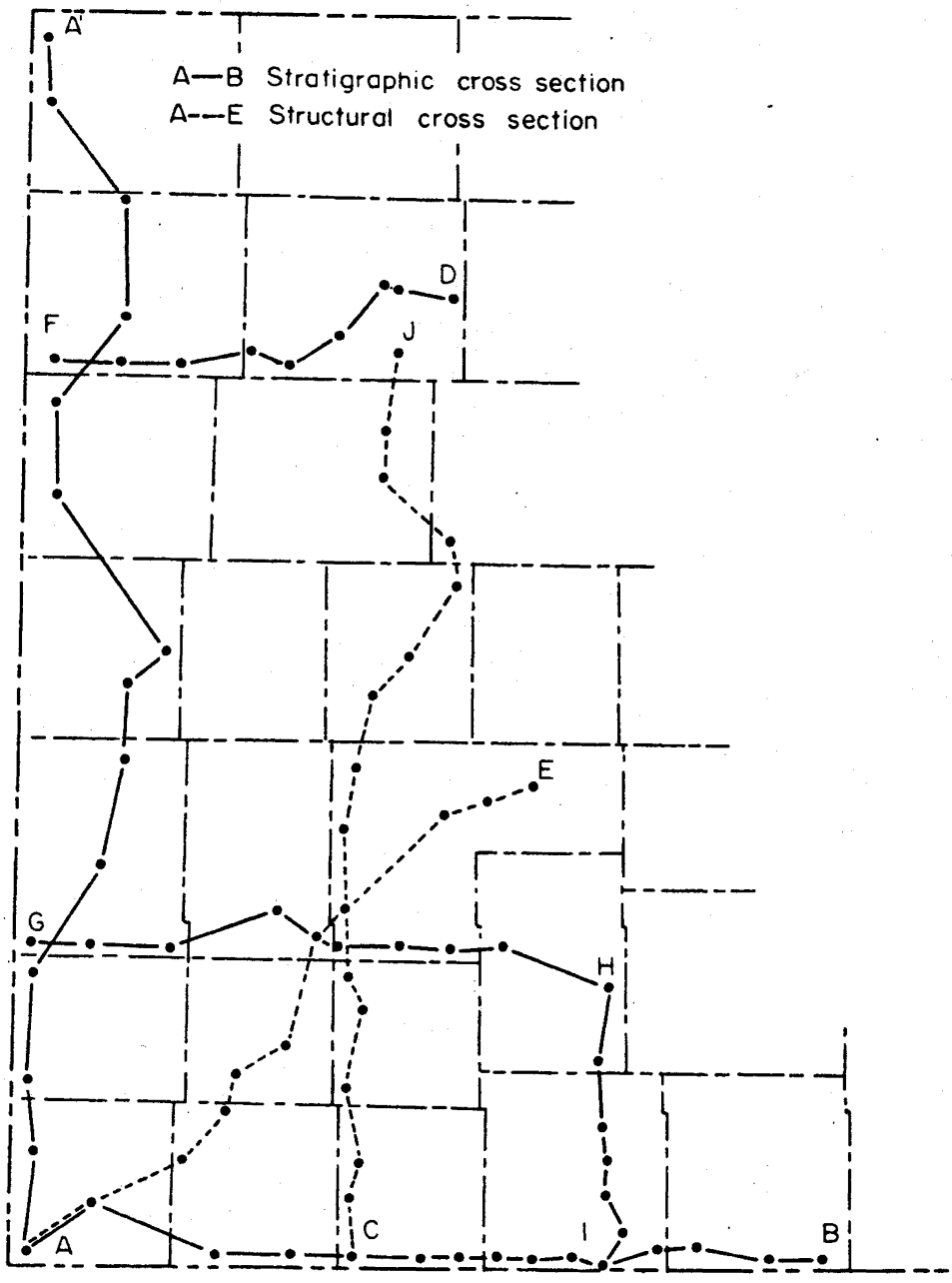


FIG. 2. Index map showing location of cross sections used in this report.

The investigation is based on data from 725 wells (Pl. 1), and includes examination of cores, well cuttings, sample logs of the Kansas Sample Log Service, and electric and radioactivity logs. The methods used in examining, plotting, and analyzing the data are standard subsurface techniques such as are fully described in any recent publication on the subject -- for example, texts by Haun and LeRoy (1958) and Sloss, Krumbein, and Dapples (1949). Modifications made by the present writer are discussed at the appropriate place.

Previous Work

Early workers on the subsurface Pennsylvanian deposits of western Kansas (Roth, 1930; Gordon, 1938) considered the sequence below the Marmaton Group to consist solely of the thick Cherokee Group with a variously named conglomerate or sandstone at its base. Only faunal remains of Desmoinesian age were described, mainly from the upper part of the section, and thus no mention was made of pre-Cherokee Pennsylvanian rocks, although previous studies had resulted in the identification of Mississippian rocks as young as the Chesteran stage in the southwestern corner of the state. The unconformity between the two systems was thought to represent Morrowan and Atokan time.

In later reports dealing with petroleum exploration in southwestern Kansas and bordering states (Schoenfelt, 1938;

Ver Wiebe, 1942; Ryniker, in Schoff, 1943) mention was made of the presence or possible presence of Morrowan rocks. The first detailed discussion of Morrowan deposits in the area was by Thompson (1944) who described the fusulinid fauna and compared it with that of the type Morrowan in northwestern Arkansas. His report deals primarily with the succession as exhibited in the Stanolind Oil and Gas Company No. 1 Patterson well in Kearny County, Kansas. This is the type section for the Kearny Formation which he proposed for the sequence of limestones and shales between the "Patterson sand" of Cherokee age and the underlying Mississippian limestone.

After Thompson's work several cross sections through western Kansas and the adjacent states were published by the State Geological Survey of Kansas (for example, see Maher, 1946, 1947). Many of the sections referred to the Pennsylvanian strata below the Cherokee Group as "Pre-Cherokee rocks", although some sections, particularly those including the Patterson well in Kearny County, correlated the sequence identified by Thompson as Morrowan throughout the rest of the area. Delimitation of the "Morrowan", however, was inconsistent. On recent cross sections, such as those prepared by the Kansas Geological Study Group (1950) and, especially, the Liberal Geological Society (1956, 1958), the Morrowan rocks that are present in the southwestern corner of the state are equivalent to the Kearny Formation as

here redefined. The location of cross sections prepared for the present report is shown in Figure 2.

The pre-Desmoinesian Pennsylvanian rocks extend westward into the subsurface of eastern Colorado where they have been studied in somewhat more detail, particularly in numerous papers by Maher (1945-1958). These studies have permitted the Kearny Formation to be correlated with the Glen Eyrie Shale which crops out along the Front Range in the Colorado Springs area, and the Atokan rocks to be traced into the lower part of the Fountain Formation. Although difference of opinion has existed as to the age of the Glen Eyrie Formation (McLaughlin, 1947; Kellett, 1948), it is now generally accepted as Morrowan.

Morrowan and Atokan deposits of northwestern Oklahoma and the Texas and Oklahoma panhandles have been discussed in some degree by Totten (1956), Dobervich and Parker (1958), Glidden and Borg (1958), Barby (1958), Jordan, Pate, and Williamson (1959), and Pate (1959). Several recent papers on the Hugoton Embayment have included some treatment of these deposits, the reports by Veroda (1958) and Abels (1959) being the most detailed discussions of the Kansas section since that of Thompson.

Stratigraphic Nomenclature

Various names, both formal and informal, have been used in a lithostratigraphic sense for the sequence of beds

below the Cherokee Group (Fig. 3), the largest units being referred to as "Morrow" and "Atoka." Although rocks of the Morrowan and Atokan Stages are present in the area, the use of these terms in a lithostratigraphic sense is thought to be objectional and misleading in certain respects. Also, it is questionable whether the "Morrow Group" should be considered present in a region so far from the type area, separated from it by several structural features, and representing a different distributive province. The same argument applies to the Atoka Formation.

The name Kearny Formation, therefore, will be used in the report in place of Morrow whenever the reference is to the rock unit. Any use of the term Morrowan will be strictly in a time-stratigraphic sense based upon the fossils contained in the lithostratigraphic units. The top of the Kearny has been placed by original definition at the base of the "Patterson sand." It is proposed, however, to place the top of the formation at the base of the lowest limestone, or locally a basal sandstone, that forms an intrinsic part of the dark limestones and shales containing Atokan fusulinids. This level is commonly marked by a well-developed coal bed. Such a redefinition, although not affecting the type section, provides a more stratigraphically useful delimitation.

Although the Atokan sequence in northwestern Oklahoma and the Texas and Oklahoma panhandles is referred to, at

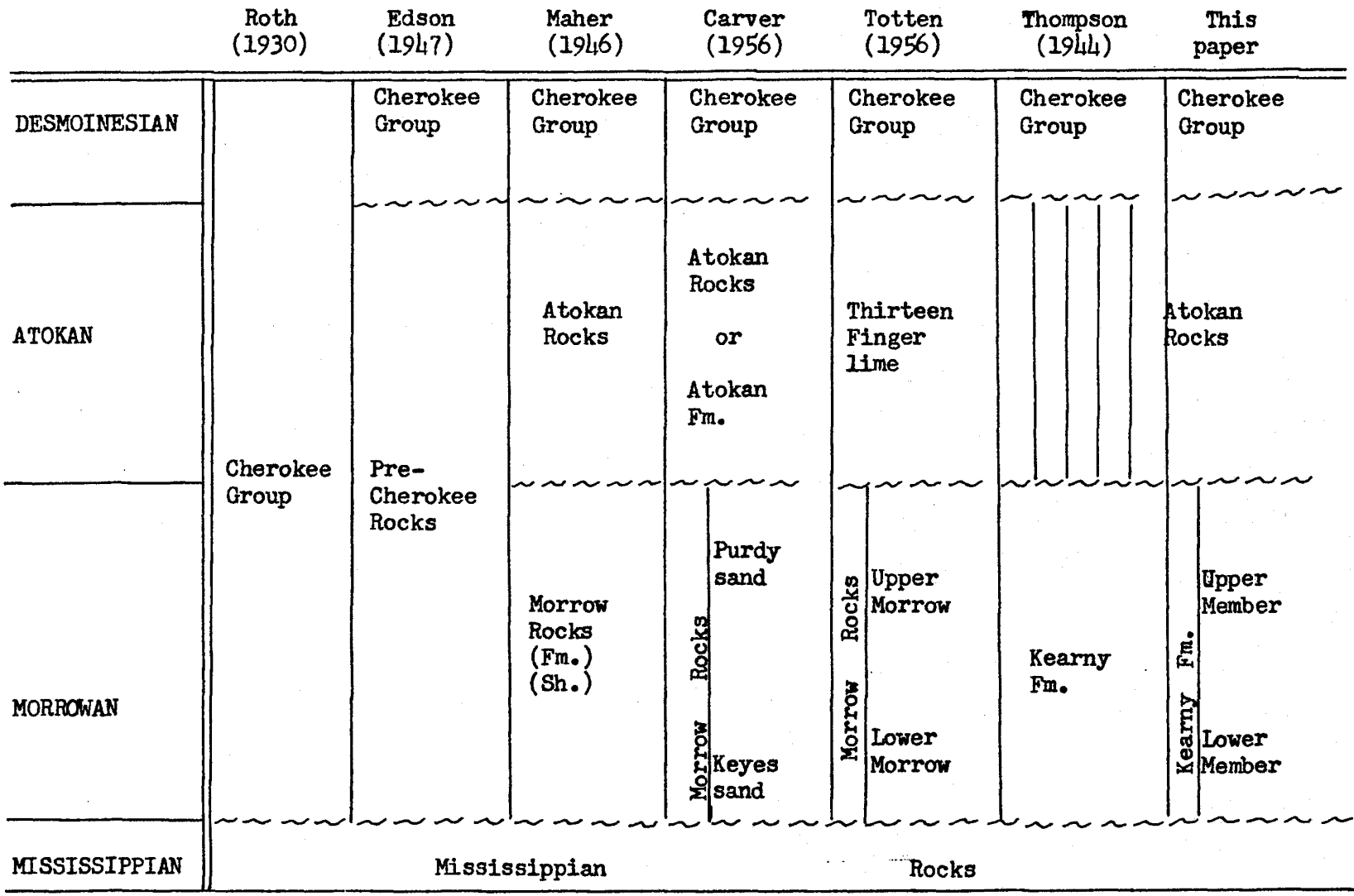


FIG. 3. Example of diverse nomenclature for pre-Cherokee Pennsylvanian rocks in western Midcontinent.

least in part, as the "Thirteen Finger lime" by some geologists, correlative deposits in Kansas are here designated as "Atokan rocks" until a better understanding of the relationships is reached.

Several subdivisions have been recognized within the Kearny Formation, and although most of them are producing sandstones with informal names, some of these names, as Keyes Sandstone, have been used formally. No subdivisions are listed in Wilson, Sando, and Kopf (1957), nor has any attempt been made to relate them to each other or to the formation as a whole. Therefore, no previous formal subdivisions within the Kearny Formation are recognized at this time.

Most of the sandstones that have been informally named are local, and their exact correlation from one field to another is often extremely conjectural; however, two sandstones warrant special mention. In the southwestern corner of the state the so-called Keyes sand at the base of the Kearny and the Purdy sand in the upper part of the formation appear to be somewhat more widespread and well-defined than the other sandstones. Yet, they are better considered as producing zones rather than members.

The two members recognized in this report are traceable throughout western Kansas and into the adjacent states with the upper member overlapping the lower one. These members are thought to represent principal changes in conditions of

deposition during this time, and therefore not to have locally restricted characteristics, although within each member are abundant local variations.

Acknowledgements

Especial thanks are due the State Geological Survey of Kansas which supported this investigation and made available the samples and logs for study. Particularly helpful was E. D. Goebel of the Oil and Gas Division. Also, thanks are due Professor R. C. Moore for his advice and guidance. The illustrations were drafted by the Drafting Department of the State Survey, and the typing was done by Mrs. Betty Vequist; to them I extend my appreciation.

STRATIGRAPHY

Mississippian Rocks

Deposits of Mississippian age in the subsurface of western Kansas consist predominantly of limestones and dolomites with minor amounts of shales and sandstones. As the sequence thickens into the Anadarko Basin, younger beds are preserved as the uppermost limit of the system, so that the basal units of the Pennsylvanian rocks rest on formations of Early to Late Mississippian age. The prime difference between the deposits of the two systems is the greater percentage of limestone and dolomite in the older one, and the difference in type of carbonate deposits. The association between the Kearny and Mississippian rocks is best understood if the underlying rocks are grouped into three units: 1) the older Mississippian rocks of the northern part of the area, 2) the Meramecian rocks of the central part, and 3) the Chesteran deposits of the south.

In the northwestern part of the region the Mississippian rocks directly beneath the pre-Pennsylvanian unconformity are commonly cream-tan, medium-crystalline, partly crinoidal limestones that are easily distinguished from the Kearny deposits of sandstone and shale. In places, however, the Mississippian limestones are covered by a residuum of weathered chert representing the remains of younger cherty

limestones of the system. Where the Kearny sandstones rest on the chert residuum, the systemic boundary is drawn at the top of the chert.

Probably the most common marker of the boundary between Mississippian and Pennsylvanian rocks in the western Kansas region is the white to light-gray Kearny sandstone resting upon white, arenaceous, micro-oolitic Meramecian limestone. In such an association the contact is readily identifiable in samples or on logs; however, the upper part of the limestone may be represented by a very calcareous sandstone, in which case the unconformable relationship is obscured.

Depending upon which part of the Chesteran sequence directly underlies the Kearny, the basal unconformity can be very evident or decidedly obscure. Where the Kearny sandstones rest on the limestones and silty limestones of the lower Chesteran units, the contact is sharp and definite. The lower Chesteran deposits include some cryptocrystalline to fine-crystalline, light-gray to light grayish-red, dense limestones which, although similar in texture to some of the limestones of the Atokan and Desmoinesian deposits, are very distinct from the arenaceous and crinoidal limestones of the Kearny. Commonly associated with the dense Chesteran limestones is a dark brownish-red, blocky shale which differs from the brown shale of the upper member of the Kearny by its reddish tinge. The most characteristic rock type in the lower Chesteran succession, especially in the vicinity

of the Keyes Dome, is a very silty, light brownish-red to grayish-red limestone which locally grades into a calcareous siltstone. This rock does not resemble any type from the Lower Pennsylvanian, either in texture or color. Very fine quartz sand grains are present in the limestone in places and even form a calcareous sandstone, although quartz silt grains are the predominant element of the rock in general. The lower part of the section is a white, micro-oölitic limestone; however, the oölites are more abundant and characteristic in the underlying Meramecian limestone, a white cryptocrystalline filling of the interstices between light cream-brown oölites.

In areas where the basal unconformity separates the Kearny from the upper Chesteran deposits, the systemic delimitation is less marked, a condition that arises from the close lithologic similarity between the two units. Instead of the highly-colored red and purple shales of the lower Chesteran units there are pale-green, dark-gray, and light-brown shales which commonly contain bryozoan remains, such as Archimedes, Rhombopora, and Fenestrellina. The upper Chesteran limestones are light gray, cream, light brown, and grayish-brown, fine- to medium-crystalline, and very commonly crinoidal. The resulting rock types are extremely similar to those of the overlying Kearny Formation, which in the southern and southeastern part of the region consists mainly of shales and crinoidal limestones.

However, the Kearny limestones are more commonly arenaceous, and slightly to profusely glauconitic. Also, the white, glauconitic sandstones of the Kearny, containing some phosphatic material, are noticeably absent from the older deposits, although sparingly-glauconitic, thin, silty zones are present in the Chesteran rocks. Finally, the blastoid Pentremites, which occurs sparsely in the Chesteran deposits, is unknown in Kearny beds, even though it is abundant in some beds of the type Morrowan succession.

The boundary between the Mississippian and Pennsylvanian systems in the area of the Kearny Formation, then, is an unconformity which represents the absence of a progressively greater number of Mississippian deposits toward the north. A structural contour map drawn on top of the Mississippian rocks (Pl. 1) shows the regional southern dip into the Anadarko Basin with some local exceptions, as the Keyes Dome. A series of isopachous maps of the Mississippian formations by Maher and Collins (1949) shows that the rocks thicken into the basin. A northeastward trend across the northern part of the map probably represents a spur of the Las Animas Arch, north of which is a reversal of dip. Asscciated with the high and in the area to the south for some distance the unconformity is characterized by appreciable local relief reflected as isolated highs and lows on the surface. In general, the unconformity separates the Kearny from the older Mississippian limestones along the

northeast arch and to the north, whereas the micro-oölitic limestones underlie the unconformity along the gentle southern flank with its irregular relief. Along the slope break and the flanks of the Keyes Dome the lower Chesteran deposits are subjacent to the Kearny until the upper Chesteran rocks cap the system nearer the axis of the Anadarko Basin. In neither of these areas, however, is the local relief as great as in other parts of the region, although the surface on the flanks of the dome shows considerable local erosion. Thus the unconformity is progressively less well-defined toward the south until it becomes very obscure in the axial part of the Embayment.

Kearny Formation

On a regional scale the Kearny Formation of western Kansas is essentially a shale formation, despite its content of significant thicknesses of sandstone and limestone; however, the local variations are both numerous and strongly marked in the areas available for study. The inequality in detail of the local descriptions of the formation is a result of the denseness of well control, which varies from excellent control in the oil fields producing from the Kearny and older formations to very poor and widely spaced control in the Hugoton Gas Area and sparsely drilled territory in the northwestern part of the state.

The formation is divided into two members that are regionally persistent and are separable on the basis of a pronounced lithologic change. Inasmuch as future refinement in definition of stratigraphic units is likely to be called for by petroleum exploration in the region, the members are unnamed here. The upper, more extensive member is characterized by a thick section of dark gray to black shale in much of the area, and the lower, relatively thinner unit is composed of more prominent sandstones and limestones.

Lower Member

Distribution and thickness. The lower member of the Kearny Formation is a shale unit with thick sandstones and limestones. It thickens to the southwest and is bounded by the Mississippian rocks below and the overlapping upper member above. A development of the member that is thought to be most typical is represented in western Stevens County, as shown by the Panhandle Eastern Pipeline Co. No. 1 Shafer well. This section, which combines the thick sandstones with the thinner shales, is described and illustrated in the Appendix.

The member attains a maximum thickness of about 250 feet in parts of Morton County, and thins rapidly to the southwest toward the Keyes Dome (Pl. 2). Although the member thins also toward the north and east, the change in

these directions is more gradual, and some local thickenings occur near the zero line which runs southeastward from Greeley County to Seward County. The local thickenings are in places related to major changes in lithology; however, such an association is more readily observed in the thickness variation in northern Morton County and southern Stanton County at the extreme northern limit of the Keyes Dome.

Many of the structural irregularities developed on the unconformity surface prior to the deposition of the member are partly or completely blanketed by these initial deposits of the Pennsylvanian. Some of the high areas at the end of the Mississippian, however, such as the Keyes Dome and a small high in northern Kearny County, were persistent throughout the deposition of the lower member.

Although some of the local structures have a northwest trend, the lower member as a whole does not reflect a thickening along the axis of the Hugoton Embayment, nor is there a pronounced increase in thickness toward the main part of the Anadarko Basin. Instead, the isopachous map shows the increased thicknesses to occur in a radial pattern with the Keyes Dome at the center. Thus, active subsidence of the Anadarko Basin during this part of the Morrowan is judged to have been chiefly to the south, nearer the axis of the basin.

Lithology and paleontology. The great degree of variation among the sandstones, limestones, and shales comprising the lower member has produced so many transitional deposits that different students have assigned the same rock to different taxonomic end members of the sedimentary-rock classification. And indeed, many of the fragmental, arenaceous limestones, for example, might be better considered along with the sandstones in reconstructing the depositional history.

Although the presence or absence of limestone in the section is important in considering the depositional history, of far more importance in this unit is the relationship between the sandstone and shale. The sandstone-shale distribution map (Pl. 3) shows the member to be composed mainly of shale, with the sandstone confined to certain subregional areas. In describing the member, reference can be made to northern and eastern arms of increased sandstone content radiating from the Keyes Dome. Between the arms the member is less sandy. The regional description will progress up the northern arm from the sand area in the southwest corner of the state, through the central small area in southern Stanton County, to the large sand district at the north. Then, shifting clockwise through the shale area between the arms, the discussion will turn to the eastern arm along the southern border of the state.

The sandstones in the southwestern corner of the state are commonly white to light-gray and fine- to medium-grained, although many are very fine-grained and even more are coarse-grained. In general, the coarser-grained rocks seem to occur in the lower part of the section, and contain the coarsest grains at the base of the member. The degree of roundness of the quartz grains is fairly constant for each grain size, most of the grains being subangular; however, the larger grains, particularly the coarse and very coarse grains and granules, are more rounded.

The degree and type of cementation is varied, especially between lower and upper sandstones in the section. Many rocks are very porous, with little cement in the interstices between the rare point contacts of grains; however, more commonly, some slightly calcareous cement is present. In association with increased grain size toward the base of the member, the type of grain contact changes from point contacts to long contacts, i.e., from the abutment of grains at points to contact of grain surfaces. The resulting sandstone is cemented with calcareous or siliceous material in the narrow interstices and thus forms a very dense basal deposit.

Although most of the quartz sand grains are clear to light-gray, some grains of pink, yellow, and orange are present. Most of the colored grains are coarser than the enclosing grains, and as such are slightly more rounded.

Glauconite, as light- to dark-green, and even blackish-green, very fine- to medium-grained pellets, is the second most common component of the sandstones, and forms a high percentage of some of the rocks. The other accessory minerals, pyrite and mica, although locally important, do not compare with glauconite in abundance. Likewise, the small feldspar grains, which give many sandstones a slightly feldspathic composition, are not abundant.

Sandstones in the lower member have been referred to as the Keyes sand, although usually only the lower part of the sandstone has been so designated. The lensing that is characteristic of lesser sandstones, particularly in the upper part of the member, causes difficulty in ascertaining which part, if anything other than a zone, is a continuation of the producing sand in Cimarron County, Oklahoma. A generalized division of the member is possible into an upper limestone-sandstone complex, a relatively thick shale locally containing several significant sandstones, and a lower sandstone unit including some shales. It is thought that the last-named unit is a continuation of the Keyes sand of Oklahoma.

The limestone of the lower member, best developed toward the top of the unit, is grossly impure. Typically it is an arenaceous crinoidal limestone: light-brown to cream-tan, fine- to medium-crystalline with large grains dominant in a fine-crystalline groundmass. Fine to medium

grains, and at places coarse grains of quartz form as much as half the rock; gradation into a very calcareous sandstone is common. Chiefly the quartz is clear to milky, subrounded to subangular, and commonly more abundant toward the bottom or top of the depositional unit. Some grains of rose quartz and yellow quartz are present, as are rare to common glauconite grains, and sparse angular fragments of feldspar. Crinoid columnals are an important constituent of many of these limestones, and in places form the bulk of the rock. Commonly associated with the crinoid remains, but far less in abundance, are fragments of brachiopod shells and spines belonging to such genera as Dictyoclostus and Marginifera, ramose and fenestrate bryozoans, especially Rhombopora, and small turbinate gastropods.

Some limestones are very argillaceous and flaky; others contain less clay and are much denser. These limestones are commonly dark gray and form thinner beds than the arenaceous types. The intercalation of argillaceous limestone and dark shale is a common association, as is the arenaceous limestone-calcareous sandstone association.

The shale of the lower member is very similar to that of the thicker section developed in the upper member. Principally the shale is dark gray to black, although some light- to dark-green shales and a few brown shales are present. Very thin laminations, and pronounced fissility in the black shale, are characteristic of the rock, as is

the common occurrence of thin intercalations of argillaceous limestone and calcareous sandstone. Part of the shale section is silty, and in places isolated very fine to medium quartz sand grains are present. The latter condition is especially common in the shale directly overlying a sandstone, and if the sandstone is exceptionally glauconitic, a few pellets of glauconite may be interspersed with the quartz grains.

Many of the characteristics of the limestones, sandstones, and shales in the sand area in the southwestern corner of the state are also applicable to the rocks in the small central sand area in the northern arm. The latter area is represented by a northwest trend from Morton County into Stanton County on both the isopachous map and sand-shale ratio map. It is a locality of irregularly thick sandstones bounded by thinner sandy shales, the sandstones occuring in essentially a single trend, but composed of several bodies. In the thickest part, where the sandstones ~~and~~ one dominant and contain a basal conglomerate, the member is as much as 200 feet thick, but it thins rapidly to the northeast to less than 100 feet.

Principally the sandstone is calcareous with cryptocrystalline to fine-crystalline calcite cement between the common point grain contacts. Among the variations are those with lessened cement but no increase in grain contacts; however, a more common variety shows decline in amount of

cement accompanied by increased grain contacts to the point of developing very abundant long contacts between grains. Even though argillaceous cement occurs in the form of white clay, it is better developed as black shale cement grading into an interlamination of dark shale and sandstone. Ferruginous cement is even less important.

Glauconite is far the most important accessory component of the sandstone, and occurs predominantly in the form of very fine to medium, subrounded, dark green grains, although commonly light green and pistachio green, and locally yellowish-brown colors are present. In some parts of the member the mineral almost forms a cement, but mainly it is a sparse to common accessory constituent that also occurs as local, poorly cohesive, irregular patches of coarse grain size in which the mineral is powdery.

Very fine-grained flakes of white mica are a much less important accessory component, as are the locally common pyrite grains. Angular fragments of pink feldspar, although small in amount, are worthy of note. Also present are some grains of chert and a few fragments of dense limestone.

Of the few sedimentary structures available for study in the region, the most apparent one, an interlamination of black shale and very fine-grained sandstone, is well-developed in this central sand area of the northern arm. The interlamination grades downward in scale from laminae of shale between sandstone deposits an inch or more thick,

through a relatively even alternation of laminae of the two rock types, to the development of micro-lenses of very fine-grained glauconitic sandstone or siltstone in a black shale. The lamination contacts appear very sharp because of the pronounced color difference between the two rock types; however, closer inspection shows the shale to be a series of discontinuous, irregular, black, micaceous films on a sandstone surface having very irregular micro-relief.

At places the shale laminations are not horizontal, but show a cross-laminated relationship with the sandstone. A continuation of this structure produces shale laminae that anastomose vertically and horizontally, a condition developed principally in very fine-grained sandstones and siltstones.. This feature probably represents a transition between the sandstone-shale interlaminations and the shales with micro-lenses of sandstone.

In the upper part of the member the sandstone grades into arenaceous limestone, a medium-crystalline rock with common quartz sand grains and dominant large grains in a cryptocrystalline groundmass, although in places it is fine-crystalline, with a subordinate cryptocrystalline texture. Crinoid columnals and dark gray limestone pseudo-oölites are common.

The fauna, as recorded by crinoid, brachiopod, and bryozoan remains, is better represented near the sandstone area than in the surrounding shale areas, although the

crinoid columnals form an important part of many limestones, and are present in most of them, regardless of the associated rock type. Typical genera include Hustedia, Marginifera, Rhombopora, and Fenestrellina.

The shale sections most distant from the sandstone area consist mainly of dark-gray to black, thinly-laminated, fissile, micaceous shale, which is rarely without sandstone impurities. Closer to the area interlamination of the shale with very fine- to fine-grained sandstone is common, as is the interbedding of the two rock types.

In places along the eastern margin of the northern arm of sandstones, as in central Stanton County, the lower boundary of the formation is not so apparent, because of the development of a thick basal section. One or two thin sandstones locally separate this shale from the underlying Meramecian micro-oölitic limestones, but the lower, very fine-grained, micro-oölitic sandstone is the basal Chesteran deposit. Commonly overlying the Chesteran sandstone is the light-gray, conglomeratic, slightly feldspathic, basal Pennsylvanian sandstone.

Continuing to the north, the final district of increased sand content in the arm extends from northern Stanton County to southern Greeley County. As in the areas to the south, certain narrow sandstone bodies stand out within the district, which as a whole contains somewhat thicker deposits than the adjoining areas. In general, the basal

sandstone passes upward through arenaceous limestone and shale into a crinoidal limestone.

The thick shale sequence that occurs between this sand area and the smaller area to the south continues to the northwest and becomes the dominant development along the western margin of the northern arm. Very commonly this thick shale intervening between a basal sandstone and the thicker, main sandstone part of the member tends to obscure the lower contact of the formation on electric logs.

The lithology of the basal sandstone is characteristic of most of the lower sandstones in the member in this northern part of the depositional area, and differs from that of the upper sandstones in the large grain size, poorness of sorting, and lack of common gradation into arenaceous limestone. Grains of glauconite are present in almost all the sandstones. Lithologic gradation into the sand area has resulted in common interlamination and interbedding of sandstones and shales in parts of the sequence.

Although the limestones of this part of the region occur in several variations, they can be grouped into two broad lithologic and stratigraphic types: 1) a lower, light-colored, very arenaceous limestone, and 2) an upper, dark-colored, crinoidal limestone. The limestone is very fossiliferous, containing abundant medium- to coarse-grained crinoid columnals which are slightly larger than those farther south; common productid spines and shell fragments,

especially of the genus Dictyoclostus; rare ramose bryozoans; and rare large ostracodes.

Continuing westward into Colorado, the member is composed of a section of limestones and shales which characterizes it to the Front Range. Turning to the east, one likewise discovers a decline in content of quartz sand grains, particularly in the absence of sandstones. This area, located between the arms of sand development, occupies parts of several counties in southwestern Kansas.

The limestones differ from those just described associated with the sand area mainly in the smaller quantity of quartz sand grains; actually only a very small percentage of this limestone is arenaceous. Likewise, truly crinoidal limestones are not characteristic of the section here where the rock might better be described as a medium-crystalline limestone. The faunal remains in the rock include crinoid columnals, in a variety of sizes, productid spines and shell fragments, and ramose bryozoan remains. A few specimens of Enteletes are also present.

Dark-gray to black, partly carbonaceous shale and some light-green shale form the main part of the section, which besides the carbonized remains also contains sparse Rhombopora and Thamniscus fragments and some small nuculid pelecypods (Nuculopsis?).

Sandstones in this area are notable for the lack of coarse quartz grains. A slight increase in sand content

occurs locally in the eastern part of this district, such as in Haskell County; however, essentially the same conditions mark the southeastern part of the district. The eastern sandstones are shaly, fine-grained, micaceous, glauconitic, and calcareous. The associated dark, micaceous, thinly-laminated shales are silty and sandy in places, and locally contain pyrite. Although some impure coal beds are present, they are much less developed than those of the upper member.

The limestones in this eastern part of the inter-arm area show a continuation of the crystalline character previously described, but crinoidal remains in the form of columnals are again an important part of the rock. Although the arenaceous limestones are cream-gray, the more common, glauconitic, fossiliferous, argillaceous types are grayish-brown.

Along the southern margin of the area, as in Stevens County, near the fork of the arms of sand accumulation, a significant variation in lithology occurs, marked by the change from a section that is mainly shale, containing a sparse fauna (Nuculopsis?, Myalina?) and some associated limestones, to one that is composed predominantly of sandstone.

Grading into the sandstones are dark-gray to cream-tan limestones having a fine- to medium-crystalline texture with subordinate large grains in a fine-crystalline groundmass.

They are very similar to the limestones in the shale district to the north, but are very arenaceous and in part feldspathic. Crinoid columnals are almost invariably abundant, as is the glauconite which also occurs as fossil replacements, especially of ramose bryozoans.

The arenaceous limestones grade into light-gray to cream-tan, very calcareous sandstones that are composed of fine-grained to granule size, subangular to subrounded quartz grains, and commonly contain little crystalline calcite cement. Much of the sandstone, however, is better sorted, being composed mainly of very fine- to fine-grained quartz. Glauconite and crinoid columnals also are present in the sandstone.

Farther east along the eastern arm of sand accumulation, in southern Seward County, is the final sand area of the lower member. In localities some distance away from the main sandstone concentration the limestones are a continuation of the fine- to medium-crystalline, crinoidal variety present in the shale area to the north. Besides glauconite, the rock also contains some fragments of argillaceous dark limestone and shale galls. Fossil fragments are abundant, and consist primarily of crinoids; brachiopods, including Marginifera, Hustedia, and Dictyoclostus; bryozoans, such as Fenestella and Rhombopora; and ostracodes. Many of the ostracodes occur as internal molds.

Nearer the sandstones, the limestone is much more arenaceous and similar to varieties occurring farther west along this arm. The main faunal elements of the arenaceous limestones are crinoids, brachiopods, gastropods, ramose bryozoans, and trilobites. Trilobites form one of the rarer groups of the Kearny fauna, and when present, commonly occur as fragments. One large segment of a pygidium is tentatively referred to as Paladin.

Not only do the limestones and sandstones grade laterally into one another, but at places they are interbedded and very difficult to delimit. More commonly, however, the sandstones are relatively separate bodies of slightly lighter color than the limestones, and in places they have little calcareous cement between the long grain contacts. Although many of the lower sandstones are medium- to coarse-grained, most of the quartz grains are in the fine-grain size. In some of the finer-grained sandstones laminae of dark shale are common, with the shale as irregular films. Rose quartz, yellow quartz, and small dark shale grains are some of the less common sandstone components.

One of the main characteristics of the shale sequence in this area is local coquinoid assemblages of fine-grained crinoid columnals. Otherwise, the shale is much the same as in the rest of the region. Locally, as in some other areas, the shale contains fragments of Composita and Chonetes, especially near the limestones.

Upper contact. In the southwestern part of the region the contact between the members is relatively distinct where it occurs at the top of the arenaceous limestones or calcareous sandstones forming the bulk of the lower member. Here the lowermost shale of the upper member commonly contains quartz sand grains or thin sandstones and limestones. Nearby, however, the change in environment from the sandstone and limestone to the gray and black shale is less distinct, resulting in a thick transitional sequence. The gradational relationship suggests that the contact should be placed at the top of the limestone and at the base of the sandy and limy shale, a horizon that is not particularly obvious on the electric logs. In general, in this part of the region the contact is judged to separate rock units reflecting two major depositional units.

In the northern part of the northern arm of sand accumulation the lower member is overlain by thick limestones and sandstones of the upper member that are very similar to the lithologic types in the lower unit. However, these developments can be traced laterally into the thick shale sequence that represents the upper member in most of the southwestern part of the region. Therefore, the contact between the members is placed below these developments, at the top of the limestone-sandstone complex that forms the most characteristic part of the lower member.

Between this area and the wedge edge on the eastern side of the region the members are easily separable, as few limestones or sandstones are present in the upper member. In the area toward the eastern end of the eastern arm of sand accumulation in the lower member, the upper member thins and contains several thick limestones and sandstones, but the lateral gradation into the thick shale section can be shown as the formation thins and the lower member wedges out. Lithologically the two members are very similar in the eastern part of the region, as it is an association of stratigraphic overlap and ecologic transgression.

Upper Member

Distribution and thickness. The upper member of the Kearny Formation displays two main developments: 1) a thick shale section overlying the lower member, and 2) a thin, less argillaceous phase extending laterally beyond the lower unit. The former sequence is considered most typical and is shown in the Superior Oil Company No. 1 Wade well in Stanton County. A supplementary well from Meade County, the Deep Rock Oil Corporation No. 1 R. E. Adams "B" well, exemplifies the thinner development. The sections from both wells are described in the Appendix.

The upper member overlaps the lower one to the north and east, and extends to a line from Cheyenne County to

Clark County that marks its eastern limit. Atokan rocks overlie the upper member in the west, whereas Desmoinesian strata rest unconformably upon it in the east.

Ranging in thickness from a wedge edge to over 350 feet, the upper member is somewhat thicker than the lower one, and presents a significantly different pattern (Pl. 4). Diminution in thickness outward from the Keyes Dome is not so striking as in the lower unit, but southward thickening into the Anadarko Basin is much more pronounced. Thus is shown in the upper member a more definite response of deposition to tectonic activities of the basin and embayment. The axis continues north-northwestward from Stevens County to Greeley County, a trend that is also present on the map of the lower member.

Although some local irregularities exist, the deposits of the upper member lack many of the local changes observed in the lower member, thus indicating the blanket effect of the lower member in reducing the significance for later deposits of the erosional relief on the pre-Pennsylvanian surface.

Lithology and paleontology. Discussion of the composition of the upper member can follow the clockwise pattern used for the lower unit, beginning in the southwestern corner of the state. Sandstone-shale distribution in the upper member (Pl. 5), however, lacks the large areas of sand concentration characteristic of the lower part of the

formation. Instead, the largest part of the map shows a shale development, bordered on the northeast and southeast by districts of sand accumulation.

On the flanks of the Keyes Dome the upper member is dominantly a dark-gray to black shale with associated light-gray and greenish-gray shale, and lesser amounts of brown and red shale. The shales, although obviously representing various environments, contain few fossils; but thin limestones intercalated with the shales in places have remains of marine fossils. A few shales, especially in the upper part of the member, contain carbonized plant remains and some thin coal beds, but in much smaller quantity than deposits farther north or northeast.

At its base the member shows several variations due to the local occurrence of thin limestone or sandstone beds. Interbedded calcareous to arenaceous shale and thin limestones and sandstones in places grade downward very evenly into the arenaceous limestones and calcareous sandstones of the lower member.

The upper part of the member is characterized by shale and interbedded limestones and sandstones which mostly are thin, although some thick beds occur locally. Below this uppermost part the shale is black and fissile, and beneath this section are developed the main sandstones, which can collectively be called the Purdy sand. Commonly below the sandstones, but at places associated with them, the shale

is very calcareous and contains a few thin limestone beds; even though it is not conspicuously developed, this part of the member is persistent throughout much of the region.

Limestones of the upper member are divisible into two types. The upper ones are dense and argillaceous, prototypes of the overlying Atokan limestone lithology, whereas the lower ones are a holdover of the arenaceous crystalline limestones of the lower member. Some of the latter limestones contain brachiopods, horn corals, ramose and fenestrate bryozoans, high-spired gastropods, and crinoid remains. Locally the fossil content increases until shelly limestones are formed with abundant brachiopod remains, especially Dictyoclostus and Marginifera. The microfauna consists of a few foraminifers, such as Tetrataxis, Millerella, and Paramillerella, and a sparse to abundant ostracode assemblage, including Jonesina and Kirkbya.

Although many of the sandstones are conglomeratic along the flanks of the Keyes Dome, the grain size tends to diminish toward the north until the most typical rock is a very fine- to fine-grained, subangular, slightly feldspathic sandstone containing some interstitial clay and black shale laminae. Glauconite is present in a few of the sandstones, but is not nearly so common as in those of the lower member. The continued diminution of grain size is shown by the common occurrence of siltstones in the vicinity of Hamilton County where the member begins its pronounced northward

thinning. A typical siltstone is light-gray, thinly-laminated, calcareous, and micaceous, with some very fine quartz sand grains.

Shales also show variation away from the southwestern corner of the region. Although the shale is principally dark-gray to black, other types are also present, such as the light greenish-gray, thinly-laminated shale with abundant small crinoid columnals that occurs near the top of the formation in some wells. Shale of the latter color is also present in the lower part of the member in association with light- to dark-brown, blocky shale. This brown shale, however, is different from the more clayey, light-brown shale occurring with some of the thin coals and probably representing an underclay. Some sparse, very small seedlike remains occur in this part of the section. The middle part of the member is generally less varied and is a dark-gray to black, calcareous shale. Black shales are most common slightly above the base of the member. Near the top of the unit light-brown, pyritic, thinly-laminated shale and dark brownish-gray, silty, blocky shale are present.

The member thins in central Hamilton County and undergoes several lithologic changes. In effect, the previously described southern part of the region differs markedly from the northern areas. The relatively persistent shale sequence containing few siltstones and limestones passes into a section with more common sandstones and limestones;

however, the shale continues mainly as dark-gray, black, light-green, and dark-brown rocks. The last type of shale is commonly blocky and clayey, whereas the others are thinly-laminated. In places the black shale and light-green shale show an interdigitation of color along the lamination plane. Much of the shale is silty. Specimens of Chonetes, Lingula, Orbiculoidea, Rhombopora, Nuculopsis?, and Myalina? are most common in the poorly preserved fauna; the impure coals contain plant remains.

The coals, which are very characteristic of the member, mainly occur in thin beds, but a coal bed two to three feet thick is developed at the top of the formation throughout most of the northern half of the region. A thinner coal bed is present at this horizon in much of the southern part of the region. Some shales associated with the coal beds contain carbonized material, mostly as carbonaceous films. One type of shale is light-gray, somewhat bleached in appearance, and contains abundant, small, black, rootlike markings anastomosing throughout the shale.

Sandstones in the northern half of the region are mainly very fine- to fine-grained, although coarser rocks are present. Diminution in grain size and in the content of accessory minerals continues toward the north.

Limestones, which are relatively more important in some sections in the northern part of the region than they are in the south, are in part very arenaceous. Along the

western margin of the region is some quartz sand grains, and abundant fragments of crinoids, Hustedia, Marginifera, Dictyoclostus, Rhombopora, Fenestella, and small gastropods, which in some of the siltier parts of the rock form a "fossil hash." This rock type is perhaps better referred to as a crinoidal limestone than arenaceous limestone, and forms the most common limestone type in the northern part of the region. The crinoidal limestone continues as far north as southern Sherman County where it begins to change into sparse, thin, crinoidal, silty limestones that form a very small part of the thinning section. Some thin limestones contain dense limestone pseudo-oölites in a crystalline groundmass , but the dense argillaceous limestones such as occur in southwestern Kansas do not form an appreciable part of the section in the north.

A reference cross section across northwestern Kansas (Pl. 6A) shows the thinning of the member to the east until it pinches out on the flank of the Central Kansas Uplift.

In the northern part of the region some small areas of sand concentration occur along the eastern margin of the member (Pl. 5). Associated with the one in Logan County are poorly-developed coals and light greenish-gray shale containing carbonized plant remains. Probably these are the beds referred to by Gordon (1938, p. 202) in citing occurrence of spores. Some of the shales grade into dark brownish-red varieties, but chiefly the shales are gray,

black, and green, thinly-laminated, and partly micaceous. Intercalated in the shales are thin siltstones and sandstones.

Characteristically the siltstones are light-green to yellowish-brown and associated with silty shale. Sandstones are fine- to very fine-grained with the subangular, clear quartz sand containing little calcareous cement between the very abundant long grain contacts. Thick intercalations and the basal sandstone are poorly sorted and locally contain abundant coarse grains at the base of a depositional unit. Laminae of black shale increase in abundance in the rock until an interlamination of the two types forms the dominant lithology. Nearer to the eastern margin of the formation chert fragments from the underlying Mississippian rocks, along with a few micro-oölites, are more common in the lower sandstones. Throughout the east-central part of the region the main developments of sandstone appear where the formation is relatively thin, as is shown for example by the Finney-Wichita trend (Pl. 5).

South of the central part of the region, central Wichita County, limestones again become somewhat important in the section. The small amount of arenaceous and crinoidal varieties, however, shows a closer relationship with lithologies in the southern part of the region than those previously described along the western margin of the area. The limestone is mainly cream-tan and medium-crystalline with large grains dominant in a fine-crystalline groundmass

that is slightly oölitic in places. Glauconite and quartz sand grains occur sparsely in the rock. The crystalline texture makes identification of fossil material difficult; however, some crinoid and brachiopod remains are present. Locally underlying the above type of limestone is a light-gray, very shaly limestone containing fine-grained crinoid columnals, a rock type transitional with the dark shales.

Continuing southward into the south-central part of the region, the member begins to thicken more rapidly. To the north and east of this change in thickness the limestone in the upper member is lithologically more like that of the lower member than that of the Atokan sequence. The type section occurs in the thinner part of the member, and therefore, although containing some dark gray, argillaceous limestone in the upper part, is comprised mainly of lighter-colored, more crystalline, glauconitic, crinoidal, and slightly arenaceous varieties. Specimens of Millerella and Paramillerella are common.

Associated with the thickening of the member into the axial part of the embayment is a lessening in the thickness of limestones and sandstones, and a decline in variation within the shale. The shale in the uppermost part of the Kearny contains thin coal beds, thin very fine-grained sandstones, and thin limestones similar to the dense overlying Atokan limestones. This sequence of shale-coal-limestone-sandstone is truly a transitional section between the

environments of the two formations. In the lower part of the member are a few coals, more crystalline limestones, and some sandstone intercalations in the shale. A very poorly represented fauna consists mostly of sparse, small, nuculid pelecypods, a few ostracodes, and some thin-shelled brachiopods.

This association of shales, sandstones, and limestones continues eastward into Haskell County with perhaps an increase in the number of thin coal beds. The uppermost shale becomes especially characterized by very thin sandstones. To the south, in Seward County, the coal beds in the upper part are reduced to paper thin laminae in the shale. Similarly the dense limestone lessens in thickness and importance, the dominant type being a cream-tan to light grayish-brown, medium- to fine-crystalline variety. In the thicker sections to the west, closer to the axial part of the embayment, the dense limestone is present to some extent. Most of the crystalline limestones are fossiliferous, including crinoid remains, and such genera as Rhombopora, Fenestella, Dictyoclostus, and Marginifera. More common than fossil remains are fine to coarse quartz sand grains which occur in many places at the base of a limestone unit, although lateral gradation of the limestone into sandstone is more common.

Two broad types of sandstones are recognizable: 1) a light-gray, very fine- to fine-grained, subangular, slightly

glauconitic variety with sparse to common calcareous cement between the point grain contacts, and 2) a much coarser, subangular to subrounded, poorly sorted variety. The latter type occurs primarily in the areas of thick sandstone development, whereas the former type is characteristic of the most common and widely distributed sandstone in this part of the region.

The final area to be described is the Meade-Clark area in the southeastern corner of the region where the relatively thin section forms the main sand district in the member. A much less rapid thickening into the basin characterizes this district (Pl. 6B).

Gray, green, and black shales also mark the section here, with rarer varieties reaching importance locally, such as the blocky, medium-green shale with light-brown mottles, or the mouse gray, soapy, pyritic shale. In addition to sparse remains of marine invertebrates, including Myalina?, Nuculopsis?, Chonetes, Enteletes, Marginifera, and crinoids, the shale also contains carbonaceous material at various horizons and thin coal beds which are most common near the top of the formation.

In much of the area the sandstone is light-gray, very fine- to fine-grained, subangular, with sparse slightly calcareous cement between the rare point grain to abundant long grain contacts. In northern Meade County the sandstones are more argillaceous, and a similar lithologic change is

shown on approaching the formation border to the east in Clark County where basal coarse grains and phosphatic nodules are present. Toward the limit of the formation the shales become very arenaceous and contain fragments of Mississippian rocks.

Throughout the area the fine-grained, glauconitic sandstone that is most common also contains some medium to coarse grains, especially at the base of a depositional unit. The basal unit of the member is conglomeratic in places with some phosphatic material and chert fragments; some lenticular parts appear to be developed in channels in the underlying Mississippian rocks, as pointed out by Renfroe (1955, p. 100). In the finer-grained rocks laminae of black shale are common, and an interlamination of the types may result with the laminae of black shale occurring as small irregular flakes over an uneven surface of sand grains. Micro-lenses of sandstone in the shale laminae are not uncommon. In part of the area an abundant white crystalline cement appears to surround the subrounded quartz grains of the sandstone.

Except along the southern edge of the area the composition of the limestones is very similar to that in the rest of the region. Although some light- to dark-gray, cryptocrystalline, fossiliferous limestones are present toward the eastern margin, the main type is a brownish-gray, fine- to medium-crystalline, glauconitic, fossiliferous

variety, which is ordinarily crinoidal and commonly arenaceous. Some of the cream-tan, medium- to fine-crystalline, arenaceous, clastic, glauconitic type occurs here, particularly in the southwestern part of the sand district; however, in that same part of the area are medium-crystalline limestones that consist of white crinoid columnals, oölites, and algal-coated fragments in a dark-brown, crystalline calcite cement.

Upper contact. Throughout most of the region the upper contact of the Kearny Formation is a readily recognizable horizon occurring at the base of the lowest prominent limestone of the overlying sequence of dark-gray to dark-brown, cryptocrystalline, argillaceous limestones and dark-gray to black shales. In parts of the region, as in southwestern Morton County, a sandstone occurs at the base of the dark limestones in the thinner sections and appears to be a basal sandstone of the overlying unit. In much of the region this horizon is marked by a thick coal bed.

From Hamilton County to Sherman County, and eastward to the margin of the region the Kearny is very commonly overlain by a fine-grained, slightly conglomeratic sandstone, which in places is referred to as the "Patterson sand." In the type area of the Kearny this sandstone is classed as part of the Cherokee Group (Thompson, 1944, p. 414). Possibly not all the sandstone is the same age, as part of it appears to be overlain by Atokan limestones, and

some of it may actually be upper sandstone of the Kearny.

In the southern half of the region the contact is at the base of the dark limestones of the Atokan, or of the somewhat lighter limestones of the Cherokee, although locally a basal sandstone introduces the upper sequence. Commonly there is some type of detrital zone at the base of the Atokan section, perhaps only a thin calcareous siltstone with coarse fragments of the underlying shale (Renfroe, 1955, p. 100).

The upper contact as identified here separates the thick shale sequence of the Kearny Formation containing Morrowan fossils from the limestone and shale development of the Atokan rocks and the limestone dominance of later Pennsylvanian time.

Atokan Rocks

Rocks in the subsurface of western Kansas containing fusulinids of Atokan age are mainly a sequence of interbedded dark-gray, black, and dark-brown, cherty limestones and dark-gray to black shales. A few fine-grained sandstones occur, particularly at the base of the unit; however, the limestone-shale succession by far is dominant.

The limestones contain a representative fauna including small specimens of Fusulinella which are locally very abundant, together with other foraminifers, brachiopods,

crinoids, gastropods, pelecypods, and a few ostracodes. This sequence continues into the lower part of the Cherokee Group, so that a separation of the two groups is not so obvious as is that between the Atokan deposits and the Kearny Formation. For this reason the contact between the Atokan and Desmoinesian Stages is not shown on the regional cross sections.

Regional Summary of the Kearny Formation

Although sandstones and limestones form a very important part of the composition and depositional record of the Kearny Formation, when the members are considered together and the formation is viewed as a whole, it is essentially a shale unit (Pl. 7). Care must be used, however, in drawing conclusions from the sand-shale ratio map, for comparison with the isopachous map of the formation (Pl. 8) shows a significant change in thickness throughout the region. The gradual increase in thickness toward the southwest, the various local anomalies, and the larger effect of the Keyes Dome are the major influences. The thick shale in the southwestern part of the region effectively masks the sandstones found there. An attempt to remove the masking effect of the thick shales has resulted in the consideration of a lower, primarily basal, transgressive part of the formation (Pl. 9). Although the transgressive unit

is not defined as a rock unit, being composed of parts of each member, nevertheless it presents a somewhat sharper picture of sediment distribution by the advancing Morrowan sea.

Although considerations have dealt chiefly with the relationship between the sandstone and shale content of the formation, the limestone can not be ignored, and indeed it is a very significant part of the formation along a northwest trend through the center of the region (Pl. 10). The masking effect of the thick shale sequence is also reflected in this map. The essentially en echelon pattern of the main limestone development and the local absence of the limestone from the section where abundant sandstones occur are the most outstanding features of the map.

Vertical variations in the stratigraphic and sedimentologic development of the Kearny are shown in several cross sections. A cross section from Morton County to Cheyenne County (Pl. 11) shows the northward thinning of the formation, in particular as far as Greeley County where the lower member pinches out. The scattered sandstones and limestones of the upper member become somewhat more persistent north of that point. Turning eastward from the southern terminus of the above cross section one sees the more pronounced thinning of the formation to the east (Pl. 12A). The upper member again develops more persistent limestones and sandstones at about the position where the

lower member pinches out, but to the west the thick shale section is present. Although the limestone and sandstone content of the formation increases in the vicinity of the Keyes Dome, the limestones are mainly thin beds. An intermediate cross section between Hamilton County and Gray County (Pl. 12B) shows a similar development, but a somewhat less abrupt change in lithology accompanies the thickening of the upper member.

A final consideration of the stratigraphic setting of the formation is concerned with the upper surface (Pl. 13) upon which some features existing on top of the Mississippian surface are again reflected, for example, the northeast-trending arch through the northern part of the region and the Keyes Dome. Some of the small structures also reappear on the map of the younger surface. In general, however, the surface is shown as having a gentle southern dip that increases markedly into the Anadarko Basin.

To the southeast the Kearny development on the Northwest Oklahoma Platform is similar to that in the adjoining part of Kansas with its clastic limestones, thin coal beds, and well-cemented, glauconitic sandstone and limestone lenses in the lower part. Although the sandstones are sporadic, the basal sandstone is most prominently developed in local lows on the unconformity surface (Barby, 1958, p. 137). The upper sandstones tend to conform to a northwest trend of cleaner sands (Pate, 1959, p. 56; Barby, 1958,

p. 140). On some of the structural highs abundant limestone is developed as local reeflike deposits owing to the action of limestone-secreting organisms, and no sandstone is present (Barby, 1958, p. 140). Although faunal evidence for the Morrowan age of these deposits now is lacking, regional studies suggest such a correlation (Jordan, Pate, and Williamson, 1959, p. 84).

The stratigraphic sequence on the platform represents the thinning toward the northeast from the deeper part of the basin by local overlap of younger units and convergence in the upper parts (Barby, 1958, p. 136). In Ellis County, northwestern Oklahoma, the presumed Morrowan strata have thickened to as much as 1400 feet (Glidden and Borg, 1958, p. 214). In this area and in the panhandles of Oklahoma and Texas the section is more fully a shale sequence containing fewer limestones and sandstones, and Morrowan assignment is based primarily upon lithology and stratigraphic sequence, corroborated by some faunal identifications (Dobervich and Parker, 1958, p. 215). The Morrowan strata in the northern part of the western Anadarko Basin are separable into upper and lower divisions (Totten, 1956, p. 1955) that are comparable in a general way to the upper and lower members of the Kearny Formation of this report in that the lower division is described as having more sandstones, arenaceous limestones, dolomitic limestones, and quartz conglomerates than the upper division with its

light- to medium-gray, thinly-laminated, papery shales. A thin coal bed and underclay mark the top of the Morrowan sequence in places, although other thin coal beds occur in the upper part of the deposit (Totten, 1956, p. 1956).

In this area diagnostic fusulinid control is lacking in the sequence and in the overlying dark-gray to black shale and dark-gray dolomitic limestone of the "Thirteen Finger lime," so that age assignment of and contact placement between units separating Mississippian and Cherokee rocks are uncertain (Totten, 1956, p. 1957).

Although the sequence is slightly thinner than in Morton County, the Kearny Formation on the Keyes Dome is a continuation of the Kansas lithology, mainly as black and gray shales with traces of green and red shales, coal seams, and two or three units of medium- to coarse-grained, subangular quartz washes (Carver, 1956, p. 131). The Atokan deposits are reported to consist of brown and gray crystalline limestones with thin beds of chert and arkosic material. On the dome the thickness of the basal sandstone, Keyes sand, appears to be somewhat controlled by irregularities of the underlying erosion surface developed on the Mississippian rocks, as the sandstone generally thins over the tops and thickens on the flanks of the structures (Carver, 1956, p. 132).

The Kearny Formation continues to thicken westward from Kansas into eastern Colorado where a maximum thickness

of the Morrowan rocks, according to Maher and Collins (1953), is found near the southeastern corner of Colorado in Baca County. The lithology is essentially a continuation of the development in the Kansas part of the embayment, and is described by Maher (1948, p. 7) as consisting of black and green shales; cream, glauconitic, crinoidal limestones; and white, calcareous sandstones. The lithology of the Atokan rocks is likewise the same as in the eastern part of the embayment. A short distance to the west the Kearny wedges out against the flanks of the Sierra Grande Uplift; however, the Morrowan rocks extend farther up the flanks than do the Middle Pennsylvanian deposits (Maher, 1953a, p. 919).

To the north is the northeast-trending Las Animas Arch which is separated from the Apishapa and Sierra Grande uplifts by a narrow sag. The Morrowan deposits thicken off of the arch into this saddle, the Hugoton Embayment, and the Denver Basin (Maher and Collins, 1953). Studies of the rocks from east to west through the sag have shown that the lithology of the lower limestone and shale beds of the Morrowan sequence in the area corresponds to that of the Glen Eyrie Shale which crops out at the Front Range (Maher, 1946a, p. 1761). Also in this area specimens of Millerella have been found in the thin limestones of the Morrowan where the upper part of the unit is arkosic (Maher, 1946a, p. 1761), and have been compared with forms that

Henbest (1946) reported from the Glen Eyrie Shale and correlated with those of the type Morrowan section in northwestern Arkansas. Thus the close relationship is shown between the Kearny Formation and the Glen Eyrie Shale, for the same correlation of fusulinids with the type Morrowan section was made by Thompson (1944) from the type section of the Kearny Formation in Kearny County, Kansas.

The identification of Morrowan, Atokan, and Desmoinesian fusulinids is possible as far west as a line that roughly corresponds to the initial thinning of Morrowan rocks toward the Front Range. West of this line Morrowan deposits comprise the Glen Eyrie Shale, but the younger rocks pass into the arkoses and feldspathic sandstones of the Fountain Formation (Maher, 1958, p. 71). In the Denver Basin a thin section of Morrowan and Atokan rocks is present (Fentress, 1958, p. 79).

Near the Front Range the Morrowan rocks contain some arkosic beds and a few limestones. The Glen Eyrie outcrops show brown, black, and purple shales separated by sandstone layers and a few thin limestone beds (Maher, 1953a, p. 925). The lithologic correlation, Morrowan age of the fusulinids identified by Henbest, and Pottsville age of the plants identified by David White (Finlay, 1916, p. 17), not only date the shale formation, but together with some fossils occurring in thin limestones intercalated with the arkose, they indicate that the thick clastic deposits overlying the

Glen Eyrie and associated with the Apishapa-Sierra Grande Uplift and the Front Range are Atokan to Upper Leonardian in age (Maher, 1958, p. 71).

SEDIMENTOLOGIC REFLECTION OF ENVIRONMENT

Although many writers, such as Mason (1958, p. 285), have pointed out that the sedimentary processes of erosion, transportation, and deposition fundamentally represent the flow of energy from a higher to lower potential or intensity, most geologists have traditionally ignored the energy level aspects of the processes and have concentrated on the materials produced or influenced by the processes, or else they have overlooked the basic energy relationships and, instead, have turned to the study of individual processes. Based upon studies of wave action, stream velocity, and other separate processes, a grouping of environments has been made; for example littoral, paludal, and alluvial environments are commonly recognized. Comparison of the environments so identified, which is necessary in order to gain an understanding of the entire region of sedimentation, is often difficult, however, because of the lack of a common denominator. The organic and inorganic materials deposited in a swamp or on land are not the same as those deposited in a shallow-water marine environment, nor can the processes of formation be compared except as separate and often poorly related factors, such as variations in current velocity, availability of sediment, and fluctuation in water level. Yet, the description of such factors as so

many individuals in a somewhat loose network is the common form used in discussing environments. Sedimentologists, however, are coming to realize that the concept of energy levels forms the common basis for sedimentary processes. Some of the chief works in this field are those of Keller (1954), Pettijohn, (1957), and Folk (1959).

The emphasis on energy levels is not meant to exclude the importance of the materials, for as Keller (1954, p. 66) noted, it is the interplay of the two factors that governs the type of sediment to be found and the nature of the environment. In the present report the drop of energy level throughout the sedimentary cycle is not dealt with, but variations are considered in the lower levels, at the sedimentation end of the cycle.

The variations in energy level, designated as high and low energy-levels, together with variations in materials, appear to have produced several rock types in the Kearny Formation, representing a certain number of environments. The materials preserved are divided into five lithologic classes, using the limestone terminology of Folk (1959): 1) microcrystalline limestones formed of calcareous ooze, 2) allochemical limestones or detrital limestones containing crystalline calcite cement, 3) chemical-matrix sandstones, 4) detrital-matrix sandstones, and 5) clay rocks.

The concept of energy-level-rock-type relationship as a basis for environmental interpretation has been used to

some extent by previous workers. Folk (1959) discussed the limestone-energy level significance. The relationship of sandstone and energy level in the present report is very similar to that recognized by Pettijohn (1957, p. 290, 520, 590). The importance of the two sandstone classes in the interpretation of environments has been noted by Williams, Turner, and Gilbert, (1955, p. 289-324).

Description of the five lithologic classes will be followed by a discussion of the relationship of each class and level of energy to the nature of the environment.

Limestones

The limestone terminology used in this report is a modification of that suggested by Folk (1959). This nomenclature, although including new terms, is more closely related to the energy-level concept than are alternate systems, and is more closely associated with similarly oriented and widely accepted sandstone classifications, such as that of Pettijohn (1957, p. 290). The concepts of a group of limestones composed of calcareous ooze versus one composed of particles of ooze or fossil fragments in a crystalline calcite cement are expressed in the recognition of two families of limestones, the microcrystalline and allochemical limestones, respectively. Most of the limestones in the Kearny belong to the allochemical family.

Biosparite

According to Folk (1959, p. 14) a biosparite is an allochemical limestone with significant fossil remains in a sparry calcite cement. In the Kearny this group is very abundant and forms one of the most common associations with other rock types, especially sandstones.

Shelly limestone. Among the biosparites of the Kearny Formation are a few that consist almost entirely of the shells of brachiopods, particularly productids, and which may more definitely be referred to as shelly limestones. Fragmented remains of crinoidal material are present in some of the rocks, and indeed, a gradation from the present rock type into one with a far greater percentage of crinoidal remains is not uncommon. Some detrital quartz sand grains are also present.

For depositional conditions of the Kearny Formation this rock type is thought to represent an environment characterized by a high level of energy, although not a maximum. The presence of strong or persistent currents is indicated by the absence of microcrystalline ooze associated with the cement, although the possibility of the origin of the cement by recrystallization of the ooze is realized; however, in the present relationship it is judged more likely that current activity, while supporting the population with food, also removed any ooze that might

have been present. The environment appears to have been above wave base and with low turbidity. As it was, and for a while remained, an area where calcium carbonate deposition was dominant, a relatively high pH and, in this area, positive redox potential characterized the association.

In comparison with sandstones the shelly limestone would appear to represent a stage in textural maturity slightly past mid-point, for although the microcrystalline ooze, which would correspond to the clay content of the sandstone, is absent, other factors seem less developed than in different allochemical limestones, or even other biosparites. Providing the application of the concept of textural maturity to these rocks is possible without a significant change in the implications, this conclusion is valid; however, as pointed out by Pettijohn (1957, p. 239) the concept of compositional maturity lacks meaning if applied to carbonate rocks in the same way as to the clastic rocks.

Crinoidal molluscoid calcarenite. An increase in content of bryozoan and crinoid remains distinguishes the crinoidal molluscoid calcarenite from the shelly limestone (Fig. 4). The implication is not intended, however, that gradation from one to the other is a common occurrence in the facies of the Kearny, for the present type of biosparite far exceeds the shelly limestone in abundance.

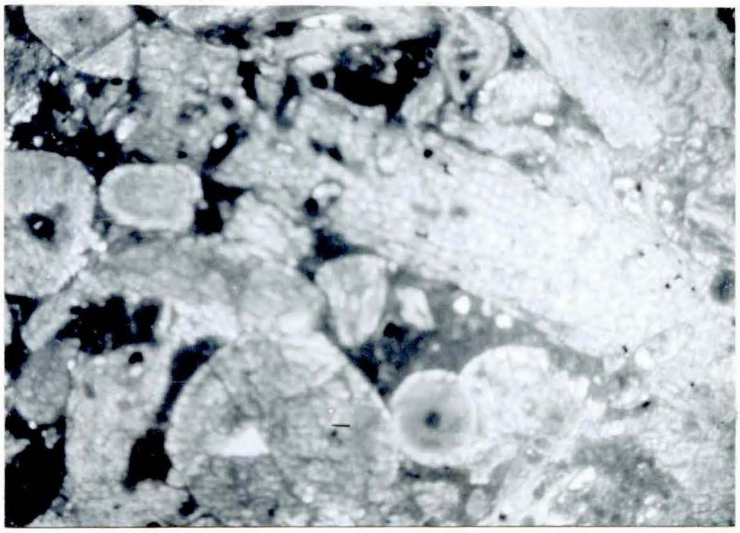


FIG. 4. Photomicrograph of crinoidal molluscoid calcarenite from lower member of Kearny Formation. Note abundance of crinoid and bryozoan fragments. (X35)

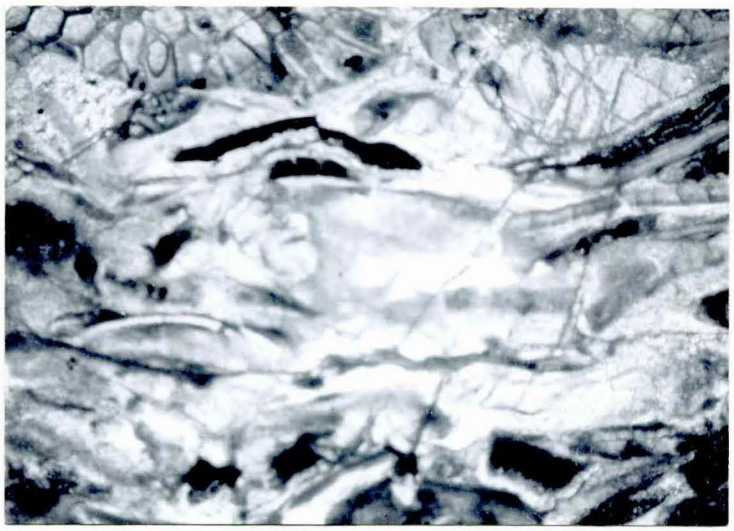


FIG. 5. Photomicrograph of allochems. Intraclasts and fossil fragments, especially bryozoan and brachiopod remains, in sparry calcite cement. From lower member of Kearny Formation. (X35)

The most common type of bryozoans in this rock, the ramose type, have been referred by Elias (1937, p. 418) to the zoarial type described by Stach (1936, p. 60) as indicative of sheltered or deep water with little wave or current action. This assignment would mean that the skeletal fragments in the rock had been brought to the site of deposition, possibly by translation waves from slightly deeper and quieter water farther from shore, a distributive method suggested by Laudon (1957, p. 962) to account for disarticulated crinoid remains. Indeed, as fragments of these two animals are associated together in the calcarenite, such a dual purpose transport could have been active.

Many of the factors governing the formation of the shelly limestone likewise control the calcarenite. Although slightly different conditions might characterize the habitats of the bryozoans and crinoids, the subsequent deposit is a continuation of the processes forming the previous rock type. Perhaps the most important change, although it is still only one of degree, is the increase in level of energy in the environment assumed to be represented by the calcarenite. This conclusion seems well borne out by the composition of the rock. The various particles forming the framework of the rock, comprising so-called allochems, include some particles of microcrystalline limestone called intraclasts (Folk, 1959, p. 4) in a sparry calcite cement (Fig. 5).

Crinoidal calcarenite. With lessening abundance of the brachiopod and bryozoan remains, the biosparite passes into a crinoidal calcarenite that is essentially a mixture of crinoid columnals and intraclasts. Although crinoid remains are ubiquitous in the allochemical limestones, common in the microcrystalline ones, and are present in many of the sandstones and shales, their acme is represented by this type of biosparite and a quartzose variety (Fig. 6).

The size of the crinoid columnals in the Kearny Formation varies greatly, reaching a maximum of more than 1 cm in diameter. Generally the smaller stems are associated with finer-grained rocks in less dynamic environments. Most of the stem fragments in the crinoidal calcarenite are large, and not uncommonly are found with fine to medium grains of detrital quartz in a variety of rock more accurately referred to as a quartzose crinoidal calcarenite.

The paucity of crinoidal remains other than stem fragments can be explained by several hypotheses, such as the absence being due to the presence of predators; however, Laudon (1957, p. 961) noted that a minor disturbance of the environment after death produces major disarticulation of the skeletal parts. Of the various parts so separated, the small subspherical columnals or subrounded stem fragments would be most susceptible to mechanical transport. Indeed, of the three types of biosparite discussed, this type might represent a more texturally mature variety.

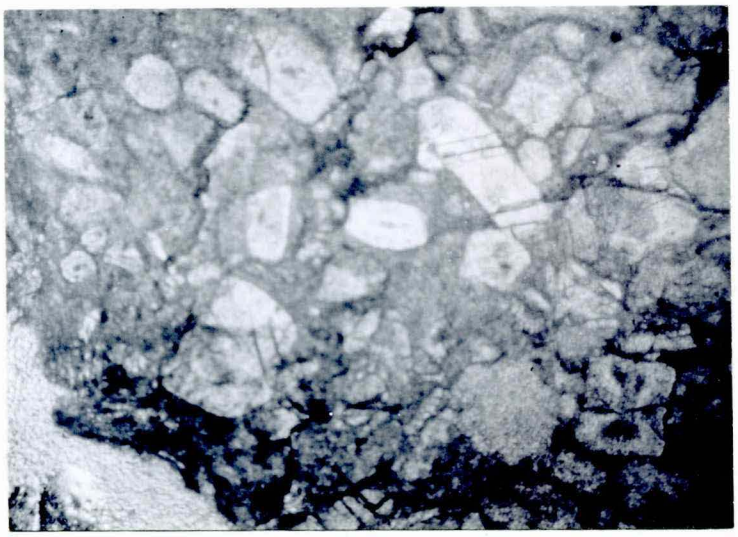


FIG. 6. Photomicrograph of crinoidal calcarenite from lower member of Kearny Formation. Crinoidal debris in a very fine-grained sparry calcite cement. (X35).

The quartzose crinoidal calcarenite, which is at least equally as common as the non-quartzose variety, is produced by terrigenous additions to the rock, mainly as detrital quartz sand grains but in places also as sparse feldspar or rock fragments. Reflecting more on conditions of dispersal than those of deposition, the two biosparite varieties are quite compatible, and the transitional nature of the Kearny sedimentation is commonly displayed in the repetition of the two types.

The quartzose variety represents by its influx of terrigenous material the beginning of a gradation from biosparites into a highly transitional rock type whose parameters of environmental significance are more extrabasinal. This rock type, the quartzose calcarenite, will be described later.

The general conditions of formation of the various types of biosparites are essentially the same, but some modifications of low-order environmental importance are effective. The modifications are referred to as fourth-order variations in lithology to distinguish them from the higher order changes producing a shift from limestone to sandstone accumulation. Inasmuch as the principal delimiting components of the biosparites are the animal types, a convenient way to relate the varieties is on this basis (Fig. 7).

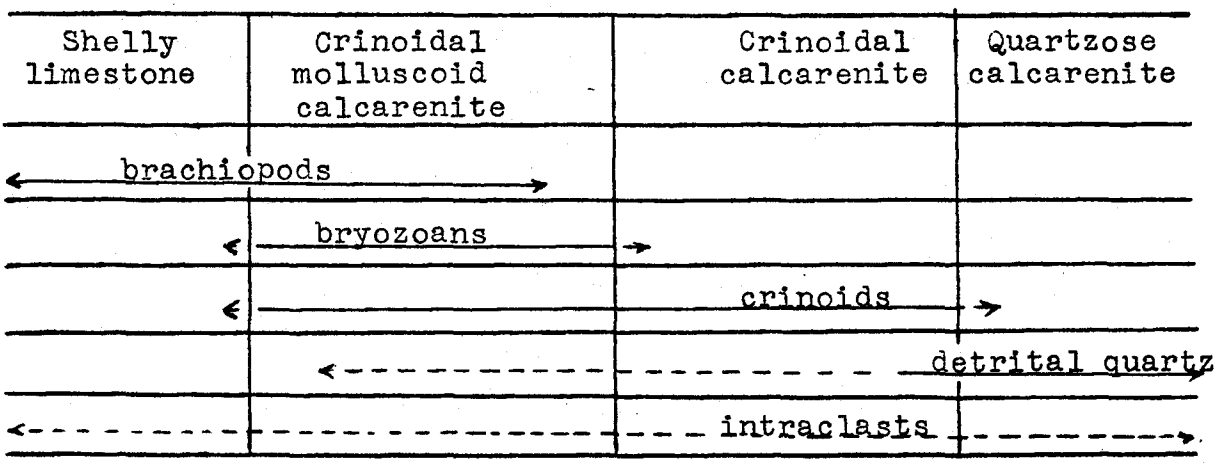


FIG. 7. Variation between biosparite types and principal components.

Oösparite

The second group of allochemical limestones termed oösparites, are differentiated from the biosparites on the basis of a higher percentage of oölites, rather than by the lessening of fossil remains (Folk, 1959, p. 14). In the Kearny Formation, indeed, only a slight decline in organic remains distinguishes the two rocks, and some of the biosparites are even oölitic. The close relationship of the two types is not unexpected, however, for they represent only third-order variations in lithology. Subdivisions of the oösparite group, as for the biosparites, are classed as fourth-order variations.

Although oösparite is a very minor lithologic type in the Kearny, it is significant as a depositional indicator.

Its importance in environmental studies has been expressed so often that only a brief discussion will be made here. The alkaline pH, positive redox potential, dominant calcium carbonate deposition, and low turbidity characteristic of the environment are less important reflections of the rock than are some other parameters. In fact, the dynamic aspects in an environment are probably best shown or at least most apparent in an oösparite. Studies of oölites, such as that by Illing (1954), have shown that the rock is characteristic of areas above wave base with strong or persistent currents, i.e., environments containing factors and agencies of high energy-level, or more simply high-energy environments. Although a similar environment is pictured for the biosparite, it is judged that the oösparite represents an environment containing high energy-levels, particularly when features such as common cross-bedding are considered.

The oösparite possibly represents the closest approach to textural maturity in the limestones consisting solely of intrabasinal components. Certainly the well-sorted oösparite is closely comparable with a well-sorted quartzose sandstone in sorting, roundness, and nature of cement.

According to Pettijohn (1957, p. 402), some geologists attribute the sparry cement of oölites to recrystallization of original microcrystalline ooze. As Folk (1959, p. 22) points out, however, the different energy-levels characterizing the oölite-forming and microcrystalline ooze-producing

environments would lead one to consider the oölitic oozes as uncommon associations, and therefore the recrystallization of lesser importance. A variation in current velocity, of course, could produce a cement of different texture.

Commonly associated with the oölites are similar size pseudo-oölites formed by calcareous algae encrusting a shell fragment or other base. Such an association likewise indicates the well-aerated environment with sufficient current activity to permit overturning of the algae base and the encrustation to surround the object (Fig. 8).

Intrasparite

The third group of allochemical limestones is the so-called intrasparite group, which consists of sparry calcite cement filling a framework composed of intraclasts. Although most of the intraclasts in the Kearny are particles of microcrystalline limestones, the intraclasts defined by Folk (1959, p. 5) represent "the entire spectrum of sedimented, aggregated, and then reworked particles [of carbonate sediment], regardless of degree of cohesion or time gap between deposition of the original layer of sediment and later reworking of parts of it." Some of the intrasparites in the Kearny Formation are particulate in a size and manner more readily understood by describing them as conglomeratic limestones; however, less dynamic conditions of origin are characteristic of the Kearny intrasparites as a whole.

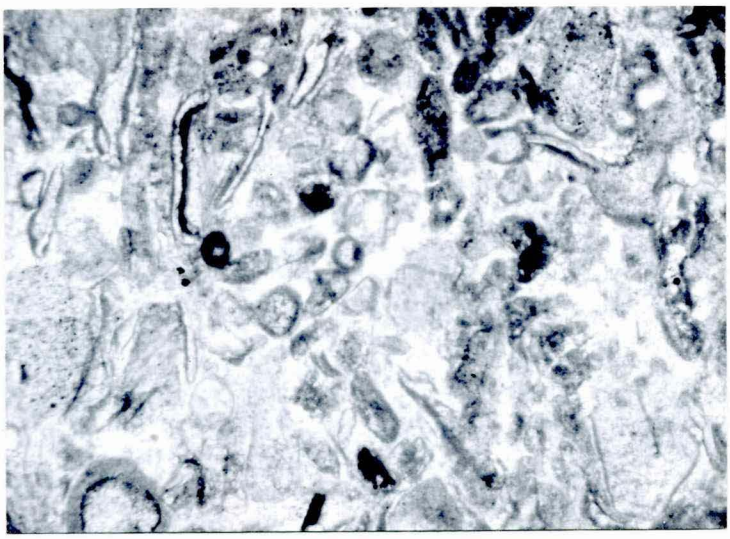


FIG. 8. Photomicrograph of algal oösparite from lower member of Kearny Formation. Note algal coating on shell fragments and difference in size from accompanying oölites. Rare lithologic type in Kearny. (X30).

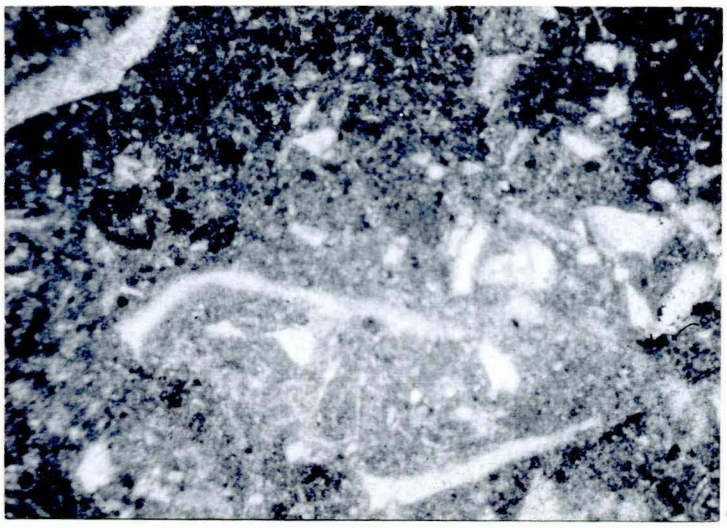


FIG. 9. Photomicrograph of microcrystalline limestone with stringers of sparry cement. Note absence of intraclasts and fossil fragments. From upper member of Kearny Formation. (X35).

Whereas the original delimiting value of intrasparite was established as 25 percent by volume of intraclasts out of a total allochem composition of intraclasts, oölites, fossils, and pellets, a slightly higher boundary is used in this report. The original definition of intrasparite regarded intraclasts as most important because of the implied lowering of wave base or possible tectonic uplift. Even though this is a valid argument, the fossil content, and to a lesser degree the oölitic composition, seem to be very significant to the understanding of conditions in Morrowan time. Limestones of later Pennsylvanian and of Permian ages in the Midcontinent have been shown by numerous writers to contain even more environmental and depositional significance if the biotic content is given a high place in considering the rock. Therefore, the rocks described here as intrasparites would probably form a small part of the group as originally defined.

Variations within the intrasparite group are due to additions of detrital quartz grains or fossil fragments to the rock, but a medium to high energy-level in the environment is still indicated. Inasmuch as the intraclasts are principally composed of dense limestone, probably representing a microcrystalline ooze, a significant change in energy-level in the environment is suggested. Such a change could well be due to a lowering of wave base as suggested by

Folk (1959, p. 22); this change, corroborated by other lithologies and the faunal remains, reflects the metastable environments of much of the Kearny Formation.

Micrite

A second family of limestones, the microcrystalline limestones, is recognized by Folk (1959, p. 12) as consisting almost entirely of microcrystalline ooze with few allochems (Fig. 9). Many factors of the environment are the same as for the allochemical limestones, but differences exist which are judged in this report to represent second-order variations in lithology, to distinguish them from the lower order variations within the family.

Not only can microcrystalline types be found that are correlative with each of the allochemical types, but an endemic type is also present. The micrite group, defined by Folk as consisting almost entirely of microcrystalline ooze (Fig. 10), has no representative in the allochemical group, for obviously a rock composed entirely of sparry calcite cement would not be formed.

The fact that micrites represent lower energy-levels than the allochemical rocks is shown by the absence of strong or persistent currents that would carry away the ooze. Any currents present would be sporadic and weak, indicating that the environment was below wave base;

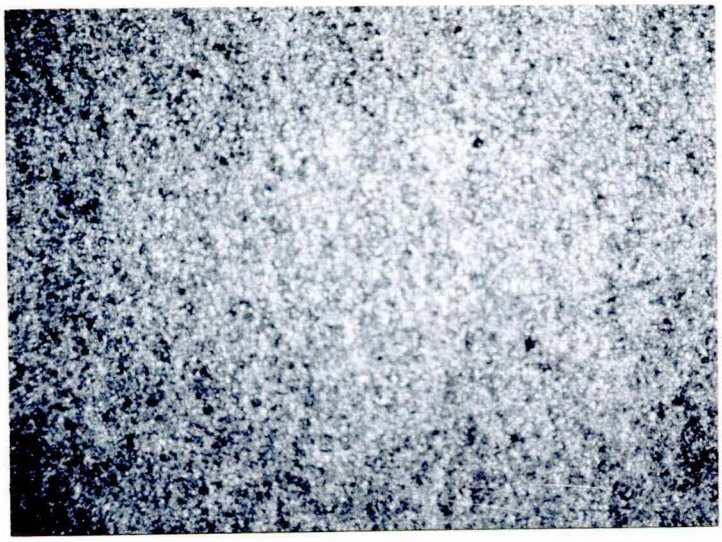


FIG. 10. Photomicrograph of micrite from upper member of Kearny Formation. Low energy-level shown by very fine grain size and absence of coarse material. Associated with dark, thinly-laminated shales. Uncommon in lower member. (X35).

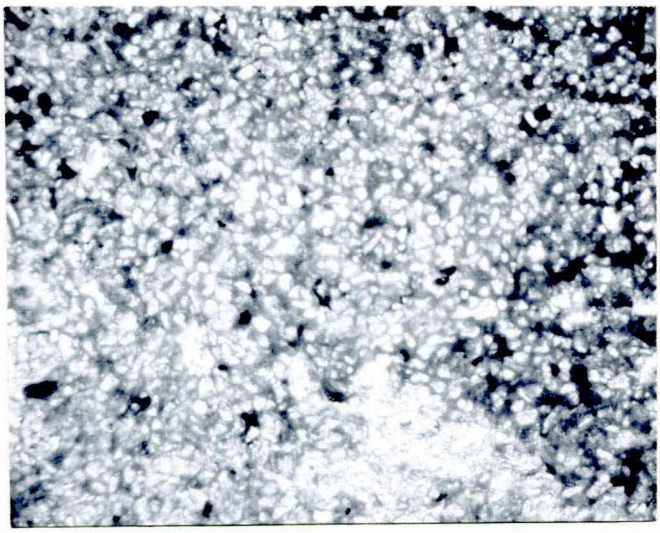


FIG. 11. Photomicrograph of fine-grained sandstone from lower member of Kearny Formation. Quartz grains well-sorted and subangular; typical Kearny sandstone. Compare size of grains with micrite ooze of Figure 10. (X35).

however, it does not seem necessary to conclude that the water was relatively deep, for an area of shallow and sheltered water could conceivably produce the same results.

The pH of the environment may not have varied much, but the redox potential is thought to have been less constant, as shown by the dark, pyritic limestone indicating possibly a more reducing environment than for the rest of the rock. Although the water at times may have been relatively clear, the common argillaceous impurities reflect the presence of local turbidity that produced a rock type having even less textural maturity.

The micrites of the Kearny Formation are more common toward the top of the unit, although not all the dense argillaceous limestones of Atokan-type lithology are classified in this category, particularly because many of them are fossiliferous. The relationship between micrite and shale is determined by a first-order variation in lithology as shown by change in the ratio of microcrystalline ooze and clay flocculates. The relationship with the most closely associated allochemical limestone is shown by the intrasparite being composed of particles of micrite. The mere change in energy-levels of the latter relationship is judged to represent a second-order variation in lithologic controls.

Biomicrite

With addition of fossil remains micrite grades into biomicrite, a rock that is also very common in the upper part of the Kearny. The absence of other representatives of the microcrystalline rocks is probably due to the metastable environments characterizing Kearny deposition and, as pointed out by Folk (1959, p. 22), the generally uncommon relationships required for the origin of the other rocks.

Most of the faunal remains in the biomicrite, as the thin-shelled brachiopods, indicate a low-energy environment similar to that of the micrite.

Quartzose Calcarenite

Although it is not included in Folk's classification, the term quartzose calcarenite is here applied to the rock type spanning the border between the allochemical limestones and the calcareous sandstones. It is considered basically as a limestone containing very abundant quartz sand grains. In the Kearny this highly transitional rock is more closely related to the biosparites than to any other group of allochemical limestones.

The common occurrence of the quartzose calcarenite is especially worthy of note in that it appears to represent the highest energy-level in any of the Kearny environments.

This conclusion is based on the possible progression away from the rock through types reflecting lower levels in both the limestone and sandstone divisions. In the limestone division the levels are represented by the various biosparites shown in Figure 7, and in the sandstone divisions they are shown by a series including the calcareous sandstones, less-mature sandstones with chemical cement, and detrital sandstones.

The quartzose calcarenite, therefore, combines many of the environmental indications of the allochemical limestones and the sandstones, and depending upon the regimen of which of these prime lithologic divisions is dominant at a given locality, the rock can be considered either a limestone or sandstone. The facies change from porous sandstone to quartzose calcarenite is thought to be important in the formation of stratigraphic traps for petroleum and natural gas in the Kearny rocks.

Sandstones

Although limestones vary in their environmental representation, the common types can be somewhat well-assigned to origin. With sandstones, however, the relationship is not so simple, and many detailed analyses are necessary before certain environmental implications can be drawn, if then. Yet, there are certain depositional characteristics of the sandstones that can be inferred from a regional

study of this sort. The rocks are considered under the main groupings of subgraywacke, feldspathic sandstone, argillaceous sandstone, and micaceous siltstone.

Subgraywacke

Most of the sandstones in the Kearny Formation are relatively pure quartz sandstones with only minor amounts of feldspar and rock fragments; however, they lack the high degree of grain roundness and blanket deposit shape of the quartzose sandstones (orthoquartzites) of Pettijohn (1957, p. 296, 298). These sandstones are therefore assigned to the subgraywackes, although the low percentage of rock fragments might better establish them in the "protoquartzites" of Krynine (Payne, and others, 1951, sheet 2) which Pettijohn states may form by the "cleaning up" of subgraywackes. This association is similar to some of the lower sandstones described by Siever (1957, p. 235) in the Eastern Interior Basin.

Although several variations of the group are represented in the Kearny succession, a single variant need not always reflect the same range of environmental conditions where ever encountered in the section, at least on the level of study here undertaken. The characteristics of a sandstone which might distinguish it as a deltaic, lagoonal, or tidal deposit are not nearly so evident as similarly significant clues in the limestones described above. Lithologic details

and the relationship to contiguous deposits are highly significant to an understanding of origin.

The most common type of sandstone is a gray, fine-grained, subangular, calcareous sandstone which generally contains small pellets of glauconite (Fig. 11). Each of the characteristics varies within certain limits; however, the main features are an association of small grain size, subangularity of grains, minor mineral components other than quartz, and a mineral cement. Regardless of these variations or others, such as nature of grain contacts, certain depositional conditions are very similar to those of the allochemical limestones.

An environment of strong or persistent currents is indicated by the lack of fine detritus or microcrystalline ooze, thus suggesting a location above wave base, although this includes a wide range in environmental types. The lack of fine detritus in the matrix, together with the fair to good sorting but low degree of roundness, indicates a rather high level of textural maturity, which is accompanied by an advanced stage of compositional maturity shown by the high quartz content or the quartz/feldspar ratio.

The principal chemical parameters of the environment could have varied appreciably, especially the pH, the exact conditions somewhat reflected by the precipitates forming or other minerals present. Nevertheless, a relatively high energy-level is assumed for the sandstone

accumulation, irrespective of the precise local nature of physical conditions.

Another principal type of subgraywacke is the gray, coarse-grained, subrounded, calcareous to siliceous sandstone (Fig. 12). Not only does this type differ from the other one in grain size and degree of roundness, but the quartz grains are also different, or at least the present sandstone includes grains not represented in the other type. Essentially the coarse-grained sandstone contains an addition of yellow and rose quartz grains and has more variable cementing material. The two types generally grade into one another, for the coarser one represents only a slightly higher energy-level and is more common at the base of a depositional unit. Gradation into quartzose calcarenites is more common with the finer sandstone.

A third type of subgraywacke is gray conglomeratic sandstone. Basically this rock represents conditions that include the controls of both the previous types of sandstone. Gradations can be found from basal conglomerate through coarse-grained sandstone into fine-grained sandstone, and then into quartzose calcarenite. Such a progressive relationship might be best thought of as one indicating an increasing loss of dispersal energy.

Several highly transitional rocks occur that cannot be adequately classified. Fortunately these types do not form thick sections in the Kearny, but they are important

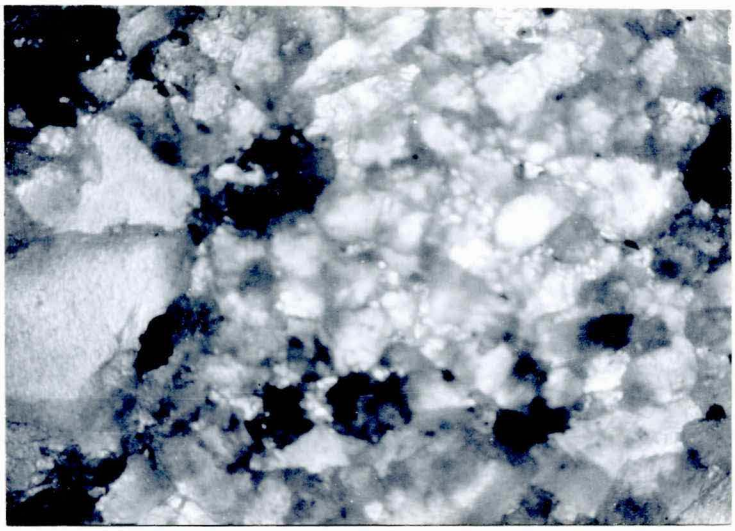


FIG. 12. Photomicrograph of coarse-grained sandstone from lower member of Kearny Formation. Poorly sorted but with higher degree of roundness than typical Kearny sandstone. Occurs as subgraywacke or feldspathic sandstone. (X35).

in showing the gradational of the rock types. One of these sandstones might be called a calcareous quartzose sandstone, a type that is closely related to the quartzose calcarenite in that it consists of isolated grains of subrounded, well-sorted quartz sand in a cement of light-brown, sparry calcite.

Feldspathic Sandstone

Sandstones of the Kearny Formation do not contain abundant grains of feldspar in any part of the region, although some sandstones have a small feldspathic content which is thought to be significant enough to warrant separating them from others in the formation. Mainly the rocks are gray, fine-grained, subangular, slightly feldspathic sandstones, commonly containing some rock fragments and small pellets of glauconite. Only a small increase in feldspar content distinguishes these rocks from the subgraywackes.

Geographically the sandstones are most common in the western part of the region, especially along the flanks of the Keyes Dome; and stratigraphically they are most common in the lower member. To the east they grade into the subgraywackes or quartzose calcarenites.

The prime change in environmental factors noted in the sandstones is the lessening of compositional maturity, as shown by the lower quartz-to-feldspar ratio. Otherwise,

most of the controls are the same, or more accurately, they vary within limits similar to those of the other sandstones with detritus-free matrix. Owing to the small amount of feldspar in many of the sandstones, only a slight shift in conditions of provenance or dispersal could change the classification of the resulting deposit from feldspathic sandstone to subgraywacke.

Argillaceous Sandstone

Recognition of argillaceous sandstones as a separate group in the formal classification of sandstones is not reflected in the works of Pettijohn and others. In relation to the sandstones of the Kearny, however, the designation, argillaceous sandstone, seems warranted in order to delimit a particularly common group of rocks and a certain interrelation of rock types.

The argillaceous sandstones are fine-grained rocks containing common to very abundant black shale laminae. Actually, a series of types is present between end points of fine-grained sandstone and black shale, but the variations also include changes in evenness and thickness of lamination, in addition to differences in composition.

At the sandstone end of the series the environmental factors are those of the subgraywackes or feldspathic sandstones, but lower energy-levels would be necessary for the deposition of the shale. For the rock as a whole, the

environment appears to have been mainly below wave base, contained weak or sporadic currents, and permitted little calcium carbonate deposition. The compositional maturity of the sandstone is somewhat greater than the textural maturity. Chiefly the environment represents alternating conditions of turbidity, as reflected with other factors by the shifts in energy-levels in the environment from sandstone to shale deposition.

Micaceous Siltstone

Although not forming a large part of the Kearny section, micaceous siltstones are locally very important, especially in the upper member. The siltstones, which are light-colored and contain an appreciable amount of white mica flakes, grade into silty limestones and very fine-grained sandstones. The most common occurrence is in the western part of the region.

The fine size of detritus forming the rock, together with the common very-fine lamination and abundant mica flakes on the stratification planes, indicate depositional conditions more similar to those of the microcrystalline limestones than the dynamic environments of the chemical-matrix sandstones and allochemical limestones.

Shales

The classification of shales used in this report is less formally organized than is that of the sandstones or limestones, primarily because such an organization for the argillaceous sediments involves a study of the clay mineralogy. A petrologic study of the Kearny shales would be an interesting, important, and rewarding investigation in itself. Such a study was undertaken by Weaver (1958) on the Upper Mississippian and Lower Pennsylvanian deposits of most of the central United States. Samples from northwestern Oklahoma and southwestern Kansas were included, but formed a very minor part of the study.

Weaver noted a difference in the clay minerals in the Chesteran, Springeran, and Morrowan rocks, and carried this distinction into the northwestern part of the Anadarko Basin. A transitional zone consisting of mechanically mixed Morrowan and Chesteran shales separates the thicker, illitic part of the Kearny from the mixed-layer clays of the Chesteran shales. Where Springeran rocks separate the Chesteran and Morrowan beds, Weaver showed the transitional zone to occur between the Springeran and Morrowan deposits. In the part of southwestern Kansas where the Kearny is thin, Weaver found the shale to be composed more of mixed-layer clays than illite and thus mineralogically akin to the transitional zone. The overlying Atokan shales are composed dominantly of montmorillonite and mixed-layer clays.

Farther west the influence of western source areas changes the clay mineral content of the shales.

On the basis of the delimiting features used in the present study, the shales of the Kearny show only slight variation in many of the depositional controls. Four types of shale are recognized: 1) unfossiliferous, dark, thinly-laminated shale, 2) fossiliferous, dark, thinly-laminated shale, 3) arenaceous shale, and 4) reddish-brown, blocky shale. The first type is by far the most common.

Unfossiliferous, Dark, Thinly-laminated Shale

An unfossiliferous, dark, thinly-laminated shale is quantitatively the most common lithologic type in the Kearny Formation. Chiefly the shale is medium- to dark-gray, but thick sections of black shale are present. Interlamination with the gray shales as well as the dark color of the green and brown varieties places them also in this group. Many of the black or dark-gray shales are genetically very close to the green shales, as is shown by the very common interlobation of gray and light-green colors along lamination planes. Some isolated patches of green occur in the black shale.

Practically all the shales consist of thin laminae, and only a few local varieties are blocky, this feature rather being characteristic of a different type of shale. Some of the dark-gray shales and most of the black shales

are fissile. All in all, an environment characterized by a low energy-level is indicated for the shales with weak or sporadic currents, little wave action, and similar moderated factors.

Fossiliferous, Dark, Thinly-laminated Shale

The addition of fossil remains of various organisms to the several varieties of dark, thinly-laminated shale produces a type of deposit that for the sake of brevity is referred to as fossiliferous shale. The various types of fossiliferous shale include light-green to gray shales containing common ramose bryozoans and indicating a habitat of little disturbance. Such an association may represent the source of the bryozoan remains in the crinoidal molluscoid calcarenite. Some thin-shelled brachiopods occur in the shale, but are more common in the dark, impure limestone intercalations. Local accumulations of ostracodes are also present.

Probably the most characteristic fossils in the shale are pelecypods and plant remains. The nuculid and myalinid pelecypods are not common in the section but are probably more abundant than the brachiopods, gastropods, and ostracodes, and according to Elias (1937, p. 411) represent nearer-shore environments. Newell (1942, p. 16) points out that the Paleozoic Mytilacea lived in shallow turbid waters of the shore zone, and according to Krumbein (1947, p. 102)

particularly the brackish environments. Some of the mollusks occur in the section very close to horizons containing orbiculoid brachiopods. These phosphatic brachiopods are also considered indicative of brackish water environments (Moore, 1948, p. 126). The recognition and division of the fossiliferous shales into shales with plant remains, those with orbiculoids and pelecypods, ones with calcareous brachiopods and bryozoans, and a final group with supplementary gastropods and crinoid remains aggregates the various components of the shales into certain relatively closely related groups.

Plant remains in the shales are mainly in the form of carbonaceous films which represent the finer fragments of the plants; however, a few seedlike remains are present, as are some markings which possibly represent rootlets. Ordinarily these shales are associated with the thin coal beds, and some, such as those containing the rootlet markings, are found directly beneath the coals. A coal bed is not always developed in the sequence, however.

The presence of pyrite and the small stature of some of the fuanal remains, together with the thinness of their structural units, indicate that much of the dark shale, including the fossiliferous shale, was formed under reducing conditions.

Arenaceous Shale

The arenaceous shales of the Kearny Formation are chiefly developed in association with the argillaceous sandstones. Essentially the shales are of two types. One type contains isolated fine to medium grains of quartz sand, whereas the other one contains thin laminae or microlenses of very fine-grained sandstone. Although several types of shales contain the isolated sand grains, particularly the red shales, the association of sandstone laminae and lenses is practically restricted to the dark-gray and black shales.

The depositional controls of the arenaceous shales of either type indicate a two stage development which is reflected as changes in energy-levels. On the one hand the quiet conditions of shale formation are augmented by the increased energy of the environmental factors as indicated by the introduction of coarser material into the milieu. A subsequent drop in energy-level, possibly represented by a lessening of current velocity, caused deposition of the isolated quartz sand grains; however, the velocity was not sufficient for erosion of the clay material forming the base (see diagram, Hjulström, 1939, p. 10). Similarly, periods of increased energy, such as those characterized by storm waves or local currents, could account for deposition of the laminae or produced the microlensoid features in the shale. In the intervening time quiet conditions

of deposition prevailed when thinly-laminated shales were laid down.

Reddish-brown, Blocky Shale

Although reddish-brown, blocky shales occur throughout the region, they are not particularly common except toward the eastern and northern margin of the depositional area, where they are also more arenaceous. Probably they are related to the brown shales in the dark, thinly-laminated shale section, and represent more highly oxidizing conditions of deposition.

Coal

The thin coal beds of the Kearny are associated with the dark, thinly-laminated shales, and commonly overlie thin beds of clayey shale that contain rootlet marks and appear to be underclays. Therefore, many of the coals are judged to be autochthonous, especially those occurring in the upper part of the formation and marking the top of the Kearny in much of the region. Some of the thin coals in the middle part of the unit may consist of transported material.

Summary

The lithologic types represented in the Kearny Formation are grouped into five classes: 1) microcrystalline limestones, 2) allochemical limestones, 3) chemical-matrix sandstones, 4) detrital-matrix sandstones, and 5) clay rocks. Closely associated with the classes are four orders of variation in lithology. The five classes can be reduced to the standard three divisions of limestone, sandstone, and shale, delimited by first-order variations in lithology. An even more fundamental grouping, however, might place the microcrystalline limestones and shales together, as distinct from the "cemented rocks." The relationships of many of the environmental parameters, particularly the associated energy-levels, tend to indicate the validity of such a two-fold classification; however, several of the critical factors must undergo a slight change in meaning as the observer shifts from the extrabasinal material to the intrabasinal material, and the significance of the change has not yet been sufficiently evaluated.

If, then, one assumes a first-order variation between the limestones, sandstones, and shales, second-order variations occur between the allochemical and microcrystalline limestones and between the chemical-matrix and detrital-matrix sandstones. Second-order variations within the clay rocks are probably related to the clay mineral content, and

therefore are unrecorded here. Thus the five main classes of lithology are established.

As noted previously, sedimentation is governed mainly by the nature of the materials and the level of energy in the environment. Although this relationship has been discussed by several writers, such as Keller (1954) and Folk (1959), some features have not been noted. The five classes of sedimentary material recognized in this report grade into each other in a circular pattern of clay rock: microcrystalline limestone: allochemical limestone: chemical-matrix sandstone: detrital-matrix sandstone. The gradation also reflects energy-levels in the environment, in addition to changes in material. Clay rocks are formed at the lowest energy-levels of the environmental factors. Increased levels are represented by microcrystalline limestones, and then allochemical limestones on one side of the gradation circle, and by detrital-matrix sandstones, followed by chemical-matrix sandstones on the other side. The recognition of such a relationship of material and energy is essential to a fundamental view of sedimentation. Whereas previous methods of environmental studies, dwelling on such features as tides and currents, cannot include continental and marine environments as variations of the same few factors, interpretation in terms of energy levels and types of deposits makes this possible. Therefore it is judged to represent a more fundamental approach to paleoecological analysis.

Within each of the five lithologic classes third-order variations produce types that show difference in the main components of the rock framework, such as intraclasts or oölites in the limestone, or significant feldspar and rock fragments versus solely quartz in the sandstone. In the latter relationship the varieties are equivalent to stages of compositional maturity in the sandstone. When the concept of compositional maturity is applied to the clay rocks, it is likewise reflected in a series of third-order variations: 1) clay particles, 2) feldspar and rock fragments addition with quartz, and 3) quartz addition. The addition of quartz to clay particles forms shale, the most mature form of clay rock. Admittedly the application of the concept to the clay rocks involves a slightly different interpretation. The limestone series of spar or ooze, intraclasts, and oölites can be similarly classed; however, at the present time these third-order changes are not put into a genetic series.

Fourth-order variations within each of the third-order compositional types, such as the various biosparites or calcareous sandstones, are considered to represent minor variations in the energy-level of the environment, commonly indicated by the textural maturity of the rock. Inasmuch as energy-levels are thought to be very low during the formation of clay rocks, the variations are poorly-expressed, except in the nature of the nonclay fraction. It is on

the basis of this fraction that the variations are recognized.

The five rock classes can be grouped in various ways with relation to individual environmental features. Thus the allochemical limestones and chemical-cement sandstones are set off from the other classes by environments above wave base with strong or persistent currents and a more common positive redox potential. A progression is evidenced from the clay rocks through the microcrystalline and allochemical limestones with a mirror image progression through the detrital-matrix and chemical-matrix sandstones in regard to increasing energy-levels, decreasing turbidity, and increasing textural maturity. The clay rocks, detrital-matrix sandstones, and to some extent the chemical-matrix sandstones are delimited by the masking or prevention of calcium carbonate deposition and an accompanying higher variability in pH content of the environment.

AGE AND DEPOSITIONAL HISTORY

Tectonic Framework

In considering the age and depositional history of the Kearny Formation and contiguous strata in the subsurface of western Kansas, more than merely paleontologic and lithologic composition of the units is involved, for the presence and distribution of these components reflect many aspects of the tectonic and sedimentologic environment. Because of these relationships, the tectonic framework of the region during the time of accumulation of these strata should be an important element of the study.

Although from the previous discussion of the composition of the Kearny it is obvious that the formation in this region does not record strong diastrophic movements, the bounding unconformities indicate the possibility of very important events in earth history having occurred during the time represented by no deposits. Therefore, in a tectonic sense the Kearny is important for indicating what occurred before and after its deposition, and what did not happen during its accumulation.

The main tectonic features of the region and bordering areas are shown in Figure 1, although not all the features were produced at the same time nor during the formation of Kearny deposits. The northwest-trending Anadarko Basin

and Hugoton Embayment are bordered on the northeast by the positive features of the Central Kansas Uplift and associated structures. Trending parallel to the embayment on the southwest, is the Wichita axis which continues to the Front Range and Ancestral Rocky Mountains. The Kearny Formation occupies the more stable, yet continually subsiding, area between the positive features (Pl. 14A). Within the depositional area of the Kearny are several small structures; however, the only ones worthy of note are the Las Animas Arch in eastern Colorado and the Keyes Dome in the Oklahoma panhandle (Pl. 14B).

Deposition of Mississippian Rocks

According to Maher and Collins (1949, sheet 1), Mississippian deposition in the area reached its northernmost extent in Meramecian time and a gradual retreat of the sea over the low-lying area characterized the remainder of the Period. Not only do Chesteran deposits differ from the older Mississippian rocks by being restricted to the southernmost part of the region, but also by containing more clastic material, although it is of fine-grain size.

Characteristically the Mississippian rocks, excepting Chesteran strata, are composed of limestones and dolomites, very commonly cherty (Lee, 1940), and as such represent more stable and less turbid conditions of deposition than occurred during later times. The addition of shales and

sandstones to Chesteran lithology indicates a change in regimen, and indeed, the Chesteran deposits are separated from the Meramecian limestones by an unconformity that represents the removal of a thick section of older rocks (Lee, 1940).

Chesteran sediments in the region are thought by Weaver (1958, p. 302) to have come chiefly from the Central Kansas Uplift and related northern areas. As the sea continued to recede, the area of deposition was reduced until the first subsidence of the Anadarko Basin occurred, outlining the depositional area (Beebe, 1956a, p. 121). Indication of strong orogeny during this time, however, is lacking (Van der Gracht, 1931, p. 1011).

Therefore, just prior to the end of Mississippian time a relatively thick sequence of shallow-water-platform carbonates was capped by the somewhat more tectonically unstable deposits of the Chesteran which complemented the newly subsiding area of the Anadarko Basin.

Morrowan-Mississippian Boundary

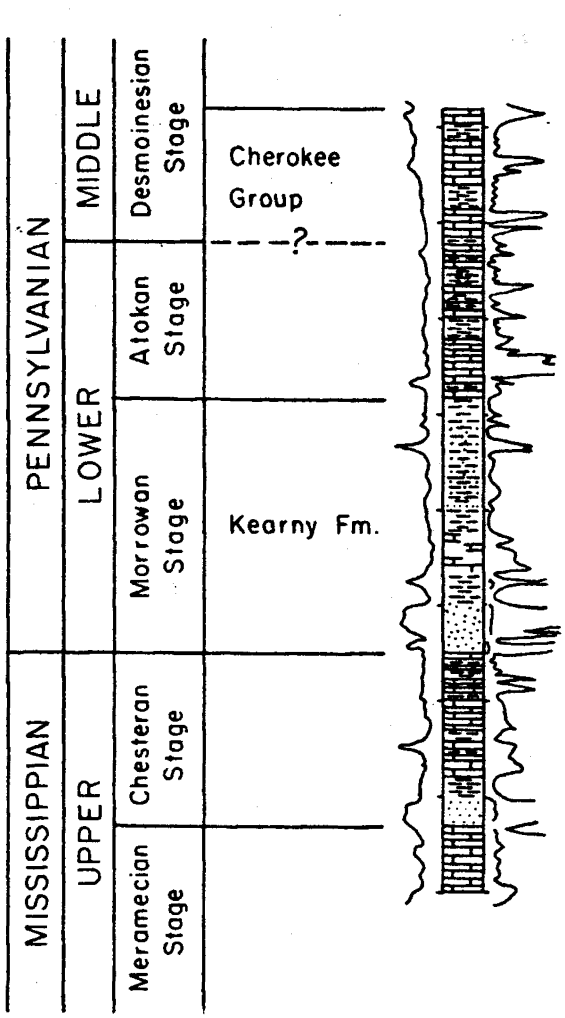
The Kearny Formation in the original description was assigned a Morrowan age on the basis of the presence of the fusulinid Millerella and the absence of more specialized forms (Thompson, 1944, p. 413). As has been explained in many papers, Millerella and Paramillerella are the sole

fusulinid genera in the Lower Pennsylvanian rocks of this country, and therefore these rocks are referred to as the Zone of Millerella (Thompson, 1945, p. 40; Moore and Thompson, 1949, p. 290). Although the genus Millerella occurs in Chesteran deposits in some places, Paramillerella has been reported only from Morrowan rocks (Thompson, 1951, p. 118); however, the latter association has not yet been recognized sufficiently to warrant using the genus as a Morrowan guide fossil.

The genus Millerella also continues into younger Pennsylvanian deposits as probably does Paramillerella; however, it is intimately associated there with more advanced forms in the family.

A brief study was made of the fusulinids contained in some of the samples and cores. Below horizons containing Fusulina species of Middle Desmoinesian age occurs a sequence that includes forms transitional between Fusulina and Fusulinella. In the dark limestone and shale succession are small specimens of Fusulinella that appear to be as old as Middle Atokan (M. L. Thompson, personal communication). Below this sequence is the dark shale of the Kearny Formation with its thin limestones containing Millerella and Paramillerella (Fig. 13). The remainder of the fauna is less definite than the fusulinids in age determination.

The main fossils in the Chesteran strata, Archimedes and Pentremites, are not restricted to the Mississippian,



*Fusulina, *Wedekindellina, Mesolobus, Phricodothyris, Euomphalus, Chaetetes

*Fusulinella

*Millerella, *Paramillerella, Tetrataxis, Marginifera, Chonetes, Hustedia, Dictyoclostus, Composita Rhombopora, Fenestella, ostracode molds, small gastropod molds, nuculid and myalinid pelecypods, trilobites, plant remains and seed

*Archimedes, *Pentremites

*Lithostrotionella

FIG. 13. Generalized section of part of the Mississippian and Pennsylvanian rocks of the western Midcontinent showing representative genera with emphasis on the Kearny Formation. Genera marked with an asterisk are considered characteristic of those rocks, although not necessarily restricted to them. In part after Girty (1940), Maher (1946b, 1947), and Renfroe (1955).

but are also found in the Morrowan rocks of the Midcontinent. The species of Pentremites in the rocks underlying the Kearny in part of the region are assigned a Chesteran age by Galloway and Kaska (1957). In conjunction with faunal relationship is the distribution and general character of the deposits. Strata containing the Archimedes and Pentremites remains appear to be separated from the Kearny Formation by a regional break in sedimentation that is especially noticeable toward the margins of the depositional basin. The break is most strikingly shown by the beveling of Chesteran rocks on top of the Keyes Dome and other small structures in the embayment. Also, this time marks the beginning of erosion of Mississippian rocks on the Central Kansas Uplift and Cambridge Arch (Merriam, 1955, p. 91). For further discussion of the presence of Chesteran deposits in this region the reader is referred to works of Dille (1932), Lee (1940), Moore and others (1951), Renfroe (1955), and Roth (1930).

Rocks of Springeran age are present only as far north as Ellis County, Oklahoma (Boler, 1959, p. 12). These rocks consist of shales and sandstones that, according to Weaver (1958, p. 303), are mineralogically and genetically akin to those of the Chesteran. He also points out that the areal variation in clay mineralogy is similar in rocks of the two ages. The clay mineralogy study not only shows the Springeran to be a more areally restricted continuation

of Chesteran deposition, but Weaver has also shown that while the montmorillonitic Chesteran-Springeran-type deposition was ending in the western part of the Ardmore Basin, the illitic Morrowan-type deposition was first appearing in the eastern part. In Kansas Springeran time was an interval of weathering and erosion of older rocks. After deposition of the Springeran sediments major local uplifts occurred in the Criner Hills and Wichita Mountains (Beebe, 1956b, p. 170), and probably coincided with the maximum withdrawal of the sea from the western Midcontinent. With the spread of Morrowan sedimentation a different clay mineral suite was established, probably reflecting the newly developed source area of Chesteran and Springeran rocks along the southern border of the Anadarko Basin (Weaver, 1958, p. 305).

Therefore, when the tectonic pulsations separating the various stratigraphic series and stages are taken together with the sediment distribution, lithologies, and contained fauna, it is judged that the interval of geologic time represented by the Kearny Formation is equivalent to at least part of the Morrowan Stage; however, the Morrowan-Mississippian boundary in the deeper part of the embayment is very indistinct.

Deposition of Kearny Formation

As the local tectonism along the Wichita Mountain trend became dormant in the early part of Morrowan time, the sea began to spread back over the areas of previous deposition. An integral part of this advance is the transition zone of clay minerals described by Weaver (1958, p. 285) as resulting from the reworking of Springeran or Chesteran deposits by the Morrowan sea (Fig. 14). The transition zone of Weaver is considered to be approximately equivalent to the lower transgressive part of the Kearny of this paper (Pl. 9).

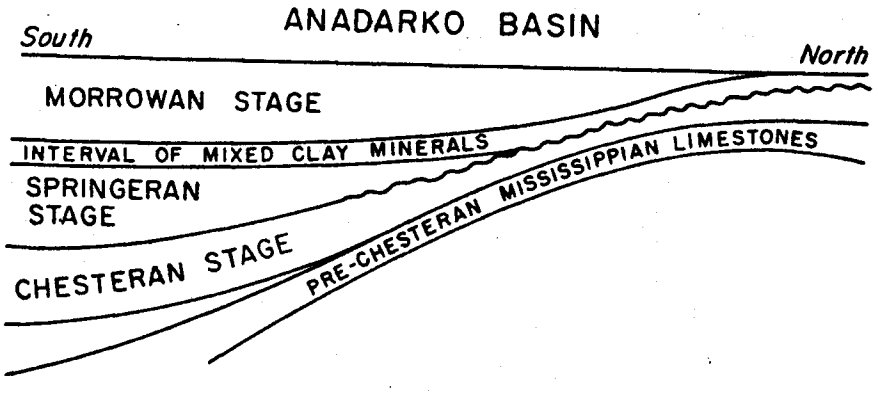


FIG. 14. Generalized cross section through Anadarko Basin (after Weaver, 1958).

Lower Member

As the Kearny sea spread into Kansas, it was probably guided by the topography of the adjoining higher areas of the Keyes Dome and the northeastern part of the Hugoton Embayment. Although much of the sediment deposited in the sea was derived from the underlying rocks, a significant part of it probably came from the more positive areas. Thus, sandstone is abundant on the flanks of the Keyes Dome, and shows a decrease in abundance outward from the dome and a decrease in grain size upward from the base of a depositional unit. The eroded Chesteran rocks on the dome probably furnished much of the sediment in this part of the region. The waters that transported and deposited the clastics moved at a high-energy level that prohibited the settling out of any associated fine particles.

The chemical matrix and associated features of the sandstone show that the deposit was formed above wave base, and probably represents reworking in the surf zone of the sea. The slightly reducing conditions generally assumed for the formation of glauconite, which is common in the sandstones, are not at odds with the picture of an open-shelf environment. Much of the material carried in from the adjacent highlands, however, was deposited as thin deltaic strata. The high-energy level in the environment prevented the preservation of more than a few organic remains, including some plant fragments.

The dark, thinly-laminated shales interbedded with some of the sandstones are interpreted as representing calmer marine conditions in the area. The shale laminae could also represent the closer approach of the depositional factors to a state of equilibrium, a so-called profile of depositional equilibrium, so that a reduction in grain size of transported material was produced. When conditions arrived at equilibrium, deposition would cease or not increase in that part of the area.

The thick sections of dark shale which are very common directly above the basal sandstone, are not considered to be indicative of significantly deeper water, inasmuch as relief on the Mississippian landscape over which the Kearny sea advanced was not great. Therefore, only a slight relative increase in sea level could produce an advance of the shoreline some distance laterally, leaving quieter, yet shallow, water in the area of the previous shoreline. The relative lowering of an area below wave base or the close approach to the profile of depositional equilibrium in the area could form the shales, but such sediments also characterize quiet, lagoonal environments. Further discussion of origin of the dark shales will be postponed until the upper member is considered, for in the younger rocks they form a very thick section.

The environment in the lower part of the formation shifted from one of sandstone accumulation to one of dark

shale development, and then to a combination characterized by the presence of very fine-grained sandstones and shales that are interlaminated and cross laminated with associated bedding disruptions. Continuous reworking and scouring is suggested by the nonparallelism of the stratification. Such conditions could well have occurred in a lagoonal environment where, according to Emery and Stevenson (1957, p. 733), tidal currents in very shallow areas commonly produce cross stratification owing to continuous erosion and redeposition. The sparse molluscan fauna supports such an environmental designation.

Therefore, the advancing sea overran an area of some relief. Channel sands were deposited in the deltaic sediments carried from the Central Kansas Uplift and Keyes Dome. The high-energy level of the open-shelf position permitted the accumulation of much coarse material, although in some protected areas, such as in Stevens and Stanton counties, muds were formed. A slight deepening of the water permitted the subsequent accumulation of dark muds; however, lagoonal and tidal environments became dominant.

After the quiet conditions of the lagoonal environment and the somewhat calm offshore conditions, more active controls returned to the final phases of deposition of the lower member in the southwestern part of the region. Not only were sandstones more commonly developed, and without the associated fine particles, but also the quartzose

calcarenites accumulated, where the calcium carbonate could form and not be masked. Locally the limestones form on the top of structures reflecting the topography of the basal unconformity and sandstones are restricted to the flanks. Such an association was also reported in Oklahoma by Barby (1958, p. 140). Although some of the limestone is composed of shell material, mainly the calcium carbonate is present as sparry cement. The quartzose calcarenite grades into various biosparites, particularly the crinoidal calcarenite, and the gradation is thought to indicate a slight drop in energy-level in the environment, especially current velocity, as well as indicating lesser amounts of extrabasinal material. The biosparite environments suggest areas marginal to the main currents, both tidal and those extending from the rivers of the adjoining land.

In places, as in Stanton County, a basal sandstone passes upward through a quartzose calcarenite into a crinoidal calcarenite, showing the general lessening of extrabasinal material in the deposits. Although the gradation probably involves a decline in energy levels to some degree, the change in available material is a more important factor. The dual effect of energy drop and provenance change is also shown in the sandstones by the decrease in grain size, better sorting, and calcarenite gradations in the upper part of the section. A more varied fauna, suggesting locally more favorable habitats, characterizes

the uppermost limestones in part of Hamilton and Greeley counties.

In Kearny and Grant counties intrasparite and dark shales with a molluscoid fauna are the dominant lithologies. Although current velocities were sufficient to erode the partly consolidated sediment, the environment was goverened by less dynamic factors than in the areas of quartz sand accumulation to the west. Possibly one of the reasons for the absence of quartz grains is that the area was covered with very shallow water and was partly separated from the area of stronger currents. The presence of marine invertebrates and plant remains suggests a series of fluctuations from shallow-water nearshore to marsh or swamp environments.

Environments represented in the rest of the region are variations of the previous examples. Therefore, a general description of the depositional history of the lower member of the Kearny Formation can now be made.

The Kearny sea, a shallow body of water containing no important restrictions of circulation, encroached on the area from the south and reworked the sediments forming the landscape at the end of Mississippian time. In places such as the flanks of the Keyes Dome and Central Kansas Uplift the sea overran small channels carrying debris away from the structures and incorporated the sandstones into the deltaic Kearny sediments. More commonly, though, the action of the surf and tidal currents was augmented by that

of long-shore currents which oriented the sand into northwest-trending bars. Interspersed with the bars, as in central Morton County and Stanton County, were more protected areas of the shore where muds were formed, a condition that commonly occurs along the marginal parts of present seas (Shepard, 1948, p. 152).

Although initial deposits of coarse-grained sandstones reflect the high-energy level of the advancing sea, some fine-grained sandstones are also present, particularly farther away from the source areas of the adjacent land. The calmer environments that resulted in the south as the sea carried the shore zone farther north were associated with the deposition of finer sand. Somewhat nearer the source areas lagoonal and tidal flat deposits were formed. The lagoonal beds are thought not only to indicate areas of local protection from the open sea, but to mark periods of low-water level noted farther north and east by the development of carbonaceous shale and impure coals.

In parts of the region, such as Seward County, conditions were favorable for the growth of a relatively numerous fauna which, although containing crinoids and some other forms, consists mainly of molluscoids. Essentially the limestones indicate a well-aerated environment not clouded by terrigenous material, although detrital quartz sand grains are common. A more vigorous environment characterizes the rocks near to the concentration of quartz sand;

however, many of the organic remains were transported into such an environment and in themselves suggest slightly quieter conditions. Some of the sand bodies represent offshore bars developed by longshore currents, but others may well be channel fills in the sea floor where the currents were concentrated. The common gradation from sandstones into biosparites suggests that the former relationship is more common.

In Kearny, Grant, and Haskell counties conditions of deposition were relatively quiet throughout the time of accumulation of the member. Locally sandstones were important, probably filling small depressions in the land surface as the sea advanced, but primarily the area is characterized by the quiet formation of dark shale with intercalated intrasparite and biosparite. The deposits indicate that the area alternated between normal marine and lagoonal conditions. The fluctuations were possibly very sharp, to particulate the ooze into the intraclasts of the limestones. At times the lagoonal controls were exceeded and the area was slightly above water, extending the paludal environment for the previously retreating vegetation. During none of the low-water periods was there sufficient time or conditions for the development of thick coals. According to Barrell (1917, p. 783), on a sinking surface of deposition scouring will occur, which will leave the coarser particles and carry away the finer ones. The pulsation of

environmental factors in the region, together with the down-warp of the embayment, could account for the interlamination of fine-grain sandstone and shale.

In Hamilton County and adjoining areas the Kearny sea was periodically characterized by more dynamic conditions than farther east. Thus the lower, poorly-sorted, coarser-grained sandstones are thought to indicate the addition of material from the more feldspathic source areas to the southwest and possibly to the north. At slightly later time reworking by the sea resulted in a much better degree of sorting, chiefly evidenced by absence of the larger and rounder quartz grains. The high-degree of roundness of the coarse grains indicates more sedimentary cycles than the subangular grains mainly characterizing the Kearny sandstones. Associated with the better sorting and finer grain size of the sandstones are intercalations of dark shale, indicating a further reduction and a certain pulsation of energy levels in the environment. Many of these intercalated sequences are considered to have formed in areas protected by the barlike sandstone bodies.

The decline in extrabasinal material permitted the formation of quartzose calcarenites which ordinarily grade laterally into calcareous sandstones. A further reduction in terrigenous material resulted in the dominance of the various biosparites. To the east the biosparites grade into intrasparites, indicating a very significant change

in the environment, for according to Thorson (1957, p. 484) the physical-chemical composition of the sediment may be the main factor determining the broad pattern of animal-community distribution on level bottoms. The change in types of allochemical limestones is accompanied by a pronounced change in animal distribution. Possibly the nature of the currents or the water turbidity in the eastern area may have restricted the faunal development, or many of the forms may have been carried away. A fluctuating wave base producing the intraclasts could have hindered faunal growth.

In summary, it appears that the advancing Kearny sea carried some detritus from southern source areas. Along the shores were some deltaic channels transporting material from local areas of provenance. Shallow bays and lagoons formed behind sand bars and were filled with muds and deltaic sands. In areas of less turbidity allochemical limestones formed and contained a common fauna of shallow-water organisms. Fluctuations in sea level resulted in the development of paludal environments. Toward the end of the period represented by the lower member, fairly widespread conditions of limestone deposition were prominent, indicating a decline in the supply of extrabasinal material from the debouching streams, although current activity maintained an almost constant supply of detrital quartz grains. Also at this time the fauna expanded greatly and was most abundantly preserved.

Upper Member

Although the contact between members is gradational, a major change in sedimentologic controls is associated with the upper member. The upper member, consisting of a thick, dark shale facies and a thinner, more limy and sandy facies, suggests the presence of two broad areas of differing environmental conditions.

On the flank of the Keyes Dome the member is composed of, from the base upward: 1) thin limestones and sandstones interbedded with dark shales, 2) dark shale, partly calcareous with thin limestones, 3) interbedded sandstones and shales, 4) dark shales, and 5) dark shales with thin limestones and sandstones. The limestones that occur at the base of the member are quartzose calcarenites and biosparites, lithologically almost indistinguishable from those in the lower member. Less uniformity in conditions of calcium carbonate accumulation and an increase in the turbidity, as reflected by the intercalated fine muds, are indicated. Possibly the deposits were formed in slightly deeper water occurring in the south as the sea advanced to the north and east. Times of storms or shifts in the current patterns in the shallow water could be represented by the deposition of thin beds of fine-grained sandstone. Included within some of the lower limestones are the shelly limestones, composed primarily of productid remains and indicating a slightly lower energy-level which might

possibly be due to semi-protection in a local area.

Continued quiescence and inflow of material resulted in the deposition of dark-gray to black and green shales in shallow lagoons, and represents the beginning of an environmental type that dominated much of the sedimentation during formation of the upper member. No doubt as subsidence increased, there were times when the baselevel of deposition was dropped sufficiently below its former position to permit the entrance of currents capable of transporting coarse material into the lagoon, either as tidal channels or deltaic streams. The sparse fauna of pelecypods and plant remains in the shales accompanying the coarse clastics suggests that the depth of water was not great.

The water level fluctuated very commonly during the deposition of the rest of the member as is shown by the presence of many thin limestones and impure coal beds. The micrite or biomicrite dominance in the upper limestones, plus the presence of the thin coals, indicates that the fluctuations in sea level were gentle, without vigorous currents, wave actions, or other high-energy level factors. Such an environment is interpreted as successive additions of more saline waters to the lagoon with the resulting precipitation of calcium carbonate ooze and increase in the molluscoid element of the fauna.

The sandstones are mainly fine-grained, subangular, and slightly feldspathic with some laminae of black shale

in the finer part of the succession. Yet, parts of the environment were conducive to the formation of conglomeratic sandstones, especially in the southwest where the increase in energy level in the environment may be associated with tectonism along the embryonic Wichita-Amarillo trend.

The dark, thinly-laminated shales are judged to represent various low-energy or relatively calm paralic environments, from slightly offshore to paludal. Although some of the brown shales resemble underclays, most of the shales suggest an origin in a broad, shallow lagoon, partly restricted and little effected by coarse terrigenous material from the adjoining land areas to the northeast and southwest. Thus the deposition of fine muds could occur with only periodic interruptions by coarser material, as when there were storms at sea or flooding on the land. Bottom muds of present-day normal lagoons are high in hydrogen sulfide and commonly black, owing to the formation of ferrous sulfide (Emery and Stevenson, 1957, p. 732). Besides the associated negative redox potential, Emery and Stevenson also point out that in much of the world the mud-bottom estuaries and lagoons, marshes, and even tidal flats are also characterized by low pH on the bottoms, because of organic acids, and by low concentration of calcium carbonate.

Lagoonal filling by tidal deltas might have added to the accumulation of sediment derived from adjacent land

areas. Periodic influx of normal marine waters increased the molluscoid fauna and deposited the biomicrites and micrites, whereas the withdrawal of the sea may have permitted the development of extensive tidal flats. Although as Hantzschel (1939, p. 203) states, fossil tidal-flat deposits probably are not common in the geologic section owing to the ease of erosion and general thinness of width. In the upper member of the Kearny Formation, however, some silty and fine sandy deposits are considered to be remains of this environment. In some localities it is possible that deposition was slower, so that marshes developed instead of barren areas. Certainly the description by Bucher (1938, p. 732) of the Waddens consisting of finely-laminated, argillaceous silts and fine-grained sands containing large and small scale channel cross-bedding is very similar to that of parts of the upper member. The lagoonal or paludal origin suggested for some of the contiguous beds corroborates the interpretation. On these flats probably were minor channels which, according to Emery and Stevenson (1957, p. 677), would be more serpentine than old age streams; and as they would be the depositional sites of the coarser material, this relationship could explain the very irregular distribution of some of the sandstones in this part of the Kearny.

In Hamilton County, where the upper member begins to thin toward the north, is a thick argillaceous crinoidal

calcarenite. Local conditions of slightly decreased accumulation of clay material permitted the calcium carbonate to greatly increase in relative percent. Laterally this development passes into the common lagoonal environments. Possibly the area of limestone formation represented the barrier break between lagoons; and inasmuch as coarse terrigenous material was not available to be deposited there, marine deposition of limestone became the dominant control.

In the lower part of the member the conditions characterizing the lower transgressive part of the member are dominant. Thus, high-energy crinoidal calcarenites and related biosparites occur in the western part of Wallace County, and somewhat transitional types continue as far north as Sherman County where they pass into thin silty limestones of the microcrystalline family. The sea floor in the northern part of the region was goverened by less-restricted factors than in the southern part, resulting in more abundant normal-marine rocks, although lagoonal deposits are very common. The sandstones are finer-grained than in the south, or more accurately, they contain fewer coarse grains, and also fewer accessory minerals. Such an increase in level of compositional maturity in this area probably reflects more on the nature of the region of provenance than on dispersal media. The Cambridge Arch and Siouxia supplied slightly different sediments.

Shale in the northern part of the region is more variable in color and texture than in the other areas. A range of paralic environments (lagoonal, brackish water, tidal flat, and possibly subaerial) is inferred from the relatively thin section of red and brown shales, carbonaceous shales, shales with orbiculoid brachiopods, and shales interlaminated with siltstones and very fine-grained sandstones. At the top of the section is the coal representing final retreat of the Kearny sea.

The limestones in the northeastern part of the region are less arenaceous and fossiliferous than those to the west, a relationship also characteristic of the lower member. Possibly this gradation is due to the absence of a supply of coarse detritus and to the metastable conditions of intraclast formation in the east. In Grant and Stevens counties the limestones begin to grade into dark shales that form practically the entire section slightly farther south, although some interbedded limestones and sandstones are present near the top.

The upper member of the Kearny Formation is pictured as representing the continued advancement of the sea after deposition of the lower member, a continuation that was accompanied by the formation of some offshore shales in the southern part of the area. Not long after the beginning of deposition, however, some of the depositional factors became restricted, resulting in the development of a

pronounced lagoonal environment over much of the region. Along the eastern margin of the region the restrictions were ineffective, so that high-energy allochemical limestones and chemical-matrix sandstones could form. Some of these sandstones are probably the remains of channel deposits in the Mississippian rocks, whereas others represent offshore accumulations into linear bodies. Possibly these bars and similar ones in Oklahoma helped divert the currents sufficiently to add to the restriction of the rest of the region, but the deflection of currents was not complete, for it appears that relatively good circulation was common along an area extending northwestward across the region to Wallace County. At the ends of this belt, particularly the southern end, are deposits formed by high energy-levels in the environment, whereas in the middle are intrasparites and fine sandstones that show a less active environment.

To the north and east of the belt coal beds, red shales, quartz detritus, basal phosphatic nodules, and chert fragments are more common, indicating a nearness to the margin of the depositional area where the fluctuations of sea level were more heavily marked in the deposits and by the absence of deposits. Many of the marginal sediments grade laterally into the lagoonal accumulations where the relatively thick coal beds become thin streaks.

Periodically the barriers were breached, mainly from the south, and normal marine conditions covered the region, producing irregular beds of micrite in the lagoons. At

other times terrigenous material was dominant. A very delicate balance of parameters seems to have governed the environments.

Finally, toward the end of Kearny time, conditions were even less persistent, particularly along the Central Kansas Uplift and Keyes Dome, and rock types were more commonly interstratified; however, recession of the sea was the order of events. Thus the coal beds are slightly more common, until the final retreat of the sea produced the thick paludal deposit that caps the formation throughout much of the region.

During deposition of the upper member subsidence increased in the Anadarko Basin and southern part of the Hugoton Embayment, so that thick deposits of shallow-water sediments accumulated. The hinge line in the region ran from Meade County to Greeley County. The initial pulsations of the post-Morrowan disturbances are recorded by the alternating lithologies near the top of the Kearny.

Sediments representing the lagoonal environment of the Kearny continue westward into Colorado, although close to their western limit they become slightly arkosic near the top (Maher, 1946a, p. 1762), reflecting much more strongly than in Kansas the beginning of the tectonism ushering in the Middle Pennsylvanian Epoch. During the deposition of Kearny rocks the subsidence of the Hugoton and Anadarko areas was accompanied by subsidence to the west of the

Las Animas Arch (Maher, 1945, p. 1664). The positive tectonic elements influencing deposition included the Pratt Anticline in south-central Kansas (Pate, 1959, p. 48) and the Central Kansas Uplift and Cambridge Arch to the north of it.

Conclusions

The depositional history of the Kearny Formation reflects the presence of many environments and a variety of rock types. Yet, certain basic controls guided the nature of sedimentation under each set of conditions. These controls represent the features of the sea, the land, and the climate. Inasmuch as the Kearny is primarily of marine origin, the depositional controls based upon the nature of the sea are interpreted as having been most important. The effects of land and climate are subordinate elements.

According to Fleming (1957, p. 101), the oceanographic features of a coastal area are controlled by four factors: 1) local water balance, or the ratio of water-inflow to water-loss, 2) isolation of the area, 3) tides and tidal currents, and 4) topography of adjacent land areas and the underlying sea floor. Climatic influences are revealed in all these factors, but especially in the first and fourth. Similarly, the addition of lithologic composition to the

last factor would include the principal effects of the land or extrabasinal controls. When the factors are augmented by taking account of change with time and influence of diastrophism, the main guides to understanding deposition of the Kearny sediments are provided.

The local water balance for the Kearny sea was not static throughout Morrowan time, but fluctuated from net inflow to net outflow with variations in accumulation and concentration of the water. Accumulation of water on the land adjoining the sea was primarily governed by the climate, and effected by topography, vegetation, and land distribution. Although the inferred nature of past climates usually is highly speculative, previous workers on the Pennsylvanian rocks of the Midcontinent have tended to consider a humid and equable climate as being characteristic of this Period (Moore, 1929). In regard to the nature of the Morrowan climate, evidence is furnished not only by the characteristics of the marine organisms, but also by those of the plant remains, particularly the plants discussed by Finlay (1916, p. 12) from the Glen Eyrie Shale. According to Elias (1936, p. 694), such plants are part of an association representing a humid climate. A warning was made by Giles (1930), however, that many of the organic criteria may indicate local environment rather than broad climatic type.

A rather luxurious plant growth is judged to have bordered the Kearny sea. Associated with the plants probably were many streams, so that fresh-water transportation was dominant in the areas marginal to the sea. The composition of the lagoonal sediments in the Kearny suggests that the fresh-water dominance extended beyond the shoreline and produced at least dilution of the surface water in the lagoon. Such a condition would result in the outflow from the lagoon of the warmer diluted surface water and a slow inflow of sea water at depth (Fleming, 1957, p. 99). Dilution would affect the chemical factors of sedimentation, as well as the nutrient supply to the organisms. As the fresh water flowed out of the lagoon, a slow replacement of bottom water would occur, but, as noted by Emery and Stevenson (1957, p. 689), the replacement would be by subsurface water of the open sea, itself sometimes relatively low in oxygen. The outlying barriers would protect the lagoon from the major effects of currents and waves, whereas the density stratification of the water in the lagoon would prohibit minor turbulence. Thus, bottom conditions might become even more stagnant than in an ordinary lagoon, and inhospitable to oxygen-consuming life. The intensity of conditions could have been emphasized by the effect of the shallow depth of the Kearny sea on the replenishment of subsurface water in the lagoon. The periods of greatest encroachment of fresh water over

lagoonal water, producing greatest density stratification of the water, stagnation, and quiescence on the bottom, might correspond to periods of accumulation of the black fissile shale.

Although the local water balance is intimately associated with the other factors, particularly the tidal currents, it appears that the Kearny sea was primarily an inshore area of net outflow of water during much of the time. The greatest change in conditions is judged to have occurred at the contact between the lower transgressive part of the unit and the rest of the formation where a change from net inflow to net outflow of water is suggested. Many sedimentologists have used the concept of water balance as an important criterion in their classification of sedimentary environments, although not considering it as such or realizing its associated factors.

The second control of oceanographic features is isolation of the area. Most of the early deposits of the Kearny reflect an environment open to general conditions of marine control, particularly in regard to the sandstone bars and the limestones and sandstones formed at high energy-levels. Later deposits in the formation indicate an increase in isolation by the development of lagoonal environments, thick dark shales, and brackish water organisms. The deposition of offshore bars probably increased the isolation which was further aided by net outflow of water. At no

time, however, is it postulated that the Kearny sea was completely separated from the ocean.

Degree of isolation is reflected in the physical factors mainly by a drop in energy-level in the environment with a subsequent effect on lithology, stratification, and texture. The expression in the chemical factors can be even more outstanding, for redox potential and pH are intimately related to degree of isolation and can, with only a small variation in degree of isolation, produce strikingly different lithologies.

Tides and tidal currents are very important forces in the inshore areas of many seas, particularly if the area is not isolated to any degree from the rest of the sea. As with the other factors, variations are common. Stronger currents, which reworked the previous material, apparently characterized the lower part of the formation. The early deposits include the major part of the allochemical limestones and chemical-matrix sandstones that are very closely related to strong or persistent currents in the depositional area. A reduction in strength of the tides and tidal currents is assumed to have accompanied the development of partial isolation of the area, but periodic increases in current activity, probably associated with lessening in degree of isolation, could have resulted in erosion of underlying sediment, transportation of coarser material, and deposition in parts of the tidal channels. Locally

tidal and longshore currents are thought to have been sufficiently strong or persistent to develop offshore bars, primarily as a series of en echelon small bodies rather than long, irregularly continuous bars.

One of the most important factors to be considered is the topography of the adjacent land and the sea floor. The extrabasinal sediments show, for example by their fine grain size, that the areas of provenance were low, reduced in relief by erosion that began, depending upon the area, anytime after the Meramecian. Much of the Kearny detritus appears to have come from areas of the Central Kansas Uplift and Pratt Anticline, which recurrently in Early Pennsylvanian time appear to have been broad, low land masses. The low land area formed by the Cambridge Arch is also thought to have contributed sediment to the Kearny deposits, but in a minor amount and for a shorter period of time. The topographic relief developed in the Wichita Mountains to the south, together with other factors, was not sufficient to produce stream currents or sediment load capable of affecting deposition of the Kearny Formation in Kansas. Detritus from the area of the Sierra Grande Uplift did not become abundant until Atokan time, but a few thin beds of coarse clastics can be found in the upper part of the Kearny.

Topography of the neighboring land, commonly referred to by the terms "high land mass" or "low land mass," is

related to the development of streams and the characteristics of the sediment transported to a basin. Although the development of topographic relief may be closely linked with the rate of denudation and accompanying sediment dispersal, the relation to rate of sedimentation in the adjacent basin appears to be obscure. As Barrell (1917, p. 748) points out, the rate of sedimentation may be determined more by the rate of discontinuous depression of the surface of deposition, than by the rate of supply of sediment. Therefore, low relief of the source areas of Kearny deposits does not in itself imply that the thick shale sections represent relatively long periods of time.

Topography of the sea floor is an important depositional control where local relief is great; however, depressions in the erosion plane on the Mississippian rocks were probably quickly filled-in by sediments in the Kearny sea, so that a relatively smooth sea floor characterized Kearny sedimentation. Even in the lagoonal realm there were probably few irregularities. A submarine topography such as this would tend toward a similarity of marine factors during deposition of the sediment; however, a minor irregularity in the floor of the Kearny sea could have a magnified effect on the environment owing to the shallowness of the water.

Related to topography are the profiles of equilibrium, both subaerial and submarine, which are probably the most restrictive controls on sedimentation. Thus, low relief of

adjacent land areas of sedimentary rocks would be reflected by low-gradient streams of low competency. Toward the beginning of Kearny deposition, however, the streams were also characterized by high capacity. The detritus was commonly carried through paralic coal basins where some of the coarse material could well have settled out. On entering the Kearny sea the sediment was transported until the velocity of the current, energy of Brownian movement, energy of electrical charge, and other factors controlling movement of the various types of particles dropped sufficiently in level of energy to prevent further transportation of particles. Then deposition resulted. The site of deposition of extrabasinal material, therefore, would depend upon particle size and level of energy in the environment.

Owing to increased subsidence in the southern part of the region, the relative distance between successive former equilibrium profiles was increased, which had the effect of producing a convergence of beds toward the north and east. Deposition in the thin sections was prevented probably by a coalescence of depositional surface and baselevel, or else some deposits were removed by erosion. The former condition was probably more common. A similar convergence is illustrated by Barrell (1917, p. 790, fig. 4). Although convergence is judged to be the prime factor involved in the thinning of the Kearny, a certain amount of offlap occurs, especially at the top of the upper member.

Associated with topography to a degree is diastrophism, which during the deposition of the Kearny was dormant in this region. Periodic movement along the Central Kansas Uplift and associated features, and probably to a certain extent along the Wichita axis, appears to have taken place during this time, but movement was more evident after deposition of the Kearny.

The discussion of local water balance, isolation, tides and tidal currents, topography, and diastrophism has shown the nature of the factors controlling the milieu in which were developed the local environments reflected by the Kearny deposits. Briefly, then, the depositional history of the Kearny Formation in western Kansas is as follows. After the beginning of weak diastrophic movements in the adjacent land masses, the region was invaded by the Kearny sea. Open-circulation littoral and sublittoral environments were developed on the undulating erosion surface formed on the Mississippian rocks. Channel sandstones and deltaic deposits were deposited near the source areas to the northeast and southwest. In some parts of the region were mud-bottom bays. By the end of deposition of the lower member an area of limestone formation extended northeastward to a line from Greeley County to Meade County and contained the dominant remains of the Kearny epifauna. With continued advancement of the sea and increased subsidence of the Anadarko Basin, a paralic domain was

established, dominated by lagoonal environments and offshore bars with periodic invasions of restricted marine, euxinic, and paludal deposits. The change to net outflow of water by weak tidal currents sided the isolation. A rhythmic alternation of deposits is suggested, but a cyclic repetition is not demonstrated. Toward the end of Kearny time the northeastern shoreline had advanced far up the flank of the land mass formed by the Central Kansas Uplift and extended into Nebraska and eastern Colorado. The final retreat of the sea produced an extensive paralic coal basin over most of the region.

Atokan-Morrowan Boundary

Although Lower Atokan deposits may be present in the deeper parts of the Anadarko Basin, the succession in the present region begins with the middle part of the Stage. Thus, a significant period of time is represented by the break between rocks of Morrowan and Atokan age in western Kansas, but in this tectonically stable environment little disturbance is evidenced.

The dark microcrystalline limestones and dark shales of the Atokan sequence indicate a continuation of the Kearny environments characterized by low-energy levels, but a greater marine influence is present, even though some coal swamps were developed during the early part of sedimentation. Commonly at the base of the succession is a thin

zone of disturbance, represented mainly by a fragmented limestone or very fine-grained sandstone, but locally consisting of thick, coarse-grained sandstones.

The unconformity separating Lower and Middle Pennsylvanian rocks has been reported by Moore and Thompson (1949, p. 287) to be well-developed throughout the southern Midcontinent and adjacent areas from Arkansas to Utah, and from Kansas to Texas. They consider it indicative of one of the greatest diastrophic disturbances in the Pennsylvanian Period.

At the end of Kearny deposition, uplift occurred around the rim of the Anadarko Basin, for as Beebe (1956a, p. 122) observes, all the succeeding sediments close to the uplifted areas contain large quantities of arkosic material and granite washes. This relationship is particularly evident along the southern and western margins.

The Wet Mountains-Apishapa-Sierra Grande axis is a southwest trend that plunges into the northwestern part of the Anadarko Basin and is en echelon and genetically related by contemporaneous movement to the Criner Hills-Wichita-Amarillo Mountains system (Beebe, 1956b, p. 169). The uplifting of these areas was accompanied by the rise of the Front Range and the rest of the Ancestral Rocky Mountains. Associated with the uplifts was abundant faulting, particularly along the Front Range and at the eastern end of the Sierra Grande Uplift (Maher, 1953a, p. 935).

Thus, there appears above the marine sediments of the Kearny Formation and Glen Eyrie Shale the coarse arkosic clastics of the Fountain Formation and Sangre de Cristo Formation. Similar "granite washes" also came from the southern areas and can likewise be traced into the fossiliferous Middle Pennsylvanian marine beds of the more stable areas. For the rest of the Pennsylvanian Period and into the Permian these structural highs controlled depositional history in the northwestern Anadarko Basin (Beebe, 1956a, p. 121).

Deposition of Atokan Rocks

Associated with the deposition of Atokan rocks was a shift in the axis of the Hugoton Embayment slightly farther south. Although Atokan deposits overlap the Kearny in places, the Atokan sea was somewhat less extensive, and deposits were confined more to a northwest-trending trough crossing the southwestern part of the region. The dark cherty limestones and dark shales that characterize the sequence in Kansas become more shaly and sandy in eastern Colorado until they grade into arkose near the Front Range and Sierra Grande Uplift (Maher, 1958, p. 71). The contact separating the Atokan and Desmoinesian is less distinct in the Kansas deposits than is the basal limit of the Atokan, and correspondingly appears to be less reflective of tectonism in the adjacent land masses.

CONCLUSIONS

1. Deposits of Early Pennsylvanian age are represented in Kansas by the subsurface Kearny Formation which is divisible into two persistent members, here unnamed.

2. The lower member is thinner and less extensive than the upper one, indicating continued transgression of the sea during deposition of the formation.

3. An unconformity at the base of Kearny deposits is obscure where the formation lies on upper Chesteran rocks. In such places, paleontologic, sedimentologic, and tectonic criteria are all needed for recognition of the boundary.

4. Local elongate, narrow sandstone bodies occur in the lower member on the flank of the Keyes Dome and in the area to the north. Fossiliferous, arenaceous limestones are common, reaching greatest development during the last phases of deposition of the member.

5. The contact between members is gradational, mainly reflecting change from fossiliferous, crystalline limestones, below, to dark-gray shales, above.

6. Although the upper member is composed of a thick sequence of dark shales in southwestern Kansas, it contains more prominent limestones and sandstones where it thins to the north and east and overlaps the lower member. Thin coal beds are common, particularly toward the margin of

the member. Interbedded with the thick shales are thin sandstones and limestones.

7. The upper contact of the formation occurs at the base of the Atokan limestones or basal sandstone; commonly this horizon is marked by a well-developed coal bed.

8. Lithologic types represented in the Kearny Formation are grouped into five classes: 1) microcrystalline limestones, 2) allochemical limestones, 3) chemical-matrix sandstones, 4) detrital-matrix sandstones, and 5) clay rocks.

9. Lithologic variations representing four orders of magnitude are recognized, and are based on relation of type of depositional material and level of energy in the environment.

10. Most of the limestones in the lower member are allochemical types, indicating environments containing relatively high energy-levels; whereas those toward the top of the formation are microcrystalline types, representing lower levels of energy. The most common limestone variations are quartzose calcarenites in the lower part and micrites in the upper part.

11. The Kearny sandstones, which are primarily fine-grained, glauconitic, subgraywackes, reflect environments containing high energy-levels, although interlamination with dark shales is common.

12. Shales are mainly either dark and thinly-laminated or reddish-brown and blocky. The latter group is most

commonly developed near the margin of the depositional area.

13. Most of the thin coal beds are inferred to be autochthonous, and some have an associated underclay.

14. The most characteristic marine invertebrates in the Kearny, although not restricted to it, are the fusulinids Millerella and Paramillerella.

15. The epifauna is most abundant in the limestones of the lower member, and consist mainly of Dictyoclostus, Hustedia, Marginifera, Chonetes, Composita, Enteletes, Rhombopora, Fenestella, Thamniscus, and crinoids (represented by abundant fragments). High- and low-spired gastropods, trilobites, small to large smooth ostracodes, calcareous foraminifers, nuculid and myalinid pelecypods, phosphatic brachiopods, seeds, and plant remains complete the biota.

16. After retreat of the Springeran sea from northwestern Oklahoma and upwarp of the Central Kansas Uplift and Wichita axis, the Kearny sea advanced into Kansas from the south.

17. Initial deposits of channel fills, deltaic sediments, and offshore bars were interspersed with mud-floored bays and lagoons. Primarily the environments were littoral and sublittoral. The sands were brought mainly from the Keyes Dome and Central Kansas Uplift, although some material was probably transported from the south. Net water inflow and strong tidal currents characterized the region.

18. Dark muds of lagoonal and tidal flat environments were deposited, commonly with associated silt and very fine-grained sand in the latter environment. A few thin coal beds indicate periods of paludal development.

19. Increased circulation and higher energy-level marked late stages of accumulation of the lower member. Allochemical limestones formed near sand bars and graded into them. An abundant epifauna developed, its fragments being easily transported by the currents.

20. Increased isolation ushered in deposits of the upper member with formation of offshore shales. Normal-marine sublittoral conditions changed to paralic, and the upper member was dominated by lagoonal, paludal, and transitional environments.

21. The presence of micrites and calcareous shales intercalated in the dark lagoonal muds indicates breaching of the barriers by normal marine waters. The thin coal beds reflect extension of the terrigenous domain. A fresh-water cap on the lagoon possibly caused the euxinic environment that produced the black fissile shale.

22. Tidal channels that developed in the lagoons and tidal flats are represented by irregular sandstone bodies. Some of the sandstones in the upper member, however, are considered to represent offshore bars.

23. Adjacent allochemical limestones and chemical-cement sandstones indicate that normal sublittoral environments

existed in the southcentral part of the region outside the partly restricted area.

24. Abundant coal beds and red shales characterize the sequence to the northeast. The northeastern shoreline possibly extended well up on the flank of the land mass formed by the Central Kansas Uplift.

25. At the end of Kearny deposition the sea retreated from the region, leaving a broad paralic coal basin.

26. Major uplifts along the Criner Hills-Wichita-Amarillo Mountains axis, the Sierra Grande-Apishapa-Wet Mountains trend, the Ancestral Rocky Mountains, and the Central Kansas Uplift marked the end of Morrowan time, although deposits in western Kansas were unaffected, and little erosion of the Kearny took place prior to the deposition of the Middle Atokan limestones and shales.

27. The Morrowan-Atokan contact marks the beginning of limestone and shale deposition that characterizes the rest of the Pennsylvanian Period.

REFERENCES

ABELS, T. A., 1959, A subsurface lithofacies study of the Morrowan Series in the northern Anadarko Basin: Shale Shaker, v. 9, no. 7, p. 5-21.

BARBY, B. G., 1958, Subsurface geology of the Pennsylvanian and Upper Mississippian of Beaver County, Oklahoma: Shale Shaker Digest II, p. 133-154.

BARRELL, JOSEPH, 1917, Rhythms and the measurements of geologic time: Geol. Soc. America Bull., v. 28, p. 745-904.

BEEBE, B. W., 1956a, Northwestern Anadarko Basin: Oklahoma City Geol. Soc., Guidebook 35th Anniversary Field Conference, p. 120-125.

-----, 1956b, The Ancestral Rocky Mountains: Oklahoma City Geol. Soc., Guidebook 35th Anniversary Field Conference, p. 168-171.

BOLER, M. E., 1959, Pre-Desmoinesian isopach and paleogeologic study of northwestern Oklahoma: Shale Shaker, v. 9, no. 10, p. 6-18.

BUCHER, W. H., 1938, Key to papers published by an institute for the study of modern sediments in shallow seas: Jour. Geology, v. 46, p. 726-755.

CARVER JR., H. S., 1956, Keyes Field: Oklahoma City Geol. Soc., Guidebook 35th Anniversary Field Conference, p. 130-135.

DILLE, G. S., 1932, Western Oklahoma, Mississippian, (abstract): Tulsa Geol. Soc., Summaries and abstracts 1932.

DOBERVICH, GEORGE and PARKER, R. L., 1958, Morrowan Series of North Texas Panhandle (abstract): Am. Assoc. Petroleum Geologists Bull., v. 42, p. 215.

ELIAS, M. K., 1936, Late Paleozoic plants of the Midcontinent region as indicators of time and of environment: International Geol. Cong., Report of the XVI Session (1933), p. 691-700.

-----, 1937, Depth of deposition of the Big Blue (Late Paleozoic) sediments in Kansas: Geol. Soc. America Bull., v. 48, p. 403-432.

EMERY, K. O., and STEVENSON, R. E., 1957, Estuaries and lagoons: in Hedgpeth, J. W., ed, Treatise on Marine Ecology and Paleoecology, Geol. Soc. America Mem. 67, v. 1, p. 673-750.

FENTRESS, G. H., 1958, The Denver Basin: Kansas Geol. Soc., Guidebook 22d Field Conference, p. 78-88.

FINLAY, G. I., 1916, Colorado Springs Folio, Colorado: U. S. Geol. Survey Geol. Atlas, Folio 203, p. 1-15.

FLEMING, R. H., 1957, General features of the oceans: in Hedgpeth, J. W., ed., Treatise on Marine Ecology and Paleoecology, Geol. Soc. America Mem. 67, v. 1, p. 87-108.

FOLK, R. L., 1959, Practical petrographic classification of limestones: Am. Assoc. Petroleum Geologists Bull., v. 43, p. 1-38.

GALLOWAY, J. J. and KASKA, H. V., 1957, Genus Pentremites and its species: Geol. Soc. America Mem. 69, p. 1-104.

GILES, A. W., 1930, Pennsylvanian climates and paleontology: Am. Assoc. Petroleum Geologists Bull., v. 14, p. 1279-1299.

GIRTY, G. H., 1940, Report on fossils of Mississippian age from well cores in western Kansas: in Lee, Wallace, Subsurface Mississippian rocks of Kansas, Kansas Geol. Survey Bull. 33, p. 97-112.

GLIDDEN, C. H. and BORG, W. M., 1958, Morrow formation of northwestern Oklahoma (abstract): Am. Assoc. Petroleum Geologists Bull., v. 42, p. 214.

GORDON, G. H., 1938, A subsurface study of the black shales of western Kansas: Kansas Acad. Sci. Trans., v. 41, p. 201-205.

HÄNTZSCHEL, WALTER, 1939, Tidal flat deposits (Wattenschlick): in Trask, P.D., ed., Recent Marine Sediments, Am. Assoc. Petroleum Geologists, p. 195-206.

HAUN, J. D. and LEROY, L. W., 1958, Subsurface geology in petroleum exploration: Colorado School of Mines, Golden, Colorado, 887p.

HENBEST, L. G., 1946, Stratigraphy of the Pennsylvanian in the west half of Colorado and in adjacent parts of New Mexico and Utah (abstract): Am. Assoc. Petroleum Geologists Bull., v. 30, p. 750-751.

HJULSTRÖM, FILIP, 1939, Transportation of detritus by moving water: in Trask, P. D., ed., Recent Marine Sediments, Am. Assoc. Petroleum Geologists, p. 5-31.

ILLING, L. V., 1954, Bahaman calcareous sands: Am. Assoc. Petroleum Geologists Bull., v. 38, p. 1-95.

JORDAN, LOUISE, PATE, J. D., and WILLIAMSON, S. R., 1959, Petroleum geology of Harper County: in Myers, A. J., Geology of Harper County, Oklahoma, Oklahoma Geol. Survey Bull. 80, p. 69-92.

KANSAS GEOLOGICAL STUDY GROUP, 1950, West-east cross section, southern Kansas: Kansas Geol. Soc., Wichita, Kansas.

KELLER, W. D., 1954, The energy factor in sedimentation: Jour. Sedimentary Petrology, v. 24, p. 62-68.

KELLETT, BETTY, 1948, Atoka ostracodes in Glenn Eyrie formation, Colorado: Am. Assoc. Petroleum Geologists Bull., v. 32, p. 129-130.

KRUMBEIN, W. C., 1947, Shales and their environmental significance: Jour. Sedimentary Petrology, v. 17, p. 101-108.

LAUDON, L. R., 1957, Crinoids: in Ladd, H. S., ed., Treatise on Marine Ecology and Paleoecology, Geol. Soc. America Mem. 67, v. 2, p. 962-972.

LEE, WALLACE, 1940, Subsurface Mississippian rocks of Kansas: Kansas Geol. Survey Bull. 33, p. 1-96.

LIBERAL GEOLOGICAL SOCIETY, 1956, Cross section no. 1, east-west cross section Comanche County, Kansas, to Baca County, Colorado; Liberal, Kansas, two panels.

----------, 1958, Cross section no. 2, north-south cross section through the Hugoton Embayment; Liberal, Kansas.

McLAUGHLIN, K. P., 1947, Pennsylvanian stratigraphy of Colorado Springs quadrangle, Colorado: Am. Assoc. Petroleum Geologists Bull., v. 31, p. 1936-1981.

MAHER, J. C., 1945, Structural development of Las Animas Arch, Lincoln, Cheyenne, and Kiowa counties, Colorado: Am. Assoc. Petroleum Geologists Bull., v. 29, p. 1663-1667.

-----, 1946a, Correlation of Paleozoic rocks across Las Animas Arch in Baca, Las Animas, and Otero counties, Colorado: Am. Assoc. Petroleum Geologists Bull., v. 30, p. 1756-1763.

-----, 1946b, Subsurface geologic cross section from Ness County, Kansas, to Lincoln County, Colorado: Kansas Geol. Survey Oil and Gas Inv., Prelim. Cross Section no. 2, 13p.

-----, 1947, Subsurface geologic cross section from Scott County, Kansas, to Otero County, Colorado: Kansas Geol. Survey Oil and Gas Inv., Prelim. Cross Section no. 4, 11p.

-----, 1948, Subsurface geologic cross section from Baca County to Yuma County, Colorado: Kansas Geol. Survey Oil and Gas Inv., Prelim. Cross Section no. 6, 11p.

-----, 1953a, Permian and Pennsylvanian rocks of southeastern Colorado: Am. Assoc. Petroleum Geologists Bull., v. 37, p. 913-939.

-----, 1953b, Paleozoic history of southeastern Colorado: Am. Assoc. Petroleum Geologists Bull., v. 37, p. 2475-2489.

-----, 1954, Pennsylvanian correlations in Crowley and Pueblo counties, Colorado: Am. Assoc. Petroleum Geologists Bull., v. 38, p. 2045-2048.

-----, 1958, Stratigraphic classification and correlation of Paleozoic rocks in southeastern Colorado: Kansas Geol. Soc., Guidebook 22d Field Conference, p. 51-77.

----- and COLLINS, J. B., 1949, Pre-Pennsylvanian geology of southwestern Kansas, scutheastern Colorado, and the Oklahoma Panhandle: U. S. Geol. Survey Oil and Gas Inv. Prelim. Map 101, 4 sheets.

----- and -------, 1953, Permian and Pennsylvanian rocks of southeastern Colorado and adjacent areas: U. S. Geol. Survey Oil and Gas Inv., Map OM 135.

MASON, BRIAN, 1958, Principles of geochemistry: Wiley and Sons, New York, 310p.

MERRIAM, D. F., 1955, Structural development of the Hugoton Embayment: Fourth Symposium on Subsurface Geology Proc., Norman, Oklahoma, p. 81-97.

MOORE, R. C., 1929, Environment of Pennsylvanian life in North America: Am. Assoc. Petroleum Geologists Bull., v. 13, p. 459-487.

-----, 1948, Environmental significance of dwarfed faunas: Jour. Sedimentary Petrology, v. 18, p. 126.

----- and THOMPSON, M. L., 1949, Main divisions of Pennsylvanian Period and System: Am. Assoc. Petroleum Geologists Bull., v. 33, p. 275-302.

----- and OTHERS, 1951, The Kansas rock column: Kansas Geol. Survey Bull. 89, 132p..

NEWELL, N. D., 1942, Late Paleozoic pelecypods: Mytilacea: Kansas Geol. Survey, v. 10, pt. 2, 115p.

PATE, J. D., 1959, Stratigraphic traps along north shelf of Anadarko Basin, Oklahoma: Am. Assoc. Petroleum Geologists Bull., v. 43, p. 39-59.

PAYNE, T. G., and OTHERS, 1951, The Arctic slope of Alaska: U. S. Geol. Survey Oil and Gas Inv., Map OM 126.

PETTIJOHN, F. J., 1957, Sedimentary rocks: Harper and Bros., New York, 718p.

RENFROE, C. A., 1955, The Novinger Field, Meade County, Kansas: Fourth Symposium on Subsurface Geology Proc., Norman, Oklahoma, p. 99-106.

ROTH, ROBERT, 1930, Regional extent of Marmaton and Cherokee Midcontinent Pennsylvanian formations: Am. Assoc. Petroleum Geologists Bull., v. 14, p. 1249-1278.

RYNIKER, CHARLES, 1943, in Schoff, S. L., Geology and ground water resources of Cimarron County, Oklahoma: Oklahoma Geol. Survey Bull. 64, p. 42.

SCHOENFELT, C. E., 1938, Oil and gas development in eastern Colorado: Kansas Geol. Soc., Guidebook 12th Annual Field Conference, p. 91-102.

SHEPARD, F. P., 1948, Submarine geology: Harper and Bros., New York, 338p.

SIEVER, RAYMOND, 1957, Pennsylvanian sandstones of the Eastern Interior Coal Basin: Jour. Sedimentary Petrology, v. 27, p. 227-250.

SLOSS, L. L., KRUMBEIN, W. C., and DAPPLES, E. C., 1949, Integrated facies analysis: in Longwell, C. R., chm., Sedimentary Facies in Geologic History, Geol. Soc. America Mem. 39, p. 91-123.

STACH, L. W., 1936, Correlation of zoarial form with habitat: Jour. Geology, v. 44, p. 60-65.

THOMPSON, M. L., 1944, Pennsylvanian Morrowan rocks and fusulinids of Kansas: Kansas Geol. Survey Bull. 52, p. 409-431.

--------, 1945, Pennsylvanian rocks and fusulinids of east Utah and northwest Colorado correlated with Kansas section: Kansas Geol. Survey Bull. 60, p. 19-84.

--------, 1951, New genera of fusulinid Foraminifera: Cushman Foundation for Foraminiferal Research Contr., v. II, pt. 4, p. 115-119.

THORSON, GUNNAR, 1957, Bottom communities (sublittoral or shallow shelf): in Hedgpeth, J. W., ed., Treatise on Marine Ecology and Paleoecology, Geol. Soc. America Mem. 67, v. 1, p. 461-534.

TOTTEN, R. B., 1956, General geology and historical development, Texas and Oklahoma panhandles: Am. Assoc. Petroleum Geologists Bull., v. 40, p. 1945-1967.

VAN DER GRACHT, W. A. J. M. VAN WATERSCHOOT, 1931, Permo-Carboniferous orogeny in south-central United States: Am. Assoc. Petroleum Geologists Bull., v. 15, p. 991-1057.

VERODA, V. J., 1958, Morrow rocks of western Kansas and panhandle counties of Oklahoma (abstract): Am. Assoc. Petroleum Geologists Bull., v. 42, p. 214-215.

VER WIEBE, W. A., 1942, Exploration for oil and gas in western Kansas during 1941: Kansas Geol. Survey Bull. 42, 123p.

WEAVER, C. E., 1958, Geologic interpretation of argillaceous sediments, Part I, Origin and significance of clay minerals in sedimentary rocks: Am. Assoc. Petroleum Geologists Bull., v. 42, p. 254-271.

WILLIAMS, HOWEL, TURNER, F. J., and GILBERT, C. M., 1955, Petrography: W. H. Freeman and Co., San Francisco, 406p.

WILSON, DRUID, SANDO, W. J., and KOPF, R. W., 1957, Geologic names of North America introduced in 1936-1955: U. S. Geol. Survey Bull. 1056-A, 405p.

APPENDIX

TYPICAL SECTIONS OF MEMBERS OF KEARNY FORMATION

Typical section of lower member. The section described below is from the Panhandle Eastern Pipeline Company No. 1 Shafer well, center SW¼ sec. 25, T. 32 S., R. 39 W. with a ground level elevation of 3212 feet.

Unit	Depth	Description
9	5570-5898	UPPER MEMBER OF KEARNY FORMATION. Shale, dark gray to black with some light to dark green shale and thin beds of limestone and sandstone.
8	5898-5916	LOWER MEMBER OF KEARNY FORMATION. Sandstone, light-gray to cream-tan, fine-grained to granule size, subangular to subrounded quartz grains; little crystalline calcite cement in abundant long-grain contacts; common fine-grained crinoid columnals; is transitional rock into arenaceous limestone; black shale at top with fine to coarse quartz grains.
7	5916-5950	Shale, dark gray to black, with some fine-grained, argillaceous, glauconitic sandstone beds.
6	5950-5966	Limestone, dark-gray to cream-tan, fine- to medium-crystalline with subordinate large grains in a fine-crystalline groundmass; very arenaceous with fine- to coarse-grained, subangular to subrounded quartz sand grains; more arenaceous in lower part; sparse pink feldspar fragments; common to abundant, fine-grained, dark green glauconite; common glauconite-replaced ramose bryozoans; common fine-grained crinoid columnals.

Panhandle Eastern Pipeline Co.
Shafer No. 1
C SW¼ Sec. 25, T.32S., R.39W.
GL 3212 Stevens County

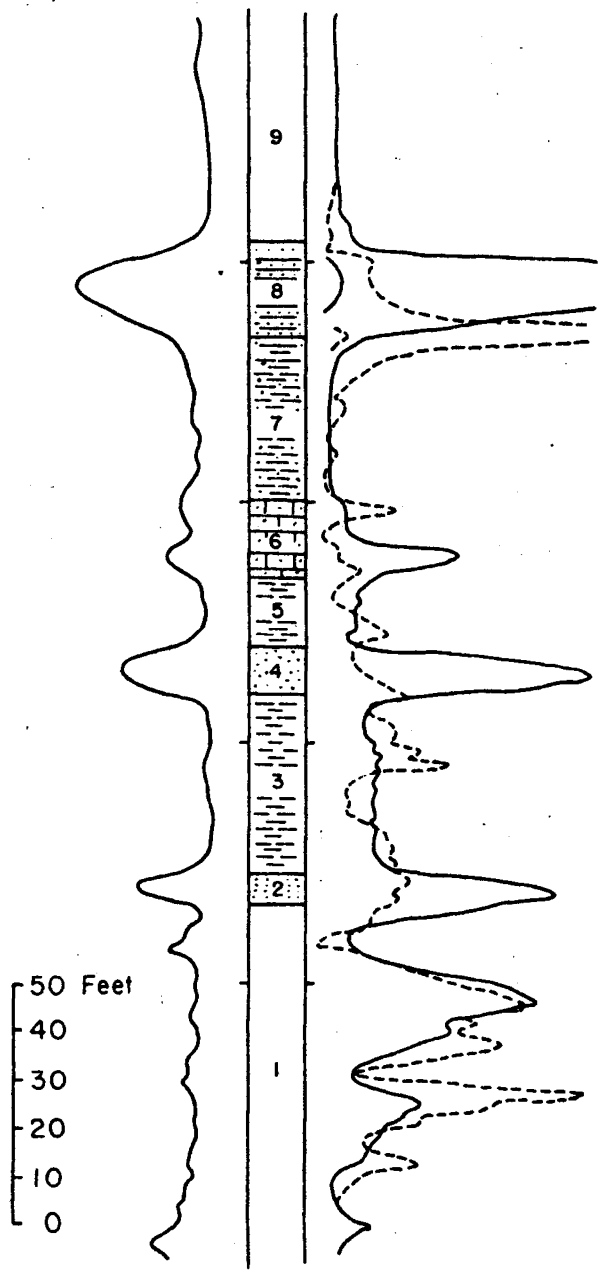


FIG. 15. Typical section of lower member.

5	5966-5980	Shale, dark gray to black.
4	5980-5990	Sandstone, white, fine-grained, subangular quartz grains with little calcareous cement between common long-grain contacts; common fine-grained, light green glauconite.
3	5990-6028	Shale, dark gray to black, thinly-laminated, with some light brownish-gray, thinly-laminated shale; sparse small pelecypods.
2	6028-6034	Sandstone, fine- to very fine-grained, subangular quartz grains; little calcareous cement; common glauconite grains.
1	6034-	MISSISSIPPIAN ROCKS. Limestone, light brownish gray, cryptocrystalline.

Typical section of upper member. The section described below is from the Superior Oil Company No. 1 Wade well, SW¼ SW½ NE¼ sec. 30, T. 29 S., R. 41 W., Stanton County, with an elevation of KB 3415.

Unit	Depth	Description
16	-5012	ATOKAN ROCKS. Limestone, dark-gray to dark-brown, argillaceous, dense, with dark-gray to black shale and light-gray siltstone to very fine-grained sandstone.
15	5012-5039	UPPER MEMBER OF KEARNY FORMATION. Shale, dark-gray, thinly-laminated, very silty at top; some thin beds of light-gray siltstone; some thin coal beds; very black, micaceous, silty shale in lower part.
14	5039-5041	Limestone, light yellowish-brown, cryptocrystalline, silty, very argillaceous, with abundant pelecypod shells.

Superior Oil Co.
Wade No. 1
SW¼ SW¼ NE¼ Sec. 30, T.29S., R.41W.
KB 3415 Stanton County

Deep Rock Oil Corp.
R.E. Adams "B" No. 1
C NW¼ NE¼ Sec. 16, T.35S., R.29W.
KB 2416 Meade County

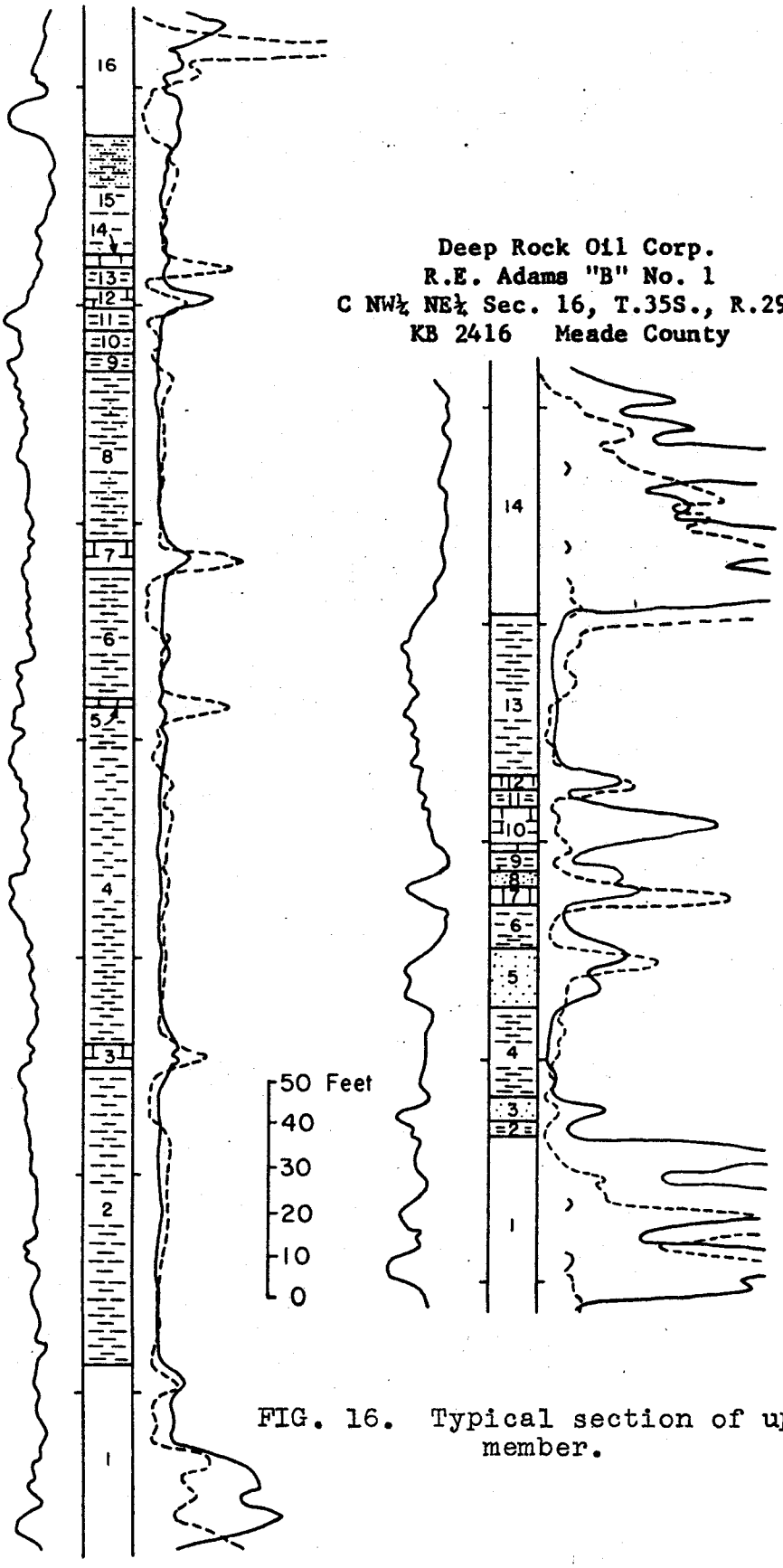


FIG. 16. Typical section of upper member.

13	5041-5046	Shale, dark gray, thinly-laminated.
12	5046-5051	Limestone, light brownish-gray to cream-tan, medium-crystalline with dominant large grains in cryptocrystalline groundmass; common fine-grained, light-green flauconite; sparse brachiopod shells and ramose bryozoans.
11	5051-5056	Shale, very calcareous.
10	5056-5062	Shale, dark-gray to black, thinly-laminated.
9	5062-5066	Shale, very calcareous.
8	5066-5105	Shale, dark-gray to black, thinly-laminated, fissile in part; with sparse thin laminae of very argillaceous sandstone with abundant very fine- to medium-grained, light-green glauconite; some dark-brown silty shale; thin coal beds near base.
7	5105-5111	Limestone, cream to light-brown, medium-crystalline with dominant large grains in cryptocrystalline groundmass; common fine to coarse, subrounded, clear quartz grains; sparse very fine-grained, light-green glauconite; abundant large crinoid columnals; rare brachiopod shells.
6	5111-5141	Shale, dark-gray to black, thinly-laminated, micaceous, fissile; some dark-brown silty shale; sparse pelecypod shells.
5	5141-5143	Limestone, very argillaceous.
4	5143-5220	Shale, dark-gray to black, as above.
3	5220-5226	Limestone, cream to medium-gray, fine-crystalline to cryptocrystalline; sparse small crinoid columnals, small dark brachiopod shells, and dark ostracode shells.

2	5226-5294	Shale, dark-gray to black, some light-gray, thinly-laminated; fissile near top; some thin very argillaceous limestones near top; some sooty black shale and silty shale; light-brown shale at base.
1	5294-5430	LOWER MEMBER OF KEARNY FORMATION. Limestone, arenaceous, fossiliferous with glauconitic sandstones and dark shales.

Supplementary section of upper member. The section described below is from the Deep Rock Oil Corporation No. 1 R. E. Adams "B" well, center NW¼ NE¼ sec. 16, T. 35 S., R. 29 W., Meade County with an elevation of KB 2416.

Unit	Depth	Description
14	-5848	ATOKAN ROCKS. Limestone, dark-gray to black and dark-brown, dense, argillaceous, with dark gray to black shale.
13	5848-5885	UPPER MEMBER OF KEARNY FORMATION. Shale, dark gray to black, thinly-laminated, with carbonaceous remains and thin coal beds near the top; dense and limy in parts.
12	5885-5888	Limestone, light-gray, medium-crystalline with subordinate large grains in cryptocrystalline groundmass; abundant crinoid columnals.
11	5888-5892	Shale, dark gray, thinly-laminated.
10	5892-5902	Limestone, light brownish-gray, fine-crystalline, even-grained; some crinoid columnals.
9	5902-5907	Shale, dark gray to black, thinly-laminated, with carbonaceous remains; dense and calcareous in parts.

8	5907-5910	Sandstone, light-gray, very fine-grained, subangular quartz grains with abundant long-grain contacts and little calcareous cement; common very fine-grained, light-green glauconite, some glauconite in streaks; sparse pyrite; common medium-grained crinoid columnals.
7	5910-5914	Limestone, light brownish-gray, clastic, medium-crystalline with dominant large grains in fine-crystalline groundmass; abundant light-green glauconite as very fine grains and as fossil replacements; some argillaceous streaks; abundant crinoid columnals.
6	5914-5924	Shale, light greenish-gray to dark-gray, glauconitic.
5	5924-5938	Sandstone, very fine-grained, with little calcareous cement among abundant long-grain contacts; abundant very fine-grained glauconite; interlaminated with dark-gray to black micaceous shale; rare pyrite.
4	5938-5958	Shale, dark-gray to black, limy at base.
3	5958-5964	Sandstone, light-gray, fine-grained, subangular quartz grains; little calcareous cement among common long-grain contacts; common black shale laminae; some thin coal streaks.
2	5964-5967	Shale, dark gray to black, thinly-laminated.
1	5967-	MISSISSIPPIAN ROCKS. Limestone, cream-gray, medium-crystalline with subordinate large grains in crypto-crystalline groundmass; abundant crinoid columnals.

2/17/61

McManus wrote a brief summary article on this subject for the AAPG. Guidebook (Oct. 1957). I feel that publication of the thesis would not be a duplication. The "meat" of the thesis was not given in the AAPG. article.

There is a definite need for subsurface sedimentation studies in Hawaii. Here is a detailed study which will be of great value to the petroleum industry if published in the near future.

Should the Survey choose not to utilize the study, let us release it for publication elsewhere before it becomes dated.

Ed Garbisch

Fig 1. It should be explained that most of the structures shown on the Map are post Kearny and have had nothing to do with Kearny deposition.

Page 9 — last Statement on page What does he mean by "an equivalent? time"?

Page 10 More recent studies in eastern Oklahoma should be added.

Page 11 He ought to more clearly in discussion of use of Morrow and Atoka as ~~rock units~~ rock units and Morrowan and Atokan as time-stratigraphic units

Page 15 — ~~The~~ 6th line from bottom of page. He should say sub pennsylvanian unconformity.

The unconformity may be early Pennsylvanian in age.

the pre-Penn-Jeotonic framework. Whatever it is

Page 96 Top ¶ says what he calls central Kansas Uplift is Ellis Arch.

However he should say that peneplanation was near the end of Devonian or beginning of Mississippian time and had revealed the Ellis and its "roots". The real framework that influenced the Kearny was the "Pre-Mississippian structural setup first described by Moore and Jewett, 1942.

I would say that he part on Pre Mississippian "structural framework" is inadequate. See Dan's pre-Miss Structure Map.

Fig 13: Seemingly he questions boundary between Cherokee and something below. Then why not Desmoinesian = Atokan?

Cherokee is not restricted by definition to Desmoinesian.

Notes: are results of a sort — of spot check.

I think this should be published.

It needs careful editing by someone who ~~is~~ has time relations well in mind.

Page 46 2nd line on page: —

Explained on Pg 53 and lower What are "long grain contacts

Pages 48 — 49. Discussion of "Patterson" 35 as to Cherokee limestone does not seem to fit Fig 19, (page 95) ?

Page 50. "Two groups" is mixed with Cherokee Jenks and Atokan (time term) deposits

KGS Open-file Report 59-5

PLATE I

STRUCTURE CONTOUR MAP ON TOP OF MISSISSIPPIAN ROCKS

Contour Interval = 100 Feet
Datum = Sea Level

0 5 10 15 20
SCALE IN MILES

DEAN A. McMANUS
1959

X = SAMPLES AND CORES
△ = LOGS OF THE KANSAS SAMPLE LOG SERVICE
○ = ELECTRIC AND RADIOACTIVITY LOGS

KGS Open-file Report 59-5

PLATE 2

ISOPACHOUS MAP OF LOWER MEMBER OF KEARNY FORMATION

Contour Interval = 25 Feet

0 5 10 15 20
SCALE IN MILES

DEAN A. McMANUS
1959

CHEYENNE
RAWLINS
SHERMAN
THOMAS
WALLACE
LOGAN
GOVE
GREELEY
WICHITA
SCOTT
LANE
HAMILTON
KEARNY
FINNEY
GRAY
FORD
STANTON
GRANT
MORTON
STEVENS
SEWARD
HASKELL
MEADE
CLARK

EASTERN LIMIT LOWER MEMBER

EASTERN LIMIT OF UPPER MEMBER

T 1S
T 2S
T 3S
T 4S
T 5S
T 6S
T 7S
T 8S
T 9S
T 10S
T 11S
T 12S
T 13S
T 14S
T 15S
T 16S
T 17S
T 18S
T 19S
T 20S
T 21S
T 22S
T 23S
T 24S
T 25S
T 26S
T 27S
T 28S
T 29S
T 30S
T 31S
T 32S
T 33S
T 34S
T 35S

R 43 W. R 42 W. R 41 W. R 40 W. R 39 W. R 38 W. R 37 W. R 36 W. R 35 R 34 R 33 R 32 R 31 R 30 R 29 W. R 28 W. R 27 W. R 26 W. R 25 W. R 24 W. R 23 W. R 22 W. R 21 W.

KGS Open-file Report 59-5

PLATE 3

SAND-SHALE RATIO MAP OF LOWER MEMBER OF KEARNY FORMATION

SAND 8 2 1 ½ ⅛ SHALE

0 5 10 15 20
SCALE IN MILES

DEAN A. McMANUS
1959

CHEYENNE
RAWLINS
SHERMAN
THOMAS
WALLACE
LOGAN
GOVE
GREELEY
WICHITA
SCOTT
LANE
HAMILTON
KEARNY
FINNEY
GRAY
FORD
STANTON
GRANT
MORTON
STEVENS
SEWARD
HASKELL
MEADE
CLARK

EASTERN LIMIT OF LOWER MEMBER

EASTERN LIMIT OF UPPER MEMBER

T 1S
T 2S
T 3S
T 4S
T 5S
T 6S
T 7S
T 8S
T 9S
T 10S
T 11S
T 12S
T 13S
T 14S
T 15S
T 16S
T 17S
T 18S
T 19S
T 20S
T 21S
T 22S
T 23S
T 24S
T 25S
T 26S
T 27S
T 28S
T 29S
T 30S
T 31S
T 32S
T 33S
T 34S
T 35S

R 43W. R 42W. R 41W. R 40W. R 39W. R 38W. R 37W. R 36W R 35W. R 34W. R 33W. R 32W. R 31W. R 30W. R 29W. R 28W. R 27W. R 26W. R 25W. R 24W. R 23W. R 22W. R 21W.

KGS Open-file Report 59-5

PLATE 4

ISOPACHOUS MAP OF UPPER MEMBER OF KEARNY FORMATION

Contour Interval = 50 Feet

0 5 10 15 20

SCALE IN MILES

DEAN A. McMANUS
1959

CHEYENNE
RAWLINS
SHERMAN
THOMAS
WALLACE
LOGAN
GOVE
GREELEY
WICHITA
SCOTT
LANE
HAMILTON
KEARNY
FINNEY
GRAY
FORD
STANTON
GRANT
MORTON
STEVENS
SEWARD
HASKELL
MEADE
CLARK

50
100
150
200
250
300
350

EASTERN LIMIT OF UPPER MEMBER

EASTERN LIMIT OF LOWER MEMBER

T 1 S
T 2 S
T 3 S
T 4 S
T 5 S
T 6 S
T 7 S
T 8 S
T 9 S
T 20 S
T 21 S
T 22 S
T 23 S
T 24 S
T 25 S
T 26 S
T 27 S
T 28 S
T 29 S
T 30 S
T 31 S
T 32 S
T 33 S
T 34 S
T 35 S

R 43 W. R 42 W. R 41 W. R 40 W. R 39 W. R 38 W. R 37 W. R 36 W. R 35 W. R 34 W. R 33 W. R 32 W. R 31 W. R 30 W. R 29 W. R 28 W. R 27 W. R 26 W. R 25 W. R 24 W. R 23 W. R 22 W. R 21 W.

KGS Open-file Report 59-5

PLATE 5

SAND-SHALE RATIO MAP OF UPPER MEMBER OF KEARNY FORMATION

SAND 8 2 1 1/2 1/8 SHALE

0 5 10 15 20
SCALE IN MILES

DEAN A. McMANUS
1959

CHEYENNE
RAWLINS
SHERMAN
THOMAS
WALLACE
LOGAN
GOVE
GREELEY
WICHITA
SCOTT
LANE
HAMILTON
KEARNY
FINNEY
GRAY
FORD
STANTON
GRANT
MORTON
STEVENS
SEWARD
HASKELL
MEADE
CLARK

T 1S T 2S T 3S T 4S T 5S T 6S T 7S T 8S T 9S T 10S T 11S T 12S T 13S T 14S T 15S T 16S T 17S T 18S T 19S T 20S T 21S T 22S T 23S T 24S T 25S T 26S T 27S T 28S T 29S T 30S T 31S T 32S T 33S T 34S T 35S

R 43 W. R 42 W. R 41 W. R 40 W. R 39 W. R 38 W. R 37 W. R 36 W. R 35 W. R 34 W. R 33 W. R 32 W. R 31 W. R 30 W. R 29 W. R 28 W. R 27 W. R 26 W. R 25 W. R 24 W. R 23 W. R 22 W. R 21 W.

KGS Open-file Report 59-5

PLATE 6 A

F *West* — D *East*

1 KB 3860 · 2 DF 3756 · 3 DF 3517 · 4 KB 3416 · 5 KB 3326 · 6 KB 3250 · 7 KB 3101 · 8 KB 3108 · 9 KB 3016

PENNSYLVANIAN / MISSISSIPPIAN

Lansing-Kansas City Group · Marmaton Group · Cherokee Group · Kearny Fm.

4500 · 5000

TD 5471 · TD 5896 · TD 5640 · TD 5487 · TD 5000 · TD 4960 · TD 4810 · TD 5100 · TD 4958

100 FEET · 50 · 0

DATUM = TOP LANSING GROUP

REGIONAL STRATIGRAPHIC CROSS SECTION F-D
SHERMAN COUNTY TO THOMAS COUNTY

DEAN A. McMANUS
1959

List of Wells

1. Van Grisso, No. 1 Golden. . . . . sec. 24, T. 10 S., R. 42 W.
2. Sinclair-Prairie, No. 1 Mercer. . . . sec. 28, T. 10 S., R. 40 W.
3. Sinclair-Prairie, No. 1 Cogswell. . . sec. 20, T. 10 S., R. 38 W.
4. Excelsior, No. 1 Marshall . . . . . sec. 17, T. 10 S., R. 36 W.
5. Lauck, No. 1 Stover . . . . . sec. 29, T. 10 S., R. 35 W.
6. Derby, No. 1 Kistler. . . . . sec. 34, T. 9 S., R. 34 W.
7. Bennett & Roberts, No. 1 Franz. . . . sec. 13, T. 9 S., R. 33 W.
8. Trans-Tex, No. 1 Keller . . . . . sec. 19, T. 9 S., R. 32 W.
9. Gulf, No. 1 Marie . . . . . sec. 26, T. 9 S., R. 31 W.

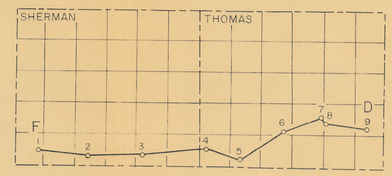


PLATE 6 B

I *South* — H *North*

1 KB 2308 · 2 KB 2440 · 3 DF 2443 · 4 KB 2546 · 5 KB 2456 · 6 KB 2616 · 7 KB 2729 · 8 KB 2716

PENNSYLVANIAN / MISSISSIPPIAN

Lansing-Kansas City Group · Marmaton Group · Cherokee Group · Atokan Rocks · Kearny Fm.

4500 · 5000 · 5500 · 6000

TD 6565 · TD 6175 · TD 5840 · TD 8083 · TD 5604 · TD 6500 · TD 6354 · TD 5167

100 FEET · 50 · 0

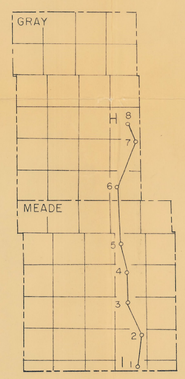
DATUM = TOP LANSING GROUP

REGIONAL STRATIGRAPHIC CROSS SECTION I-H
MEADE COUNTY TO GRAY COUNTY

DEAN A. McMANUS
1959

List of Wells

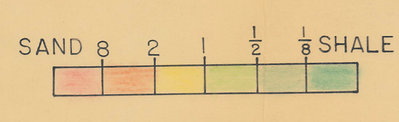
1. Rine, No. 1 Meyers. . . . . sec. 15, T. 35 S., R. 27 W.
2. Thomas & Brewer, No. 1 Isaac. . . . . sec. 12, T. 34 S., R. 27 W.
3. Skelly, No. 1 Theissen. . . . . sec. 8, T. 33 S., R. 27 W.
4. Northern Natural, No. 1 Collingwood . sec. 18, T. 32 S., R. 27 W.
5. Durbin-Bond, No. 1 Edwards. . . . . sec. 18, T. 31 S., R. 27 W.
6. United Producing, No. 1 Salmon. . . . sec. 29, T. 29 S., R. 27 W.
7. Skelly, No. 1 Slocum. . . . . sec. 2, T. 28 S., R. 27 W.
8. Kerr-McGee, No. 1 DeVore. . . . . sec. 21, T. 27 S., R. 27 W.



KGS Open-file Report 59-5

PLATE 7

SAND-SHALE RATIO MAP OF KEARNY FORMATION



DEAN A. McMANUS
1959

CHEYENNE
RAWLINS
SHERMAN
THOMAS
WALLACE
LOGAN
GOVE
GREELEY
WICHITA
SCOTT
LANE
HAMILTON
KEARNY
FINNEY
GRAY
FORD
STANTON
GRANT
MORTON
STEVENS
SEWARD
HASKELL
MEADE
CLARK

T 1S
T 2S
T 3S
T 4S
T 5S
T 6S
T 7S
T 8S
T 9S
T 10S
T 11S
T 12S
T 13S
T 14S
T 15S
T 16S
T 17S
T 18S
T 19S
T 20S
T 21S
T 22S
T 23S
T 24S
T 25S
T 26S
T 27S
T 28S
T 29S
T 30S
T 31S
T 32S
T 33S
T 34S
T 35S

R 43W. R 42W. R 41W. R 40W. R 39W. R 38W. R 37W. R 36W. R 35W. R 34W. R 33W. R 32W. R 31W. R 30W. R 29W. R 28W. R 27W. R 26W. R 25W. R 24W. R 23W. R 22W. R 21W.

KGS Open-file Report 59-5

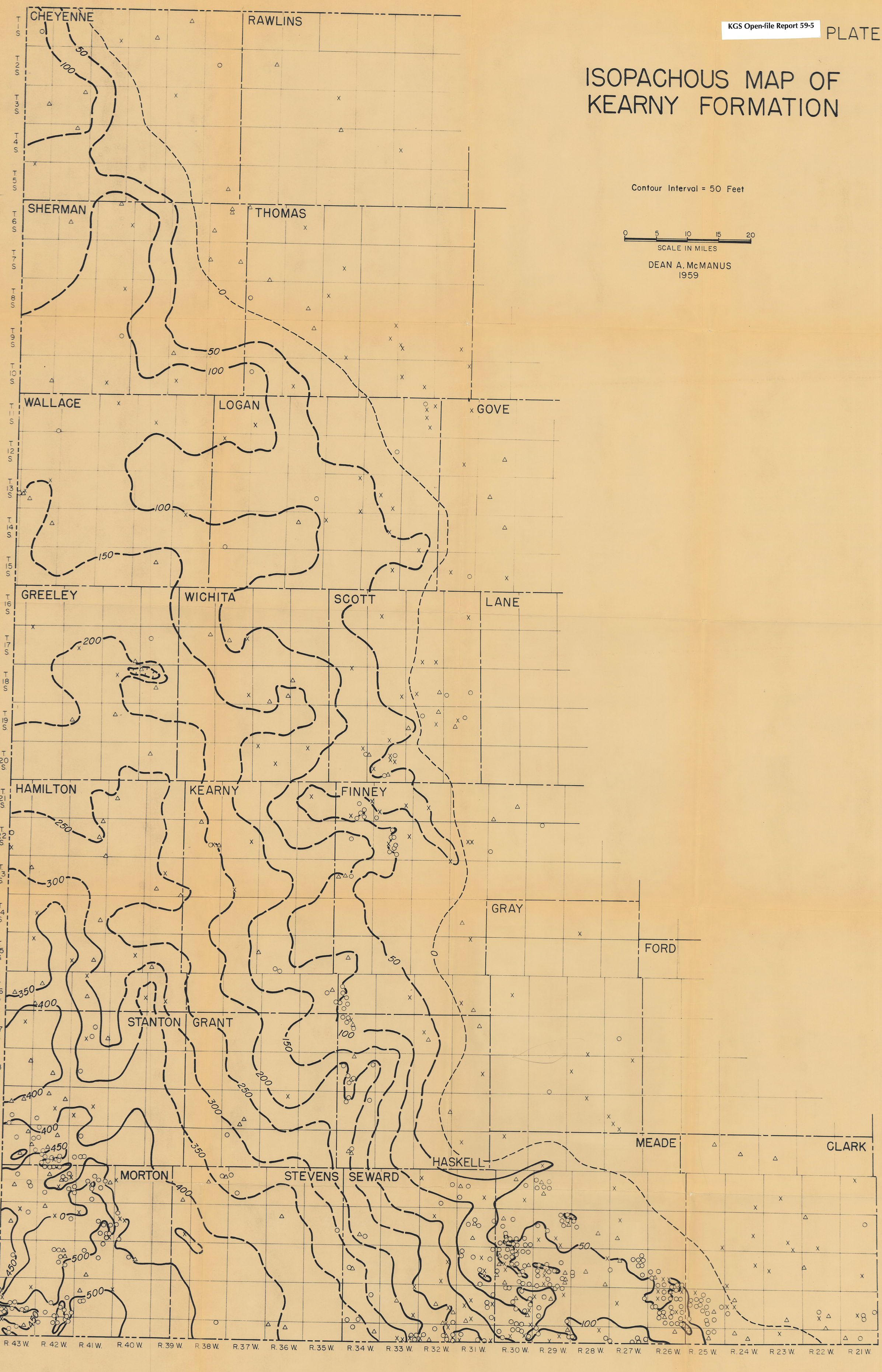
PLATE 8

ISOPACHOUS MAP OF KEARNY FORMATION

Contour Interval = 50 Feet

0 5 10 15 20
SCALE IN MILES

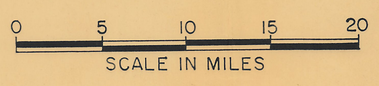
DEAN A. McMANUS
1959



KGS Open-file Report 59-5

PLATE 9

SAND-SHALE RATIO MAP OF LOWER TRANSGRESSIVE PART OF KEARNY FORMATION



DEAN A. McMANUS
1959

CHEYENNE RAWLINS SHERMAN THOMAS WALLACE LOGAN GOVE GREELEY WICHITA SCOTT LANE HAMILTON KEARNY FINNEY GRAY FORD STANTON GRANT MORTON STEVENS SEWARD HASKELL MEADE CLARK

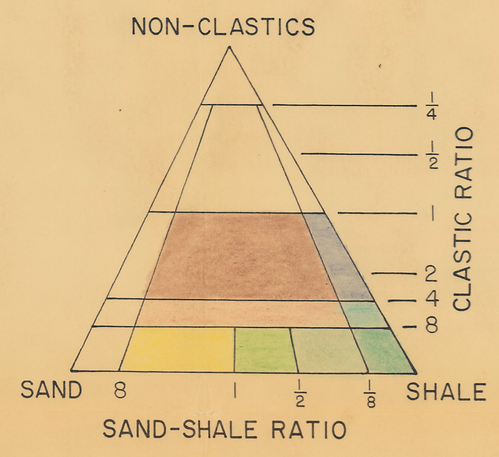
T 1 S T 2 S T 3 S T 4 S T 5 S T 6 S T 7 S T 8 S T 9 S T 10 S T 21 S T 22 S T 23 S T 24 S T 25 S T 26 S T 27 S T 28 S T 29 S T 30 S T 31 S T 32 S T 33 S T 34 S T 35 S

R 43 W. R 42 W. R 41 W. R 40 W. R 39 W. R 38 W. R 37 W. R 36 W. R 35 W. R 34 W. R 33 W. R 32 W. R 31 W. R 30 W. R 29 W. R 28 W. R 27 W. R 26 W. R 25 W. R 24 W. R 23 W. R 22 W. R 21 W.

KGS Open-file Report 59-5

PLATE 10

LITHOFACIES MAP OF KEARNY FORMATION



Clastic ratio — 8
Sand-shale ratio — 1/2

0 5 10 15 20
SCALE IN MILES

DEAN A. McMANUS
1959

CHEYENNE
RAWLINS
SHERMAN
THOMAS
WALLACE
LOGAN
GOVE
GREELEY
WICHITA
SCOTT
LANE
HAMILTON
KEARNY
FINNEY
GRAY
FORD
STANTON
GRANT
MEADE
CLARK
HASKELL
MORTON
STEVENS
SEWARD

T 1S
T 2S
T 3S
T 4S
T 5S
T 6S
T 7S
T 8S
T 9S
T 10S
T 11S
T 12S
T 13S
T 14S
T 15S
T 16S
T 17S
T 18S
T 19S
T 20S
T 21S
T 22S
T 23S
T 24S
T 25S
T 26S
T 27S
T 28S
T 29S
T 30S
T 31S
T 32S
T 33S
T 34S
T 35S

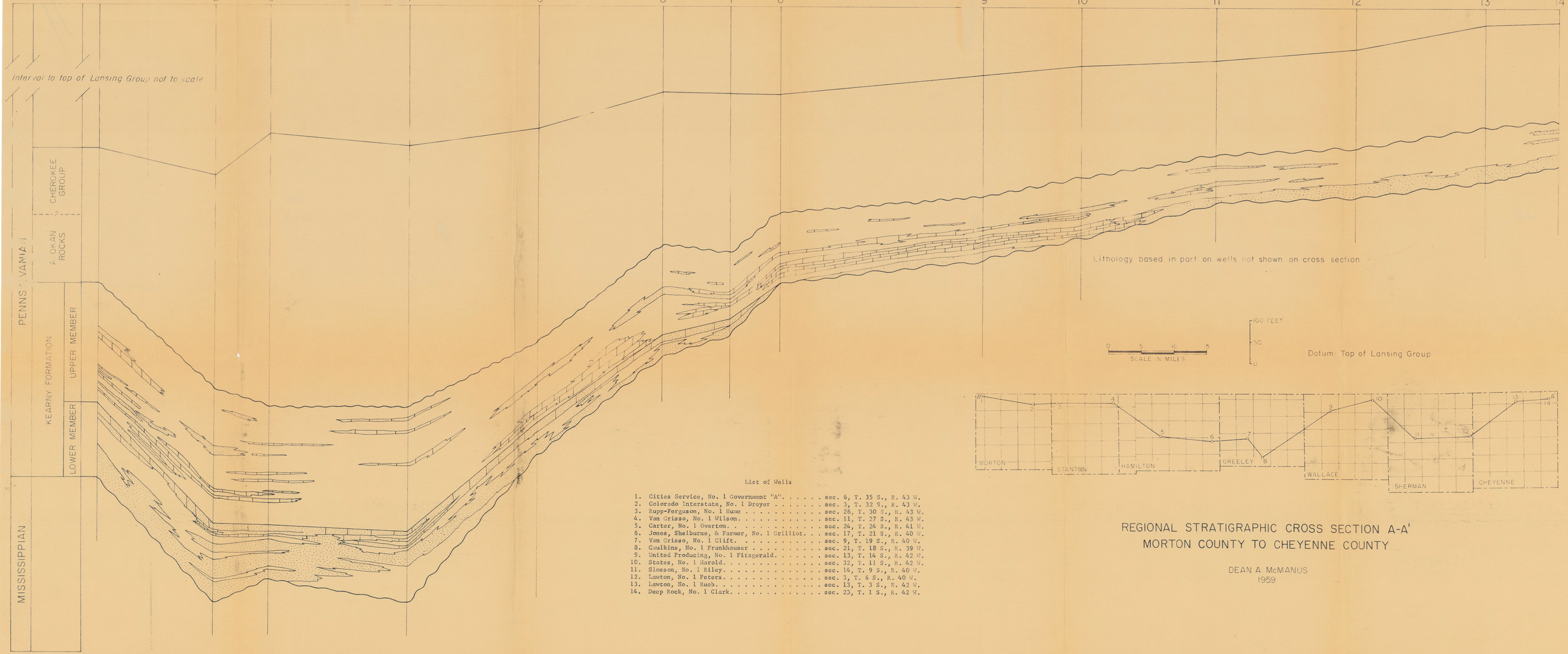
R 43W. R 42W. R 41W. R 40W. R 39W. R 38W. R 37W. R 36W. R 35W R 34W. R 33W. R 32W. R 31W. R 30W. R 29W. R 28W. R 27W. R 26W R 25W. R 24W. R 23W. R 22W. R 21W.

KGS Open-file Report 59-5

PLATE II

A South — A' North

Interval to top of Lansing Group not to scale



Lithology based in part on wells not shown on cross section

SCALE IN MILES 0 5 10 15

100 FEET 50 0

Datum: Top of Lansing Group

List of Wells

1. Cities Service, No. 1 Government "A". . . . . sec. 6, T. 35 S., R. 43 W.
2. Colorado Interstate, No. 1 Dreyer . . . . . sec. 3, T. 32 S., R. 43 W.
3. Rupp-Ferguson, No. 1 Hume . . . . . sec. 26, T. 30 S., R. 43 W.
4. Van Grisso, No. 1 Wilson. . . . . sec. 11, T. 27 S., R. 43 W.
5. Carter, No. 1 Overton. . . . . sec. 24, T. 24 S., R. 41 W.
6. Jones, Shelburne, & Farmer, No. 1 Grilliot. . . sec. 17, T. 21 S., R. 40 W.
7. Van Grisso, No. 1 Clift. . . . . sec. 9, T. 19 S., R. 40 W.
8. Caulkins, No. 1 Frankhauser . . . . . sec. 21, T. 18 S., R. 39 W.
9. United Producing, No. 1 Fitzgerald. . . . . sec. 13, T. 14 S., R. 42 W.
10. States, No. 1 Harold. . . . . sec. 32, T. 11 S., R. 42 W.
11. Slosson, No. 1 Riley. . . . . sec. 14, T. 9 S., R. 40 W.
12. Lawton, No. 1 Peters. . . . . sec. 3, T. 6 S., R. 40 W.
13. Lawton, No. 1 Rueb. . . . . sec. 13, T. 3 S., R. 42 W.
14. Deep Rock, No. 1 Clark. . . . . sec. 23, T. 1 S., R. 42 W.

REGIONAL STRATIGRAPHIC CROSS SECTION A-A'
MORTON COUNTY TO CHEYENNE COUNTY

DEAN A. McMANUS
1959

KGS Open-file Report 59-5

PLATE 12 A

West — East

A 1 2 3 4 5 6 7 8 9 10 11 B

Interval to top of Lansing Group not to scale

PENNSYLVANIAN

CHEROKEE GROUP

ATOKAN ROCKS

KEARNY FORMATION — UPPER MEMBER

KEARNY FORMATION — LOWER MEMBER

MISSISSIPPIAN

List of Wells

1. Cities Service, No. 1 Government "A" . sec. 6, T. 35 S., R. 43 W.
2. Panhandle Eastern, No. 1 Wacker. . . . sec. 7, T. 34 S., R. 41 W.
3. Benedum-Trees, No. 1 Mitchell. . . . . sec. 2, T. 35 S., R. 38 W.
4. Northern Natural Gas, No. 1 Gooch "D". sec. 3, T. 35 S., R. 36 W.
5. Weathoma, No. 1 Long . . . . . sec. 5, T. 35 S., R. 34 W.
6. Panhandle Eastern, No. 1 Light . . . . sec. 11, T. 35 S., R. 33 W.
7. Stanolind, No. 1 Adams . . . . . sec. 8, T. 35 S., R. 30 W.
8. Skelly, No. 1 Hansen . . . . . sec. 2, T. 35 S., R. 28 W.
9. Gulf, No. 1 West Higinbotham . . . . sec. 2, T. 35 S., R. 26 W.
10. Skelly, No. 1 Dunne. . . . . sec. 4, T. 35 S., R. 23 W.
11. Fure, No. 1 Tuttle "A" . . . . . sec. 7, T. 35 S., R. 21 W.

100 FEET — 50 — 0

0 5 10 SCALE IN MILES

Datum: Top of Lansing Group

Lithology based in part on wells not shown on cross section

REGIONAL STRATIGRAPHIC CROSS SECTION A-B
MORTON COUNTY TO CLARK COUNTY

DEAN A. McMANUS
1959

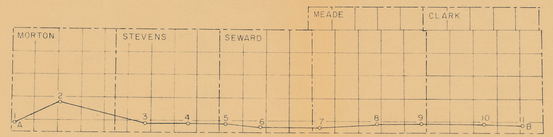


PLATE 12 B

West — East

G 1 2 3 4 5 6 7 8 9 H

Interval to top of Lansing Group not to scale

PENNSYLVANIAN

CHEROKEE GROUP

ATOKAN ROCKS

KEARNY FORMATION — UPPER MEMBER

KEARNY FORMATION — LOWER MEMBER

MISSISSIPPIAN

100 FEET — 50 — 0

0 10 20 SCALE IN MILES

Datum: Top of Lansing Group

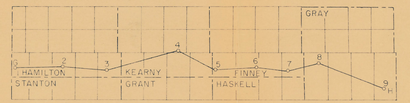
Lithology based in part on wells not shown on cross section

REGIONAL STRATIGRAPHIC CROSS SECTION G-H
HAMILTON COUNTY TO GRAY COUNTY

DEAN A. McMANUS
1959

List of Wells

1. Skelly, No. 1 Hatcher. . . . . sec. 21, T. 26 S., R. 43 W.
2. Caulkins, No. 1 Storey . . . . . sec. 21, T. 26 S., R. 41 W.
3. Stanolind, No. 1 Trussel . . . . . sec. 28, T. 26 S., R. 39 W.
4. Excelsior, No. 1 Masonic Home. . . . sec. 34, T. 25 S., R. 36 W.
5. White Eagle, No. 4 Delvin-Jones. . . . sec. 30, T. 26 S., R. 34 W.
6. Coppinger, No. 1 Beyer . . . . . sec. 24, T. 26 S., R. 33 W.
7. Continental, No. 1 Kleysteuber . . . . sec. 29, T. 26 S., R. 31 W.
8. Continental, No. 1 Laird . . . . . sec. 15, T. 26 S., R. 30 W.
9. Kerr-McGee, No. 1 DeVore . . . . . sec. 21, T. 27 S., R. 27 W.



KGS Open-file Report 59-5

PLATE 13

STRUCTURE CONTOUR MAP ON TOP OF KEARNY FORMATION

Contour Interval = 100 Feet
Datum = Sea Level

0 5 10 15 20
SCALE IN MILES

DEAN A. McMANUS
1959

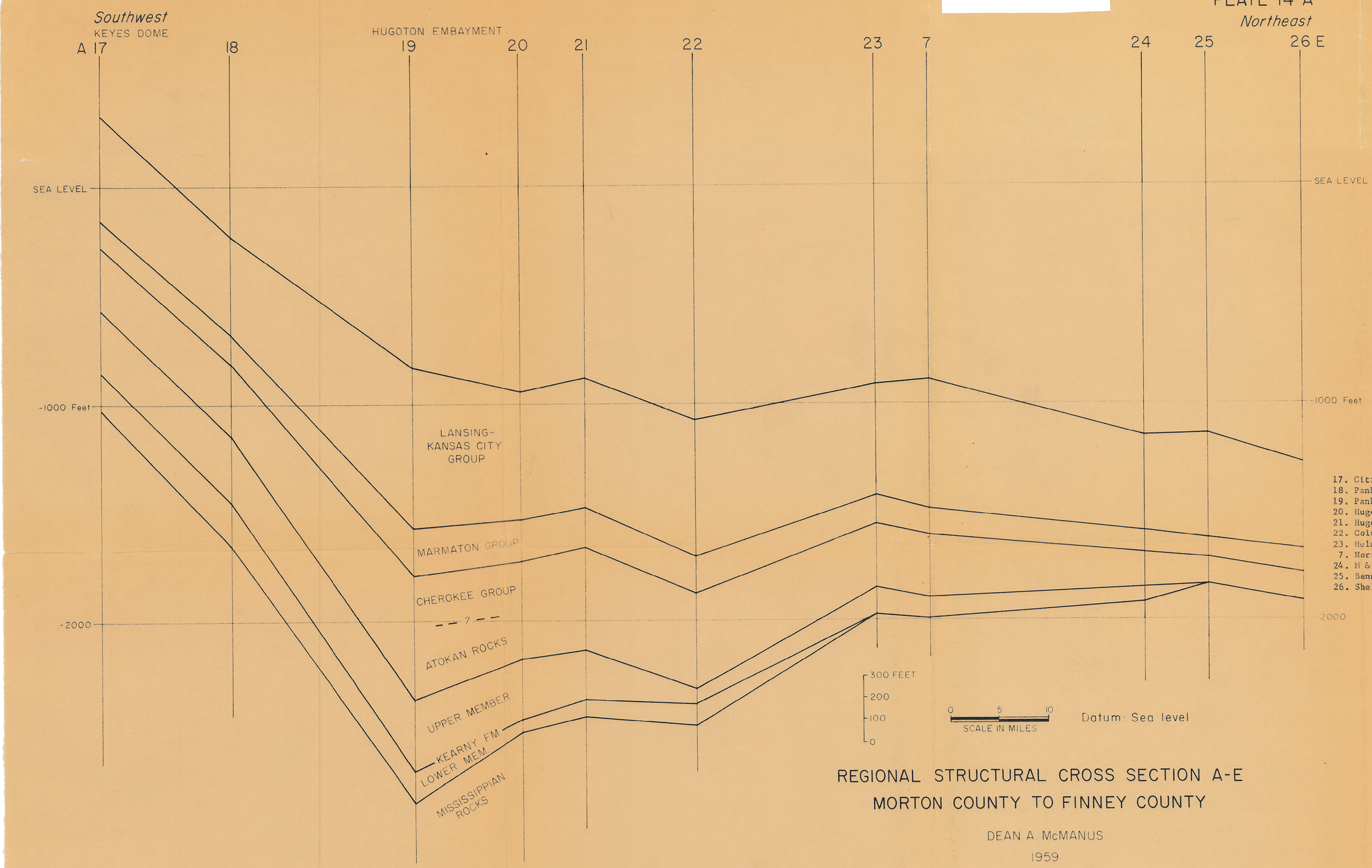
CHEYENNE
RAWLINS
SHERMAN
THOMAS
WALLACE
LOGAN
GOVE
GREELEY
WICHITA
SCOTT
LANE
HAMILTON
KEARNY
FINNEY
GRAY
FORD
STANTON
GRANT
MEADE
CLARK
MORTON
STEVENS
SEWARD
HASKELL

T 1S
T 2S
T 3S
T 4S
T 5S
T 6S
T 7S
T 8S
T 9S
T 10S
T 11S
T 12S
T 13S
T 14S
T 15S
T 16S
T 17S
T 18S
T 19S
T 20S
T 21S
T 22S
T 23S
T 24S
T 25S
T 26S
T. 27S.
T 28S.
T. 29S.
T 30S.
T. 31S.
T 32S.
T 33S.
T. 34S.
T. 35S.

R 43 W. R. 42 W. R 41 W. R. 40 W. R. 39 W. R. 38 W. R. 37 W. R. 36 W. R. 35 W. R. 34 W. R. 33 W. R 32 W. R. 31 W. R. 30 W. R 29 W. R 28 W. R. 27 W. R. 26 W. R. 25 W. R. 24 W. R 23 W. R 22 W. R. 21 W.

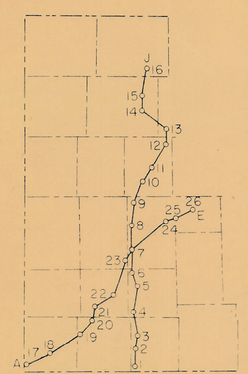
KGS Open-file Report 59-5

PLATE 14 A



List of Wells

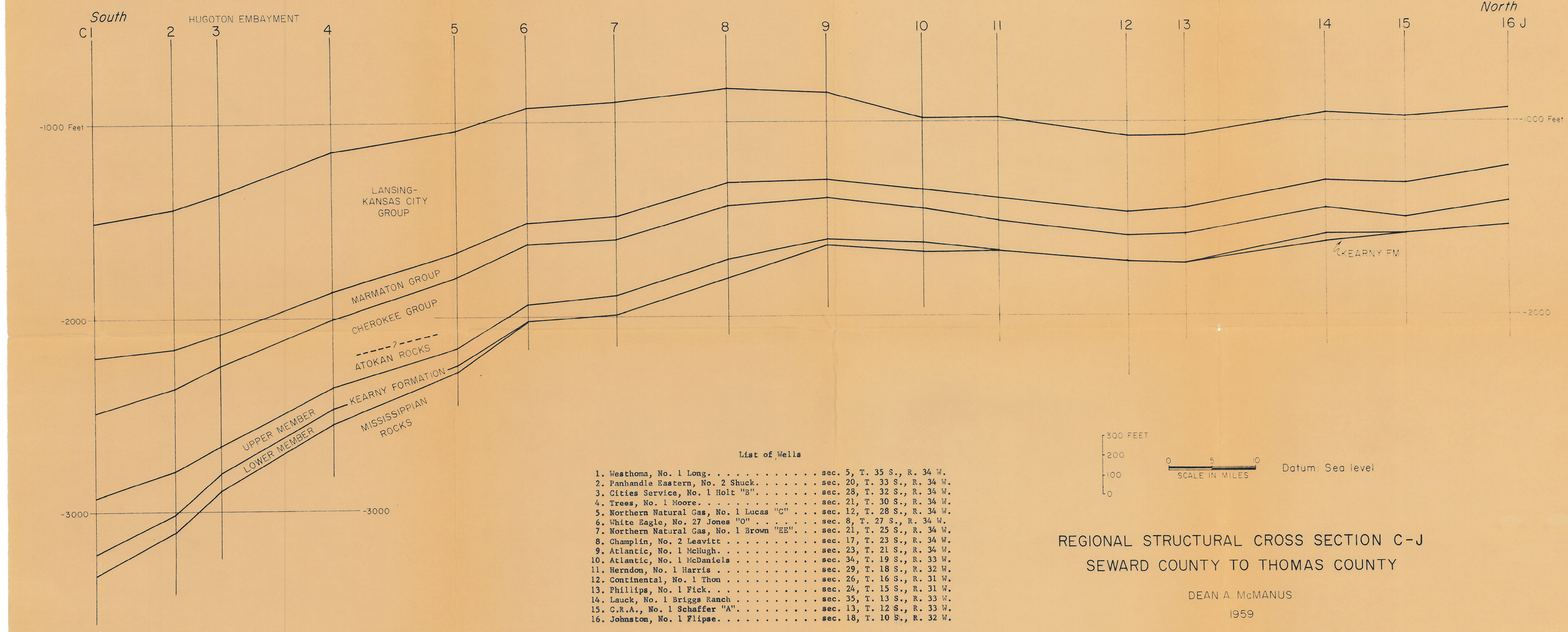
17. Cities Service, No. 1 Government "A". . . . sec. 6, T. 35 S., R. 43 W.
18. Panhandle Eastern, No. 1 Wacker . . . . . sec. 7, T. 34 S., R. 41 W.
19. Panhandle Eastern, No. 1 Shafer . . . . . sec. 25, T. 32 S., R. 39 W.
20. Hugoton, No. 2 Panoma . . . . . sec. 12, T. 31 S., R. 38 W.
21. Hugoton, No. 2 Hoffman. . . . . sec. 6, T. 30 S., R. 37 W.
22. Columbian, No. 2 English "A". . . . . sec. 2, T. 29 S., R. 36 W.
23. Helmerich & Payne, No. 4 White. . . . . sec. 13, T. 26 S., R. 35 W.
7. Northern Natural, No. 1 Brown "EE". . . . . sec. 21, T. 25 S., R. 34 W.
24. M & L, No. 1 Trekell. . . . . sec. 6, T. 23 S., R. 31 W.
25. Bennett & Roberts, No. 1 Petkin . . . . . sec. 30, T. 22 S., R. 30 W.
26. Shell, No. 1 Baumann. . . . . sec. 4, T. 22 S., R. 29 W.



REGIONAL STRUCTURAL CROSS SECTION A-E
MORTON COUNTY TO FINNEY COUNTY

DEAN A. McMANUS
1959

PLATE 14 B



List of Wells

1. Westhoma, No. 1 Long. . . . . sec. 5, T. 35 S., R. 34 W.
2. Panhandle Eastern, No. 2 Shuck. . . . . sec. 20, T. 33 S., R. 34 W.
3. Cities Service, No. 1 Holt "B". . . . . sec. 28, T. 32 S., R. 34 W.
4. Trees, No. 1 Moore. . . . . sec. 21, T. 30 S., R. 34 W.
5. Northern Natural Gas, No. 1 Lucas "C" . . . sec. 12, T. 28 S., R. 34 W.
6. White Eagle, No. 27 Jones "O" . . . . . sec. 8, T. 27 S., R. 34 W.
7. Northern Natural Gas, No. 1 Brown "EE". . . sec. 21, T. 25 S., R. 34 W.
8. Champlin, No. 2 Leavitt . . . . . sec. 17, T. 23 S., R. 34 W.
9. Atlantic, No. 1 McHugh. . . . . sec. 23, T. 21 S., R. 34 W.
10. Atlantic, No. 1 McDaniels . . . . . sec. 34, T. 19 S., R. 33 W.
11. Herndon, No. 1 Harris . . . . . sec. 29, T. 18 S., R. 32 W.
12. Continental, No. 1 Thon . . . . . sec. 26, T. 16 S., R. 31 W.
13. Phillips, No. 1 Fick. . . . . sec. 24, T. 15 S., R. 31 W.
14. Lauck, No. 1 Briggs Ranch . . . . . sec. 35, T. 13 S., R. 33 W.
15. C.R.A., No. 1 Schaffer "A". . . . . sec. 13, T. 12 S., R. 33 W.
16. Johnston, No. 1 Flipse. . . . . sec. 18, T. 10 S., R. 32 W.

REGIONAL STRUCTURAL CROSS SECTION C-J
SEWARD COUNTY TO THOMAS COUNTY

DEAN A. McMANUS
1959