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CHARACTER OF THE MISSISSIPPIAN FORMATION IN SOUTH CENTRAL KANSAS

by

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INTRODUCTION

This paper was originally prepared for presentation at the Mississippian Symposium sponsored by the Wichita Section of the Society of Petroleum Engineers. They asked me to do a paper about the Mississippian in South Central Kansas. As they needed to get out early data on the Symposium, it became necessary to title the paper before it was written. Early in my preparation of the paper it became evident that due to the time available for both research and presentation I would have to either be very general about a large area in which I had limited expertise or more specific about a smaller area in which I had spent much time and study. As I chose to concentrate on the smaller area, the paper should probably be titled "The Character of the Mississippian Formation in the Kingman - Harper - Barber County Area."

One of the purposes of this study is to determine methods by which we can optomise the amount of oil and gas discovered, developed and economically produced from the Mississippian in the area. The Barber, Harper and Kingman County area is particularly suited to this type of study in that the Mississippian Osage sub-crop band has been extensively drilled and is in a mature state of development. Much of the development in this area has taken place since 1950, therefore, good logs and records are available on a high percentage of the wells drilled in the area.

There are many indications in this study that point to the necessity of communication, cooperation and coordination between the geologists, the engineers and the service company personnel, in order that we can drill the wells at best location and complete and produce them in a manner that will allow the maximum amount of oil and gas to be economically produced and developed.

So that we may better understand the present day character of the Mississippian reservoir, I will briefly discuss the geologic history of the area, the location and the characteristics of the Mississippian subdivisions across the area, the history of oil and gas development, proper parameters for evaluation of the reservoir and the importance of using completion procedures and well stimulations based on the characteristics of the Mississippian reservoir in the local area. Proper use of all the available data will result in better completions and maximum recoveries from the wells.

I. LOCATION AND GEOLOGIC SETTING OF AREA

Slide 1 is a location map used to show the position of the Sedgwick Basin relative to the major structural features of the area.

The study area covers the west flank of the Sedgwick Basin, east of the Pratt Anticline. The Sedgwick Basin is on the northern shelf area of the Anadarko Basin and is bounded on the east by the Nemaha Ridge, on the north by a low relief and indistinct saddle that separates it from the Salina Basin, and on the west by the Pratt Anticline that separates it from the Hugoton Embayment of the Anadarko Basin. The Mississippian section is over 500 feet thick at the Oklahoma line in southern Harper County, Kansas, and the section thins or has been eroded away across the Pratt Anticline to the west and the Nemaha Ridge to the east.

Slide 2 is a map of the Southern part of the Sedgwick Basin. Shown on this map are generalized contours on the Mississippian on a 200 foot contour interval. The axis of the Pratt Anticline, to the west and the Nemaha Ridge to the east is indicated on the map. Also shown are the approximate positions of the Mississippian sub-crop bands in Barber, Harper and Kingman Counties. A sheet of "Redeposited Detrital Osage" rocks covers much of the Residual Osage and Warsaw bands and masks the true position of these bands; therefore, on these bands the sub-crop position shown is of the rocks present below the detrital, redeposited Osage that may be present over the "in-place" rocks. Oil and Gas Fields producing from the Mississippian formation are shown across the west flank of the Basin but are not shown in the Sedgwick or Sumner County areas.

Slide 3 is a diagrammatic cross section from southeastern Stafford County to the Oklahoma line in south central Harper County.

II. GEOLOGIC HISTORY

In order that we may better understand the present day character of the Mississippian in the area, I will briefly cover what is inferred to be the geologic history of the area, as it affects the Mississippian rocks - or how the rocks got to be the way they are today.

A. Sedimentation

Early Osagian limestone was deposited in warm clear water containing abundant crinoids and other marine life. During Middle and late Osage time, thick beds of limestone containing a profusion of crinoid remains and an abundance of chert were deposited. The chert is generally considered to be primary and was probably formed as masses of silica gel settled into the lime muds and intermixed with marine fossil, skeletal and detrital materials.

Rocks of Warsaw (Meramecian) age lie disconformably or unconformably on Osage rocks. During Meramecian time there was less stability in distribution of the shallow seas and less uniformity in the nature of sedimentation as compared with Osage time. Much lateral variation characterize some of these deposits, reflecting gentle warping of the sea bottom and establishment of local basins of sedimentation.

The "Cowley Facies" of extreme southern Kansas cuts across time lines from the Meramecian into the Kinderhook. The question of how it was deposited is controversial.

B. Uplift, Erosion, Redeposition and Alteration

It appears that the top of the Osage may have been affected by two periods of altering that formed the reservoir and the permeability barriers as we know them today. There is evidence to suggest that a period occurred at the end of Osage time in which the sea withdrew. During this period of withdrawal deep channels were cut in the soft siliceous lime muds and the exposed area was subject to its first period of weathering. In the Spivey-Grabs-Rhodes Pool trend, the dominant channels, cut during this period, seem to have a northeast-southwest trend, suggesting that there was subsidence in the Anadarko Basin to the southwest at this time. As shallow Warsaw seas again covered the area, the deep narrow erosional channels cut in the Osage were filled with Warsaw carbonates. This carbonate channel fill may account for the narrow bands of limestone and dolomite that provide many of the updip permeability traps that form many of the oil and gas fields in the Osage band.

The end of the Mississippian time was marked by withdrawal of the sea from most of the continent and by uplift and extensive erosion. The Central Kansas Uplift, the Pratt Anticline and the Nemaha Ridge and numerous small structural features were activity uplifted at this time and received extensive erosion and leveling. Mississippian age rocks were completely removed from the Central Kansas Uplift and from parts of the Pratt Anticline and Nemaha Ridge. This tremendous volume of detrital material was dumped into the adjacent basinal areas. The effect of this uplift and erosion was to leave the oldest Mississippian rocks wedging out or thinning over the areas structurally uplifted with the youngest Mississippian rocks being preserved in the center of the basinal area. The surface was deeply weathered and solution features developed locally. A sheet of detrital chert nodules and fragments from the Osage eroded from the structurally high areas and was deposited back on top of the Mississippian in the adjacent structurally and topographically lower areas. In some areas this caused redeposited detrital Osage chert to be deposited back over younger "in place" rocks of Meramecian age. Drainage patterns established during this time of erosion and re-deposition are one of the factors in present day trapping of oil and gas accumulations. These drainage channels, usually filled with Pennsylvanian shale and/or shaly conglomeratic chert form most of the topographic features evident at the post Mississippian unconformity.

Much of the porosity development in the weathered cherts of the residual Osage and the detrital zone probably occurred during this late Mississippian period of uplift and erosion. Dolomatization and porosity development in lower Meramecian Warsaw probably also occurred during this time period.

At the end of Mississippian time, Pennsylvanian seas invaded the area depositing cyclical sequences of non-marine and marine shale and limestone. These strata are mostly impermeable in the area and provide a good "roof" over the Mississippian rocks to stop any vertical migration of hydrocarbons. The Pratt Anticline apparently remained a positive area during early Pennsylvanian time as, over a portion of the Anticline, Cherokee rocks are absent and the Mississippian is in contact with Marmaton rocks. Basinward from the Pratt Anticline, progressively older Cherokee beds are in contact with the Mississippian.

While most of the major structural features in the Sedgwick Basin were formed during the late Mississippian - early Pennsylvanian time, structural growth of the Nemaha Ridge, Central Kansas Uplift, Pratt Anticline and many minor, generally northeast-southwest trending structural trends in the Sedgwick Basin continued through Pennsylvanian time. The saddle separating the Sedgwick Basin from the Salina Basin appears to have formed during this period. During Permian time minor structural movement and subsidence to the south in the Sedgwick Basin occurred. Structural movement other than general tilting after Permian time is probably very minor.

The following slides are designed to show the sequence by which the Mississippian was deposited and altered to its present condition. This section is a cut in the approximate position of the Spivey-Grabs Field.

Slide 4 illustrates the deposition of the siliceous lime muds in shallow Osage areas.

Slide 5 illustrates the deep erosional channels cut in the soft siliceous lime mud by the receding water at the end of Osage time. The surface was exposed to a period of weathering and leaching.

Slide 6 depicts the area after the invasion of Meramecian seas and the deposition of Meramecian Warsaw carbonates in the erosional channels cut in the Osage.

Slide 7 illustrates the condition at the end of Mississippian time. Uplift of the Central Kansas Uplift and the Pratt Anticline and extensive erosion caused post-Osage sediments to be truncated from the area of this slice and be preserved only in channels cut at the end of Osage time. A sheet of detrital Osage, washed back off the Central Kansas Uplift and Pratt Anticline, was deposited across the area. New drainage channels were cut and the whole area was subject to extensive weathering, leaching and erosion.

Slide 8 illustrates the condition of the area after lower Pennsylvanian shales and limes were deposited on the erosional surface.

C. Oil and Gas Migration

Oil and gas migration probably occurred during late Pennsylvanian and early Permian time. As oil and gas migrated updip, it was trapped against permeability barriers and in structural closures.

Slide 9 is a portion of the Spivey-Grabs Field in which a drainage pattern at the end of Osage time has been projected by connecting the wells in which the "channel-fill" limestone was encountered. It appears that the drainage was to the southwest into the Anadarko Basin. As these channels are roughly perpendicular to present Mississippian dip, they provide the trapping mechanism in much of the residual Osage band.

Slide 9A is a cross section through a portion of the Spivey-Grabs Field. The logs are hung on a Cherokee marker bed and do not show structure, but show the variation in the Mississippian reservoir across the field. Wells 1, 3, 6 and 8 are barrier wells that I have inferred to be Warsaw channel fill in the Osage. In wells with a clean porous chert section, the position of the redeposited detrital Osage is purely speculative.

The zone marked in green is a late Mississippian channel cut that has been filled with Pennsylvanian shales. Well #6 appears to have both Warsaw channel fill in the Osage and a second channel cut at the end of Mississippian time filled with Pennsylvanian shale.

III. PRESENT DAY CHARACTER OF THE MISSISSIPPIAN ROCKS

A. Osage

Osage rocks subcrop below Pennsylvanian beds in a band roughly parallel with the west boundary of the Sedgwick Basin. The thickness of the truncated Osage rocks ranges generally from 0 to 50 feet over the Pratt Anticline and thickens to the southeast toward the axis of the basin to a total of 250 feet or more. Where the total thickness between the Kinderhook shale and the top of the Mississippian is less than approximately 100 feet, the section is generally fresh to semi-weathered chert of a detrital, conglomeratic nature, washed back off the truncated areas to the north and west. This band of rocks is marked as the "Redeposited Detrital Osage" on the subcrop map.

The best Osage reservoir generally occurs when the Kinderhook Shale to top of Mississippian thickness exceeds 150 feet and the reservoir section consists for the most part of residual highly weathered chert to fractured fresh cherts. The upper part of the chert section in this band is probably detrital, but where it is deposited over the residual chert, the same environment and factors that formed the porous permeable reservoir in the residual chert probably served to do the same with the detrital zone and, therefore, made them indistinguishable from each other in well cuttings and by electric log. The Osage reservoir within this band is characterized by high porosity and low resistivity on the electric log.

Net pay sections exceeding 100' in some wells are found within this sub-crop band which includes such fields as the Rhodes, Sharon and Spivey-Grabs. The trapping in these fields is generally of a stratigraphic nature caused by updip trapping against narrow bands and areas of impermeable limestone, dolomite, chert and shale. The narrow impermeable areas are probably associated with the ancient drainage systems that were present both at the end of Osage time and again in late Mississippian time. Trappings of this type results in abrupt changes in reservoir thickness. The Spivey-Grabs Field, and other fields within this subcrop band, is made up of a series of associated "pools" or traps and not one large trap with a single updip limit, as is commonly conceived of stratigraphic fields. Each of these separate traps, or areas, within the field, has its own characteristics. The water table is not the same in each trap, some have a water drive, some a partial water drive and many or most are gas solution drive. In some areas the pay is at the top of the section, in others the best permeability and pay may be more than 80 feet below the top, even though it may look and calculate essentially the same from top to bottom on the log. These variations in permeability through the porous chert reservoir make it important that the potentially productive porous chert section be evaluated by drill stem test in intervals short enough that intervals productive of gas, oil and water may be identified before completion in order that the best completion procedure and stimulation may be used.

In some areas of these fields the base of the chert porosity section is above the water column; in other areas there is water below the pay section. Knowledge of areas in which water is a factor is important in selection of the type of completion and stimulation on a well. In some areas the Osage chert can be fracture treated with large volumes at high rates with favorable results; in other areas even very small fracture treatments at low rates bring on excessive water production.

The type of porosity present in the chert reservoir section is also a factor in determining type of fluid produced and the G.O.R. Very small fine pores in a highly weathered soft tripolitic chert will have different producing characteristics and will react differently to treatment as compared to a coarser vugular porosity in tripolitic or semi-weathered chert even though porosity log calculations may be the same. Fractured fresh chert and the degree of natural fracturing within these porosity zones are additional factors in determining the type of fluid produced and the G.O.R. from a particular interval of chert porosity. In my opinion, these variations in porosity type explain, in part at least, the variations in G.O.R. and water cut from wells producing from the same datum within an area.

In general, oil and gas production from the Osage comes when the Residual Osage is in subcrop position below the post-Mississippian unconformity, even though the best porosity, permeability and pay section may be developed a considerable distance below the unconformity. There are exceptions to this and there are areas, such as parts of the Rhodes Field, in which excellent production from the Osage chert occurs below considerable thickness of tight limestone, chert and shale in the upper portion of the Mississippian. The bulk of the Osage production, in the study area, is found in the residual Osage band. This is as the result of the presence of good reservoir rocks and suitable traps. The limefilled channel cuts in the Osage band provide excellent updip permeability traps. As the redeposited detrital Osage band consists of rocks that have been redeposited over an area leveled by erosion, these limefilled channels have been destroyed and are not present; therefore, the traps provided by these channel fills are not present. This may be the reason that few Mississippian fields have been found updip from the Residual Osage band.

B. Meramecian (Warsaw & Spergen)

Basinward, to the east and southeast of the Osage subcrop band is the difficult to distinguish Warsaw subcrop boundary. The Osage-Warsaw contact falls roughly within the 250 to 300 foot thickness interval between the top of the Mississippian and the top of the Kinderhook shale.

The Warsaw-Osage subcrop boundary is difficult to distinguish for several reasons. Where the Warsaw is in subcrop position, it was subject, during the period of uplift and erosion, to many of the same erosional and environmental conditions that were present in the Osage subcrop band. Much of the carbonate material may have been leached away leaving a residual chert having log characteristics, and many sample characteristics, similar to the Osage chert. Close sample examination of the cherts in this band reveal some general but subtle differences from the Osage chert. The residual Warsaw cherts are sometimes dolomitic or appear at times to be a siliceous dolomite. The white cherts seem to have a more blue-gray tone, a more "gritty" texture and be devitrified and dull. Covering much of the area near the Warsaw-Osage subcrop boundary is a cover of detrital redeposited Osage chert that has washed back over the top of the residual Warsaw. Erosional channels into the Warsaw filled with the detrital Osage chert are also present. In areas where there is a cover of detrital redeposited Osage chert over the residual Warsaw chert, over the residual Osage chert, it is very difficult to determine the boundaries.

Basinward, as the unconformity to base of Warsaw interval becomes thicker, beds of sucrosic dolomite, cherty dolomite, cherty limestone and siliceous limestone occur. The dolomitic zones often have excellent reservoir qualities. These porous dolomite zones have an erratic nature of occurrance that provides the stratigraphic trapping mechanism that accounts for excellent production in the northeast Kingman County area. The dolomite zones also produce in several Harper County fields.

In much of the Warsaw subcrop band there is porosity in the cherts present at the post-Mississippian unconformity, allowing oil and gas to migrate updip into the Osage subcrop band, except where structurally trapped.

Basinward, to the southeast of the Warsaw-Osage band is the subcrop of a resistive limestone and/or dolomite zone, probably of Spergen Age. This zone, ranging from dense to chalky limestone to fossiliferous coarse granular to coarse crystalline dolomite and limestone, with zones of chert, usually has poor porosity development. In areas of Harper County such as the Wharton Pool, the Hibbard and parts of the Hibbard Northeast Pool, Warsaw dolomite produces under this limestone. In general the zone does not appear to be a good reservoir in the study area, however, the zone produces, or has produced, gas from thin porosity breaks present in wells in the Wharton and Hibbard Pools in Harper County and gas shows are not uncommon in the zone when porosity is developed.

Production found to date in the area of the Spergen-Warsaw contact, in Harper County, has had several common characteristics. Productive wells in the Wharton and Hibbard fields have had relatively low gas volumes on drill stem test, but have had calculated damage ratios in the 10 to 1 range. Bottom hole pressures in the 1900# range are high for the 4600 foot depth. Neutron porisity logs generally indicate low porosity, however, this may be gas effect as Density logs have indicated good porosity in the gas zones. The wells respond well to light acid treatment (1000 gallons or less) but fracture treatment usually brings excessive water production.

C. Cowley Facies

In southwestern Barber County there is an area of Mississippian rocks known as the "Cowley Facies". The Cowley in this area is characterized by a dark gray to gray green dirty, silty dolomite, siliceous dolomite and shaly dolomitic chert. From sample examination, log analysis, drill stem test results and most of the criteria generally used to evaluate a zone this area looks generally unfavorable, however, it contains the Aetna Gas Field which is one of the larger fields in the area. With the development of hydraulic fracture treatments the Aetna Field became an important gas producing area. Many of the wells in this area drill stem test gas too small to measure, with low permeability type pressure curves. On Gamma Ray logs the zone generally appears to be very shaly. A different set of criteria has to be used to evaluate wells drilled in the "Cowley Facies" area as compared with criteria used to evaluate wells in the other Mississippian areas.

IV. HISTORY OF DEVELOPMENT OF MISSISSIPPIAN OIL & GAS FIELDS IN AREA

The first Mississippian production in the Kingman, Harper, Barber County area was in the Kingman Pool, discovered in 1926. This production was non-commercial and it was abandoned shortly thereafter.

Slide 10 Production map of Medicine Lodge Pool

In 1927 prolific Mississippian gas production was found in the Medicine Lodge Field. This field, developed on 160 acre spacing, has produced over 325 billion cubic feet of gas to date. One of the wells, the Barbara #2 Carter has produced over 26 billion cubic feet and is still a good well.

In 1934 the first commercial oil was discovered in the Whelan Pool of Barber County. This small pool has produced over 3.7 million barrels of oil.

In 1935 the Aetna Gas Area was discovered but it was not until the late 1950's, after the development of hydraulic fracturing techniques, that the field was extensively developed. The area has produced over 120 billion cubic feet of gas.

In 1946 Mississippian-Warsaw dolomite production was discovered in the Bartholomew Pool of Sedgwick County. Subsequent development extended the area into Kingman County.

Slide 11 Production map of Rhodes Pool

In 1949 the Rhodes Pool was discovered in Barber County. This pool has produced over 10 million barrels of oil and 140 billion cubic feet of gas, to date. A portion of the field has been produced under waterflood for a number of years.

Slide 12 Production map of Spivey-Grabs Field

Also in 1949 the Grabs sector of the Spivey-Grabs Field was discovered. In 1951 the Spivey sector was discovered in Kingman County. Extensive development during the 1950's and 1960's combined the Spivey-Grabs and Basil Fields into one of the larger producing areas in Kansas. To date, the Field has produced over 50 million barrels of oil and over 500 billion cubic feet of gas. Considerable drilling is still taking place in the field. In 1954, during development of the field, 40 producers and only 3 dry holes were drilled in the Kingman County portion of the field.

In 1950, the Broadway Pool was discovered, producing from the Mississippian-Warsaw dolomite. This pool has produced over 3.5 million barrels of oil and 15 billion cubic feet of gas.

Slide 13 Production map of Hardtner Pool

In 1954 the Hardtner Pool in Barber County was discovered. It has produced over 110 billion cubic feet of gas.

Exploration and development has continued through the three County area with numerous small fields being found, along with development and extension of the major fields. The development of fracturing techniques contributed greatly to the development of oil and gas fields in the Osage band and in the Cowley Facies Area.

Development over much of the Osage band is in a mostly mature state at this time. Development in the Warsaw-Spergen band has been very limited and still has considerable potential.

V. EVALUATION OF MISSISSIPPIAN RESERVOIR

It has been said that the start of a good completion starts on the Rotary Rig. I agree very much with this philosophy. The material presented to this point in this paper has been designed in part to show the necessity of pre-drilling research in an area and consultation between the geologist and Petroleum engineer in order that the well may be drilled, tested and evaluated in a manner that will allow the most successful completion. Procedures that are the most successful in one area may be completely wrong and unsuccessful in an adjacent area.

Points that should be considered before drilling are as follows:

A. What procedures have been successful in local area?

B. What type of reservoir is expected and does this make a difference in the type of completion to be used?
   1. Chert
   2. Dolomite
   3. Limestone

C. Is the pay expected in the top or at a distance below the top of the Mississippian?
   1. Are there several possible pay zones within the Mississippian?
   2. Is water present below the pay zone or do you generally run out of porosity below the pay zone?
   3. Would it be best to stop penetration above the water zone?

D. Should the well be completed through open hole or through perforations?
   1. If open hole, how much penetration?
   2. If through perforations, how much rat hole needed?

E. What Drill Stem Testing Program should be used?
   1. What intervals?
   2. What time periods?

F. Should cores be taken?

G. What logging program should be used?
   1. If well has short penetration in the pay zone and is to be completed in open hole, are open hole logs needed?
   2. For what purpose are logs being run and what types should be used?
      a. To find the gas - oil or oil water contact?
      b. To find best interval to perforate?
      c. For use in reserve calculations?
      d. For depth control?
      e. To satisfy DHM requirements?
      f. Because company policy required running a log?

As conditions that are expected to exist before a well is drilled don't always occur when the well is actually drilled it is essential that the lines of communication between the geologist and engineer be kept open during the drilling of the well. Enough flexibility should exist so that pre-determined procedures can be changed should the well conditions encountered during drilling dictate that another procedure would be better. Use the well data as it is obtained so that the best decision can be made regarding the next step to be taken.

After the well has been drilled and production casing has been set it is important that all of the information available be reviewed in order that the best completion procedure can be used.

A. Geological Report of the well site geologist, sample descriptions and time logs should be used for:
   1. Determination of zones with best sample shows and porosity indication.
   2. Determination of the lithology of zones for use in electric log evaluation and type of treatment fluid to be used.

B. Drill Stem Test recovery & pressure data should be used to indicate:
   1. Oil, gas and water productive zones.
   2. Productive capacity of zones.
   3. Indication of amount of stimulation needed for commercial production.

C. Electrical Surveys should be used to indicate:
   1. Oil and gas productive zones and their thicknesses, depth, shale content, porosity and water saturation.

D. Characteristics of this well should be compared with those in other producing wells and dry holes in local area with similar geological conditions.

It is very important that the conclusions reached from this data obtained during drilling of the well be related to the characteristics of the reservoir in the local area. Drill stem test recoveries and log characteristics that would indicate a dry hole or non-commercial production in one area might indicate commercial production in another area or the opposite of this may occur.

VI. COMPLETION PROCEDURES

It has been shown that the character of the Mississippian varies greatly across the area. In addition to the lithology differences within the age bands, producing characteristics, even within the same age band and the same general area, vary considerably. Local characteristics that affect the success of the completion and the type of completion that is most successful include:

A. The type of trap
   1. Structural
   2. Stratagraphic

B. Type of reservoir drive
   1. Water
      a. Bottom
      b. Edge
   2. Gas Solution
   3. Gas Cap
   4. Combinations

C. Extent of vertical fracturing and/or vertical permeability in the local area.

After consideration of all the before mentioned criteria, production casing is either set in or through the pay for completion through perforations, or production casing is set in the top of the pay and the well is completed in the open hole. In general, in areas having gas solution drive, or in which there is no bottom water or in which there is a thick pay section above water, completion through perforations is the most successful.

In some areas with a water drive or vertical permeability to a water drive, there has been considerable success by not penetrating into the water, setting production casing in the top of the pay and completing the wells natural or with light acid treatment in the open hole. This type of completion in these areas almost requires that commercial volumes be tested natural or can be obtained with light acid treatment, as in most instances, where these conditions exist, if the open hole is fracture treated, even with small volumes at low rates, there is a large increase in water production.

STIMULATION

A. Natural: Wells having high natural producing rates are sometimes completed without treatment.

B. Acid: Small volumes (250 to 500 gallons) of clean up acid are commonly used on wells, regardless of lithology, to clean up mud damage and cement damage and to lightly stimulate dolomitic zones.

In the dolomite zones, most all types of HCL seem to be successful, usually with treatment volumes running less than 3000 gallons. Various types from regular 15% to retarded to 28% to MOD 202 type blends are used with all claiming some success.

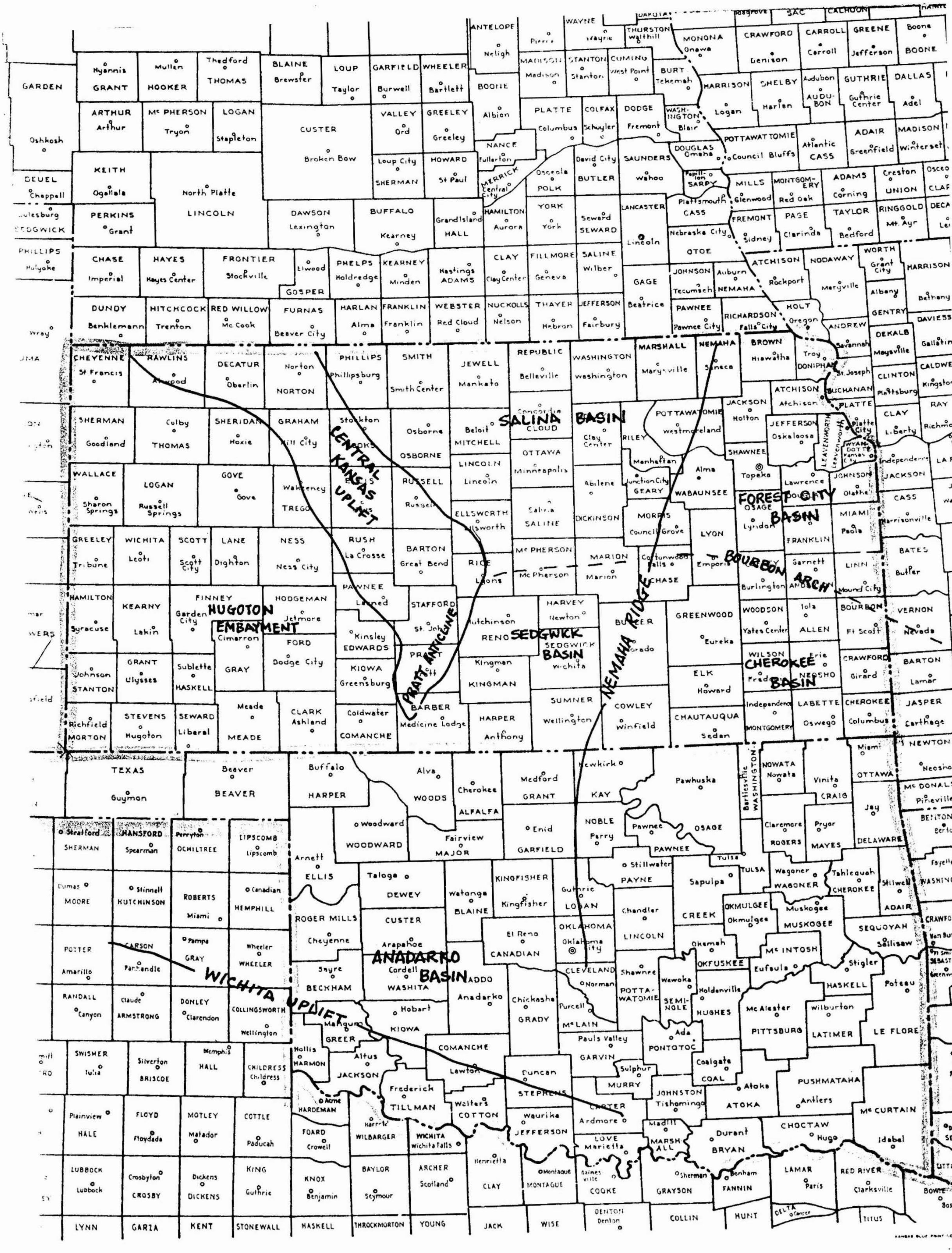
In areas, such as the Warsaw band of Harper County, where early attempts at completion through perforations with frac treatment resulted in excessive water production, there have been wells successfully completed through the open hole with acid treatments, generally 1000 gallons or less, of 15% HCL. On wells in the Wharton and Hibbard Pools, light acid treatment at low rates and maximum pressures generally less than 1200# resulted in 10 fold increases over drill stem test volume of gas.

C. Fracture Treatment: The Mississippian Osage formation and the Cowley Facies reacts very favorably to fracture treatment. The frac design, the fluid used, the volume, propant and rate used again depend on the area and the local reservoir conditions. Small volume, low rate fracture treatments are adequate in some areas while other areas require large volumes and high rates to obtain satisfactory results. As has been mentioned before, in some areas frac treatment can't be used without resulting in excessive water production, but in other areas you appear to be able to pump about as much fluid and sand as you have time and money without any harm being done. Many old wells in the area have been successfully re-fraced, generally with larger volumes and at higher rates than on the original treatment. Many of the new frac designs, new additives and new procedures by most of the service companies, have improved the results of frac treatments and have been generally applicable to the Mississippian chert in this area.

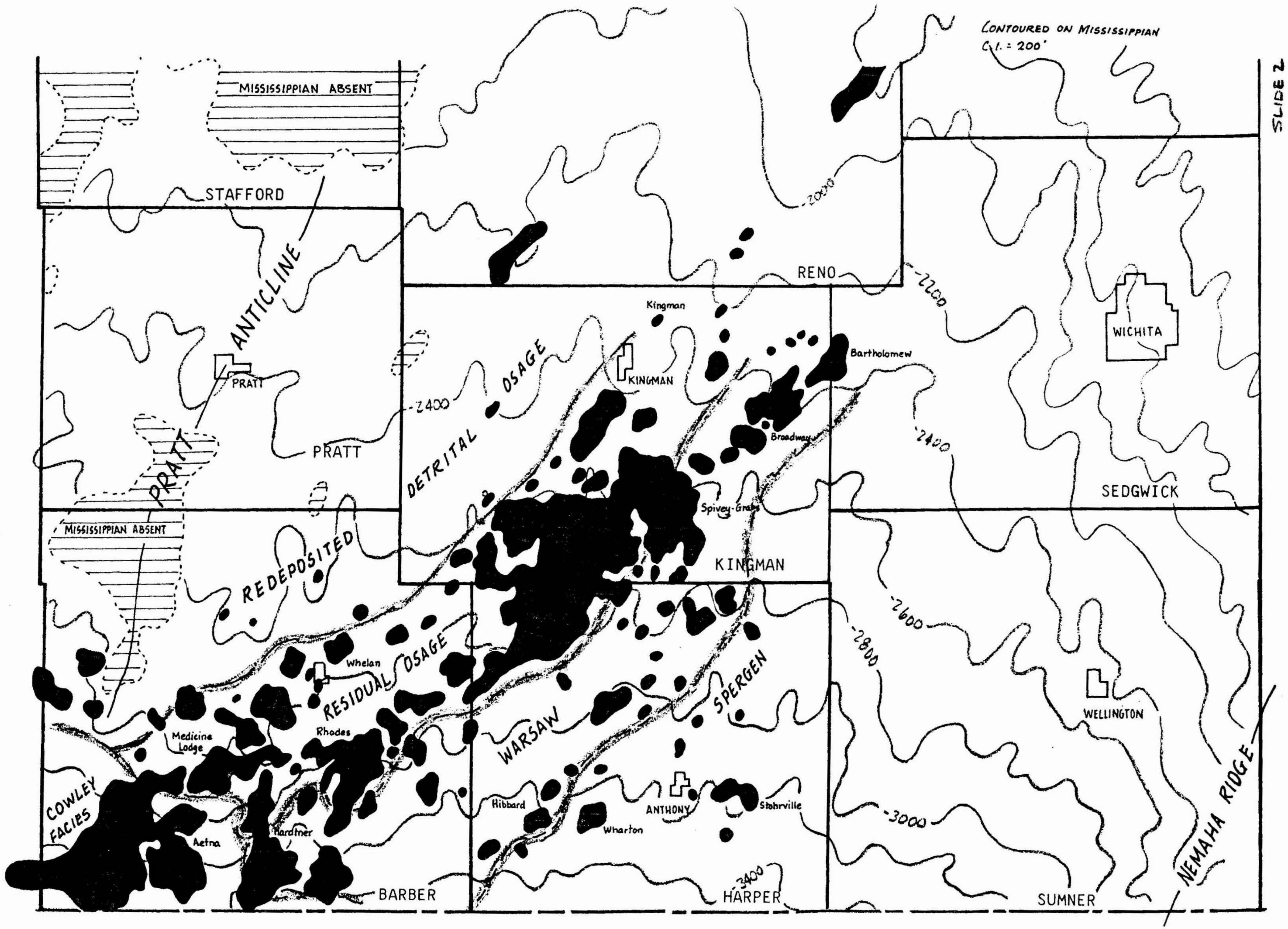
SUMMARY

In summary, this study covers the character of the Mississippian formation along the west flank of the Sedgwick Basin with emphasis on the Barber, Kingman, Harper County, Kansas area. A review of the geologic history of the area was made as an attempt to gain better understanding of the present day lithologic and structural condition of the Mississippian. It was shown that the Mississippian can be subdivided into age bands subcropping below Pennsylvanian beds across the area. While each of the age bands has its own general characteristics, the determination and identification of local characteristics is very important in establishing paramaters by which to evaluate prospects and information obtained from wells drilled in these areas. Because of the differing characteristics, the differing paramaters from which these characteristics are evaluated and the different completion procedures required based on these differences, it becomes essential that there be open lines of communication and cooperation between the petroleum engineer and the geologist. If we use all the knowledge and information available to us, we should be able to continue to develop and produce the full potential of the known reserves in the area and successfully explore for new reserves.

March 29, 1978

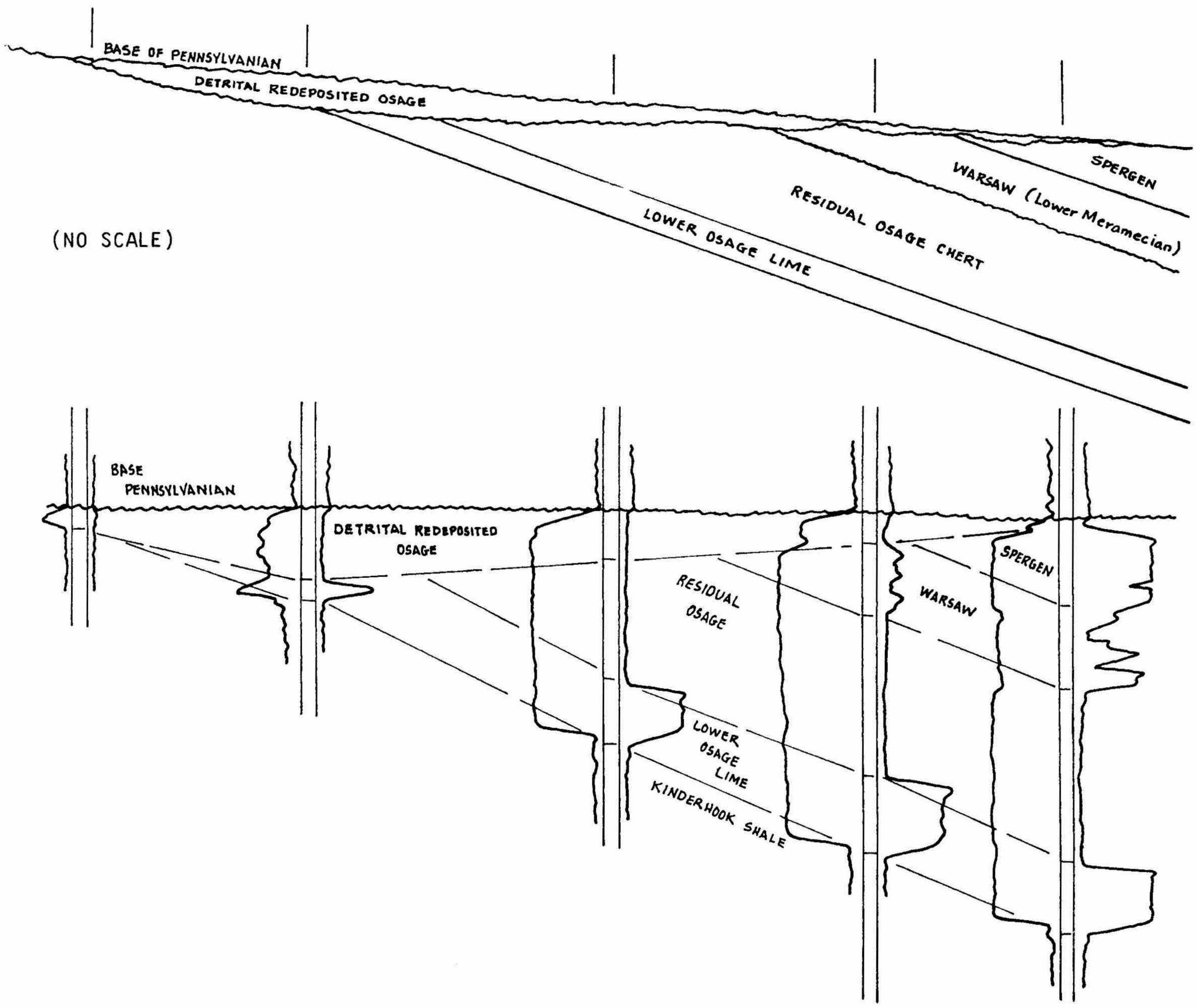

CENTRAL KANSAS UPLIFT
SALINA BASIN
FOREST CITY BASIN
BOURBON ARCH
HUGOTON EMBAYMENT
PRATT ANTICLINE
SEDGWICK BASIN
NEMAHA RIDGE
CHEROKEE BASIN
ANADARKO BASIN
WICHITA UPLIFT

SLIDE 1



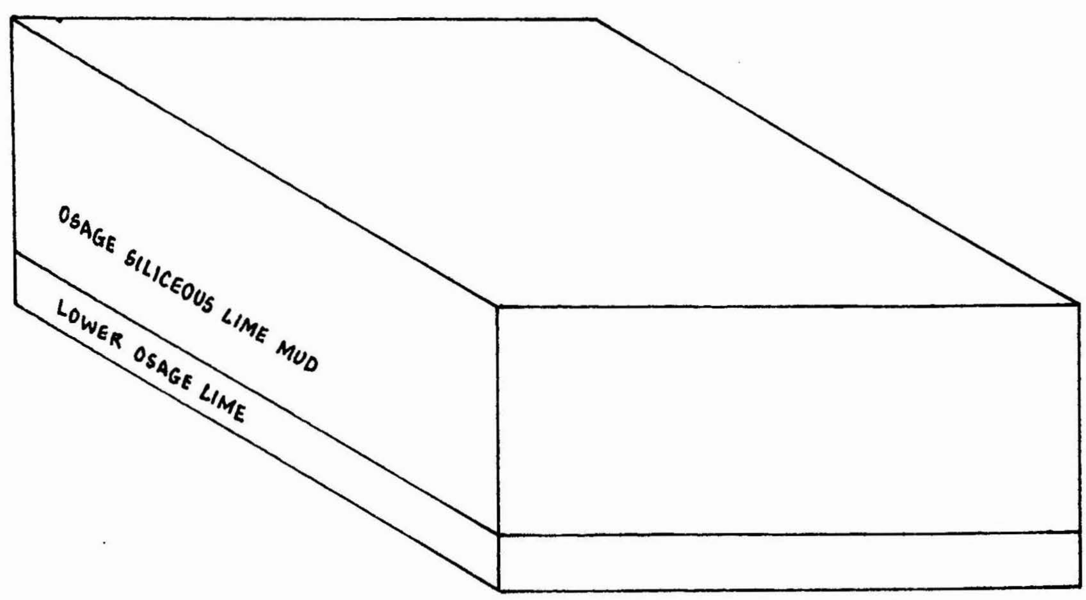
CONTOURED ON MISSISSIPPIAN
C.I. = 200'
SLIDE 2
MISSISSIPPIAN ABSENT
STAFFORD
RENO
PRATT ANTICLINE
PRATT
Kingman
KINGMAN
Bartholomew
Broadway
Spivey-Grabs
WICHITA
2000
2200
2400
2600
2800
3000
3400
DETRITAL OSAGE
REDEPOSITED
RESIDUAL OSAGE
WARSAW
SPERGEN
MISSISSIPPIAN ABSENT
SEDGWICK
KINGMAN
Whelan
Rhodes
Medicine Lodge
COWLEY FACIES
Aetna
Hardtner
Hibbard
Wharton
ANTHONY
Stohrville
WELLINGTON
NEMAHA RIDGE
BARBER
HARPER
SUMNER

(NO SCALE)



DIAGRAMMATIC CROSS-SECTION FROM SOUTHEASTERN STAFFORD COUNTY TO OKLAHOMA LINE IN SOUTH CENTRAL HARPER COUNTY

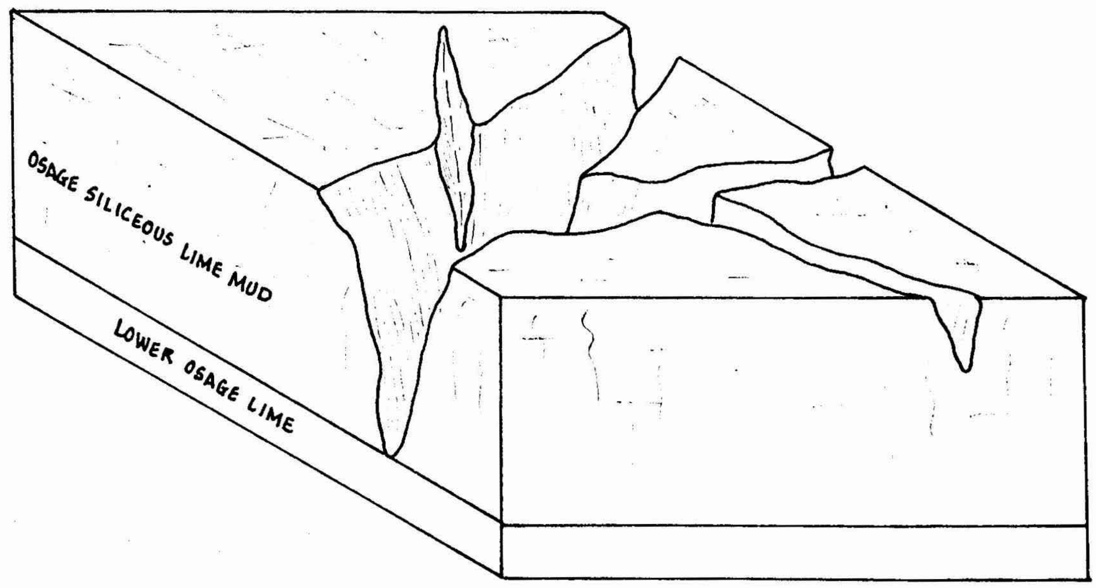
SLIDE 3



STAGE 1

DEPOSITION OF OSAGE SILICEOUS LIME MUD.

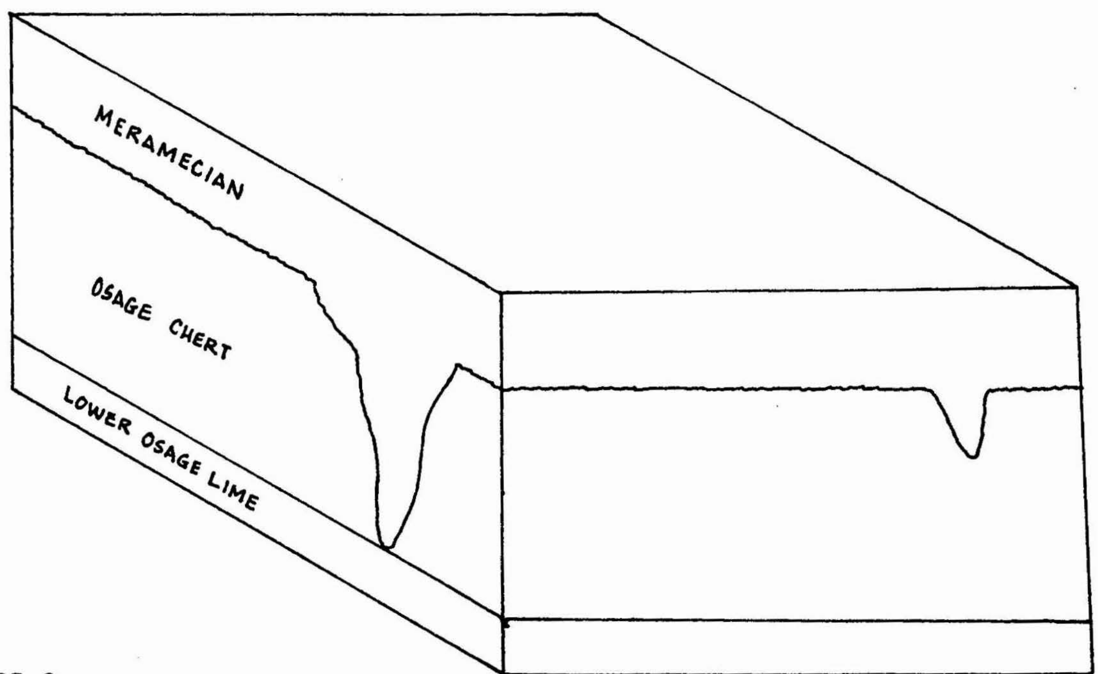
SLIDE 4



STAGE 2

WITHDRAWAL OF THE SEA CAUSED THE RECEDING WATER TO CUT DEEP CHANNELS IN THE SOFT SILICEOUS LIME MUD. THE SURFACE WAS EXPOSED TO A PERIOD OF WEATHERING.

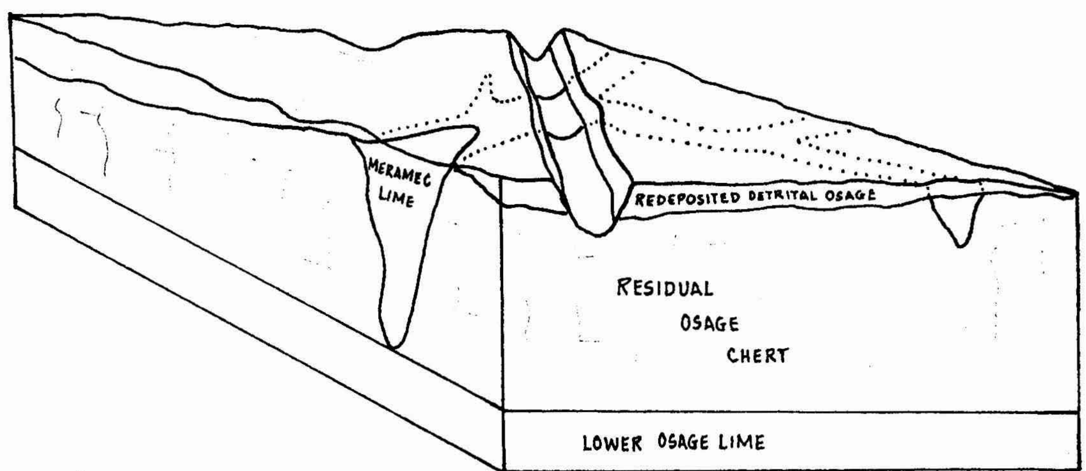
SLIDE 5



STAGE 3

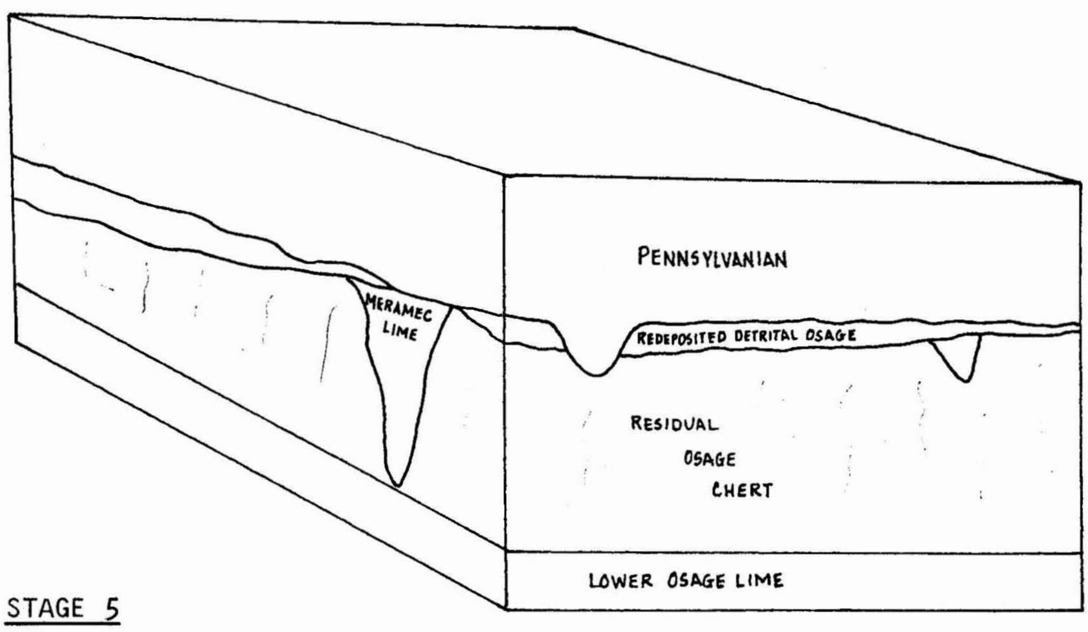
MERAMEC SEAS COVERED THE AREA. DEPOSITION OF NORMAL MERAMEC CARBONATE SEQUENCE AFTER CHANNELS IN OSAGE FILLED WITH CARBONATE MATERIAL.

SLIDE 6



STAGE 4

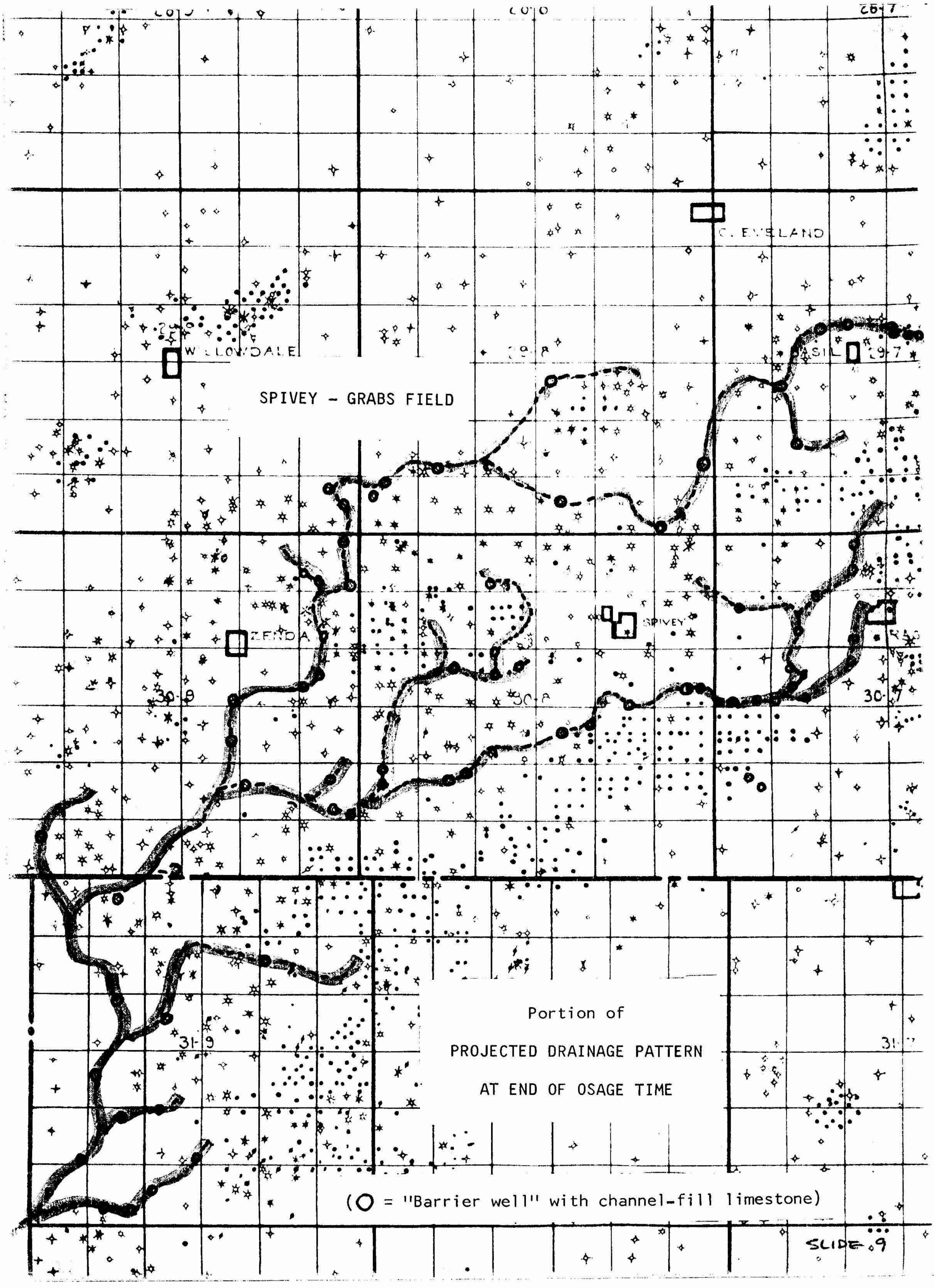
UPLIFT AND EXTENSIVE EROSION AT END OF MISSISSIPPIAN TIME. POST - OSAGE ROCKS TRUNCATED FROM AREA AND PRESERVED ONLY IN OSAGE CHANNEL FILLS. DETRITAL OSAGE REDEPOSITED OVER AREA. NEW DRAINAGE CHANNELS FORMED ON EROSIONAL SURFACE.

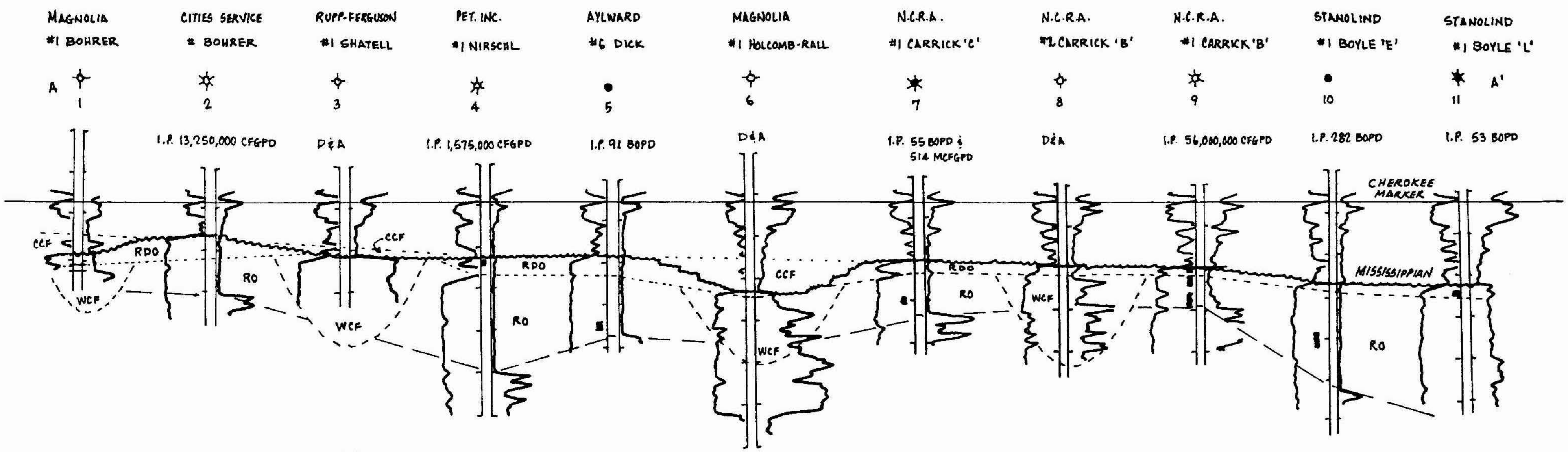


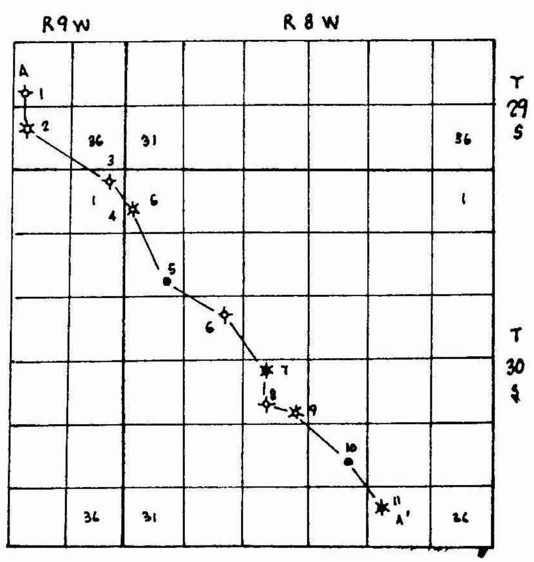
STAGE 5

INVASION OF PENNSYLVANIAN SEAS. PENNSYLVANIAN SHALES AND LIMES DEPOSITED ON TOP OF EROSIONAL MISSISSIPPIAN SURFACE.

SLIDE 8

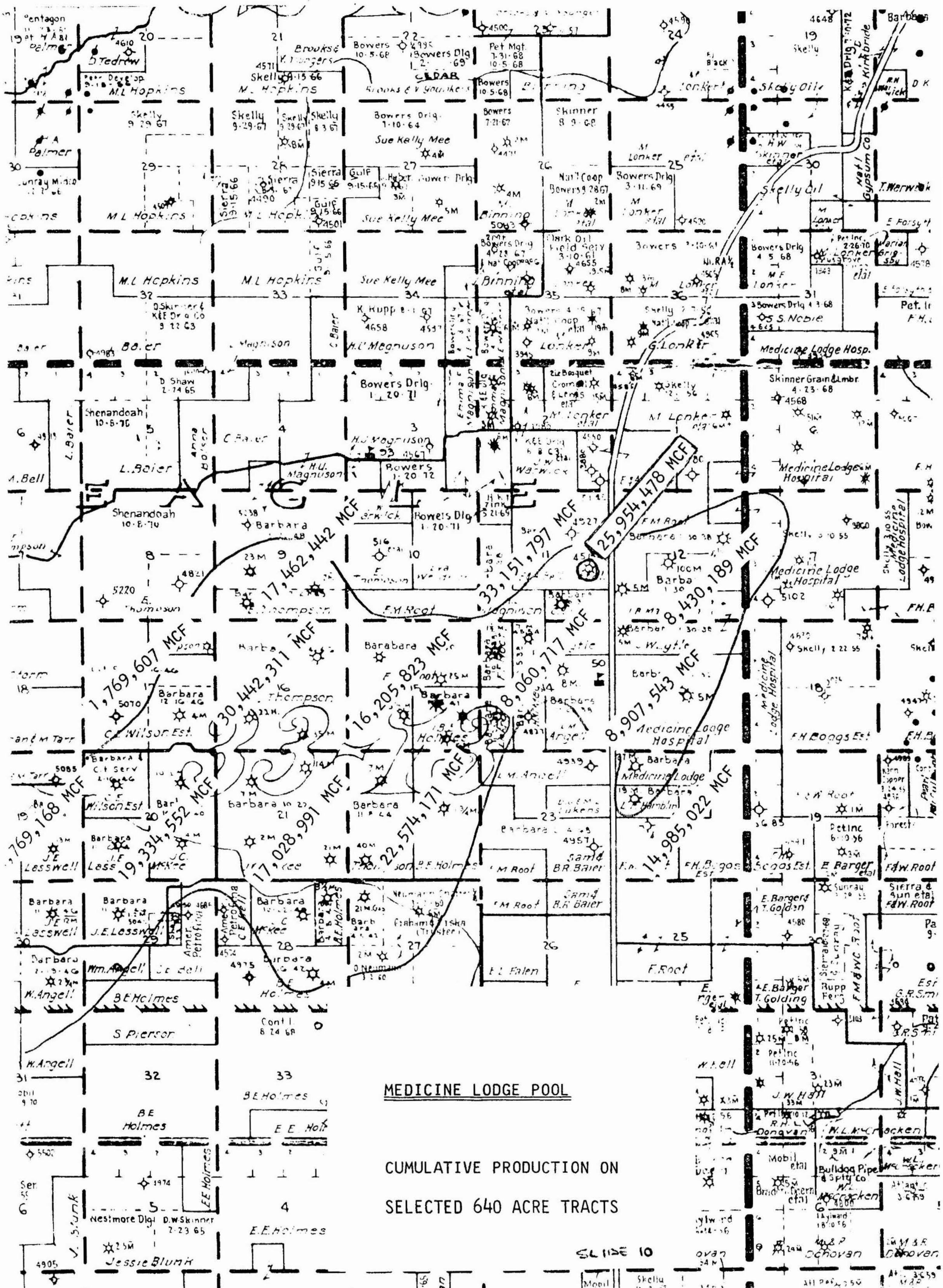

SPIVEY - GRABS FIELD
Portion of
PROJECTED DRAINAGE PATTERN
AT END OF OSAGE TIME
(O = "Barrier well" with channel-fill limestone)
ZENDA
SPIVEY
30-9
30-8
30-7
31-9
SLIDE 9

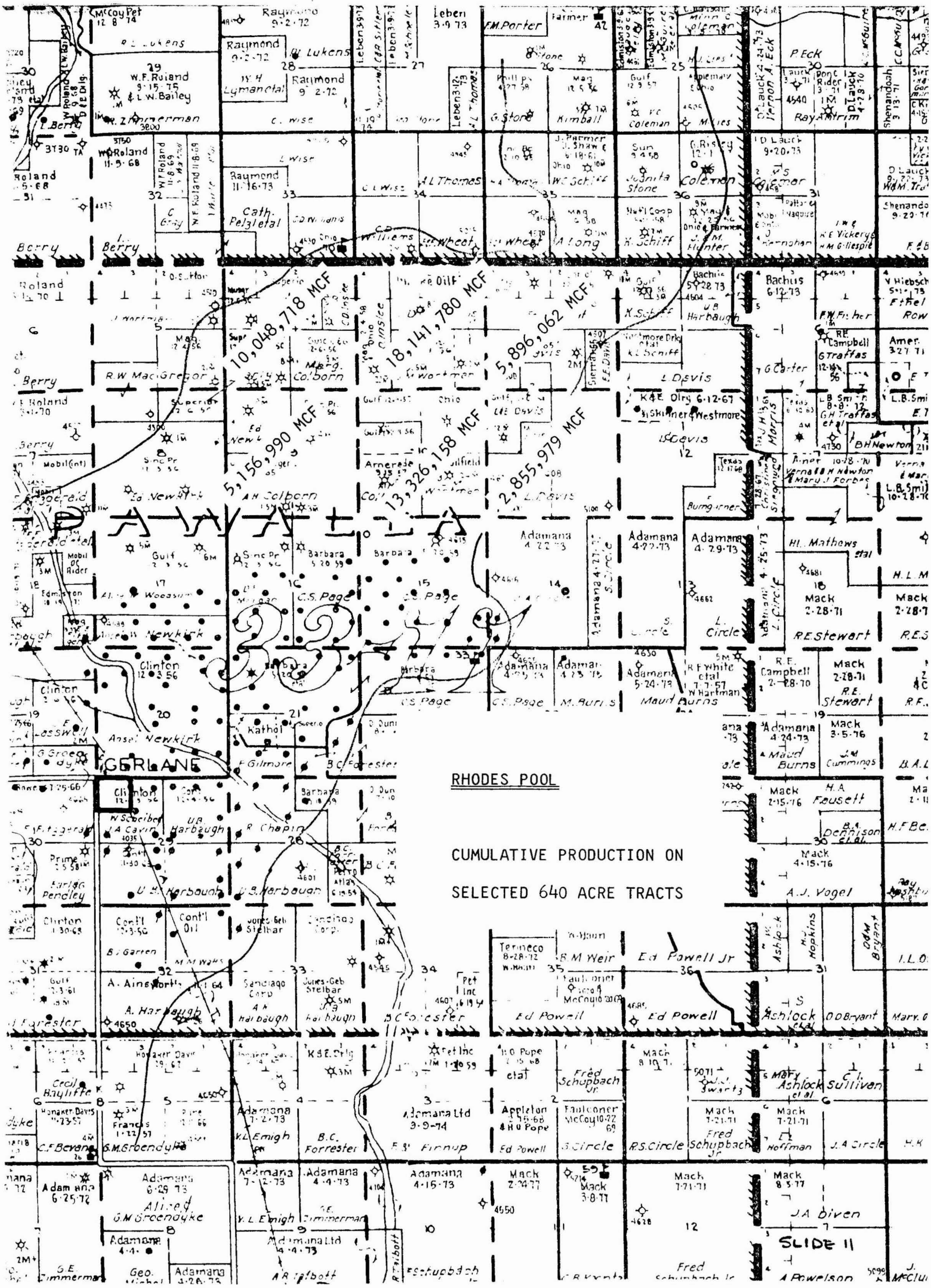




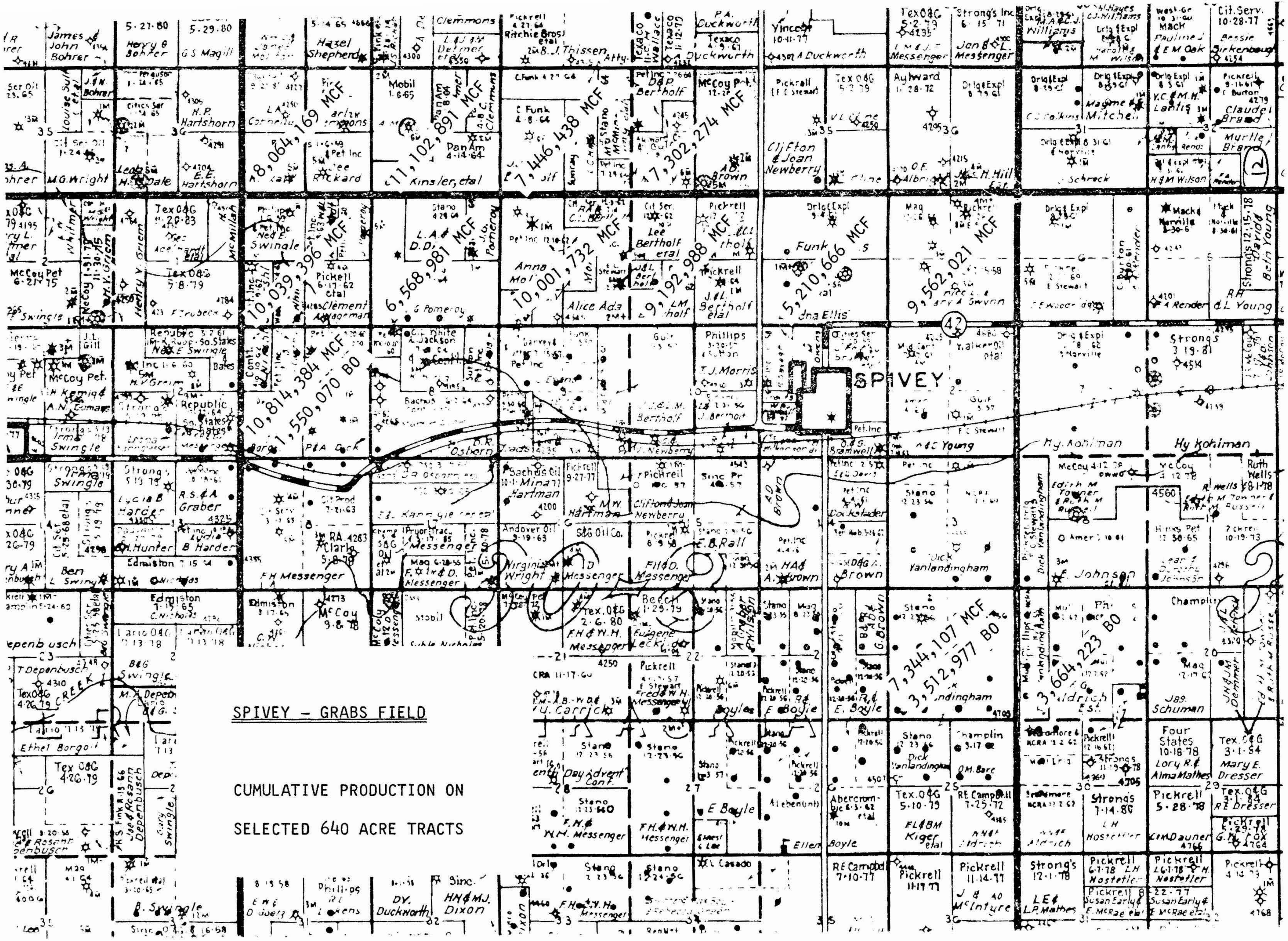
CROSS SECTION THROUGH A PORTION OF SPIVEY-GRABS FIELD

CCF = Cherokee Channel fill
WCF = Warsaw Channel fill
RDO = Redeposited Detrital Osage Chert
RO = Residual "in-place" Osage Chert
▮ = Perforated interval


MEDICINE LODGE POOL
CUMULATIVE PRODUCTION ON
SELECTED 640 ACRE TRACTS
25,954,478 MCF
33,151,797 MCF
17,462,442 MCF
8,430,189 MCF
1,769,607 MCF
30,442,311 MCF
16,205,823 MCF
8,060,717 MCF
8,907,543 MCF
769,168 MCF
19,334,552 MCF
17,028,991 MCF
22,574,171 MCF
14,985,022 MCF
SLIDE 10



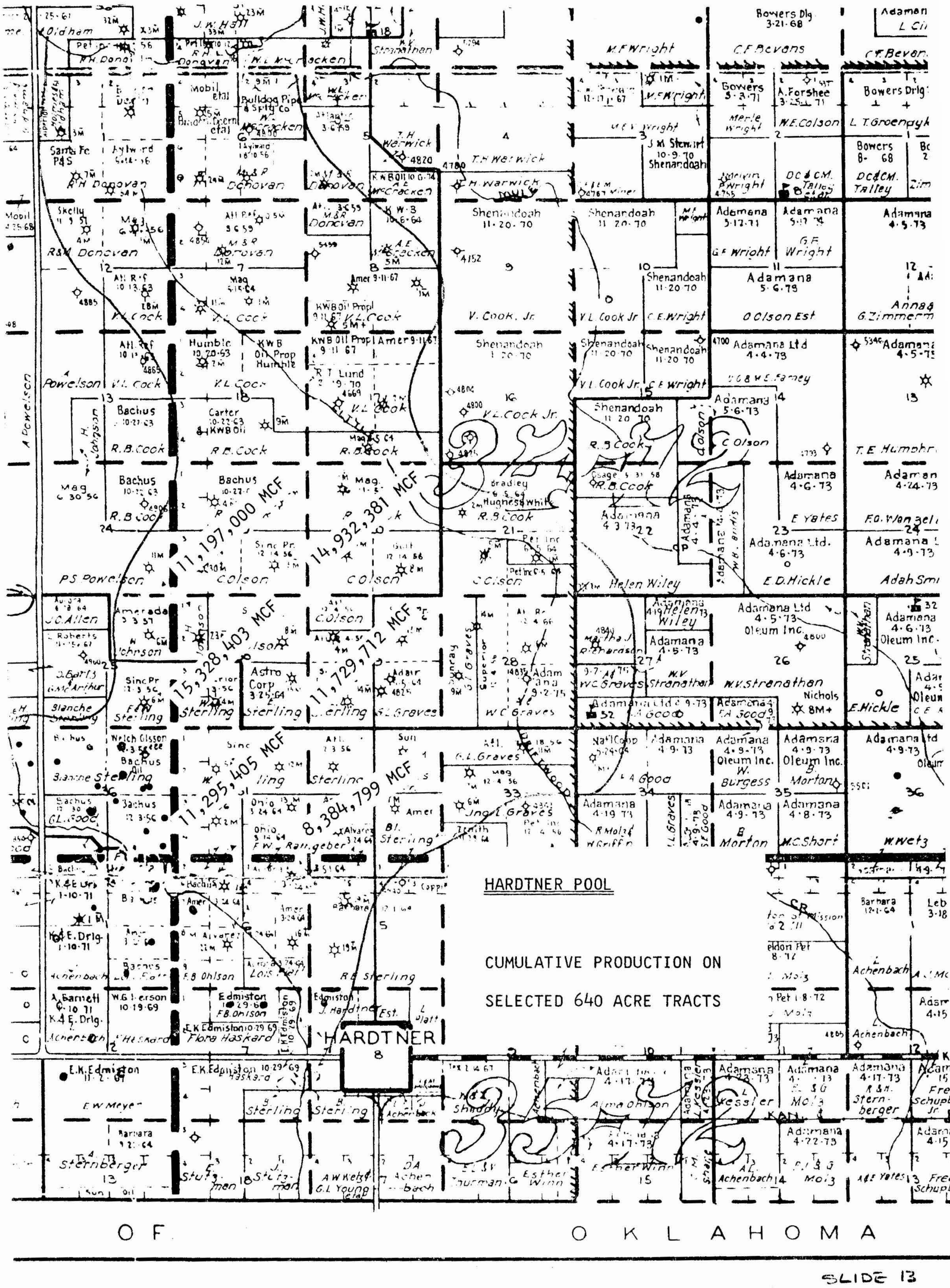
RHODES POOL
CUMULATIVE PRODUCTION ON
SELECTED 640 ACRE TRACTS
10,048,718 MCF
18,141,780 MCF
5,896,062 MCF
5,156,990 MCF
13,326,158 MCF
2,855,979 MCF
GERLANE
SLIDE 11



SPIVEY - GRABS FIELD

CUMULATIVE PRODUCTION ON

SELECTED 640 ACRE TRACTS


HARDTNER POOL
CUMULATIVE PRODUCTION ON
SELECTED 640 ACRE TRACTS
11,197,000 MCF
14,932,381 MCF
15,328,403 MCF
11,729,712 MCF
11,295,405 MCF
8,384,799 MCF
3271
3572
HARDTNER
OF
OKLAHOMA

SLIDE 13