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GRADUATE COLLEGE

PERMIAN SUBSURFACE EVAPORITES IN THE ANADARKO BASIN OF THE WESTERN OKLAHOMA-TEXAS PANHANDLE REGION

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Norman, Oklahoma
1963

PERMIAN SUBSURFACE EVAPORITES IN THE ANADARKO BASIN OF THE WESTERN OKLAHOMA-TEXAS PANHANDLE REGION

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PERMIAN SUBSURFACE EVAPORITES IN THE ANADARKO BASIN OF THE WESTERN OKLAHOMA-TEXAS PANHANDLE REGION

INTRODUCTION

General statement. The Permian basin of the south-central United States contains thick evaporites within a region covering more than 100,000 square miles, extending from southeastern New Mexico and west Texas across the Texas Panhandle and western Oklahoma into Kansas (Ham, 1960, fig. 2, p. 140).

The present study is a subsurface investigation of the evaporites of the Permian basin that occur in western Oklahoma and the eastern part of the Texas Panhandle (fig. 1). This area embraces 20,000 square miles and lies wholly within the Anadarko basin, as originally recognized by Gould (1924, p. 324). It is bounded on the south by the Wichita Mountains in Oklahoma, and, in Texas, by the buried Amarillo uplift. Permian evaporites continue westward and southward across the Amarillo uplift, and northward into Kansas, but they are not considered in this report. The northern element of the Anadarko basin has been called the Northern Oklahoma shelf by Arbenz (1956). Structural contouring on Permian strata shows that the Northern Oklahoma shelf can not be readily identified and therefore it is here considered to be a poorly defined element on the north flank of the Anadarko basin.

Permian strata of the Anadarko basin (fig. 2) range in age from Wolfcampian (Early Permian) through Leonardian and Guadalupean ("Middle" Permian) and possibly into the Ochoan (Late Permian). Beds of Wolfcampian age in this area contain no definite evaporites. In subsurface they are mostly marine carbonates and shales, whereas in outcrops of central Oklahoma they are red shale and sandstones. The oldest evaporites are in the basal Leonardian Wellington Formation and are succeeded upward by evaporite sequences in beds dated as Guadalupean and possibly Ochoan. They can be divided into four major evaporite units or cycles, each consisting mainly of salt and anhydrite interbedded within a regional framework of red clastic sediments.

Evaporites of the earlier two cycles are widely distributed in subsurface, but grade on the outcrop into red sandstones and shales that are locally interbedded with lacustrine deposits. The upper two cycles are represented by evaporites both in subsurface and on the outcrop. In this paper the subsurface distribution and character of the three lowermost evaporite cycles, of Leonardian and Guadalupean age, are considered, and as herein used they are named Wellington evaporites, Cimarron evaporites, and Beckham evaporites. These evaporites have a combined maximum thickness of 2,500 feet, and occur in a "Middle" Permian sequence having a thickness of 4,000 feet. In a general way the evaporites occur as wedging tongues that increase in thickness down dip to the west, away from the eastern land areas and shore lines.

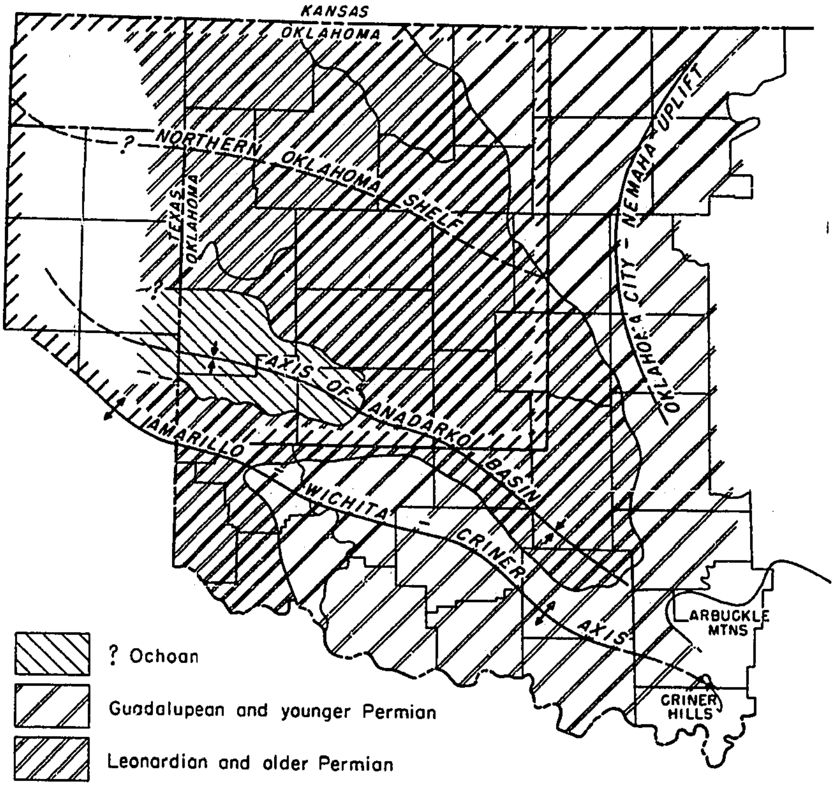

Figure 1. Index map showing geologic framework of area investigated. Modified from Arbenz, 1956. The investigated region is outlined by hachures. Patterned areas are outcrops of Permian strata.

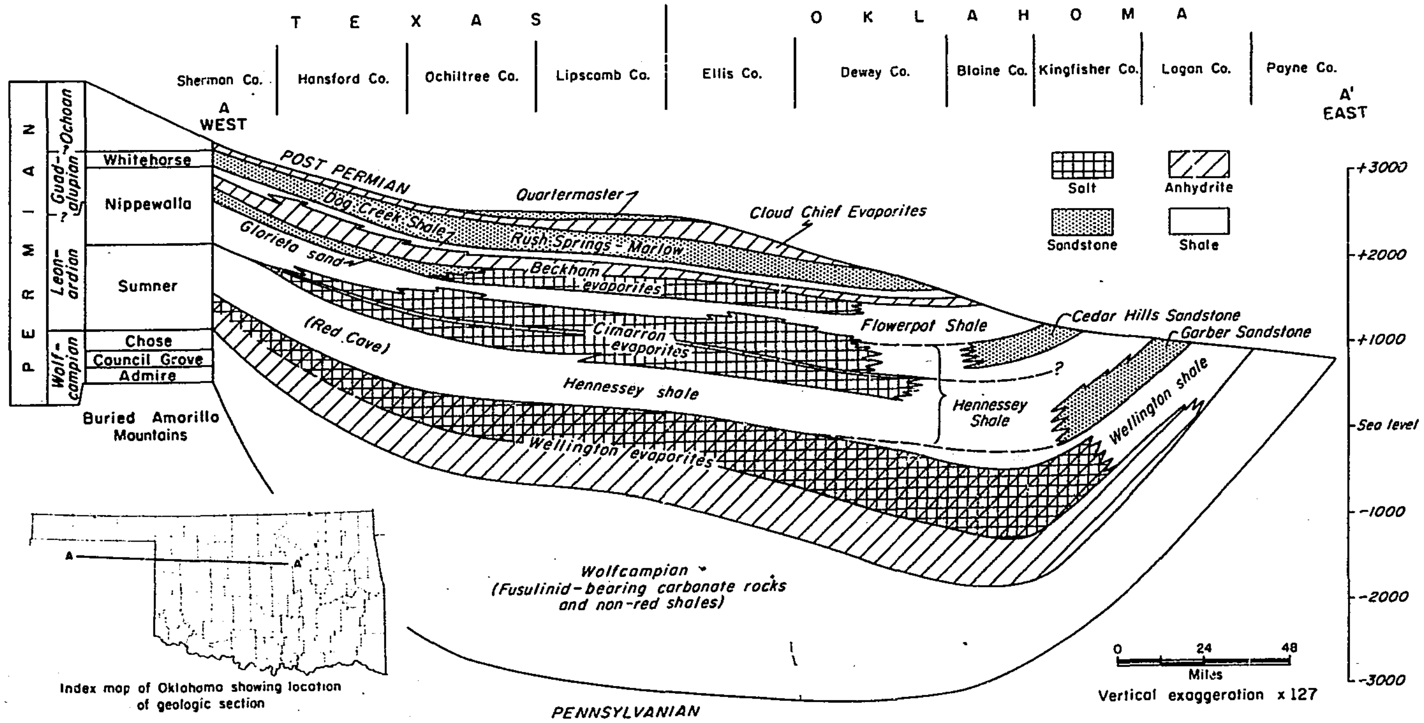

Figure 2. Generalized geologic structure section of Permian strata in western Oklahoma and Texas panhandle.

The uppermost evaporites of Permian age in Oklahoma, consisting of massive beds and lenses of gypsum and anhydrite in the Cloud Chief Formation, of possible Ochoan age, are not considered in this report.

As interpreted from well logs and a few locally available cores, the evaporite units consist of halite, anhydrite, dolomite, and shale. Halite clearly predominates and occurs in as much as 2,000 feet of strata, some of it almost pure rock salt 1,000 feet thick. In the remaining 500 feet of strata anhydrite is the dominant rock, and is associated with thin beds of dolomite and shale.

The evaporites are everywhere characterized by NaCl, $CaSO_4$, and carbonates, and in no part of the investigated area have potash salts been recognized.

Purpose of investigation. Subsurface evaporites of the Anadarko basin have long been recognized, but no regional study of these beds has been previously attempted. Although the petroleum industry has drilled several thousand wells through these rocks, their character, thickness, and distribution have been largely neglected because oil and gas have not been found in the Anadarko basin in beds younger than Wolfcampian, except locally in the Panhandle Field of Texas.

The present study has originated from a need for regional stratigraphic interpretations and a preliminary evaluation of salt resources. It has been stimulated by recently developed underground storage facilities in salt for liquefied-petroleum gas, particularly in Oklahoma, through which much new information from cores, caliper logs, and sonic logs has been made available (Jordan, 1959, 1961a, 1961b, 1962a, 1962b). In addition to the probability that new storage areas for liquefied-petroleum gas will be required in the near future, it is also likely that salt for chemical and industrial use will be produced from the enormous reserves of the region. There is also the possibility that radio-active waste may be put into underground storage in salt beds of the Anadarko basin. Finally a better understanding of the evaporite beds resulting from this study will doubtless assist in solving seismic velocity problems encountered in the exploration for petroleum.

Basic information for the present investigation has been obtained mostly from electrical well logs and gamma ray-neutron logs. More precise information is obtainable from cores, caliper logs and sonic logs, and these have been used as primary control in the few areas where they are available. Essential lithologic interpretations from the above data were used in constructing the subsurface cross-sections, thickness maps, and structure maps, subject to confirmation by coring. Well cuttings have been used only to a slight extent because most cuttings through the evaporite strata have not been saved by operating companies, and further because the soluble salt is dissolved during drilling and therefore can not be interpreted from the cuttings alone. The reliability of cuttings for determination of lithology is further reduced by the drilling techniques, such as large bit size and natural drilling mud, normally employed in drilling the Permian section down to the top of the marine carbonates assigned to the Wolfcampian.

Contamination by the cement used to set surface casing also reduces the value of cuttings. The separation of salt from anhydrite is possible with a considerable degree of confidence wherever the combination of electrical resistivity or gamma-ray surveys is available in conjunction with sonic and or caliper (section gauge) logs.

The investigation was undertaken in 1959 as a dissertation to fulfill the requirement for the Doctor of Philosophy degree in geology at the University of Oklahoma. At that time Porter E. Ward, as a member of the Ground-water branch of the United States Geological Survey, was engaged in a project sponsored by the United States Department of Public Health, which involved near-surface Permian evaporites, principally salt. Most of the data were collected with the cooperation of Mr. Ward and the assistance of T. L. Rowland during the summer of 1959. Active search for information was completed in January, 1960. The more recent data were compiled by Dr. Louise Jordan, who directed the project and gave permission to include in this report several of her previously published text figures. The compilation of data was greatly expedited by the cooperation and generous assistance of the oil industry, which is gratefully acknowledged. Miss Eileen Krall drafted the cross sections and text figures under the direction of Roy D. Davis, who drafted the maps. Careful critical evaluation of the manuscript by members of the Oklahoma Geological Survey has been a major contribution to the successful completion of the project.

Previous Investigation

Early work. Prior to this report, published work has been of reconnaissance type or grossly regional in character. The most detailed studies were surface reports. Subsurface investigation has generally been concerned with beds older than those considered herein, or have been localized pool studies in which the younger beds received scant attention.

Shumard (1852) and Marcou (1854) were the first to mention red beds in Oklahoma. Marcy (1854) in a report of the exploration of the Red River, included an early reference to gypsum deposits from Oklahoma. Cragin (1889, 1890, 1896, 1897) was the first geologist to study seriously any of the Permian units found in what is now called the Anadarko basin. Cragin's work was generally confined to Kansas, but the latter two publications on the Cimarron Series have been used in northwestern Oklahoma by most of the subsequent workers.

Gould (1902, 1905) published early reports on the stratigraphy of the red beds, as a compilation of the first work devoted to mapping and correlation of the surface units. In 1917, Aurin published a structure map contoured on the base of the red beds as part of the first general subsurface report concerning western Oklahoma. Aurin's map clearly outlined a large synclinal trough north of the Wichita Mountains. Ohern (1918) traced various surface units of Permian age around the southeastern end of the trough suggested by Aurin the year before. Ohern's map is the first surface evidence published which demonstrates the position of the Anadarko basin. Greene (1920) and Howell (1922) further established the position of the syncline.

Gould (1924), in order to resolve questions and problems arising over the previous two decades, called a conference of leading workers concerned with the Permian rocks of the southwest. This conference led to a revision of the stratigraphy and correlations previously reported by Gould (1902, 1905), and firmly established the general character of the structural and stratigraphic framework in use today.

Sawyer (1924) added to the knowledge of structure by describing the location of the Chickasha gas field and the Cement oil field as local structures near the axis of the major syncline. Gould (1926) established a tentative correlation of the Permian beds in the Texas Panhandle, western Oklahoma, and southwestern Kansas. In that same year Lockwood (1926) showed steep subsurface dips northward from the axis of the Amarillo mountains in the Texas Panhandle. The presence of the trough was further illustrated by Dwyer (1926) who showed the synclinal axis crossing the Texas Panhandle into Oklahoma, and by Clifton (1926) and Greene (1926) who also mapped the axis across the Texas Panhandle. Gould and Lewis (1926) further outlined the structure and stratigraphy.

By 1930, the major stratigraphic and structural features in the Anadarko basin were known, and the geologists working in the area began to study some of the recognized problem areas, but much of this work remained of a reconnaissance nature. Becker (1930) published a report on the structure and stratigraphy of southwestern Oklahoma, and Clifton (1930) and Evans (1931) presented similar works on the structure and stratigraphy of northwestern Oklahoma. Suffel (1930) made a detailed study of the numerous thin surface dolomites within the red beds of western Oklahoma, and at the same time Freie (1930) published the first investigation dealing with the sedimentation and sedimentary petrography of the beds in the Anadarko basin. Freie's work served to corroborate many of the general impressions presented in the previous two decades. Dott (1934) published work on overthrusting in the Arbuckle Mountains, marking the beginning of detailed structural investigations. D. A. Green (1936) studied the Pennsylvanian and Permian in west-central Oklahoma, and in 1937 correlated the major divisions of the Permian between Oklahoma and southern Kansas.

Modern work. Dott (1937) acted as editor and chairman of a conference on the Permian similar to the conference called by Gould in 1926. Tomlinson (1940) classified the Permian of the south and southwest, which although limited in area, incorporated most of the new ideas presented during the 1930's. By the mid 1940's, the Anadarko basin and southern Oklahoma were becoming the focus of petroleum exploration in Oklahoma, although only the south flank of the Anadarko basin was as yet being seriously considered as an oil prospect. Gouin (1947) and Wheeler (1947) wrote papers relating the geology of southern Oklahoma and the Anadarko basin to petroleum exploration. Wheeler (1950) discussed the tectonics in the Anadarko basin and again (1952) related the geology to oil exploration. The Tulsa Geological Society (1951) focused attention on the regional possibilities of oil in the Anadarko basin. More limited and detailed work such as pool studies was carried on by many geologists. McNeal (1953) wrote a subsurface report on a small area in the south-central part of the Anadarko basin. Schweers (1957) emphasized the complex structure of southern Oklahoma. Beams (1952) presented one of many papers about the Elk City Field.

Most of the reports mentioned in the paragraph above are limited in their treatment of the Permian, especially Permian beds younger than Wolfcamp, but these works contributed an important part of the information necessary for an understanding of the geologic history of the Anadarko basin.

Papers relating to evaporite chemistry, mineralogy, and commercial exploitation of evaporites are included in the bibliography. The alteration relationships between gypsum and anhydrite have been discussed by A. E. Hill (1937), Posnjak (1938) and Scruton (1953). Burwell (1955) presented some economic aspects of gypsum in Oklahoma. General works dealing with the conditions and mechanics of evaporite deposition include a discussion of cyclic phenomena (Hills, 1942), lithologic associations of evaporites (Krumbein, 1951) and a classification of brackish waters related to climate (Hedgpeth, 1951). O. M. Smith (1942) compiled analysis data on the waters of Oklahoma. Lang (1957) compiled an exhaustive bibliography of salt in the United States.

Moore (1951, 1954) and Widess (1952) reported the effects of subsurface salt deposits on the interpretation of seismic records. Lishman (1961) discussed the identification of salt from unfocused electrical resistivity logs run in drilling wells.

The Geologic Map of Oklahoma (Miser et al., 1954) included a summary of the surface information available on the Permian of western Oklahoma. Much of this compilation was from data obtained by reconnaissance methods. Most of the recent work dealing specifically with Oklahoma, has been published by members of the Oklahoma Geological Survey, or by the staff and graduate students at the University of Oklahoma. Fay (1958, 1962) has studied the red beds of north-central Oklahoma and has correlated the red beds in Oklahoma to equivalent strata in Kansas. Much of Fay's work is as yet unpublished. Ham (1955, 1960, 1962; and Ham and Curtis, 1958) has worked on the regional structure and stratigraphy of southwestern Oklahoma, and published reports dealing with the geology and economic potential of the gypsum and anhydrite deposits of western Oklahoma. Myers (1959) published a report on the general geology of Harper County. Several brief papers by Jordan (1959, 1960, 1961a, 1961b, 1961c, 1962a, 1962b) are concerned with salt occurrence in the subsurface of western Oklahoma, and with the storage of liquefied-petroleum gas in salt beds. Ham and Jordan (1961) established a tentative standard section for the shallow subsurface Permian section in the Anadarko basin. Ground-water reports published by the Oklahoma Geological Survey, include work by Schoff (1949, 1950) and Davis (1950). Ward (1961a, 1961b) and Ward and Leonard (1961) discussed the pollution of ground water and streams by salt springs in western Oklahoma, giving solution of shallow salt beds by circulating ground water as the chief cause of pollution.

STRATIGRAPHY

Introduction

Permian rocks of Leonardian and Guadalupean age are exposed over a wide area in central and western Oklahoma, dipping gently west and southwest into the Anadarko basin. Three "cycles" of evaporite deposition, separated by shales, are present in the subsurface. The evaporite "cycles" and the intervening shales are, in ascending order: Wellington evaporites, Hennessey shales, Cimarron evaporites, Hennessey-Flowerpot shales, and Beckham evaporites (pl. 1). Subdivisions have been made on the basis of rock type and electrical log characteristics. The thickness of the strata ranges from approximately 2,500 feet in western Beaver County, to 3,900 feet in north-central Beckham County, Oklahoma.

The nomenclature used in this report is informal. The relationship to present accepted usage is shown, in so far as it is known, both on the surface and in the subsurface (fig. 3). The area covered and the amount of control information available in many localities make this a preliminary report subject to revision as more complete data are at hand. As the exact stratigraphic position of most of these units has not been clearly established in relation to surface nomenclature, it seems desirable to use informal terms which can be

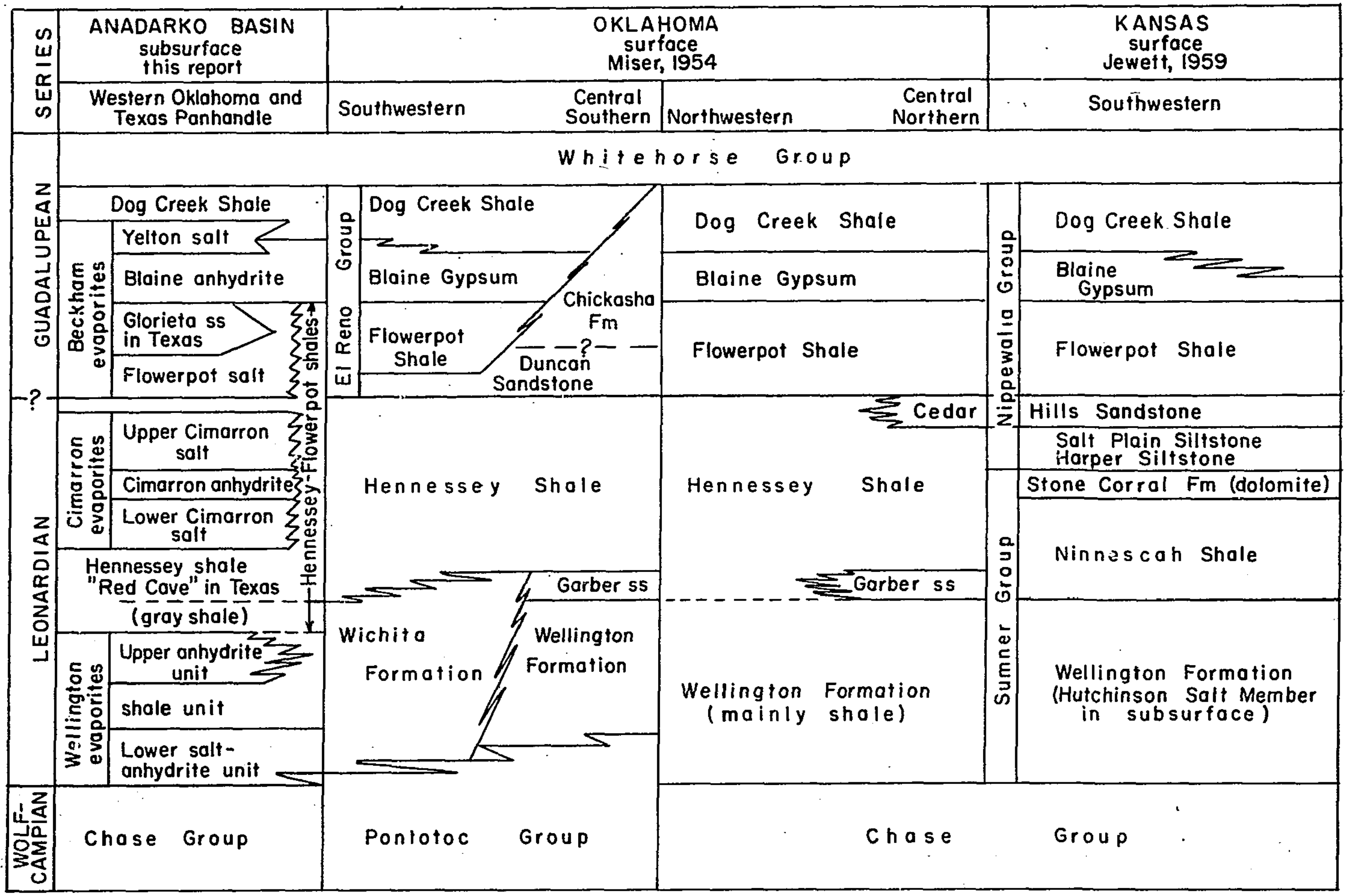

Figure 3. Stratigraphic nomenclature of Permian strata dealt with in this report, showing probable relationship between surface and subsurface units.

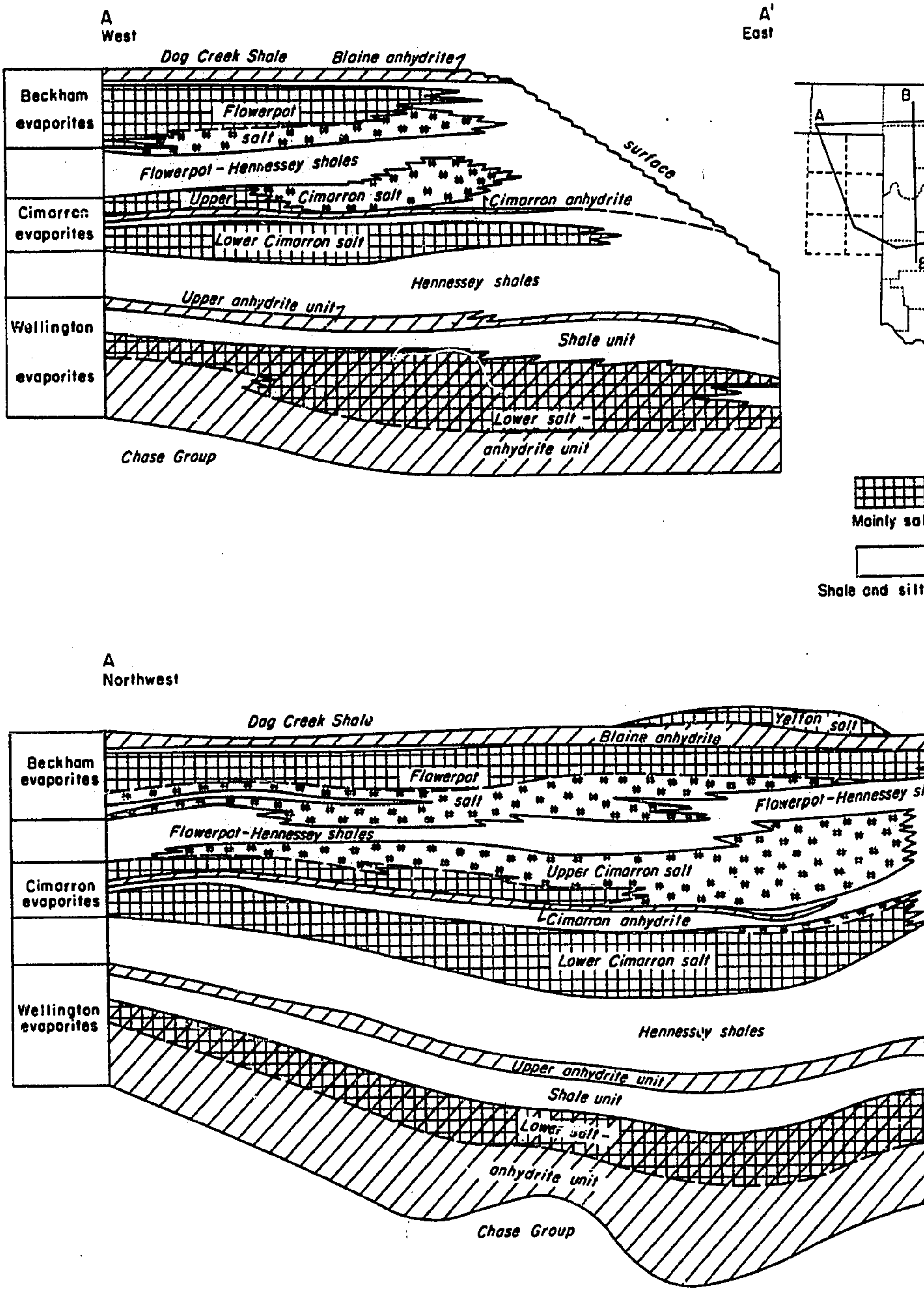

Plate I. Schematic diagrams and index map of th
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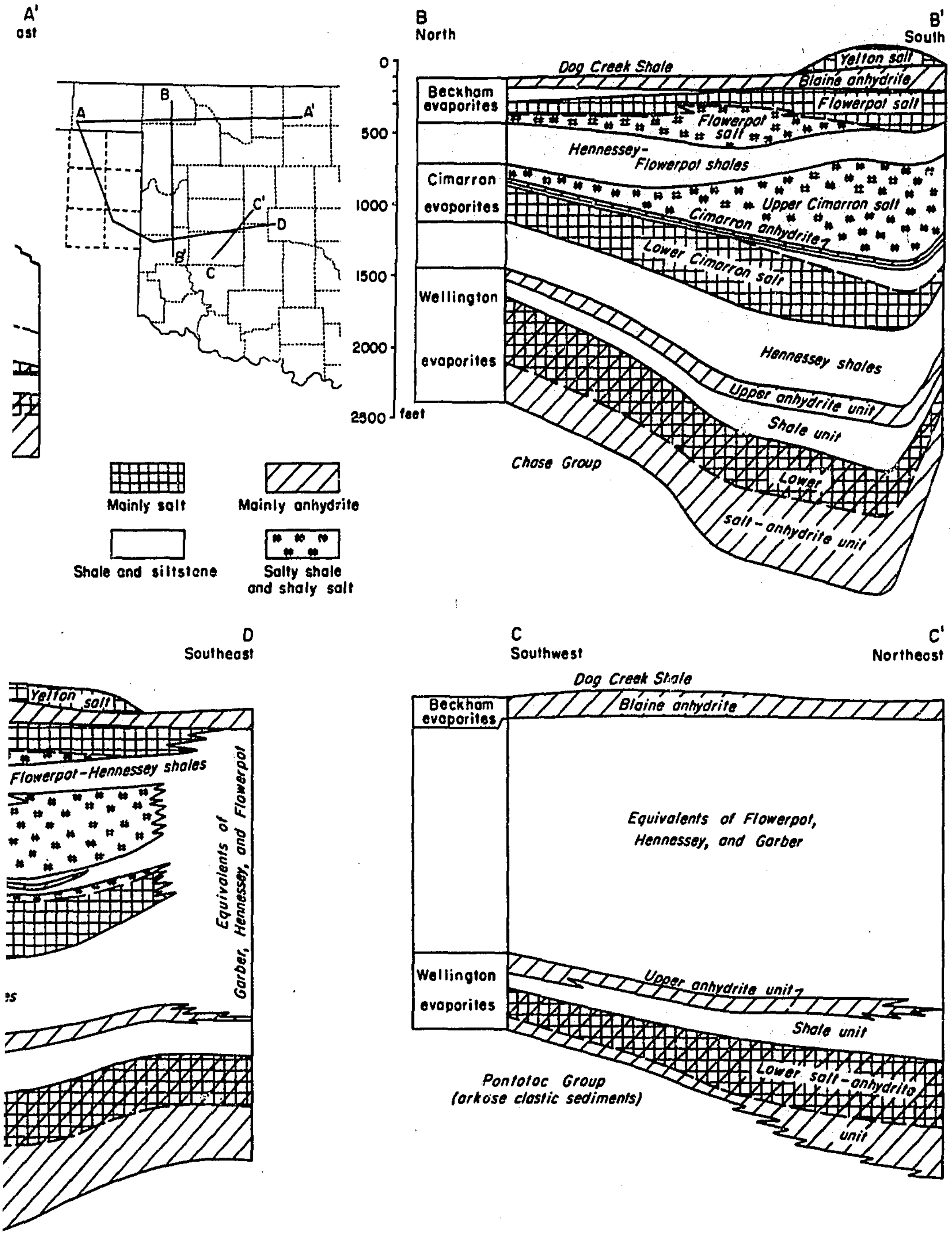

ex map of the geologic cross sections of Plate II,
ts (principally evaporites separated by fine clastics)
and to the surface.

modified easily, should more detailed investigations indicate modification is needed.

Wellington Evaporites

Nomenclature and stratigraphic relations. The term "Wellington evaporites" as used herein is essentially synonymous with the term "Wellington Formation" as commonly understood and used in the subsurface. The Wellington is underlain throughout most of the area by marine carbonates of Wolfcampian age, but around the Amarillo-Wichita mountain axis the underlying beds are clastic debris assigned to the Pontotoc Group or its equivalents. The Wellington is overlain by clastics, which in the east are called Garber Sandstone and in the central part of the area are called Hennessey Shale. In the Texas Panhandle the overlying beds are called "Red Cave". The top of the gray shale overlying the uppermost occurrence of anhydrite or dolomite cannot be readily established in the subsurface, and is therefore not included as part of the Wellington evaporites, even though these gray shale beds are assigned to the Wellington Formation of surface nomenclature. The base of the Wellington Formation is considered to be at the top of the Herington Limestone. In the subsurface, the base of the Wellington evaporites is established at the base of those beds that can be easily identified as anhydrite by the character shown on electrical or radio activity logs (fig. 4).

Distribution. The Wellington Formation crops out along a line striking north and extending from Kansas southward through Oklahoma to

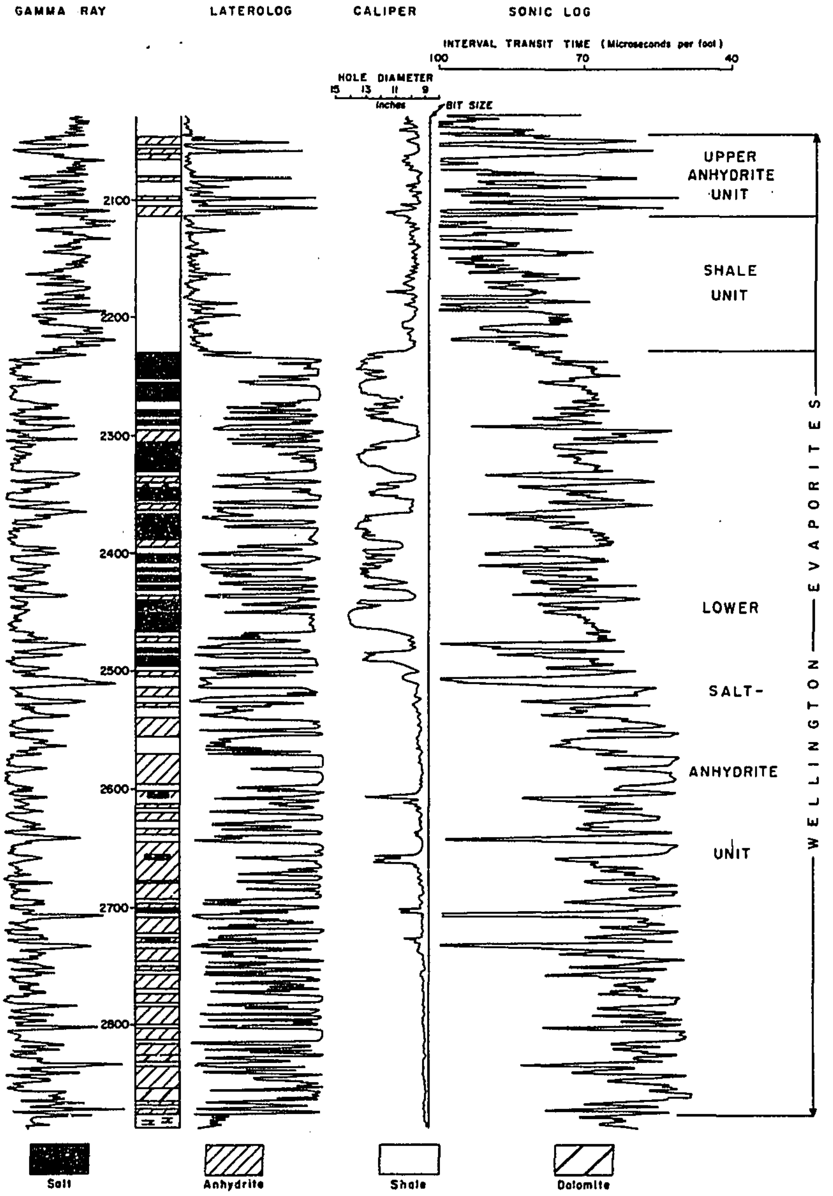

Figure 4. Subdivisions of the Wellington evaporites as shown by lithologic, gamma-ray, laterolog, caliper, and sonic logs of Gulf-Warren's SWD-1 Mocane Plant, Beaver County, Oklahoma, showing mainly salt in the upper half of the Lower salt-anhydrite unit.

the Arbuckle Mountains. Equivalent strata extend around the western end of the mountains and southward into Texas (Miser et al., 1954). Along the outcrop in central Oklahoma, the formation is mostly shale and sandstone, dipping gently west and southwest. In subsurface the formation consists predominantly of evaporites. They are recognized in all parts of the mapped area except along the northern flank of the Wichita Mountains in T. 8 N.

Thickness. Across the northern part of the area the Wellington evaporites range in thickness from 820 feet in Beaver County, to 1,110 feet in Woodward County. Farther east, in Grant County, the thickness is 860 feet, but only the lowermost 675 feet contain clearly recognizable evaporites (pl. II, cross section A-A'). In the southeastern part of the area, on the south flank of the Anadarko basin, the thickness is 475 feet near the Wichita Mountains (sec. 8, T. 8 N., R. 18 W). Here the lower part of the Wellington evaporite section grades into beds assigned to the Pontotoc Group. By slow gradation the Pontotoc gravels, sandstones, and shales are progressively lower in the section to the north and east, until 1,160 feet of evaporites are present in sec. 36, T. 14 N., R. 13 W. (pl. II, cross section C-C').

A north-south line of section (pl. II, cross section B-B') shows 950 feet of Wellington evaporites in northern Harper County, a maximum of 1,300 feet in north-central Beckham County, and 740 feet in central Beckham County.

The Wellington evaporites thicken southward from Beaver County, Oklahoma, into the panhandle of Texas (pl. II, cross section A-D). In central Ochiltree County, Texas, well 11 penetrated 980 feet of evaporites which become 1,170 feet thick (well 13) in eastern Roberts County, Texas. Southeast of well 13 the section remains nearly constant, having a thickness of 1,190 feet (well 15) in east-central Wheeler County, Texas.

Subdivisions. The Wellington evaporites are easily divisible into three units. These units are designated the Lower salt-anhydrite unit, Shale unit, and Upper anhydrite unit (ascending order). The Lower salt-anhydrite unit might also be subdivided into a "salt unit" above, and "lower anhydrite" below.

Lower Salt-Anhydrite Unit

Nomenclature and stratigraphic relations. The base of the Lower salt-anhydrite unit marks the base of the Wellington evaporites. The upper part of the unit has been called "Main Anhydrite" by many subsurface geologists. The top of this unit appears on electrical logs as an abrupt resistivity increase (figs. 5-6) from a shale value, and can be recognized in the subsurface over large areas of the mid-continent region. This resistivity change from shale to evaporites is normally indicative of the introduction of salt rather than anhydrite within the area presented herein.

Distribution. The Lower salt-anhydrite unit can be recognized throughout the area, except along the extreme southern edge near the Wichita Mountains where the entire unit grades into clastic debris assigned to the Pontotoc Group.

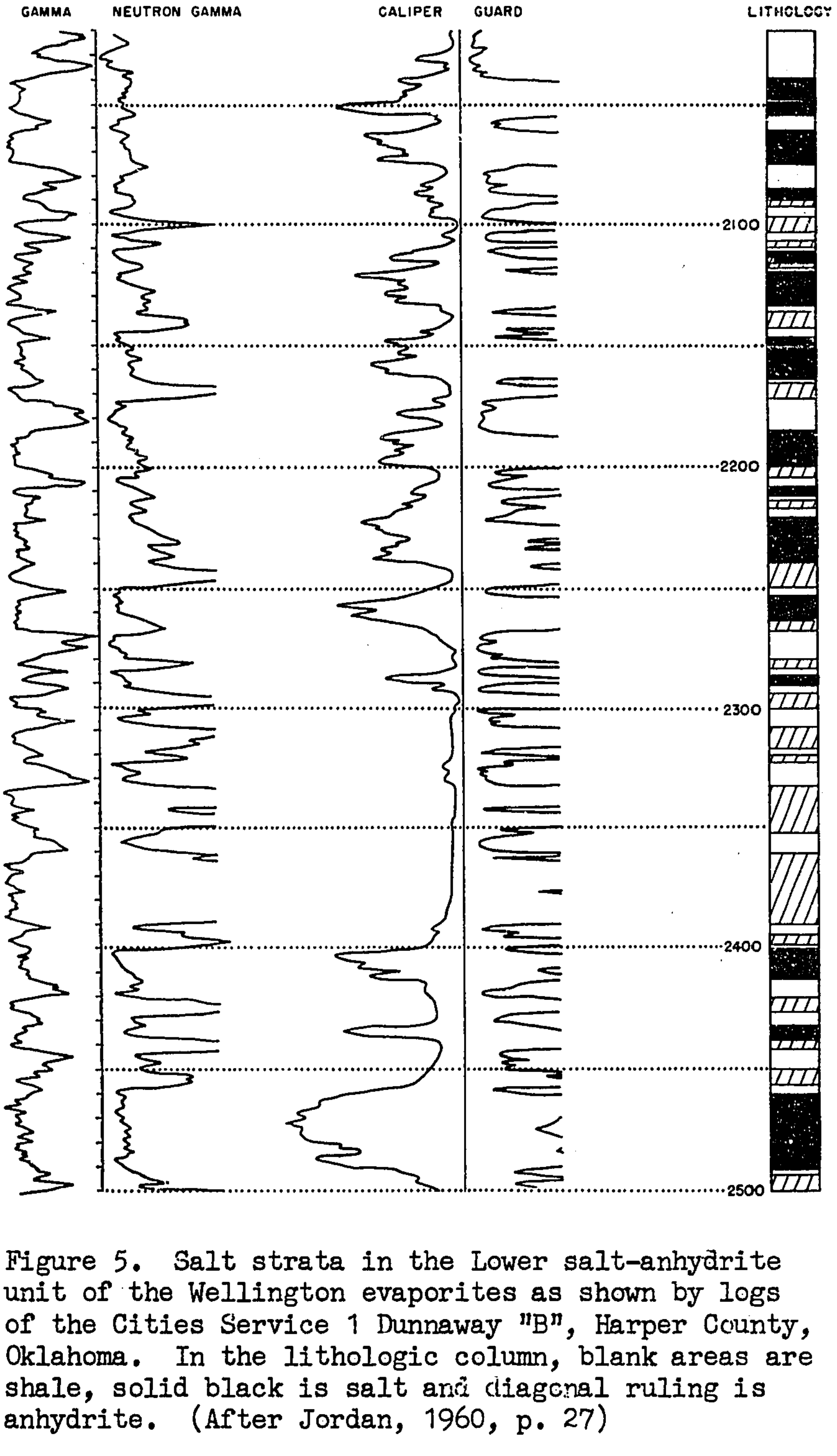

Figure 5. Salt strata in the Lower salt-anhydrite unit of the Wellington evaporites as shown by logs of the Cities Service 1 Dunnaway "B", Harper County, Oklahoma. In the lithologic column, blank areas are shale, solid black is salt and diagonal ruling is anhydrite. (After Jordan, 1960, p. 27)

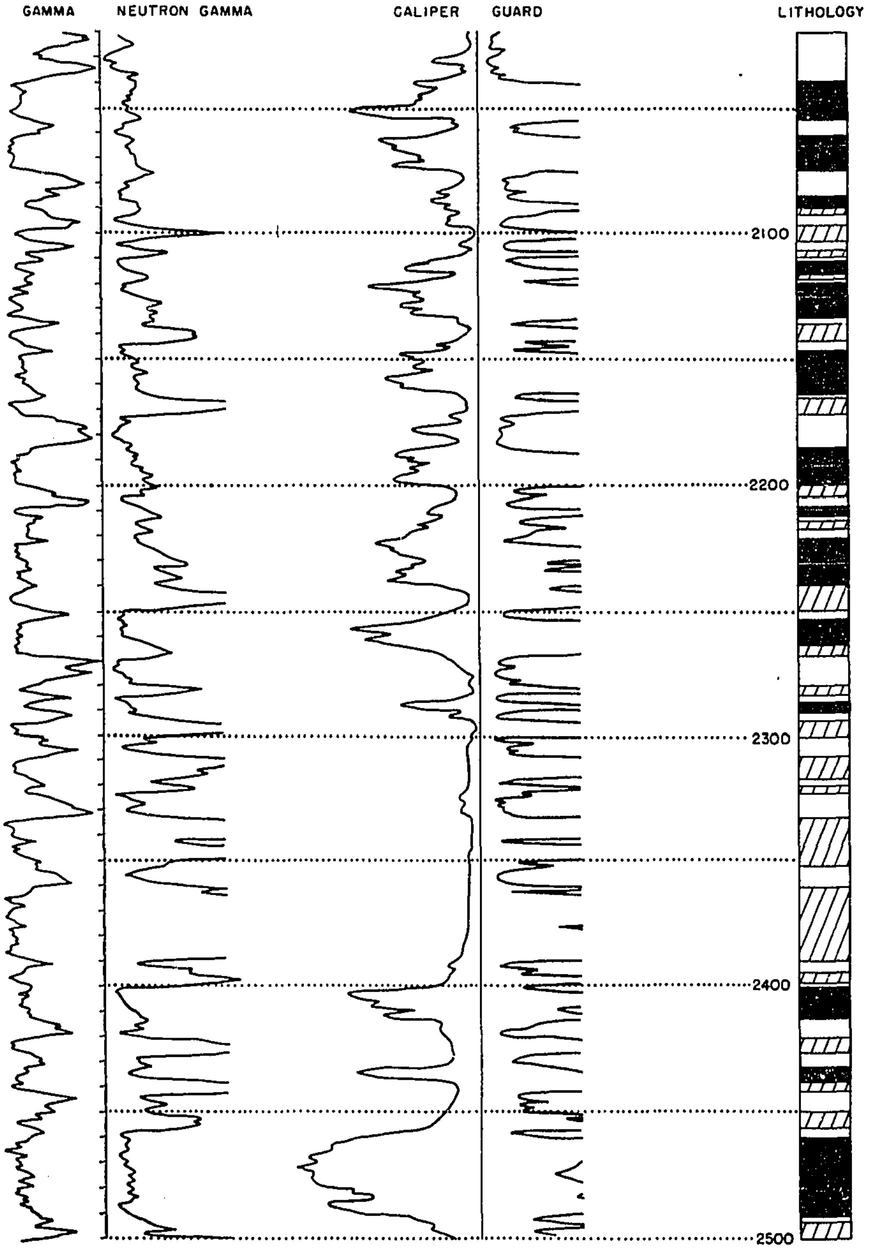

Figure 5. Salt strata in the Lower salt-anhydrite unit of the Wellington evaporites as shown by logs of the Cities Service 1 Dunnaway "B", Harper County, Oklahoma. In the lithologic column, blank areas are shale, solid black is salt and diagonal ruling is anhydrite. (After Jordan, 1960, p. 27)

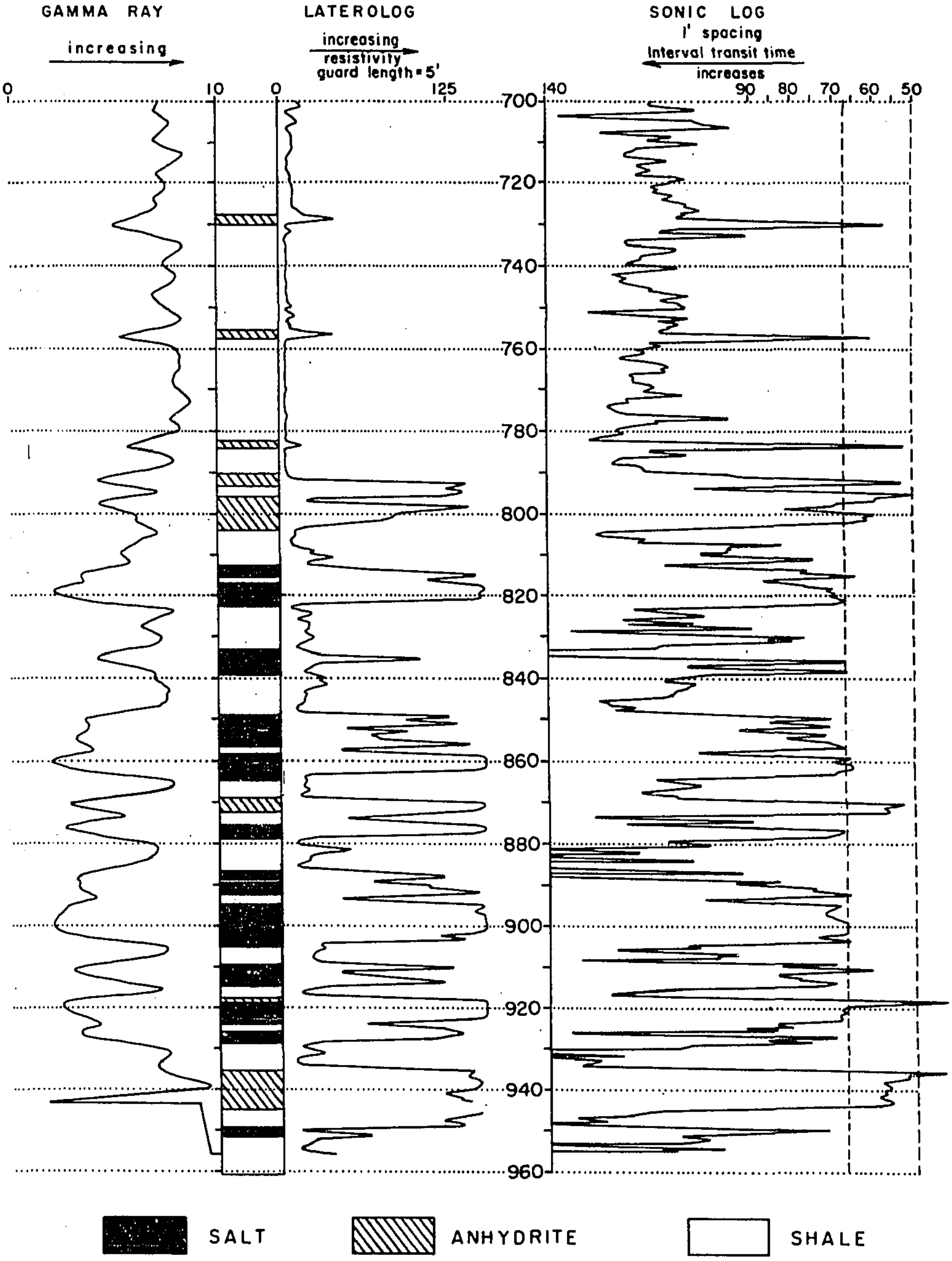

Figure 6. Salt strata in the Lower salt-anhydrite unit of the Wellington evaporites as shown by logs of the Continental Oil Company test hole in Grant County, Oklahoma. (After Jordan, 1961c, p. 273).

Character and thickness. The top of the Lower salt-anhydrite unit is clearly established from the character of electrical resistivity logs or with gamma-ray and neutron surveys. The lithologic character as shown by these logs changes abruptly from shale above to evaporites (normally salt) below. The base of the Lower salt-anhydrite unit marks the base of the Wellington evaporites as previously described. Establishment of the base is somewhat arbitrary, and it is located below those beds which are easily identified as anhydrite by means of their character as shown on electrical logs.

Approximately the lower half of the Lower salt-anhydrite unit normally consists of anhydrite and shale. Westward from Beckham County, Oklahoma, into the Texas Panhandle, this lower section becomes increasingly dolomitic until approximately eighty percent of the lowermost 200 feet of the section is dolomite interbedded with thin beds of shale and anhydrite which are at few places more than ten feet thick. This dolomite section is called the "Hollenberg Dolomite" in the subsurface of the Texas Panhandle. Locally, thin (10 feet or less) discontinuous beds of salt and salty shale are present in the lower half of the Lower salt-anhydrite unit.

The Lower salt-anhydrite unit is remarkably uniform in lithologic character throughout the area, except in the southeast (pl. I) where most of the anhydrite grades to shale. Slight thinning at a uniform rate takes place northward from the axis of the Anadarko basin (pl. II, cross section B-B'). South of the basin axis, these beds grade by change of facies (beginning at the base) into coarse clastics of the

Pontotoc Group around the flanks of the Wichita Mountains. Section A-A' (pl. II) shows a range in thickness along the northern shelf area from 570 feet in southwestern Beaver County, to 860 feet in northern Woodward County, gradually thinning from this point eastward, to 675 feet in Grant County. The salt-bearing section in Grant County (well 10, pl. II, cross section A-A') is 250 feet below the top of the unit. The beds above the salt are mostly shale with thin anhydrite stringers, which are thicker and more numerous in the upper hundred feet.

Southward from Beaver County, Oklahoma (pl. II, cross section A-D), the unit thickens to 690 feet in Ochiltree County, Texas, and to 830 feet in southeastern Roberts County, Texas. The thickening continues southeastward and reaches a maximum of 920 feet in Wheeler County, Texas, in the axis of the basin. Other wells within the axial portion of the basin show a thickness ranging from 800 to 900 feet but the maximum possible thickness may be much greater locally.

Salt. That part of the Lower salt-anhydrite unit which contains salt is illustrated in figure 4. The logs shown are from the Gulf-Warren salt-water-disposal well in sec. 18, T. 5 N., R. 25 ECM., for the Mocane gas plant in Beaver County, Oklahoma. The salt-bearing section from 2,230 to 2,490 feet, is 260 feet thick. Approximately 55 percent of this interval is salt, 26 percent is anhydrite and dolomite, and the remaining 19 percent is shale.

A similar section of salt-bearing Wellington evaporites in Harper County is illustrated in figure 5. This illustration shows about 450 feet of strata containing an estimated 42 percent salt, 30 percent anhydrite, and 28 percent shale.

The salt strata of the Lower salt-anhydrite unit in sec. 6, T. 22 N., R. 22 W., Woodward County, are 565 feet thick, and contain 37 percent salt, 34 percent anhydrite, and 29 percent shale.

Another much thinner section of salt strata present in sec. 32, T. 27 N., R. 5 E., Grant County, is shown in figure 6. A section 138 feet thick occurs from a depth of 812 to 950 feet. Salt constitutes 49 percent of the thickness, shale 46 percent, and anhydrite 5 percent.

The upper half of the Lower salt-anhydrite unit contains the salt-bearing beds assigned to the Wellington evaporites. Part or all of these salt-bearing strata is equivalent stratigraphically to the Hutchinson Salt Member of the Wellington Formation in Kansas.

The salt normally represents 40 to 50 percent of the thickness of the salt-bearing sequence, anhydrite and shale representing the remainder (fig. 7). Toward the eastern edge of the area, the shale is equal in amount (36 percent) to the anhydrite. Westward anhydrite beds are more numerous and thicken at the expense of the shales.

Future work will, in the opinion of the author, show similar conditions and perhaps much thicker salt-bearing sections within the Wellington evaporites than those discussed and illustrated in this report. These thicker sections should be found to the south and west in the depositional axis of the Anadarko basin. Present information precludes any prediction as to the actual thickness or extent of such strata.

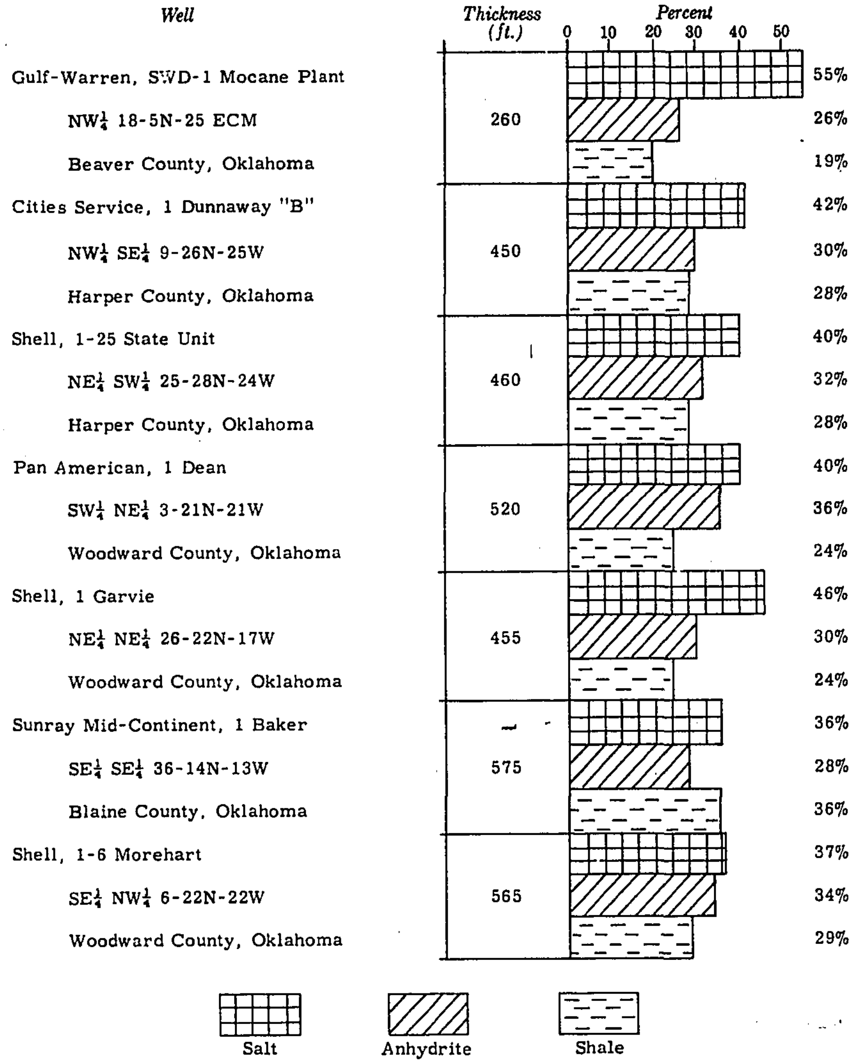

Figure 7. Chart showing thicknesses of the salt-bearing section of the Wellington evaporites in representative wells. Histograms indicate the percentage of salt, anhydrite, and shale calculated from sonic or caliper logs.

Shale Unit

Nomenclature and stratigraphic relations. The base of the middle shale unit of the Wellington evaporites is marked on electrical logs by a resistivity increase at the top of the Lower salt-anhydrite unit. The top of the unit is somewhat arbitrary, but is established at the base of a zone in which the anhydrite beds are markedly more evident than the extremely thin beds of anhydrite and dolomite within the Shale unit itself. The top can be recognized and correlated locally as a time-stratigraphic level, but time-stratigraphic correlation is not possible on a regional basis.

Distribution. This middle unit of the Wellington evaporites has been established everywhere within the area, but on both the eastern and western edges of the area recognition is locally difficult.

Character and thickness. Beds of gray, gray-green, and mottled maroon-green shales predominate, although the sequence is broken by thin stringers of anhydrite and dolomite which may be found in samples and appear as low resistivity peaks on electrical logs. The peaks are negative in character where the thickness of the anhydrite or dolomite stringer is appreciably less than the electrode spacing, and are absent if the thickness is equal to spacing.

The Shale unit has a uniform thickness of about 200 to 250 feet throughout most of the area. As much as 330 feet of strata are present (pl. II, cross section B-B') in the axis of the Anadarko basin, owing to the addition of beds near the base of the unit. A slight increase in thickness is present in the southeastern part of the area. This increase is due to the gradation into shale of some of the upper beds of the Lower salt-anhydrite unit, and also to the absence of some of the anhydrite beds near the base of the overlying Upper anhydrite unit (pl. II, cross section C-C').

The thin anhydrite and dolomite beds, generally present, increase in thickness and number westward. This increase in evaporites makes arbitrary separation of the Upper anhydrite unit and the Shale unit necessary locally in western Oklahoma and the panhandle of Texas.

Upper Anhydrite Unit

Nomenclature and stratigraphic relations. The base of the Upper anhydrite unit is established at the base of a zone of anhydrite and shale overlying the Shale unit, marked by an abrupt decrease in the amount of anhydrite. The top of the Upper anhydrite unit marks the top of the Wellington evaporites. The abrupt increase in resistivity value at the top of this unit is a striking feature on electrical logs in this part of the Permian sequence. The resistivity change marks the uppermost anhydrite or dolomite in the section. Normally the unit is overlain by not more than 50 feet of gray shale which is included in the Wellington Formation of the surface. The top of the unit has been referred to frequently in the literature of the subsurface of Oklahoma as the "First Anhydrite", or "Upper Anhydrite". The upper beds of this anhydrite unit are called the "Panhandle lime" in the subsurface of the Texas panhandle.

Distribution. The Upper anhydrite unit is present everywhere except in the extreme eastern and southeastern parts of the area. Eastward the unit becomes difficult to recognize and is projected by correlation from the west.

Character and thickness. The Upper anhydrite unit of the Wellington evaporites consists of interbedded anhydrite, dolomite, and gray shale. At few places does the unit contain more than 30 percent anhydrite and dolomite, and it normally contains less than 20 percent. Eastward the unit thins by loss of anhydrite and dolomite beds. As indicated by electrical logs, the unit is absent in western Caddo and Blaine Counties. To the north some character is recognizable as far east as western Garfield and Major Counties (pl. II, cross sections A-A' and A-D).

The thickness of the Upper anhydrite unit normally ranges from slightly less than 100 feet up to 150 feet. The thickest sections, as much as 250 feet, are present within the deeper parts of the Anadarko basin (pl. II, cross section A-D). The thinnest sections are found in the extreme eastern and southeastern parts of the area (pl. II, cross sections A-A', A-D and C-C') where thin anhydrite and dolomite beds grade to shale both at the top and at the base of the unit.

Hennessey Shales

Nomenclature and stratigraphic relations. The term "Hennessey shales", as used herein, includes all beds lying above the uppermost thin anhydrite or dolomite assigned to the Wellington evaporites and below the lowermost bed of salt assigned to the overlying Lower Cimarron salt. This is the normal relationship over most of the area, but toward the eastern margin of the area where the Cimarron salts are missing, the Hennessey shales are in contact with the overlying Flowerpot Shale. The contact between the Flowerpot Shale above, and the Hennessey Shale below, cannot be established in the subsurface from electrical logs. Where the Hennessey and Flowerpot shales are in contact they have been designated the "Hennessey-Flowerpot shales". In this region it is probable that all strata referred to as Cimarron evaporites are wholly or largely equivalent to the Hennessey Shale as it occurs here.

A thin zone of gray, mottled gray-green and red or maroon shale directly overlies the Upper anhydrite unit of the Wellington evaporites. These beds, characterized by the presence of gray shale, are normally assigned to the Wellington Formation of the surface, but are not included in the Wellington evaporites of this report. The top of this zone has been called "Base of the Red" in the subsurface by Clifton et al. (1926).

Above this gray zone are found red and red-green shales called "Red Cave" in the subsurface of the panhandle of Texas. These beds are considered to be equivalent to some part of the Garber Sandstone and Hennessey Shale which crop out five to thirty miles east of the mapped area in central Oklahoma. Stratigraphically these beds have been distinguished from the gray shales of the Wellington Formation below on the basis of surface mapping and to some extent by study of subsurface samples. The character recorded by the various logging techniques shows no significant difference between red, green, and gray shale. For this reason, the gray shales of the Wellington Formation are considered and illustrated (pl. II) as part of the Hennessey shales.

Distribution. Hennessey shales are present in all parts of the mapped area. They can be recognized in the subsurface throughout the area except along the eastern margin where the character of the Cimarron salts, as shown by electrical logs, is absent. As indicated in figure 3, the Cimarron evaporites are probably equivalent to the upper portion of the Hennessey shales. The stratigraphic position of the Cimarron evaporites is not clearly established, because the contact between the Hennessey and Flowerpot shales cannot be determined in the subsurface.

Character and thickness. As mentioned above, these beds are a mixture of red and red-green shales except for a thin zone of gray shale (assigned to the Wellington Formation on the surface) at the base. Locally, thin stringers of anhydrite or dolomite appear as resistivity peaks on electrical logs. In the Panhandle field of Texas some commercial oil and gas is produced from thin silty sandstones within the unit. These wells require some type of fracturing treatment for commercial production.

In the area investigated the thickness of the Hennessey shale unit in its normal development ranges from 270 feet to 705 feet. In a general way the thinnest sections are in northern Oklahoma and the thickest sections are in that part of the Anadarko basin lying just north of the Wichita Mountains. In northern Oklahoma it ranges from a minimum of 270 feet in central Beaver County, to a maximum of 500 feet in southwestern Woods County. The average thickness in the northern part of the area is approximately 400 feet (pl. II, cross section A-A'). The average thickness is similar in the northern Texas panhandle (pl.

II, cross section A-D), thickening to 550 feet in the axis of the Anadarko basin just west of the Oklahoma-Texas boundary (T. 11 N.) in Wheeler County, Texas. Thicknesses in Oklahoma reach a maximum of 705 feet (well 18, pl. II, cross section A-D) in northeastern Beckham County. East of central Washita County, the Hennessey and Flowerpot shales cannot be separated. Here the Cimarron evaporites, which normally serve to divide this thick shale sequence (pl. II, cross section C-C'), are absent. A similar absence of the Cimarron evaporites east of central Alfalfa County make these beds inseparable as separate units.

Cimarron Evaporites

Nomenclature and stratigraphic relations. The Cimarron evaporites are thought to be approximately equivalent to the upper part of the Hennessey Shale of the surface exposures. The exact stratigraphic position is unknown in Oklahoma, as previously stated. The Cimarron evaporites are known to be underlain by shales of Hennessey age, but the shales which overlie the Cimarron evaporites may be Flowerpot Shale or Hennessey Shale locally (fig. 3).

Distribution. The Cimarron evaporites underlie all but the eastern and southeastern parts of the area (pl. II, map C). The limit is shown on map C as a line parallel to the Wichita Mountains, trending northeast across the northwestern corner of Washita County to southern Blaine County, and there swinging northward to central Alfalfa County, Oklahoma, and eastern Barber County (R. 11 W.), Kansas.

Character and thickness. Salt is the dominant rock in the

Cimarron evaporites. Within the salt is a thin persistent anhydrite-dolomite unit termed the Cimarron anhydrite which has been used by many geologists as a datum in the subsurface. Immediately below the Cimarron anhydrite is a thin silty shale separating the anhydrite from the salt (Lower Cimarron salt) below. The salt above the Cimarron anhydrite (Upper Cimarron salt) contains a high percentage of shale, whereas the Lower Cimarron salt is relatively pure. Each salt unit locally contains a minor amount of anhydrite in the form of thin discontinuous stringers.

The maximum thickness of the Cimarron evaporites is in Beckham and Roger Mills Counties, Oklahoma, and in the Texas Panhandle at the corner common to Wheeler, Gray, Roberts, and Hemphill Counties (pl. III, map C), where the salt-bearing strata are about 1,000 feet thick. In those areas of most dense control the Cimarron evaporite thickness varies as a reflection of the presence or absence of salt. The thinnest area which contains both upper and lower Cimarron salts occurs in northwestern Beaver County, where the unit is 200 feet thick. Similar thin areas are present to the north and northeast, but here only one or the other of the salt units is normally present (pl. III, map C). In general, most of the variation in the thickness of the Cimarron evaporites occurs in the Upper Cimarron salt, whereas the Lower Cimarron salt displays a general thickening trend into the Anadarko basin (pl. II).

Subdivisions. The Cimarron evaporites are divided in subsurface into three units (fig. 8). The lowermost unit, Lower Cimarron

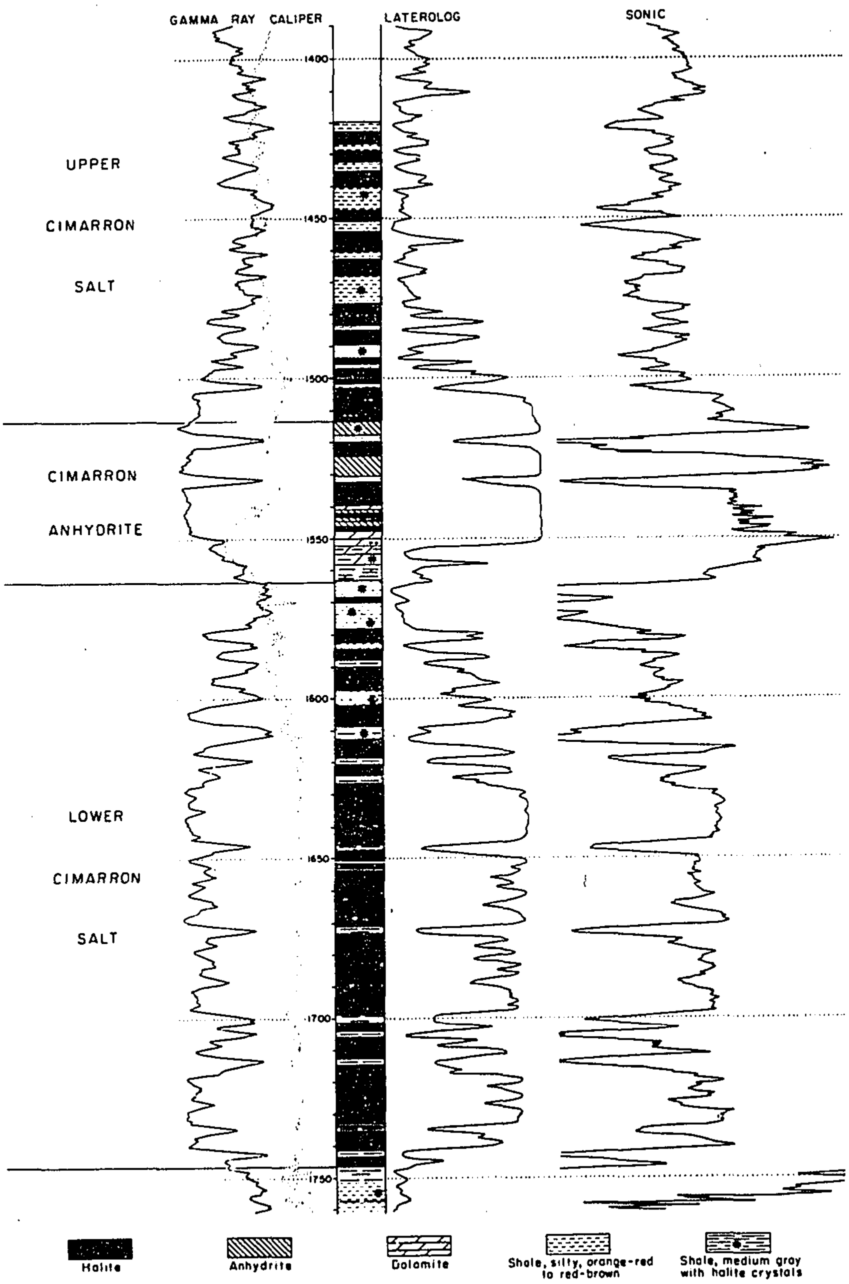

Figure 8. Cimarron evaporites, consisting of Upper Cimarron salt, Cimarron anhydrite, and Lower Cimarron salt in the Gulf-Warren SWD-1 Mocane Plant, Beaver County, Oklahoma, as shown by gamma-ray, caliper, laterlog, and sonic logs. (After Jordan, 1962a, p. 25).

salt, lies directly above the Hennessey shales. The middle unit is the Cimarron anhydrite, which separates the Lower Cimarron salt from the uppermost unit or Upper Cimarron salt.

Lower Cimarron Salt

Nomenclature and stratigraphic relations. Kulstad (1959, p. 241) mentioned "Cimarron salts" in the Hugoton Embayment, but the term Lower Cimarron salt was first used in the literature by Jordan (1962, p. 25) in discussing the liquefied-petroleum gas storage in the Mocane area, Beaver County, Oklahoma. The Lower Cimarron salt lies directly above the Hennessey shales and is separated from the overlying Cimarron anhydrite in most places by a thin silty shale.

Distribution. The geographic extent of the Lower Cimarron salt is shown on plate III, map E. The southeastern and eastern limits extend along a line through western Washita County, across west-central Custer and east-central Dewey Counties. From east-central Dewey County, the trend swings northeastward across Major County, into the southwestern part of Alfalfa County. The boundary turns northward and runs through central Alfalfa County, trending northwest through T. 29 N., R. 12 W. into Kansas.

Character and thickness. The Lower Cimarron salt is 170 feet thick in southwestern Beaver County, and thickens slowly into the Anadarko basin, reaching a maximum of about 450 feet in northeast-central Wheeler County, Texas, and about 435 feet in northern Beckham and southern Roger Mills Counties, Oklahoma (pl. II, cross section A-D).

A complete Cimarron evaporite section (fig. 8) is shown by logs of the Gulf-Warren salt-water-disposal well in SE¼ SW¼ SE¼ NW¼ sec. 18, T. 5 N., R. 25 ECM., Beaver County. Jordan (1962, p. 23) gave the following description of the Lower Cimarron salt from continuous cores taken from this well:

> The formation [Cimarron anhydrite] is underlain by 280 feet of halite with relatively few interbeds of reddish-brown or greenish-gray shale. Much of the salt is colorless and coarse crystalline, but at places the clay between crystals gives a gray appearance in contrast to the reddish-brown appearance of the salt above the Cimarron anhydrite. Orange-red fibrous halite occurs as veins in shale in both sections.

Estimations from figure 8 indicate that the Lower Cimarron salt is 78 percent halite and 22 percent shale. Anhydrite beds are absent.

Another illustration of logs from the Cities Service No. 1 Dunnaway "B", NW¼ SE¼ sec. 9, T. 26 N., R. 25 W., Harper County, Oklahoma, shows only the Lower Cimarron salt (fig. 9). The top of the salt is at a depth of 1,246 feet and is 230 feet thick. Estimated proportions are 69 percent salt and 31 percent shale.

In the northern part of the area the Lower Cimarron salt reaches a maximum thickness of 270 feet, in Harper County, Oklahoma. It thins gradually eastward, becoming more shaly, and losing its identity in western Alfalfa County (pl. II, cross section A-A'). South of Harper County, the section thickens to approximately 435 feet in the axis of the Anadarko basin in southern Roger Mills and northern Beckham Counties (pl. II, cross section B-B'). Similar thick sections are found north of the Amarillo uplift in Wheeler County and southeastern Roberts County, Texas (pl. II, cross section A-D). Northward the unit slowly thins to

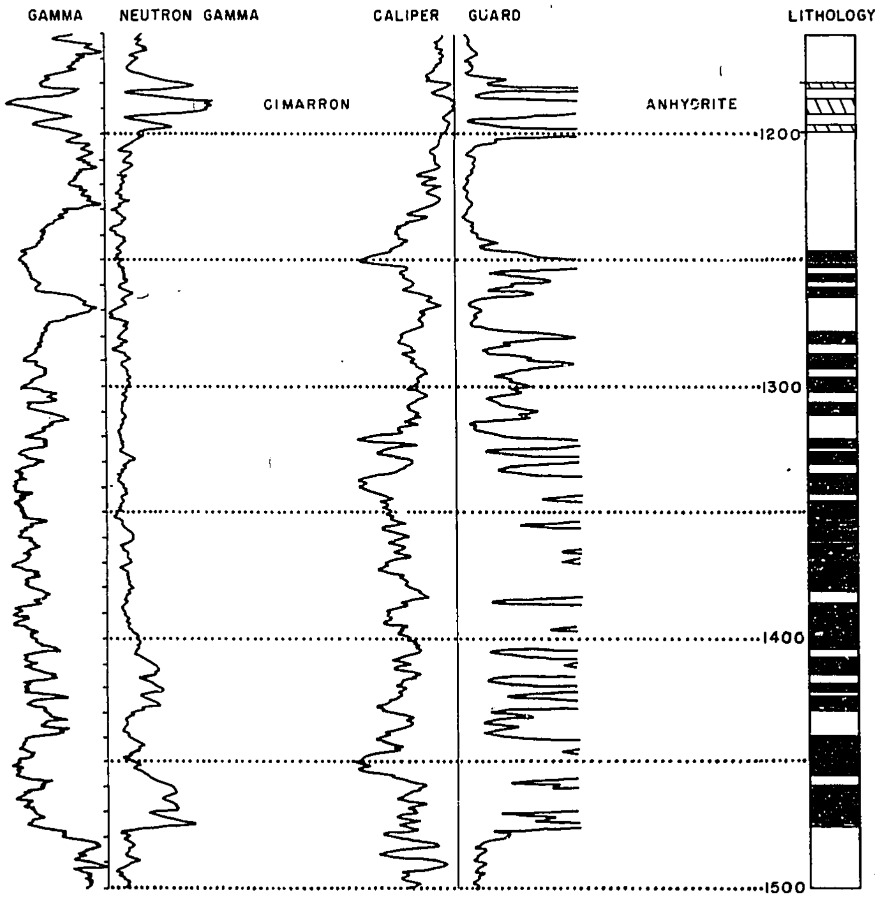

Figure 9. Cimarron anhydrite and Lower Cimarron salt as shown by logs of the Cities Service 1 Dunnaway "B", Harper County, Oklahoma. In the lithologic column, blank areas are shale, solid black is salt and diagonal ruling is anhydrite. (After Jordan, 1960, p. 25).

approximately 200 feet in northern Lipscomb and Ochiltree Counties, Texas, and to approximately 170 feet in southwestern Beaver County, Oklahoma.

Shale above the Lower Cimarron salt. At most places in the area, a thin zone of silty shale immediately overlies the uppermost salt stratum of the Lower Cimarron salt, and is beneath the lowermost bed called Cimarron anhydrite (pl. I). These beds are orange-red, red, or reddish-brown and gray. Locally coarse siltstone to very fine sandstone is present. The upper part contains thin discontinuous stringers of dolomite, dolomitic anhydrite, and anhydrite. The thickness is generally less than 50 feet.

Cimarron Anhydrite

Nomenclature and stratigraphic relations. The Cimarron anhydrite has been for many years a useful stratigraphic marker in the subsurface of northwestern Oklahoma and the Texas Panhandle. This unit is considered (Lee and Merriam, 1954, p. 3) equivalent to the Stone Corral Formation of the surface, which, in Kansas, is above the Ninnescah Shale and below the Harper Siltstone (Jewett, 1959). The correlation of the subsurface "Cimarron Anhydrite" with the Stone Corral at its type locality, was established by W. L. Ainsworth (Norton, 1939, p. 1777). In Oklahoma the equivalence of Cimarron anhydrite and Stone Corral Formation is probable but has not as yet been demonstrated conclusively. The Cimarron anhydrite of the subsurface lies above the Lower Cimarron salt and below the Upper Cimarron salt.

Distribution. Examination of various types of logs shows the Cimarron anhydrite to be best developed in northwestern Oklahoma. Here, the typical section produces three sharp resistivity peaks on electrical logs. These can be traced from western Beaver County, as far east as eastern Woodward and west-central Woods Counties (wells 1-5, pl. II, cross section A-A'). Southward from Beaver County, Oklahoma, (wells 11-15, pl. II, cross section A-D), the resistivity character can be traced across the panhandle of Texas into eastern Wheeler County, Texas. South from Harper County, Oklahoma (wells 22-24, pl. II, cross section B-B'), the sharp resistivity peaks persist only as far as central Ellis County. To the south and east the unit loses its distinctive character, as the resistivity peaks disappear one at a time. The stratigraphic position of the Cimarron anhydrite can be traced as a zone of indistinctive character by subsurface correlation almost to the Wichita Mountains. To the east the zone is indistinct beyond western Alfalfa, eastern Dewey, and central Custer Counties, Oklahoma (pl. II).

Character and thickness. The average total thickness of the Cimarron anhydrite is approximately 40 feet. As much as 80 feet has been found locally, the increase being due largely to the presence of salt beds between the beds of anhydrite and dolomite. Some sample logs in the panhandle of Texas have reported in excess of 150 feet of Cimarron anhydrite, but this thickness probably includes anhydrite beds which should be included in the Lower Cimarron salt below.

Logs from the Gulf-Warren salt-water-disposal well at the Mocane Plant SE$\frac{1}{4}$ SW$\frac{1}{4}$ SE$\frac{1}{4}$ NW$\frac{1}{4}$ sec. 18, T. 5 N., R. 25 ECM., Beaver County, are shown in figure 8. Jordan (1962, p. 24-25) described the Cimarron anhydrite from continuous cores taken from this well as follows:

> It [Cimarron anhydrite] consists of two beds each of anhydrite near the top and dolomite at the base, each pair of beds being separated by halite and minor amounts of reddish-brown shale (fig. 1). The upper medium-crystalline anhydrite contains crystals of halite, whereas the lower bed is very fine crystalline and banded. The halite strata are colorless and coarse crystalline, except for a two-foot section immediately below the upper anhydrite, which contains clear fibrous halite with a faint pink coloration. Halite just above the medium-gray very fine-crystalline dolomite is clear, colorless, and coarse crystalline. Part of the dolomite is finely oölitic.

The thickness of the Cimarron anhydrite in the Gulf-Warren well is 50 feet. At this locality the Cimarron anhydrite contains beds of salt. Thirty miles to the southeast, the Cities Service No. 1 Dunnaway "B", NW$\frac{1}{4}$ SE$\frac{1}{4}$ sec. 9, T. 26 N., R. 25 W., Harper County, contains Cimarron anhydrite as three beds of anhydrite probably associated with dolomite and separated by shale (fig. 9). The section is 20 feet thick and occurs at a depth of 1,178 to 1,198 feet.

Upper Cimarron Salt

Nomenclature and stratigraphic relations. The term Upper Cimarron salt was first used in the literature by Jordan (1962, p. 25, fig. 1). Jordan illustrated the electrical log characteristics of these beds using the Gulf-Warren well (fig. 8). The base of the Upper Cimarron salt rests at this locality upon the uppermost bed of the Cimarron anhydrite, but overlies shales of the anhydrite zone where the anhydrite is missing. The top of the salt zone is difficult to establish in some areas because the beds become more shaly upward (pl. II). In so far as can be determined, the top of the salt is placed at the base of the thickest non-salty shale sequence found above the Cimarron anhydrite and below the base of the Blaine anhydrite. This criterion, while not desirable or completely satisfactory, was found to be the most practical and workable. At places in the Texas Panhandle and in western Oklahoma, almost the entire sequence between the Cimarron anhydrite and the Blaine anhydrite contains salt (well 27, cross section B-B'; well 14, cross section A-D, pl. II). Commercial sample logs from wells in this western area show a zone of thin fine-grained siltstones and sandstones lying in approximately the same stratigraphic position as the non-salty shales to the east. The base of this sandy zone marks the top of the Upper Cimarron salt where it is present.

Distribution. The extent of the Upper Cimarron salt is shown on plate III, map C. The unit is absent in most of Harper, Woods, and Alfalfa Counties in the north, in much of Major and Blaine Counties to the east, and in Washita County to the south.

Character and thickness. Jordan (1962a, p. 23) gave the following brief description from continuous cores taken from Gulf-Warren's salt-water-disposal well at the Mocane Plant, SE$\frac{1}{4}$ SW$\frac{1}{4}$ SE$\frac{1}{4}$ NW$\frac{1}{4}$ sec. 18, T. 5 N., R. 25 ECM., Beaver County, Oklahoma:

> A 184-foot section of interbedded and intermingled coarse-crystalline halite and reddish-brown shale, from 1,330 to 1,514 feet, rests upon the Cimarron anhydrite. For the most part the halite contains clay that imparts an overall dull reddish-brown appearance.

This described section is typical of Beaver County (wells 1, 2, pl. II, cross section A-A'). Elsewhere, primarily salty shale is present in this section (pl. II).

The Upper Cimarron salt-bearing section ranges in thickness from 125 feet in southwestern Beaver County to 625 feet in southern Roger Mills County (pl. II, cross section B-B'). In the north, the unit thickens to the east (pl. II, cross section A-A'). Similar thickening to the east is seen in the south on plate II, cross section A-D.

Although reliable information is available at only a few points, the estimated percentage of salt found within the salt-bearing section decreases as the unit thickens. If the total amount of salt deposited within the unit were known, it might be found to be of similar magnitude throughout the area. This would mean that the thickening of the unit is due, not to greater salt deposition, but to greater shale deposition. A discussion of the tectonic or environmental significance of this possibility is beyond the scope of this report.

Flowerpot Shale and Hennessey-Flowerpot shales. The Flowerpot Shale is a term of surface nomenclature, referring to shale and siltstone strata lying below the Blaine Formation and above the Cedar Hills Sandstone or Duncan Sandstone (figs. 2,3,). As this sequence is traced into the subsurface the underlying clastic beds disappear, so that Flowerpot Shale is in contact with Hennessey Shale. This contact cannot be traced with confidence in the subsurface, thus the stratigraphic position of these strata in terms of surface nomenclature is obscure, and for purposes of this report are referred to as the Hennessey-Flowerpot shales (pl. I).

The non-salty strata above the Upper Cimarron salt and below the lowermost beds of Flowerpot salt, are a facies of the salt-bearing section. As mentioned above, establishment of the non-salty unit to separate Cimarron salt from Flowerpot salt is arbitrary at some places. In the panhandle of Texas, a sandy zone represents the dividing strata, whereas over most of the mapped area, the zone of non-salty shale separates the Upper Cimarron salt from Flowerpot salt. The relationship of this non-salty unit to surface nomenclature is unknown. It is thought that these beds are probably equivalent in most places to the upper part of the Hennessey Shale. However, the overlying Flowerpot salt is thin in some places, and the unit could be equivalent to the Flowerpot Shale.

Around the edges of the Anadarko basin, local clastic units are recognized on the surface. These include the Cedar Hills Sandstone in the northeast, and the Duncan-Chickasha Formations in the south. Shale beds equivalent to these clastic units may be present within the interval referred to here as Hennessey-Flowerpot shales, which separate the Upper Cimarron salt below from the Flowerpot salt above.

The Hennessey-Flowerpot shales reach a maximum thickness of 400 feet in the north and northwestern parts of the area (pl. II, cross sections A-A', A-D, and B-B'). South of Beaver County, Oklahoma, in central and southern Ochiltree County, Texas, as little as 100 feet is present. Within the axis of the Anadarko basin, thicknesses from 200 to 300 feet are present. Eastward, the unit looses its identity as the salt-bearing sections grade to shale (pl. I). Where the salt is absent the section is represented by a sequence of red shales and red fine-grained siltstones broken by thin stringers of anhydrite and dolomite. Locally, this section contains beds of fine-grained red silty sandstone, reddish-brown, maroon, and green shales. The sequence extends from the uppermost anhydrite bed of the Wellington evaporites upward to the base of the Blaine anhydrite, or to the surface if the Blaine beds are absent. The thickness from the top of the Wellington evaporites to the base of the Blaine anhydrite is approximately 2,100 feet wherever the salt units (Lower Cimarron salt, Upper Cimarron salt and Flowerpot salt) are missing.

Mappable clastic units, such as Garber Sandstone and others mentioned previously, have been traced, from their areas of outcrop around the edges of the Anadarko basin, into the subsurface using samples and electrical logs. The correlation of these clastic facies has normally been limited to local areas, and has been of questionable success on a regional basis. Adkinson (1960) correlated samples from rotary drilling along with electrical logs from Caddo County, Oklahoma, to Barber County, Kansas. He illustrated the sandy clastic units, then correlated them with dashed lines for limited distances and frequently combined them with other units using compound names.

Beckham Evaporites

Nomenclature and stratigraphic relations. The term "Beckham evaporites" is here proposed for that subsurface sequence of salt and anhydrite which occurs next above the Cimarron evaporites, and is overlain by the Dog Creek Shale. The name is taken from Beckham County, Oklahoma, wherein the maximum thickness of 700 feet is attained. Like the Cimarron evaporites, it consists of an upper and lower unit of salt separated by a medial unit of anhydrite, and these divisions are named Flowerpot salt, Blaine anhydrite, and Yelton salt (ascending order). Both the Flowerpot salt and Blaine anhydrite are widely present within the Anadarko basin, and occur also beyond it to the south, but the Yelton salt is localized in the axial part of the basin, just north of the Wichita-Amarillo uplift. The Blaine anhydrite is especially persistent in subsurface as well as on the outcrop, and the base of this unit is a valuable datum horizon that has been used for all cross sections in the present report.

Distribution. The complete section of Beckham evaporites is present in the south-central part of the area, in Beckham and Washita Counties, Oklahoma, and part of Wheeler County, Texas. Beyond this area, the salt above the Blaine anhydrite, herein named the Yelton salt, is missing (pl. III, map E). The Blaine anhydrite can be recognized in subsurface everywhere between its two lines of outcrop on the northeastern and southern margins of the Anadarko basin (Miser et al., 1954), except in the extreme southeastern part of the area. The Flowerpot salt is present generally in the area west of R. 18 W., except for the area between the South Canadian and Cimarron Rivers in which the eastern limit is approximately R. 23 W. (pl. III, map D).

Character and thickness. The Beckham evaporites consist mostly of salt, salty shale, and anhydrite. Locally in the west some sandstone is present within or immediately below the Blaine anhydrite. Minor amounts of non-salty shale are present within the Flowerpot salt.

In the northern part of the area, where the Yelton salt is absent, the thickness of the Beckham evaporites is from 170 feet in Woodward County to 580 feet in Harper County. In Beckham County, Oklahoma, and Wheeler County, Texas, where all units of the Beckham evaporites are present, the thickness reaches a maximum of 700 feet.

Subdivisions. The Beckham evaporites consist, in ascending order, of the Flowerpot salt, Blaine anhydrite, and Yelton salt. These units can be readily established from logs, either electrical or radio active type.

Flowerpot Salt

Nomenclature and stratigraphic relations. The term Flowerpot salt refers to beds of salt and salty shale which occupy the stratigraphic position of the Flowerpot Shale as defined on the surface. This unit was clearly illustrated by Greene (1926, p. 13) as lying immediately below the Blaine Gypsum, but Greene applied no name. Locally the salt may represent beds older than Flowerpot Shale, but this age assignment has not been definitely established. The salt is underlain by shales and siltstones of probable Flowerpot and Hennesey age. Overlying the Flowerpot salt is the Blaine anhydrite.

Distribution. The known extent of the Flowerpot salt is shown on plate III, map D. The unit is generally present in the western half of the area. In the south, the Flowerpot salt is present as far east as eastern Custer County, whereas in the north it extends eastward as far as western Woods County. In the central part of the area the

Flowerpot salt is noticeably absent in all but the northern part of Woodward County, and parts of eastern Ellis County. Locally in Beaver and Harper Counties, the salt is absent in small areas (pl.III, map D).

Character and thickness. The Flowerpot salt normally consists of salty shale near the base and of relatively pure salt near the top. Locally in Harper and Ellis Counties, as much as 100 feet of non-salty shale lies below the base of the Blaine anhydrite and above the purer salt beds (pl. II, cross section B-B'). In southern Ellis County two salt zones are present (well 26, pl. II, cross section B-B'), separated by salty shale. Directly below the Blaine anhydrite in the panhandle of Texas is a thin sandstone, at most places less than 20 feet thick. This bed has been recognized only in Texas, where it is recorded on sample logs as the Glorieta Sandstone. Throughout most of the area the strata immediately below the Blaine anhydrite contain thin stringers of anhydrite in either shale or salt.

The thickness of the Flowerpot salt is variable throughout the area (pl. II, map D). Locally, in the Texas Panhandle and north-central Beaver County, Oklahoma, the thickness is more than 500 feet. Less than four miles east of this thick Flowerpot salt section in Beaver County, the salt is absent. The average thickness of the Flowerpot salt is 250 to 200 feet, except near the edges of the area as shown on map D, plate II.

Logs (fig. 10) of the Flowerpot section in the Cities Service 1 Dunnaway "B" in NW$\frac{1}{4}$ SE$\frac{1}{4}$ sec. 9, T. 26 N., R. 25 W., Harper County, show

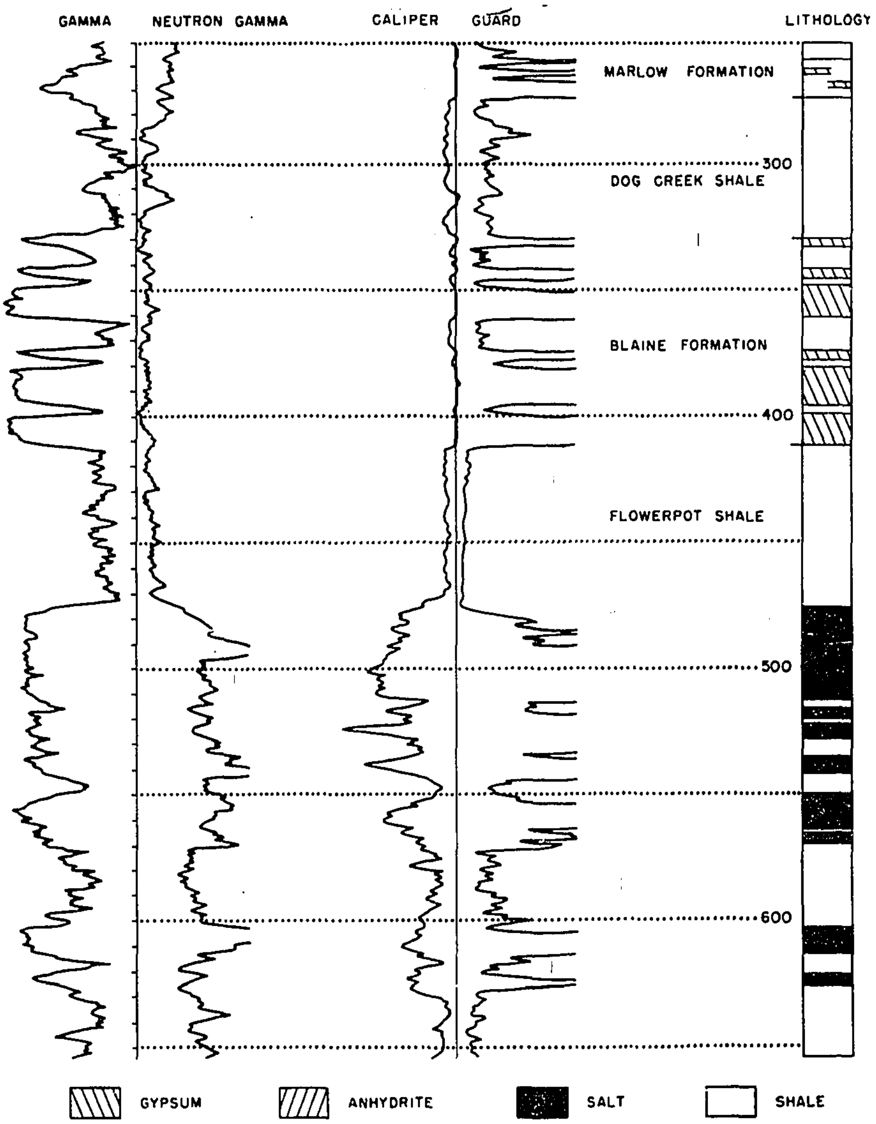

Figure 10. Gypsum strata in the Blaine Formation (Blaine anhydrite of this report) and salt beds in the Flowerpot Shale (Flowerpot salt of this report) as shown by logs of the Cities Service 1 Dunnaway "B", Harper County, Oklahoma. (After Jordan, 1960, p. 24).

60 feet of Flowerpot Shale immediately below the Blaine anhydrite. Beneath this shale a 150-foot section contains salt, of which the upper 95 feet is 81 percent salt.

Another section showing Flowerpot salt (fig. 11), from the Texaco Inc. et al. No. 1 Lehman, liquefied-petroleum gas storage well in SW$\frac{1}{4}$ SE$\frac{1}{4}$ sec. 30, T. 1 N., R. 20 ECM., Beaver County, shows the gamma-ray log of the Blaine anhydrite and Flowerpot salt. The following description of the cored section (Jordan, 1961, p. 34) was obtained from geologist L. E. Case.

> Gray shale occurs both above the basal anhydrite [Blaine anhydrite] stratum and in the underlying Flowerpot. A six-inch bed of fine-grained gray sandstone is noted at 780 feet within the Blaine anhydrite . A similar thickness of siltstone and sandstone is present in the 26 feet of Flowerpot shale which overlies the salt. Relatively pure pink salt occurs from 866 to 888 feet and from 894 to 1,030 feet, but some beds of shale, none more than two inches thick are present. The lowermost 68 feet of section contains salt with a shale content ranging from 10 to 60 percent.

The Flowerpot salt is abnormally thick in east-central Custer County (fig. 12). Figure 12 shows spontaneous potential and conductivity logs of the Gulf Oil Corporation No. 1 Burgtorf in SE$\frac{1}{4}$ NW$\frac{1}{4}$ sec. 6, T. 13 N., R. 15 W. The well has 625 feet of section below the Blaine anhydrite which is interpreted as salt. No sonic or caliper logs from the Burgtorf well are available, and other supplementary control is lacking. This interpretation cannot be confirmed at the present time, but any other lithology is not compatible with the section as it is now understood. The only exception might be shale, which is definitely not indicated by the logs available. Error in instrumentation

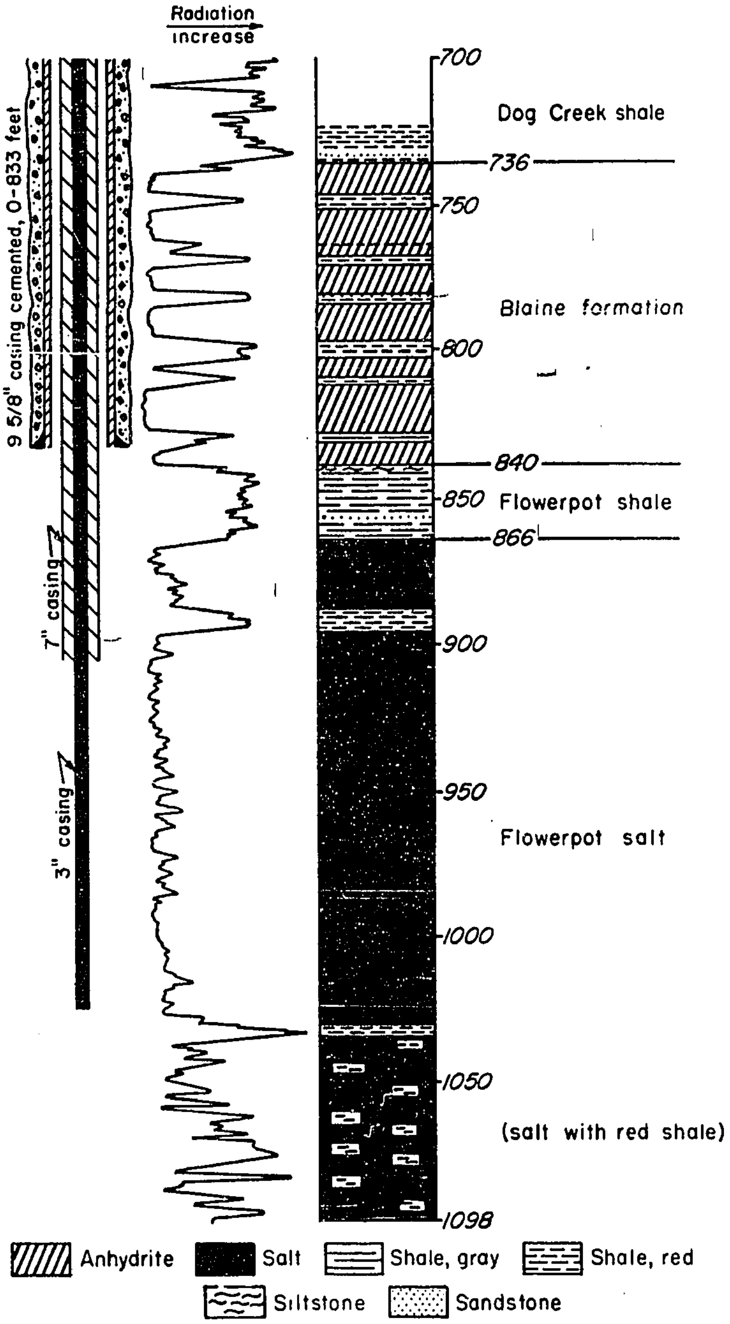

Figure 11. Blaine anhydrite and Flowerpot salt as shown by logs of the Texaco Inc. et al. 1 Lehman, LPG-storage well in southwestern Beaver County, Oklahoma, and the casing program used in the construction of the LPG-storage facility. (After Jordan, 1961a, p. 35).

at the time the log was run might account for the anomaly, but no indication of this possibility is recorded. If the interpretation that salt and salty shale are present is correct, similar thickness might be expected elsewhere in the Anadarko basin in those areas where information is lacking.

Flowerpot salt is present within 30 feet of the surface at the Big Salt Plain on the Cimarron River between Woods and Woodward Counties (Ward, 1961, p. 275). The discovery of near-surface salt came as the result of shallow core drilling by the United States Army Corps of Engineers. Salt was encountered from 30 to 175 feet below the surface in 19 test holes. Ward stated that none of the holes penetrated all of the salt, but gave the following description of the salt-bearing zone:

> The upper part of the 91-foot zone contains more shale than salt, but 80 percent or more of the lower 57 feet is salt. Most of the salt is bedded crystalline halite, but a minor amount occurs as a fibrous material filling vertical and near-vertical cracks in the shale. A considerable part of the halite is colorless, but much of it contains included shale and clay that impart an overall dull reddish-brown appearance. The shale beds of the Flowerpot are silty, gypsiferous, and blocky. Generally they are reddish-brown but may be mottled or interbedded with greenish-gray beds. The formation is characterized by intersecting veins of colorless or orange-red selenite. Some gypsum occurs in the Flowerpot as thin impure beds, and some occurs as nodules.

Blaine Anhydrite

Nomenclature and stratigraphic relations. The subsurface term "Blaine anhydrite" as used in this report is essentially synonomous with the Blaine Formation of surface usage. Along the northeastern margin of the Anadarko basin, as well as in the adjoining outcrop belt that extends

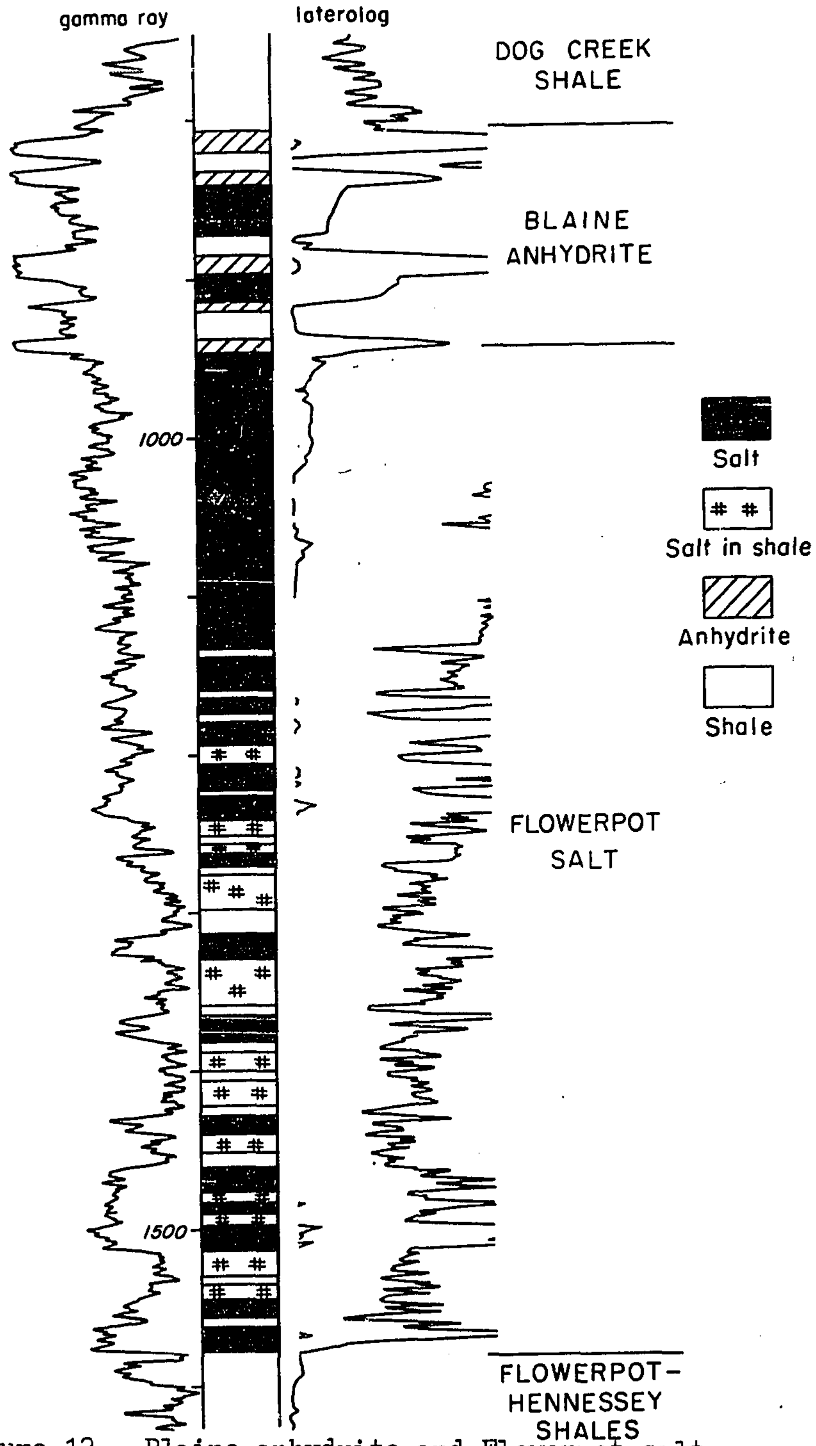

Figure 12. Blaine anhydrite and Flowerpot salt as interpreted from logs of the Gulf Oil Corporation 1 Burgtorf, Custer County, Oklahoma, showing 625 feet of salt-bearing section.

from Blaine County to Woodward County, the Blaine consists of interbedded anhydrite (or gypsum) and shale generally 100 feet thick (Myers, 1959, p. 32-33; Fay et al., 1962, p. 30; Fay, 1962, personal communication). This area contains the outcrops of the type locality in Blaine County.

In all other parts of the Anadarko basin, and in fact over most of the region, the Blaine contains additional anhydrite beds at the top, building up the evaporites generally to a thickness of at least 150 feet. This more common sequence is considered strictly equivalent to the Blaine Formation as the outcrops are classified in southwestern Oklahoma (Scott and Ham, 1957, p. 16-20; Ham, 1960; Johnson, K. S., 1962, personal communication); and because these beds are so closely related that they cannot be separated into two or more groups, they are here treated as a single unit. Thus according to the present interpretation the thicker sections of the Blaine anhydrite contain evaporite beds at the top which are not present at the type locality, these additional upper evaporites being represented at the type locality by fine clastic sediments in the lower part of the Dog Creek Shale.

The Dog Creek Shale lies above the Blaine in all outcrop exposures and in nearly all the subsurface of the Anadarko basin. Yelton salt, in part a facies of the Dog Creek Shale, occurs above the Blaine anhydrite in Beckham and Washita Counties, Oklahoma, and Wheeler County, Texas. Below the Blaine are the Flowerpot shales or nearly pure halite of the Flowerpot salt.

<u>Distribution</u>. As stated above, the Blaine anhydrite is present

in the subsurface between the lines of outcrops shown on the Geologic Map of Oklahoma (Miser, et al., 1954). To the southeast the Blaine anhydrite is absent in the subsurface as well as on the surface. Cross section C-C' represents a southeastern line of wells in which Blaine anhydrite can be easily recognized. The anhydrite beds may be traced about 25 miles farther southeast of the line of section C-C'; into central Caddo County, where they pass into beds recognized as Chickasha Formation (K. S. Johnson, 1962, oral communication).

Character and thickness. The Blaine Formation has been described from surface exposures at numerous localities by many geologists. As a general summary the formation in the eastern outcrop belt, principally in Blaine, Major, Woodward, Harper, and Woods Counties, is about 100 feet thick, whereas in the outcrop belt on the south flank of the Anadarko basin, chiefly in Washita, Kiowa, and Beckham Counties, the Blaine Formation is normally 150 feet thick. In both outcrop regions the Blaine consists of gypsum beds interstratified with shale, together with thin beds of dolomite.

Because of its widespread distribution and continuity, the Blaine has been extensively used as a datum for surface and subsurface mapping. There is some uncertainty involving terminology and correlation of individual members and beds within the formation, but discussion of these problems is beyond the scope of this report.

In subsurface the Blaine normally consists of anhydrite and shale, and for the purposes of this report it is referred to as the Blaine anhydrite. It ranges in thickness from 80 to 250 feet, and contains in its thickest sections some beds of nearly pure rock salt.

In the shallow subsurface of Harper, Beaver, Woodward, Ellis, and Dewey Counties it is mostly 80 to 100 feet thick and is much like the strata of the eastern outcrop belt. Gamma-ray logs from the Cities Service 1 Dunnaway "B" in Harper County (fig. 10) show six gypsum beds, none less than four feet thick, interstratified with shale, and the section recognized as Blaine is 82 feet thick. The Texaco Inc. et al., 1 Lehman liquefied-petroleum gas storage well (fig. 11) in Beaver County contains 104 feet of Blaine anhydrite. Jordan (1961, p. 34) gave the following description of cores from this well as described by geologists L. E. Case:

> The Blaine Formation from 736 to 840 feet consists of seven anhydrite beds, none less than five feet thick. Red-brown shale is present between the upper six anhydrite beds. Gray shale occurs . . . above the basal anhydrite stratum. . . . A six-inch bed of fine-grained gray sandstone is noted at 780 feet.

Toward the axial part of the Anadarko basin the Blaine increases in thickness to 150 feet. Most of the increase results from the addition of anhydrite beds at the top of the Blaine, these evaporite beds having graded from shales in the lower part of the overlying Dog Creek Formation. A thickness of approximately 150 feet is maintained in subsurface through Roger Mills County, the southern part of Custer County, and the eastern part of Washita County, into the surface outcrops of Beckham County, and the southern part of Washita County. The Blaine is 166 feet thick in the Gulf 1 Sprowls, NW$\frac{1}{4}$ NW$\frac{1}{4}$ sec. 28, T. 13 N., R. 23 W., Roger

Mills County, wherein the stratigraphic and lithologic sequence is entirely similar to that of the southern outcrop belt.

Within the Anadarko basin the maximum thickness of the Blaine ranges between 200 and 250 feet and is found in a depositional trough centering in northern Beckham County and western Washita County, Oklahoma, and in the adjoining parts of Wheeler County, Texas. This locus coincides approximately with the structural axis of the Anadarko basin (fig. 14). The increased thickness results principally from the addition of salt beds, especially within the upper anhydrite strata, that correlate with the Van Vacter Gypsum of the outcrop, and salt beds that lie directly above the Collingsworth Gypsum of outcrop nomenclature. The Blaine anhydrite is 243 feet in the Shell 1 Yelton of Beckham County and consists of interstratified beds of anhydrite, salt, and shale (fig. 13). In this well the Blaine is overlain by a thick sequence of Yelton salt and is underlain by the Flowerpot salt.

Yelton Salt

The Yelton Salt, the youngest of the Beckham evaporites, is underlain by the Blaine anhydrite and is overlain by Dog Creek Shale. It was first recognized and figured (Ham and Jordan, 1961, p. 7) from the Shell Yelton liquefied-petroleum gas 1 well in NE¼ SW¼ SE¼ sec. 15, T. 10 N., R. 21 W., in the Elk City Field, Beckham County, Oklahoma. Results of the present investigation show that the salt has regional distribution as a stratigraphic unit. It is here named the Yelton salt, the name being taken from the Yelton well in Beckham County. In the type well it is 215 feet thick and occurs at a depth of 1,125 to 1,340 feet. Cores and logs of the Yelton salt in this well show that it is relatively pure rock salt containing 10 to 22 percent interbedded shale (fig. 13). This sequence was described by Jordan (1959, p. 32, 34) as consisting of coarse crystalline salt with thin interbeds of brown and gray-green shale.

The thickness of the Yelton salt (pl. III, map E) reaches a maximum of 287 feet on the southwest edge of the Elk City Field in Beckham County, Oklahoma, and 275 feet in eastern Wheeler County, Texas. These two areas appear to be local areas of rapid deposition. If deposition was uniform throughout the area, then these thick areas may have subsided locally, preserving more salt than is normally present.

That the Yelton salt is a salt facies of shale beds in the lower part of the Dog Creek Formation is strongly suggested by correlation of wells along the axis of the Anadarko basin from Wheeler County, Texas, across Beckham and Washita Counties into Caddo County, Oklahoma (K. S. Johnson, 1962, oral communication).

The Yelton salt has been recognized only in the deeper parts of the Anadarko basin (pl. III. map E). Its distribution is based solely upon an interpretation of electrical logs, as no cores, caliper logs, or sonic logs are available outside the area of the Elk City Field. The northeastern limit mapped probably approximates the actual limit, but western and northwestern limits are not firmly established owing to the absence of log information from the few wells drilled.

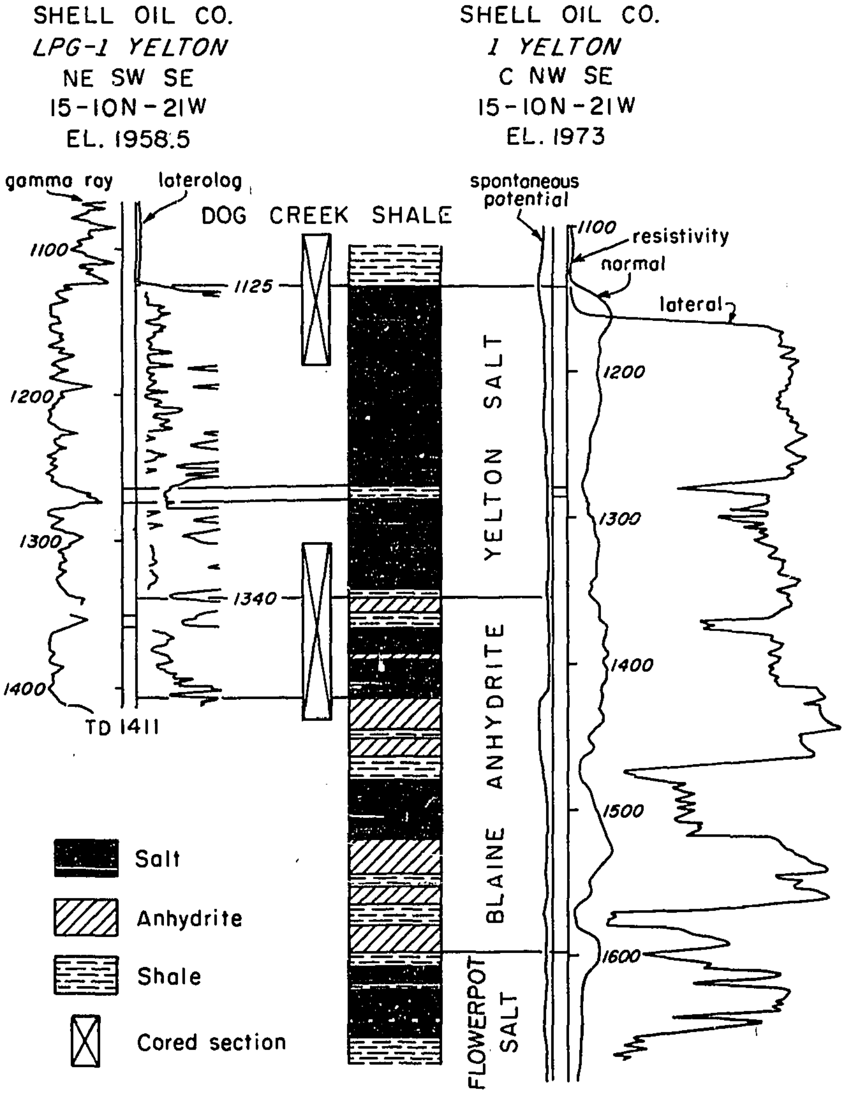

Figure 13. Type section of Yelton salt underlain by Blaine anhydrite, shown by logs of wells drilled on the Yelton lease, Elk City Field, Beckham County, Oklahoma.

STRUCTURE

General statement. Howell (1922) referred to the Anadarko basin as "Washita Syncline". Gould (1924) formally proposed the name "Anadarko Basin" as follows:

> . . . The distinguishing structural feature of the entire area [southwestern Oklahoma] is a large synclinal basin, the axis of which extends southeast-northwest across the area discussed. The southeastern end or head of this basin, as it is now understood, is located in northeastern Stephens County, a few miles northwest of the west end of the Arbuckle Mountains. From this point the axis of the basin is known to extend northwest for a distance of about 150 miles, until it appears to lose its identity, in the area occupied by the Quartermaster formation in northern Beckham and southern Roger Mills County. It is possible, however, that later investigations may show that this structural trough continues across the state line into the Panhandle of Texas, paralleling the buried granite ridge Amarillo mountains which is now believed to be the northwestern projection of the Arbuckle-Wichita Mountain axis.
>
> Toward the axis of the Anadarko Basin, the rocks dip from both sides, the dips on the south side in the vicinity of the Wichita Mountains being steeper than on the north side. The same redbed formations are exposed in the same sequence on both sides of the basin. For this structural feature the name "Anadarko Basin" is proposed. . . .

The general concept outlined by Gould in the quotation above remains with little major change. The basin axis does extend parallel to the Amarillo mountains as Gould suspected, although the mountain axis to the south of the basin is now thought to consist of the Amarillo-Wichita-Criner Hills axis, rather than a Wichita-Arbuckle Mountain axis.

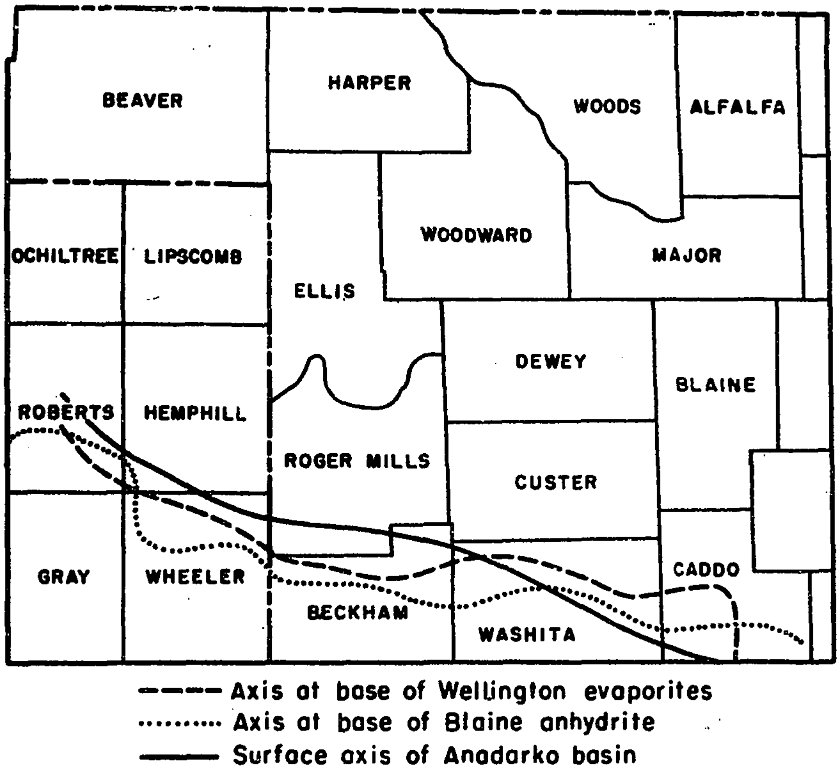

Figure 14. Structural axes at the base of the Wellington evaporites and Blaine anhydrite compared to the surface axis of the Anadarko basin.

The major structural features are shown on figure 1. East of the area is the Oklahoma City - Nemaha uplift, a subsurface feature which had little or no effect on the Permian sediments to the west. The Arbuckle Mountains lie to the southeast and during the Permian contributed fine clastics to the southeastern or headward end of the basin. This sedimentation is indicated by the disappearance of the anhydrite beds within the Blaine anhydrite approximately 25 miles southeast of the line of wells shown on plate II, cross section C-C'. The Amarillo-Wichita-Criner Hills axis dominates the southern and southwestern parts of the area shown on figure 1. Immediately north of the mountain axis is the axis of the Anadarko basin (fig. 14).

Base Wellington Evaporite Structure. The structure of the Anadarko basin, drawn at the base of the Wellington evaporites (pl. III, map B), shows the basin axis (fig. 14) to lie slightly north of the axis as shown by contouring at the base of the Blaine anhydrite (pl. III, map A). This relationship is contrary to the normal concept, namely that as sedimentation in the Anadarko basin proceeded through time, the axis would be shifted slowly northward by the clastic influx from the Wichita Mountains to the south. If it were practical, or indeed possible, to draw the structure at the base of the Wellington Formation and equivalent beds in terms of a time-stratigraphic horizon, the axis might then be shown to shift to a position south of the Blaine axis and thus conform to the general concept. The axis as drawn, however, is a lithologic change representing a depositional and environmental change which took place gradually within the basin, and did not occur everywhere at the same time.

Plate II, map B shows the structure drawn at the base of the Wellington evaporites. The axis trends eastward in southern Oklahoma in T. 10 and 11 N. Near the Oklahoma-Texas line the axis swings northwest across Wheeler County, Texas, becoming vague in Roberts County, Texas. Two axial depressions are present. The first and deepest is centered near Elk City, and the second is in northern Caddo County.

South of the axis the dips are on the order of 236 feet per mile or about 2.5 degrees. North of the axis beds are gently folded to form a broad arc, centered around the deeper depression in T. 10 N., R. 22 W. In Alfalfa County, the strike is northwest, the beds dipping gently to the southwest at approximately 19 feet per mile. Across Woods County, the strike is generally east and the dip is south at about 16 feet per mile. The strike in Beaver County, Oklahoma, and the northern panhandle of Texas is northeast and the dip is southeast at 20 feet per mile. In northeastern Hemphill County, Texas, and southwestern Ellis County, Oklahoma, the dip increases to about 37 feet per mile. This is the only part of the area which shows any appreciable increase in the dip southward into the basin axis, except for the effect of a local structure in T. 15 N., R. 16 W., in northern Custer County, Oklahoma.

The contours drawn at the base of the Wellington evaporites are more or less regular, swinging around a pivotal point in northeastern Beckham County. Local nosing is present in southern Blaine County, northern Woodward, south-central Ellis, and most of Harper County.

Base Blaine anhydrite structure. Plate III, map A, shows the structure drawn at the base of the Blaine anhydrite. The axial part of the Anadarko basin is well outlined with the deepest area centered in western Washita County, T. 10 N., R. 19 W. Compared to the structure at the base of the Wellington evaporites, the deepest part of the basin structure has shifted approximately 18 miles to the east. The axis has retained the same general configuration as that shown at the base of the Wellington evaporites, but throughout its length, has shifted slightly (maximum 10 miles) to the south (fig. 14). In Oklahoma, south of T. 17 N., the configuration is regular, although the dips shown on the north flank of the basin are steeper (38 feet per mile) than those shown for the base of the Wellington horizon. The south flank shows a dip value of 170 feet per mile, which is considerably less than the value at the base of the Wellington evaporites. North of T. 17 N., the dip values are only about 9 feet per mile, and the contours form irregular noses and local structures, both anticlinal or domal and depressional. The development of local structures in terms of relief, increases westward into the Texas Panhandle and has the highest relief and most complex configuration in northern Beaver County, Oklahoma. The structural pattern shown on map A (pl. III) does not reflect the structural attitude of the rocks found below the Blaine anhydrite, except for the upper few hundred feet. The attitude of the Cimarron anhydrite, 600 to 1,200 feet below the Blaine anhydrite, shows no relationship to the structure of the Blaine anhydrite. Apparent structures in the Blaine evidently originated by the solution of salt units between the Blaine and Cimarron anhydrites. The complexity of this solution phenomenon is shown only in those areas where control points are closely spaced. This is indicated by comparison of the pattern in Beaver County, where control is the best, as opposed to the Texas Panhandle where control (mostly commercial sample logs) is relatively closely spaced, and finally with Roger Mills and Custer Counties, Oklahoma, where control is almost absent. If uniform densely spaced control points were present throughout the area mapped, the "karst-like" pattern would probably be present over all but the deeper parts of the Anadarko basin, and in those areas where Upper Cimarron and Flowerpot salts are absent. These exceptions to the expected "sink-hole" pattern might occur under two conditions; first, if the underlying salt beds were not subjected to solution, perhaps because of saturated conditions or depth of burial, and second, if solution had removed essentially all of the salt. In the latter case, the Blaine anhydrite could be let down some amount equal to the average total thickness of the salt removed. Surface investigations have shown karst topography to be present at several localities and in various stages of development in western Oklahoma (Fay, 1958; Myers, 1960, 1962b). Similar topography is believed to have been present in the recent geologic past (Myers, 1962).

Relation of salt to structure. The present investigation indicates that the deposition of salt in the Anadarko basin generally has no relation to regional structure. In figure 15 the axes of areas of maximum thickness of Yelton salt, Flowerpot salt, and Cimarron evaporites are shown. The axes are randomly distributed and show no development of a single well-defined salt basin for any particular salt unit, and the salt maxima do not coincide from one unit to the next through time. With more control data and a detailed understanding of the part erosion and/or solution has played in the distribution of salt within the Anadarko basin, some relationship between salt and structure may become evident.

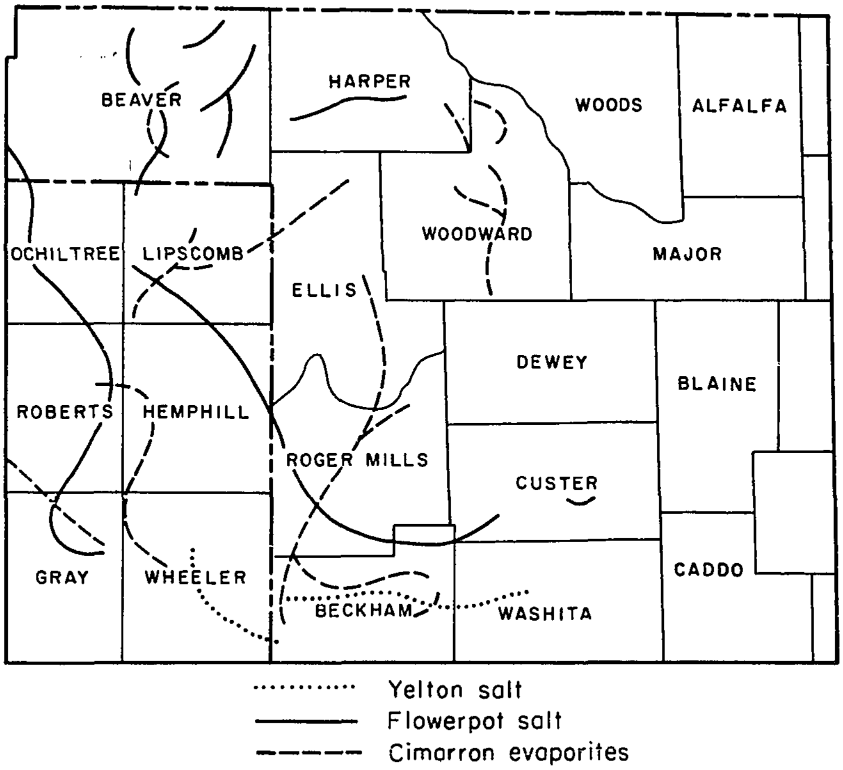

Figure 15. Lines of local maximum thickness of Yelton salt, Flowerpot salt, and Cimarron evaporites, showing lack of development of a well-defined salt basin at any particular time, and the change in position of salt maxima through time.

SALT RESOURCES

Introduction

The word "salt" commonly implies the mineral "halite", and, although core information is meager, it is probably that the greater part of the evaporites found in the Anadarko basin will be the mineral halite (NaCl). All cores examined by the members of the Oklahoma Geological Survey and the United States Geological Survey obtained from western Oklahoma, without exception, have been halite or rock salt. These cores include shallow Flowerpot salt in Woods and Woodward Counties, Wellington salt from Grant County, Flowerpot and Cimarron salt from Beaver County, and Yelton salt in Beckham County. In addition, analysis of waters from nine salt springs widely distributed throughout western Oklahoma shows that NaCl is the major salt present in the shallow subsurface (Ward, 1961, table 1, p. 84). At the present writing, potash salts such as sylvite and polyhalite have not been found, although it is recognized that potassium salts and borates as well may be present.

Previous work. The literature dealing with salt in the subsurface of western Oklahoma is sparse. Jordan (1959, 1960, 1961a, 1961b, 1961c, and 1962a) and Ham and Jordan (1961) along with Ward (1961b) have published short papers on salt in the subsurface of the

Anadarko basin. Previous to these papers, Oklahoma Geological Survey Bulletin 40, an investigation of the oil and gas possibilities in Oklahoma by counties, contains short references to salt by a number of authors (Clifton, 1926; Greene, 1926; Gouin, 1927; Six, 1930; et al.). The information presented in Bulletin 40 is to a large extent based on drillers logs compiled from cable-tool samples.

The only surface investigations directly relating to salt were carried on by Ward (1961a) as part of a project concerning salt pollution of rivers in western Oklahoma. Early investigators mentioned salt only briefly (Gould, 1902, 1908, 1910, 1911; Snider, 1913; et al.) because surface exposures are absent. The only salt found on the surface is due to the evaporation of water of brine springs to form "salt plains" or "salt flats" as described by Gould (1901) and by Ward and Leonard (1961).

Preliminary investigations of gypsum and anhydrite are largely the work of Gould (1904, 1908). The first extensive paper on gypsum and anhydrite was by Snider (1913). The modern work on gypsum and anhydrite includes papers by Burwell (1955), Ham (1958a, 1960, and 1962), and Ham and Curtis (1958). All of these reports are from surface investigations of gypsum and anhydrite.

History of production. The first commercial production of salt in Oklahoma was by Indians who collected salt from various salt springs for purposes of barter. As early as 1850, at Salina in the Cherokee Nation, the Cherokees exploited salt springs and even drilled shallow wells to increase the flow of brine (Ham, 1958b).

Before the Civil War, salt was produced by Jesse Chisholm from springs at the Blaine County Salt Plain (Ward, 1961, p. 82) along Salt Creek below the escarpment formed by the Blaine Gypsum. The source of salt at this locality is undoubtedly the Flowerpot salt, although this unit has not been mapped (pl. III, map D) east of central Dewey County because shallow subsurface control is not available.

The earliest records available on salt production in Oklahoma are for the year 1900, when 6,861 barrels of salt, or 960 short tons were produced with a market value of $6,136 (Ham, 1958b).

The Texas Company produced salt for human consumption from oil field brines in northeastern Oklahoma, but legal problems forced discontinuance of the practice.

Present day salt production is obtained from three localities in Oklahoma (McDougal and Grandone, 1961, p. 283, and Ham, 1962, oral communication). At one locality salt is produced from springs on the Big Salt Plain of the Cimarron River near Edith in Woods County (Ward, 1961, p. 82, and fig. 3, p. 84), where the natural salt incrustations are scraped up and sold without other treatment.

A second locality is in Salton Gulch on Elm Fork of the Red River in Harmon County (Ward, 1961, p. 82, 83, and fig. 4, p. 85), where salt recovery is by natural evaporation of spring waters from shallow "pans", with no refining or other treatment before marketing.

The third and largest salt plant is at Sayre in Beckham County, where fresh water is introduced into a subsurface salt stratum and recovered as a saturated brine which is then evaporated using natural gas as fuel.

The salt produced in Oklahoma is used mostly for livestock and for recharging water softeners, but minor amounts are used for herbicides and occasionally for salinity control of oil well drilling fluid.

Occurrence and Reserves of Salt in Western Oklahoma

Rock salt weighs 135 pounds per cubic foot, or 1.88 million short tons per foot-mile. Using the data of plate II and plate III, a total of 22 million short tons of salt is estimated to be present in western Oklahoma (fig. 16). Present production from this limitless potential is only about 10,000 short tons per year. Reserves of the salt-bearing units are discussed below.

Wellington salt. The available information to the author which is directly related to the salt in the Wellington evaporites is tabulated in figure 7. Examples of the electrical log characteristics in the salt-bearing section of the Wellington are given in figures 4, 5, and 6. The estimated salt reserves in the Wellington evaporites are 6.5 million million (6.5×10^{12}) short tons (table 1).

The salt-bearing strata in the Wellington evaporites range in thickness from 260 feet in Beaver County, to 575 feet in Blaine County (fig. 7). Thicker sections are present within the axis of the Anadarko basin, but definite information is not available. The percentage of salt ranges from 36 percent to 55 percent within the salt-bearing strata. The uppermost two-thirds of it contain as much as 80 percent bedded salt, and some of these beds are 50 feet thick. The top of the Wellington salt is 2,475 feet below the surface in southwestern Beaver

County, and is approximately 2,100 feet below the surface across most of Beaver and Harper Counties. As a result of erosion and regional dip north and east of the surface outcrop of the Blaine Gypsum, the Wellington salt lies nearer the surface, so that in Grant County, the top of the Wellington salt is 812 feet beneath the surface (fig. 6). East of Grant County, the Wellington salt is assumed to be present much closer to the surface, as is the case in Kansas where the salt is exploited by underground mining and by solution. To the south, the top of the Wellington salt is 3,010 feet below the surface in Blaine County, 3,440 feet deep in central Washita County, within the axis of the Anadarko basin, and 2,820 feet deep on the south flank of the basin in southwestern Washita County (pl. II, cross section C-C'). The depth to the top of the Wellington salt in the Texas Panhandle is 2,750 feet in southeast-central Ochiltree County, 2,935 feet in eastern Roberts County, 3,640 feet in western Wheeler County, and 3,765 feet in eastern Wheeler County, near the Oklahoma-Texas boundary. The maximum depth to the top of the Wellington salt is 3,810 feet in northeastern Beckham County, Oklahoma.

Production of salt using the solution method is possible throughout the Anadarko basin, except near the southern edge where granite wash or other clastics are commonly present in the Wellington. Construction of solution caverns for liquefied-petroleum gas storage should be the most successful in the western areas because of the increase in purity and massiveness of the anhydrite and dolomite beds which would serve the desirable function of acting as a roof or cap above the washed-out caverns. The successful establishment of a storage cavern in Grant County (Jordan, 1961c) indicates that storage caverns are practical in Alfalfa and Woods Counties to the west.

Cimarron salts. The thickness of Cimarron salts is shown on plate III, map C. The upper figures given on the map indicate the depths (in feet) from the surface to the top of the salt-bearing interval. The lower figures indicate the thickness (in feet) of the salt-bearing strata, not the thickness of the salt beds themselves. The contours shown are drawn using the lower figures and a contour interval of 50 feet, except on the south flank of the Anadarko basin where the contour interval is 100 feet. The contour lines represent lines of equal thickness of salt-bearing strata.

The estimated salt reserves are 12.3 million million (12.3×10^{12}) short tons (table 1) based on data from the thickness map (pl. III, map C) and the cross sections (pl. II). This salt unit contains almost twice the total salt reserves of any other salt unit discussed in this report, although the purity of the Upper Cimarron salt is in many places less than the average for all of the salt-bearing units.

The electrical log characteristics of the Cimarron salts are shown on figures 8 and 9. These illustrations, along with cross sections A-A', A-D, and B-B' shown on plate II, indicate that the Lower Cimarron salt is more nearly pure than the Upper Cimarron salt, and that the lower zone contains more massive salt beds, some as much as 50 feet thick. The best development of the Cimarron salts is found in the northwestern part of the area. In Beaver County, at the Gulf-

Warren Mocane plant (sec. 18, T. 5 N., R. 25 ECM.) the top of the Upper Cimarron salt is 1,422 feet below the surface, and extends downward to a depth of 1,528 feet, at which depth it is in contact with the top of the Cimarron anhydrite. This locality has the best development of the Upper Cimarron salt found in the area mapped. The salt-bearing section is approximately 50 percent salt, whereas the remaining 50 percent is shale and salty shale.

The top of the Lower Cimarron salt in the Mocane well (fig. 8), represented at this locality by a salty shale, is 1,563 feet below the surface. The top of the massive salt beds occurs at a depth of 1,578 feet, and the base of the salt zone is at 1,746 feet. The massive salt-bearing section (168 feet thick) is 75 percent massive salt and 25 percent shale and salty shale. The Lower Cimarron salt consists of almost 90 percent salt in the lowermost 120 feet of the massive salt zone.

For commercial exploitation, development of the Lower Cimarron salt would be more advantageous than development of the Upper Cimarron salt because the extra depth and cost required to reach the Lower Cimarron salt is small compared to the possible recovery of salt per foot drilled.

Where both the Upper and Lower Cimarron salts are present, they are mapped as a single unit (pl. III, map C). Examination of map C along with the cross sections showing the separation of Upper and Lower Cimarron salts (pl. II) will indicate the most advantageous areas for salt production. Considering the factors of depth to salt, and salt development, the most favorable areas are Beaver, Harper, and Ellis Counties, and the western parts of Woods and Woodward Counties.

Flowerpot salt. The thickness and known lateral extent of the Flowerpot salt are shown on map D, plate III. The upper figure represents the depth from the surface to the top of the Flowerpot salt, the lower figure represents the thickness of the salt-bearing strata. The contour interval is 50 feet, with the contour lines representing equal thickness of salt-bearing strata.

Flowerpot salt reserves are estimated from the thickness map (pl. III, map D) and the cross sections (pl. II). The reserves are 2.75 million million (2.75 X 10^{12}) short tons (table 1).

The electrical log characteristics of the Flowerpot salt are shown on figures 10, 11, and 12. The regional stratigraphic relationships are presented on plate II, cross sections A-D, A-A', and B-B'. Throughout most of the area underlain by Flowerpot salt, the upper part of the salt-bearing strata contains massive salt beds, whereas the lower part is salty shale and thin beds of salt.

Northwest-central Beaver County contains more than 500 feet of Flowerpot salt within 400 to 600 feet of the surface. No cores are available from wells in this area, but comparison of the logs in this area with logs (fig. 11) of the Texaco, Inc. et al., 1 Lehman, liquefied-petroleum gas storage well in sec. 30, T. 1 N., R. 20 ECM., indicate that northwest-central Beaver County is a favorable area for commercial development of salt. In Beaver County, extreme caution must be exercised because the Flowerpot salt is absent in some places (pl. III, map D). Within less than one mile east of the Mocane well (sec. 18, T. 5 N., R. 25 ECM.) the Flowerpot salt is absent. In the Lehman well, the salt is 866 feet below the surface, and extends downward to a depth of 1,098 feet. The section from 895 feet to 1,030 feet is almost pure massive salt.

The Flowerpot salt reaches 400 feet in thickness in the southwestern part of Harper County, and although the purity (fig. 10) is less than that found in Beaver County, the depth to salt (450 feet average), the stratigraphic position (below capping Blaine anhydrite), and the geographic locale (Laverne Gas District) make Harper County desirable for liquefied-petroleum gas storage in salt.

Around the Big Salt Plain of the Cimarron River in T. 27 N., R. 19 W., cores of pure salt have been recovered within 30 feet of the surface (Ward, 1961b, p. 275). This locality is near the present eastward limit of Flowerpot salt (pl. III, map D), and is considered by Ward (1961b, p. 277) to be near the actual depositional margin. In general, the thickness of the salt-bearing section is less than 200 feet, but approximately 10 miles to the southwest the thickness reaches 350 feet. Although the purity of the salt around the Big Salt Plain is not high throughout the salt-bearing section, enough pure salt layers are present at extremely shallow depths to make this area a favorable prospect for salt production on a scale much larger than that presently in operation.

In the southern half of the mapped area the average depth to the Flowerpot salt is 1,000 feet, and the thickness is in most places less than 300 feet. Two notable exceptions are present. In northern Gray and west-central Wheeler Counties, Texas, in the axis of the Anadarko basin, the thickness of the Flowerpot salt reaches 500 feet, with the top of the salt zone about 1,200 feet below the surface. No information is available as to the purity or character of the salt in this area. The second exception (discussed in the section on stratigraphy) is the Gulf 1 Burgtorf well in sec. 6, T. 13 N., R. 15 W., Custer County. The log on this well (fig. 12) shows a section, 625 feet thick, which is interpreted as bearing salt, located immediately below the Blaine anhydrite. The upper part of this section from 945 feet (immediately below the Blaine anhydrite) to 1,130 feet, appears to be massive relatively pure salt; the remaining 440 feet lower in the section is broken by numerous beds of shale and salty shale from 5 to 40 feet thick. The nearest control well approximately 10 miles northwest, in T. 15 N., R. 16 W., contains only 95 feet of Flowerpot salt.

<u>Yelton salt</u>. The thickness, depth to salt, and presently known limit of the Yelton salt are shown on plate III, map E. The estimated Yelton salt reserves are 11.3 trillion (11.3 X 10^9) short tons (table 1).

The Yelton salt at the type locality is almost pure, with only minor beds of shale. Based on estimates from the interpretation of the logs presented in figure 13, the Yelton section is 95 percent salt and 5 percent shale. Unfortunately the complete Yelton section was not cored in the Shell Oil Co., E. B. Yelton liquefied-petroleum gas well.

The thickest development of the Yelton salt occurs in two separate areas. In southeast-central Wheeler County, Texas, the maximum thickness is 275 feet. The top of the salt-bearing section is 500 feet below the surface. Information is meager, but it is the author's opinion that the salt-bearing section at this locality contains a high percentage of shale. In Oklahoma, the thickest development of Yelton salt is in the east-trending synclinal area located south and southwest of the Elk City Field anticline. Here 287 feet of salt-bearing strata are present, probably similar in character to the section at the type locality in the nearby Elk City Field. The top of this salt-bearing section is 1,020 feet below the surface.

At the present time, the Yelton salt is not considered as a favorable prospect for commercial salt production because other salt units are present in the Anadarko basin which in many places lie nearer the surface, have a greater thickness of salt-bearing strata, or are more favorably located geographically. The Yelton salt does offer an attractive prospect for storage caverns. Even though a good capping stratum is missing, the depth of overburden and the character of the overlying shales seem adequate for this purpose. It must be noted that the storage at the Yelton location is in a salt bed below the upper anhydrite stratum of the Blaine anhydrite, although a much thicker salt bed is present above the Blaine anhydrite.

TABLE 1

PRINCIPAL SALT RESERVES IN PERMIAN STRATA OF WESTERN OKLAHOMA

UNIT	EXTENT OF SALT STRATA in square miles	*AVERAGE THICKNESS OF SALT STRATA in feet	DEPTH RANGE in feet	SALT RESERVES million million short tons	FAVORABLE AREAS
Yelton salt	400	150	550 to 1,275	0.0113	eastern Beckham County
Flowerpot salt	7,344	200	38 to 1,700	2.75	Beaver and Harper Counties
Cimarron salts	13,104	500	310 to 2,150	12.3	western parts of Major, Beckham and Roger Mills Counties
Wellington salts	15,500	225	800 to 3,900	6.5	Beaver and Grant Counties
			Aggregate total	21.56	

(21,560,000,000,000 short tons)[56]

*Approximate aggregate thickness of salt beds estimated from logs showing total thickness of salt-bearing strata.

POTENTIAL USES

Summary of production and uses in the United States. Salt sold or used in 1960 by producers in the United States totaled 25,479 thousand short tons, with a value of $161,140,000. The major use of salt (9 million tons) is in the production of chlorine and caustic soda, which, together with 6.5 million tons for soda ash production, constitutes 67 percent of the annual production in the United States. The third largest use of salt is for snow and ice removal from highways.

In addition to these major uses, salt is vital for many chemical and industrial processes and is present in a wide variety of common consumer goods. The various uses of salt are listed in the Minerals Yearbook, 1960 (table 7, p. 938).

Salt reserves in western Oklahoma total more than 22 million million short tons (table 1), indicating a major source of salt for future exploitation. Establishment of chemical and industrial facilities dependent on sources of abundant cheap salt is a bright prospect for the future of western Oklahoma.

Producing methods. Underground mining for salt in the Anadarko basin would be expensive because of the depths involved. Commercial salt production can be obtained at many localities within the Anadarko basin, using solution techniques in drilled holes similar to the sulphur production along the Gulf Coast of Texas and Louisiana.

Chemical and industrial use. Chemical and industrial uses of salt, although varied and numerous, could possibly use only a small fraction of the reserves present in western Oklahoma. However, the economic impact from chemical and industrial exploitation of the salt resources would be of much greater magnitude than all of the other uses combined. It is beyond the scope of this report to include methods and processes of the various phases of industry which require salt. A general summary of the industrial uses is presented by Phalen (1949). Other less commonly considered uses of possible importance to Oklahoma are briefly discussed below.

Liquefied-petroleum gas storage. Jordan (1959) discussed the formation of underground storage caverns using the solution method. Such cavities are for the purpose of storing hydrocarbons (liquefied-petroleum gas and natural gas). Jordan (1962b, p. 129) tabulated the present status of storage in salt and other types of rock in Oklahoma. The advantage of artificial solution caverns over natural structures is the possibility of placing them in favorable locations. This is particularly true for the Anadarko basin, because salt has been shown to be present in the subsurface over much of western Oklahoma and the panhandle of Texas. A cooperative effort between parties interested in commercial salt production and those interested in hydrocarbon storage should make this technique even more attractive.

Waste disposal. Testing has been and is being conducted by the United States Atomic Energy Commission to determine whether radioactive waste products can be safely stored in salt mines. If salt proves to be a satisfactory container, artificial solution caverns similar to the liquefied-petroleum gas storage caverns might prove to be cheaper and more practical than salt mines. Solution caverns can be constructed wherever the subsurface sections contain an appreciable thickness of salt. Large volumes of radioactive waste material might create a problem in terms of the buildup of heat if placed in a mine, whereas solution cavity storage can be of any desired size, and, if necessary, widely spaced. The hazards of flooding or roof collapse in mines would not be present, because caverns could be located below sources of ground-water employed for irrigation, industrial or domestic purposes, and adequate pressure could easily be maintained to prevent collapse.

Petroleum exploration. Knowledge and understanding of the subsurface salt conditions would be of value to the mud engineer in planning a mud program for drilling wells, because the desired mud characteristics are radically altered by solution of the salt in contact with the drilling fluid.

Casing programs could perhaps be more effective if the presence of salt were known and considered. Salt strata might be sealed off to prevent contamination. Because the characteristic of salt as shown on some types of logs is not much different from that of anhydrite, where salt is suspected, the proper log types (caliper and sonic) could be run before cementing the casing in order to eliminate the possible error of using a salt layer as a casing seat.

Lishman (1961) discussed the problem of salt bed identification from unfocused resistivity logs, and considered separation possible, although the thin-bedded strata (beds less than 80 feet thick) present special cases involving tedious calculations. Lishman suggested (p. 337) the use of analogue circuits to facilitate calculations necessary in the case of thin-bedded variable strata.

Seismic problems. Widess (1952) and Moore (1951) have discussed the problems caused by the occurrence salt in the exploration of the Anadarko basin for petroleum by seismic methods. Basically, salt has a much higher seismic velocity (faster wave propagation, or lower transit time) than does shale. It can be seen from the cross section illustrations of this report (pl. II), that, generally, the salt units occur in the stratigraphic positions which are occupied by shale elsewhere. If the presence of thick subsurface salt deposits is not taken into consideration, anomalous phantom structures may be mapped. The seismic velocity problem is further complicated by the fact that solution or nondeposition has produced an erratic pattern in terms of salt thickness, making interpretation of seismic reflections extremely difficult and risky without adequate knowledge of the salt. A partial solution to the seismic velocity problem has been to establish transit-time control using specially cored holes or drilling oil wells as shot points to find the "up hole" travel time. If the holes used for transit-time control were cored with oil-base mud or saturated brine and various logs were run, the information as to what was giving the travel times recorded, would be available in terms of rock type, thickness, and depth. Comparison of the logs run in these holes with the logs of other wells drilled in the area would indicate, at the very least, where the subsurface section had changed sufficiently to require another carefully controlled test hole to re-establish an accurate transit time for the interpretation of seismic records.

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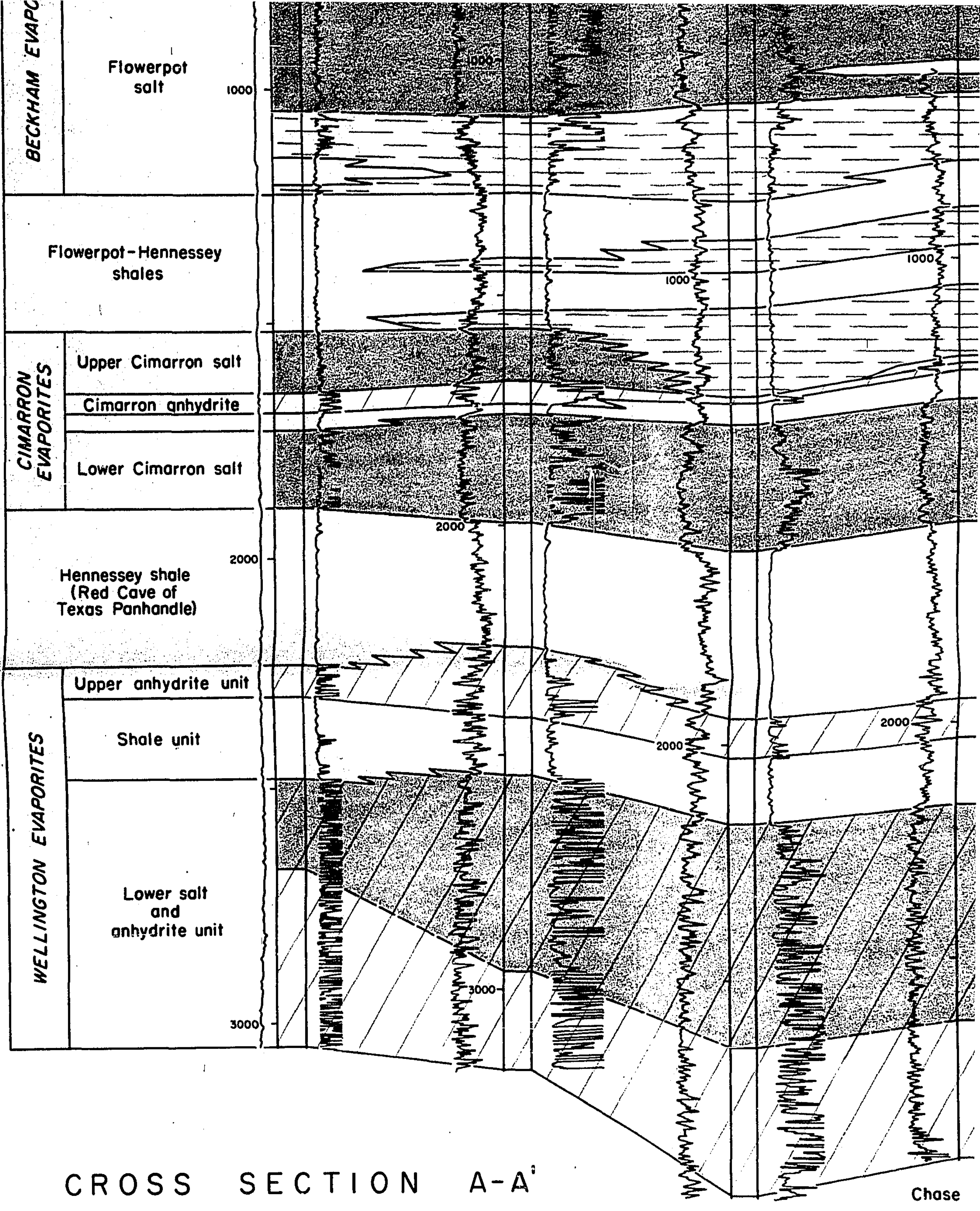

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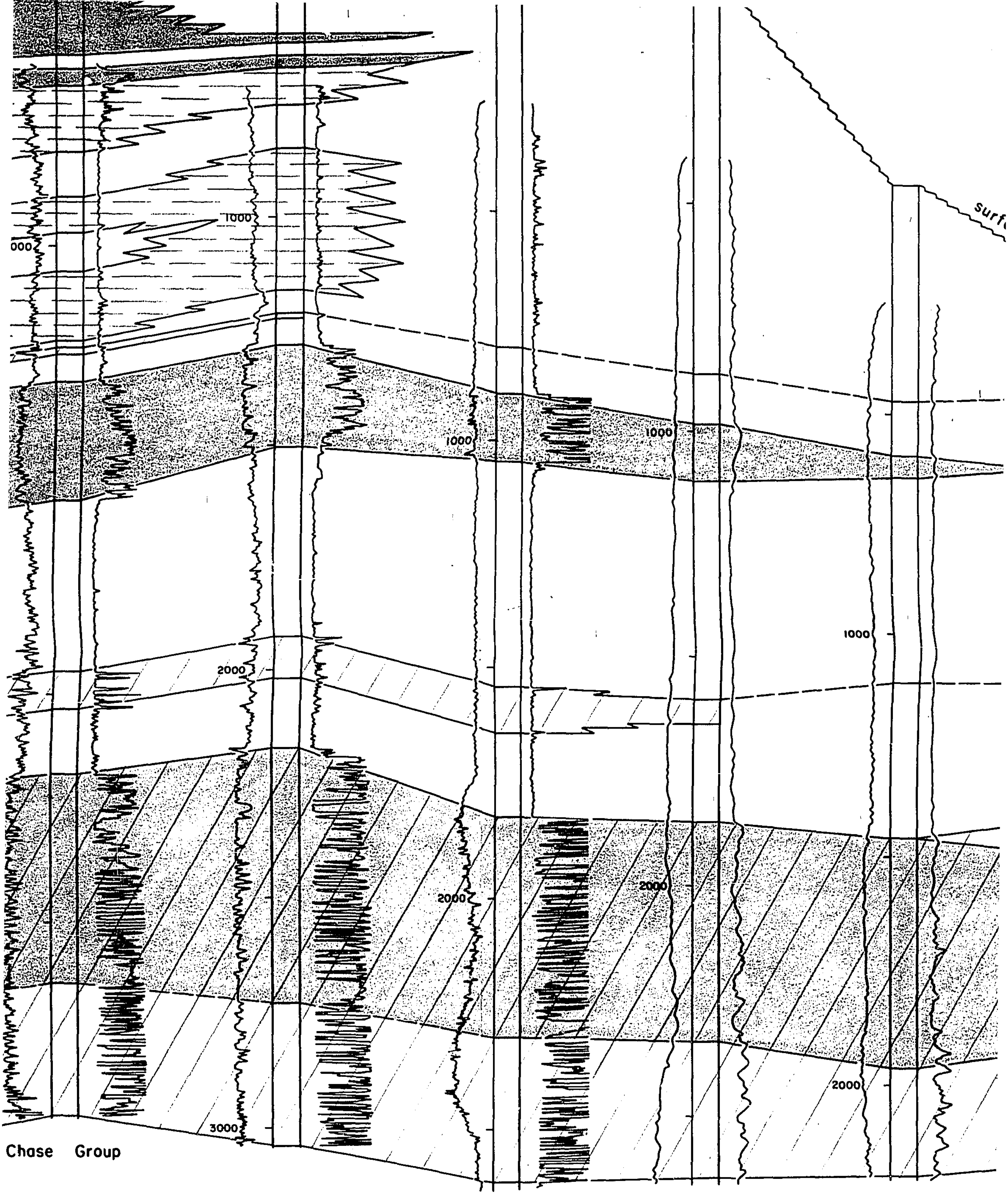

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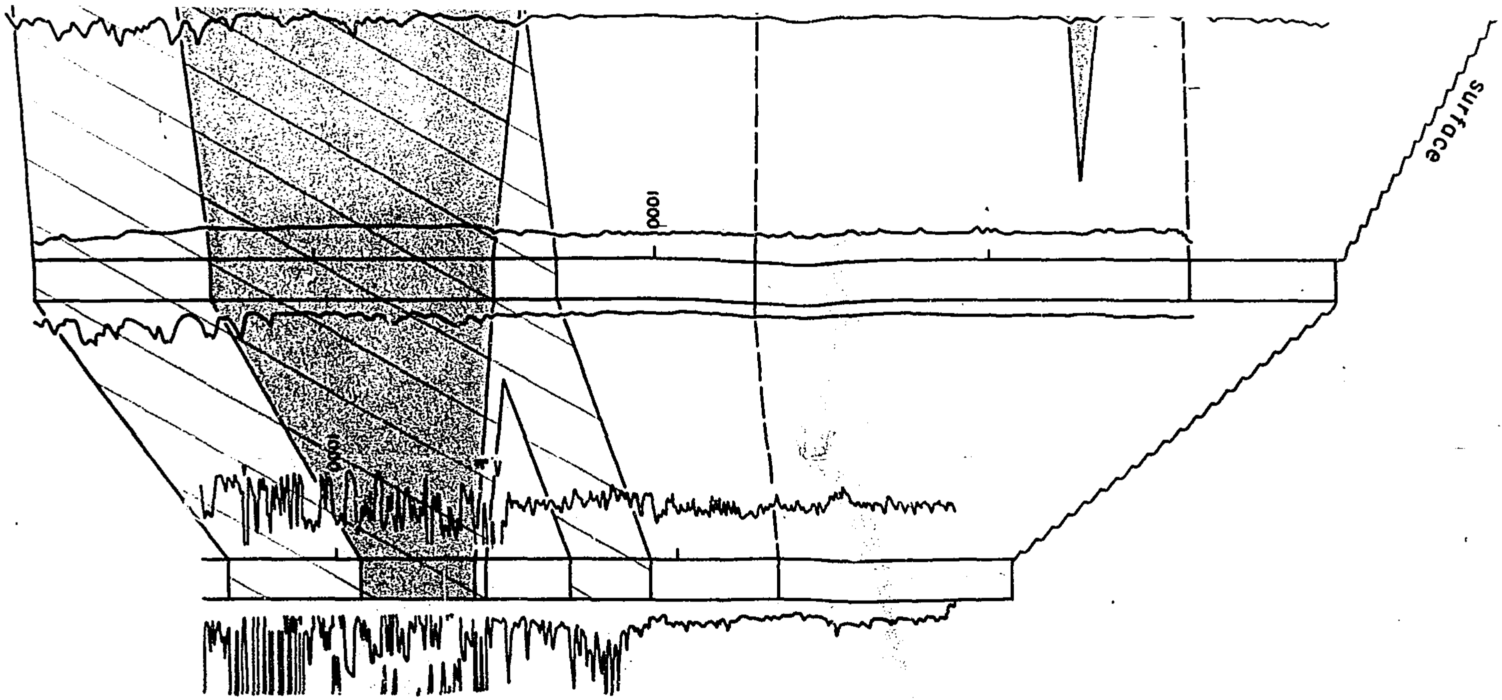

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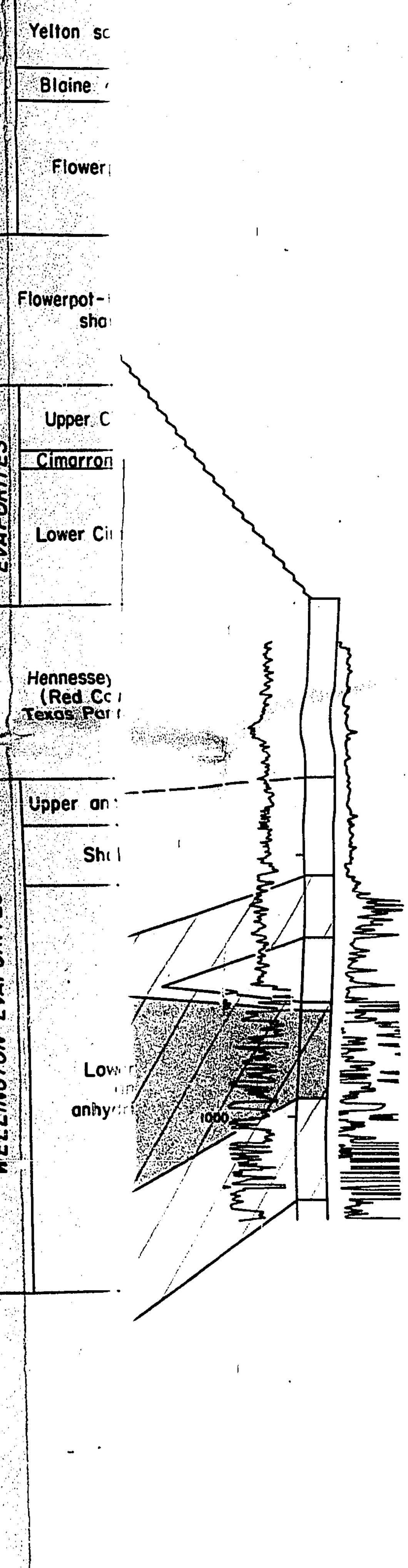
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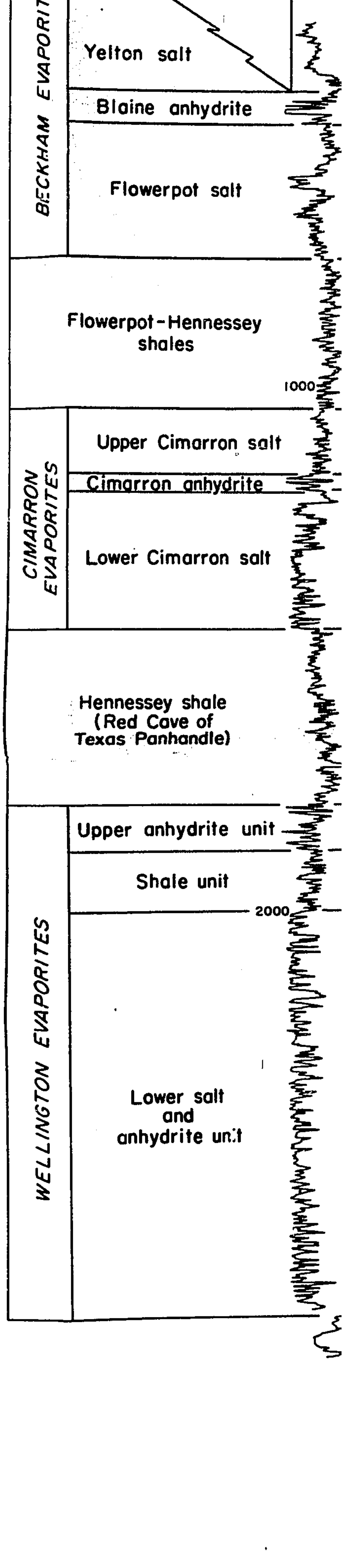
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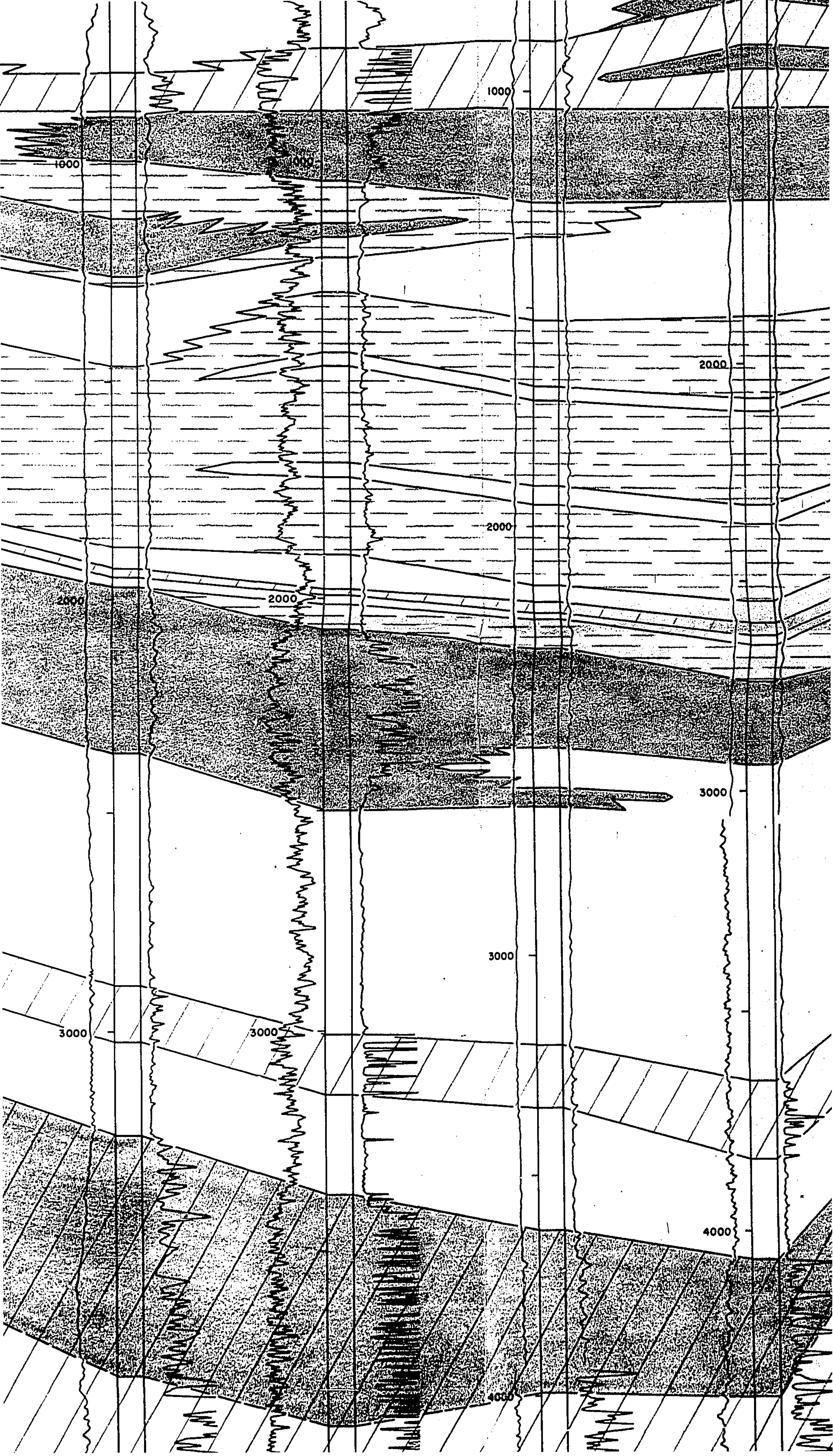
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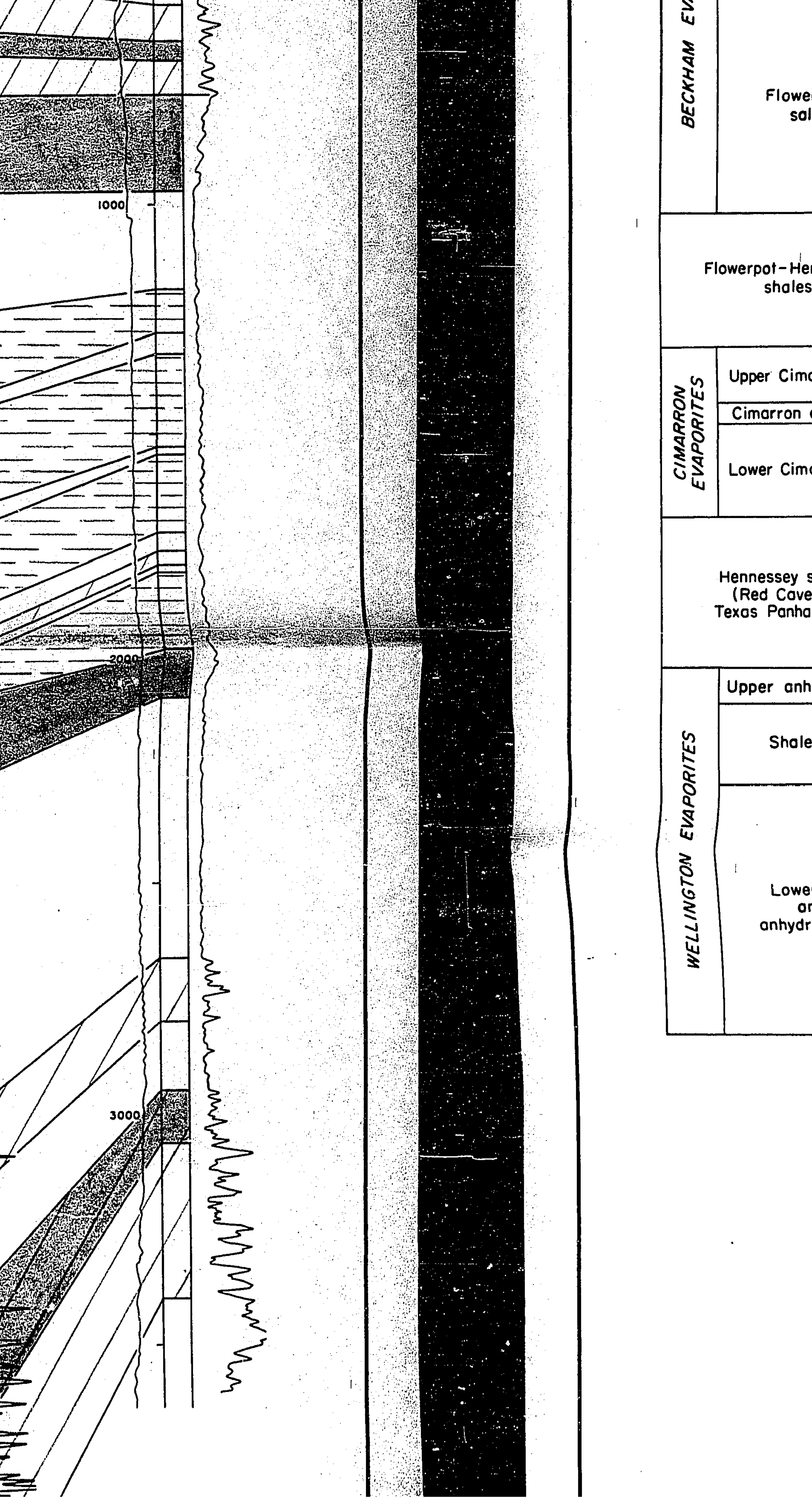
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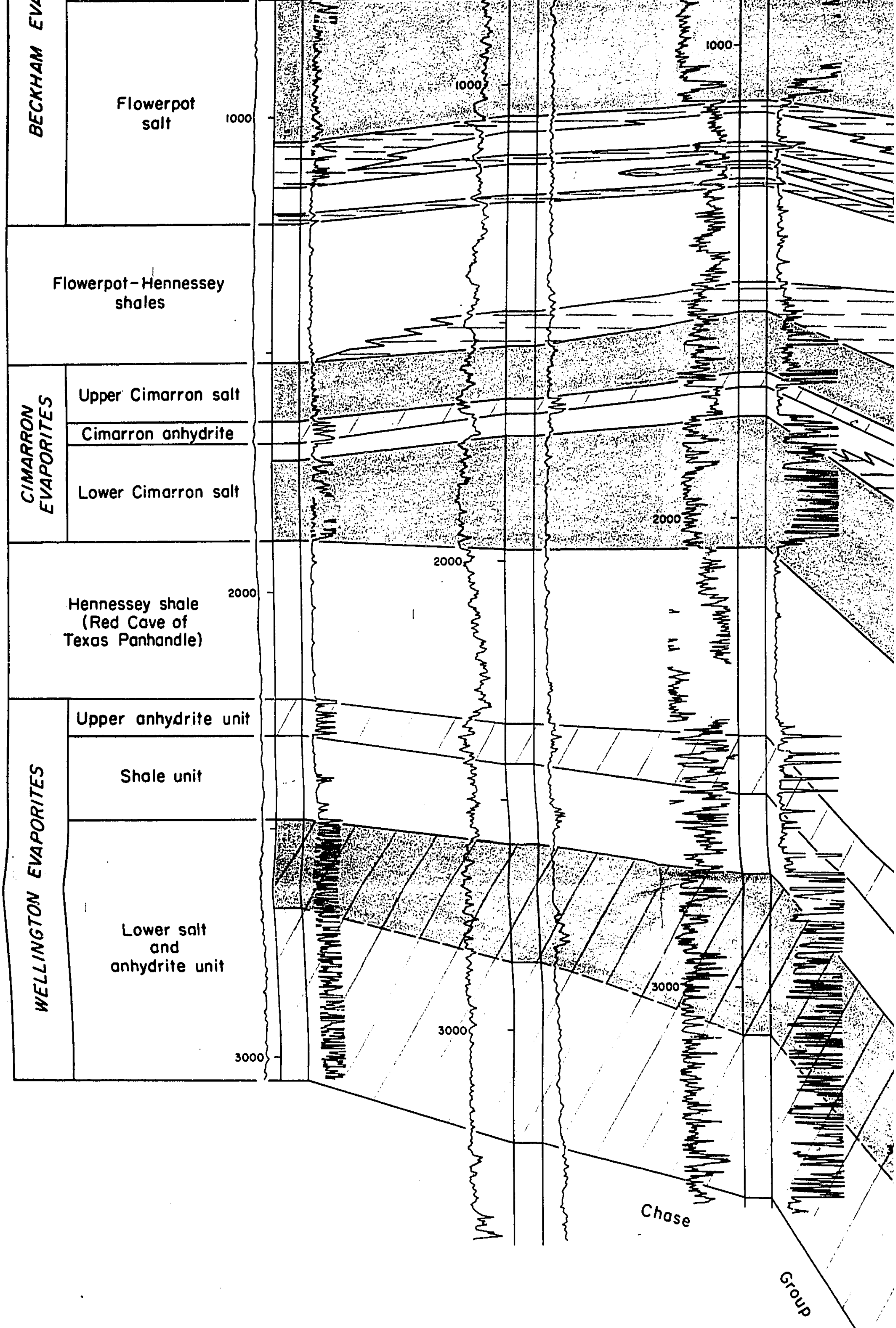

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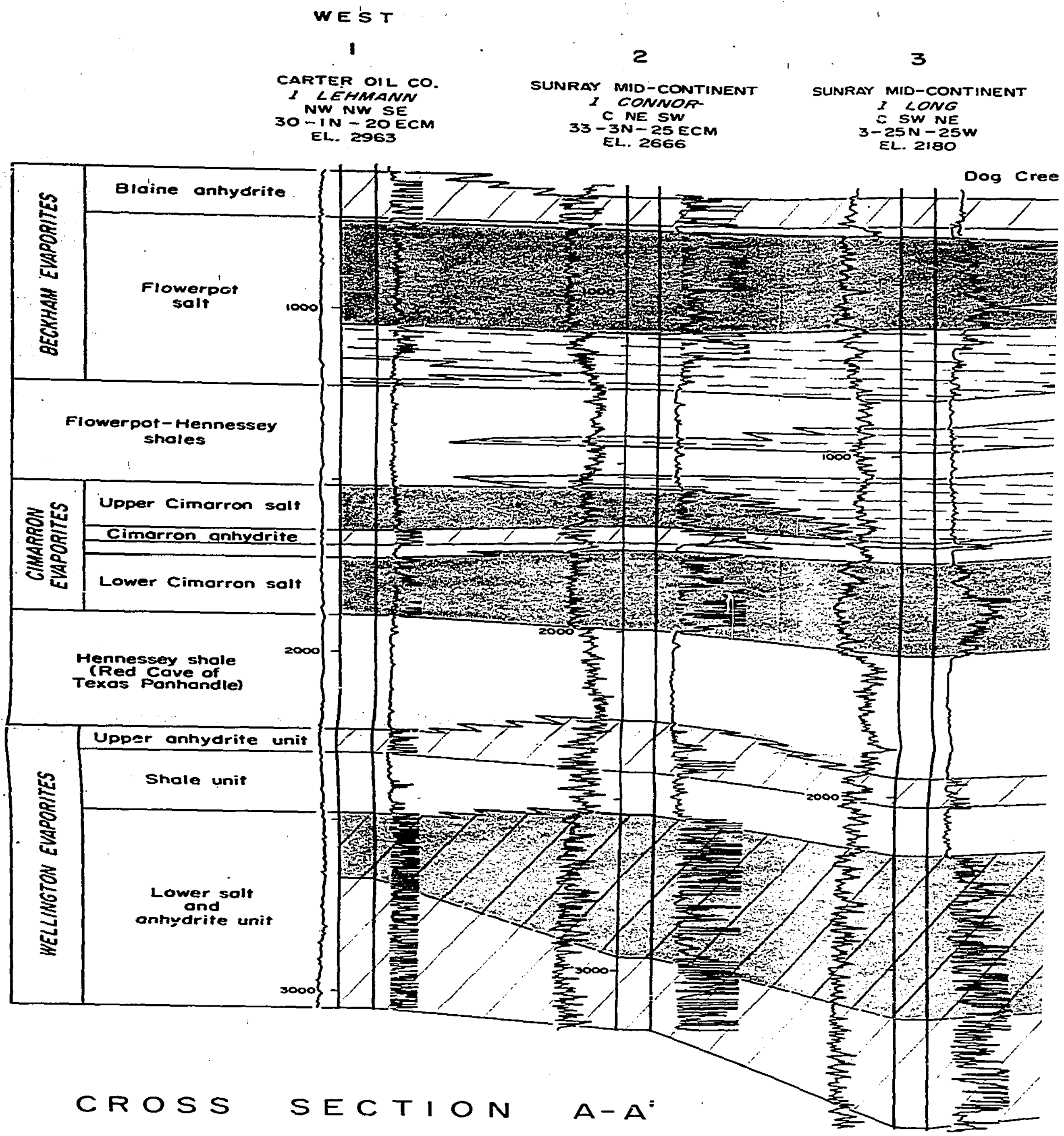

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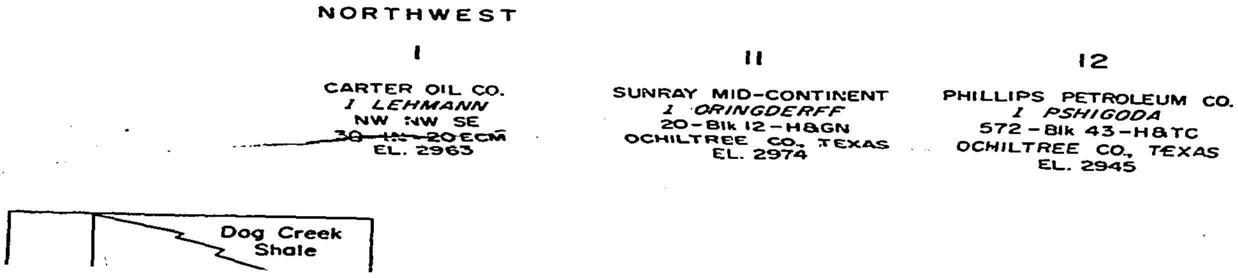

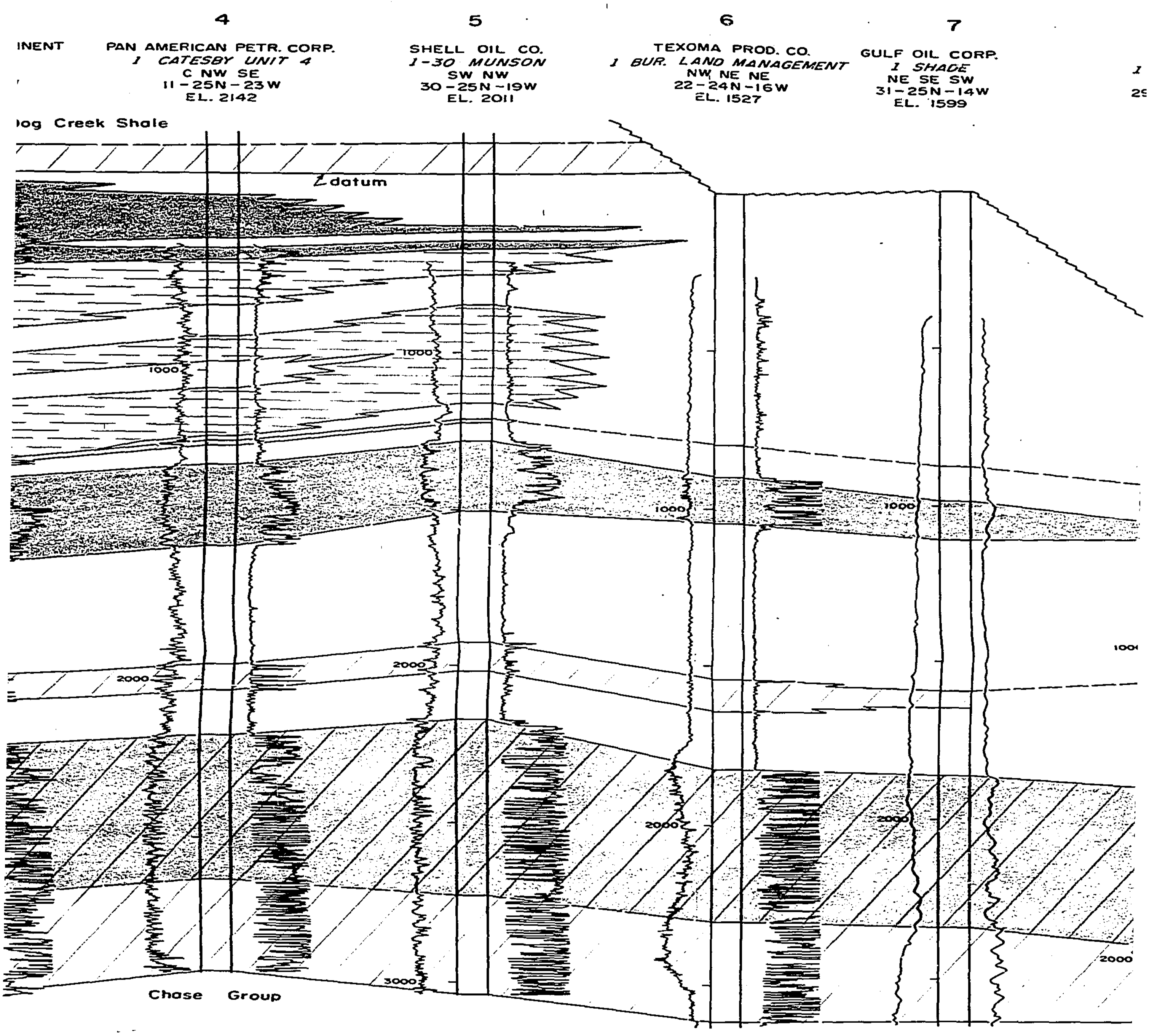
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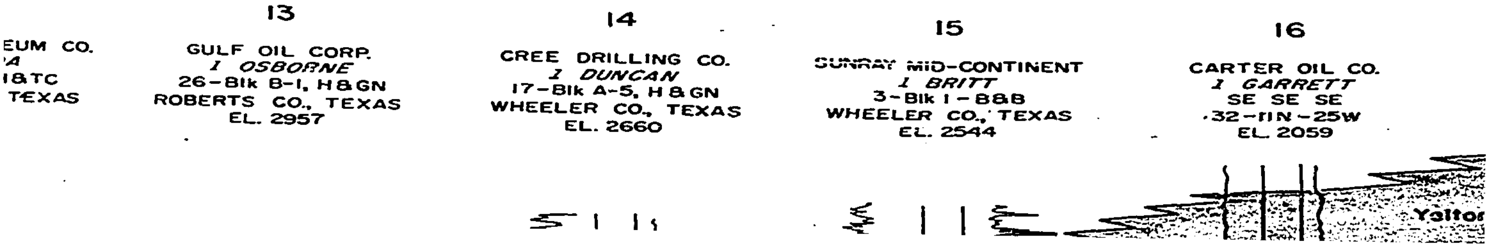
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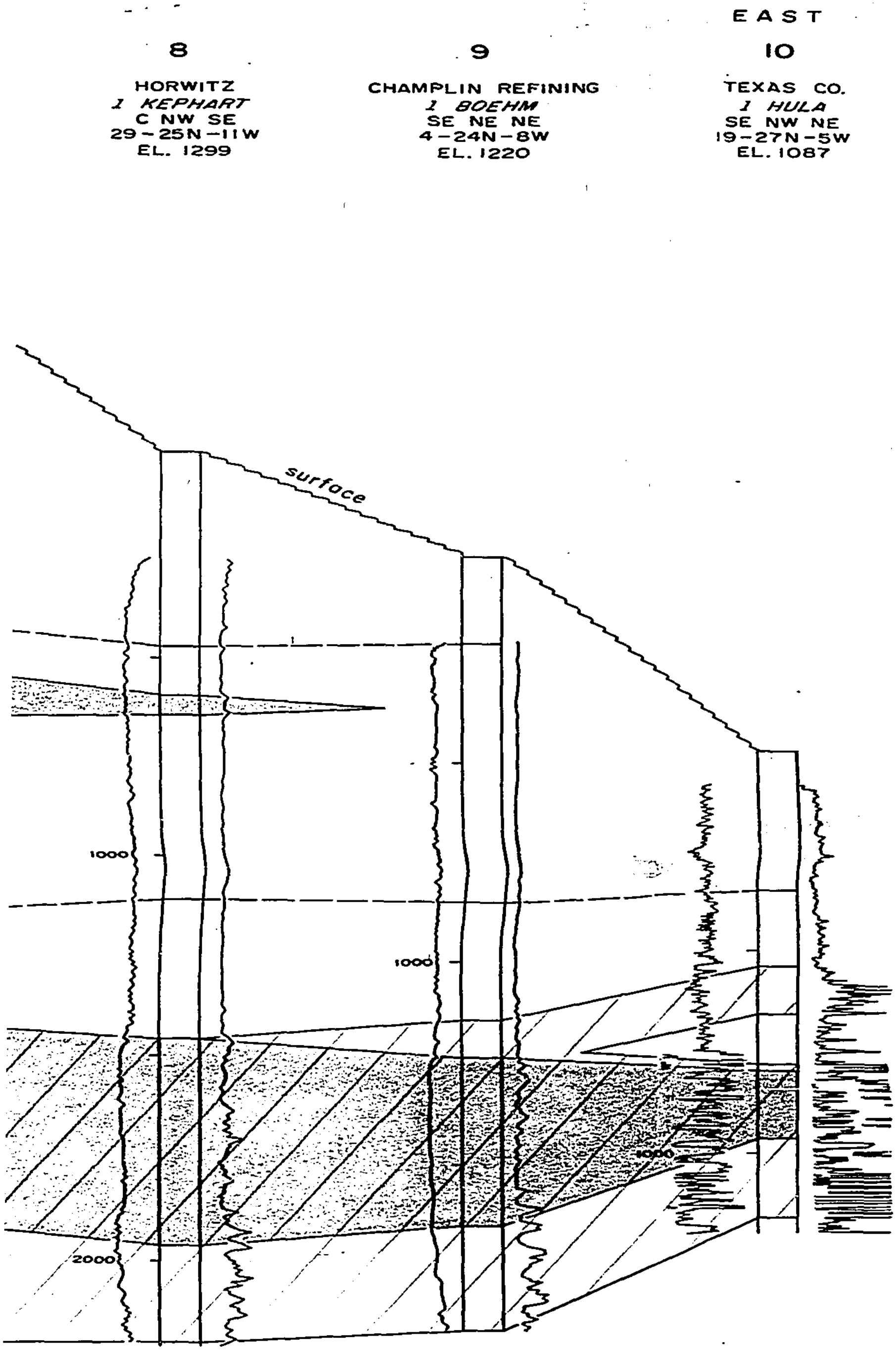
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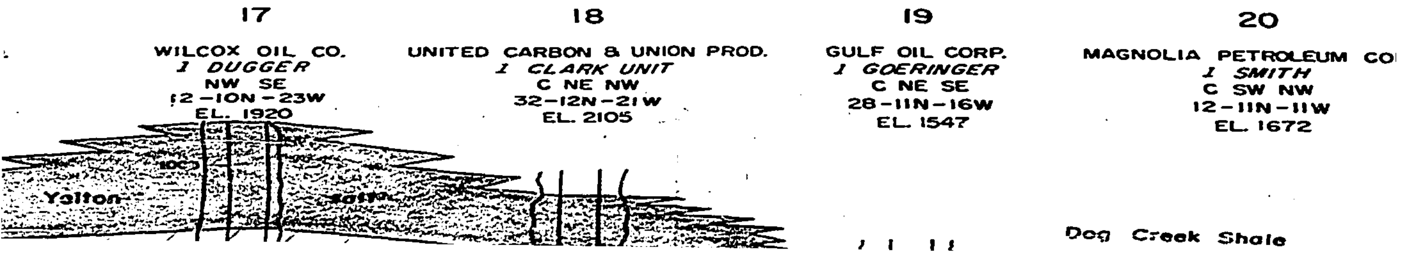
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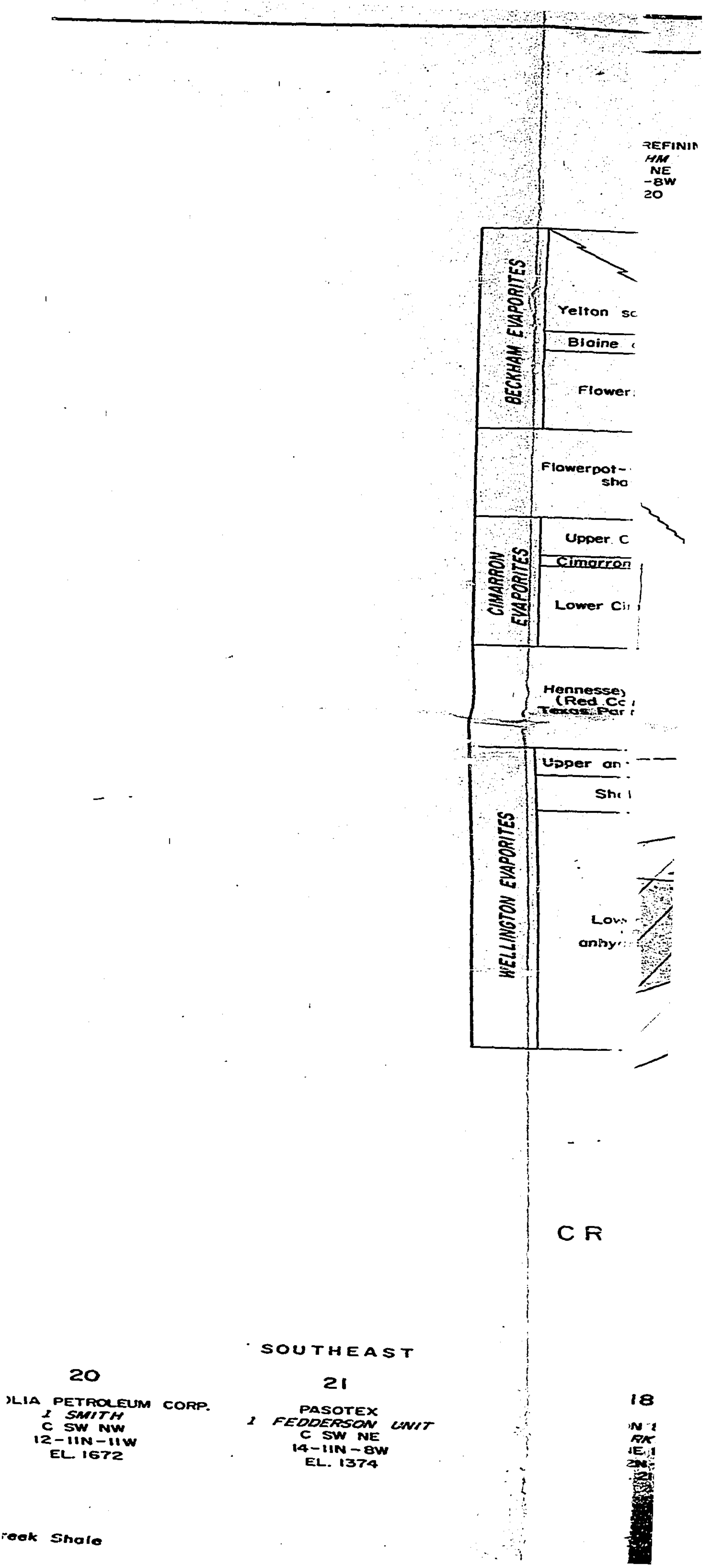
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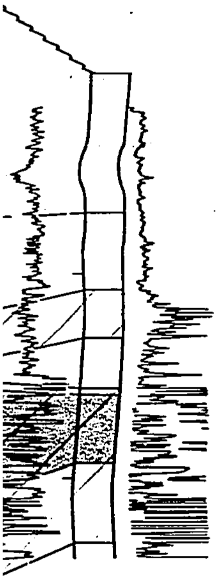
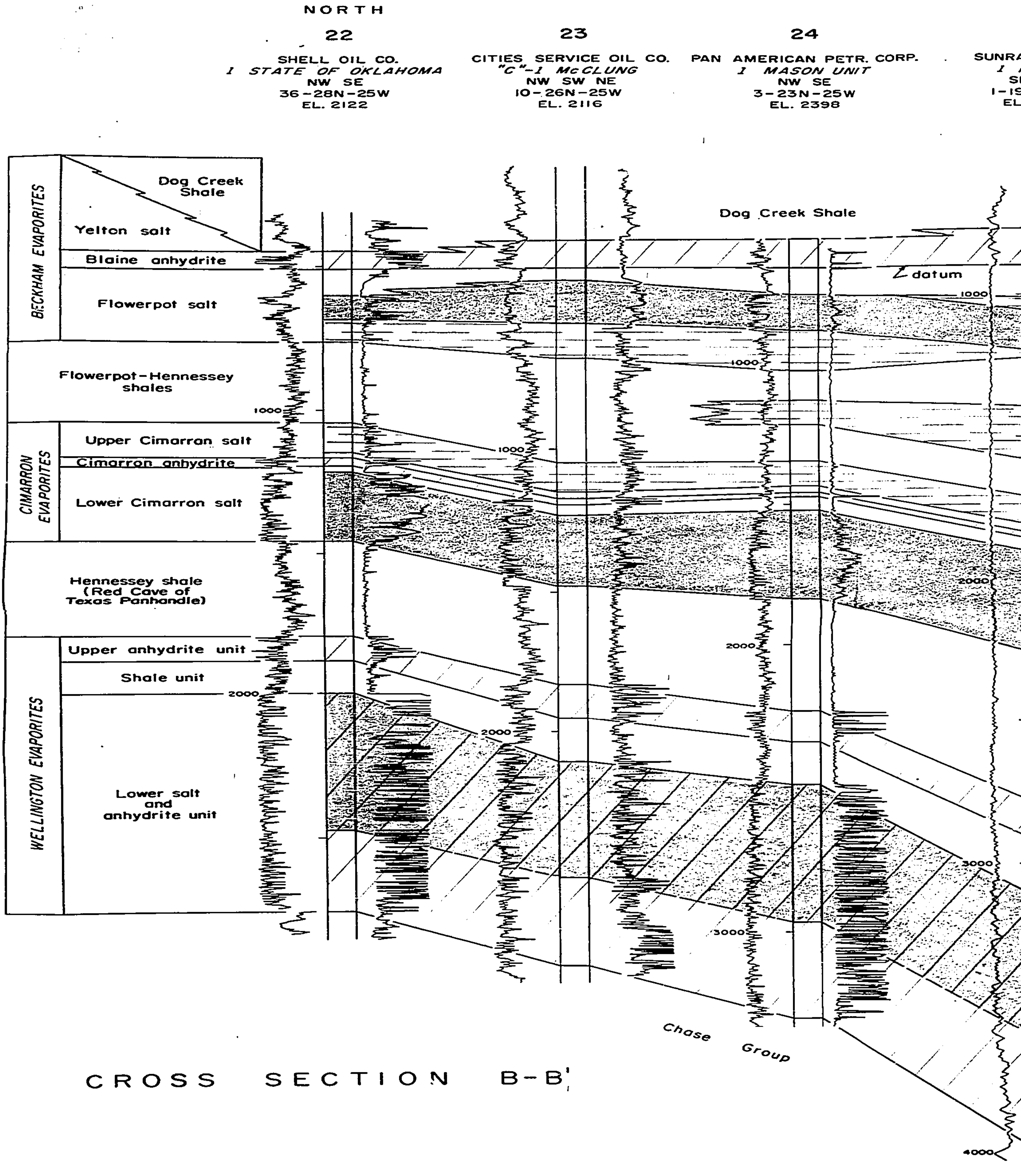


SOUTHEAST

	19	20	21
PROD.	GULF OIL CORP. *1 GOERINGER* C NE SE 28-11N-16W EL. 1547	MAGNOLIA PETROLEUM CORP. *1 SMITH* C SW NW 12-11N-11W EL. 1672	PASOTEX *1 FEDDERSON UNIT* C SW NE 14-11N-8W EL. 1374

Dog Creek Shale

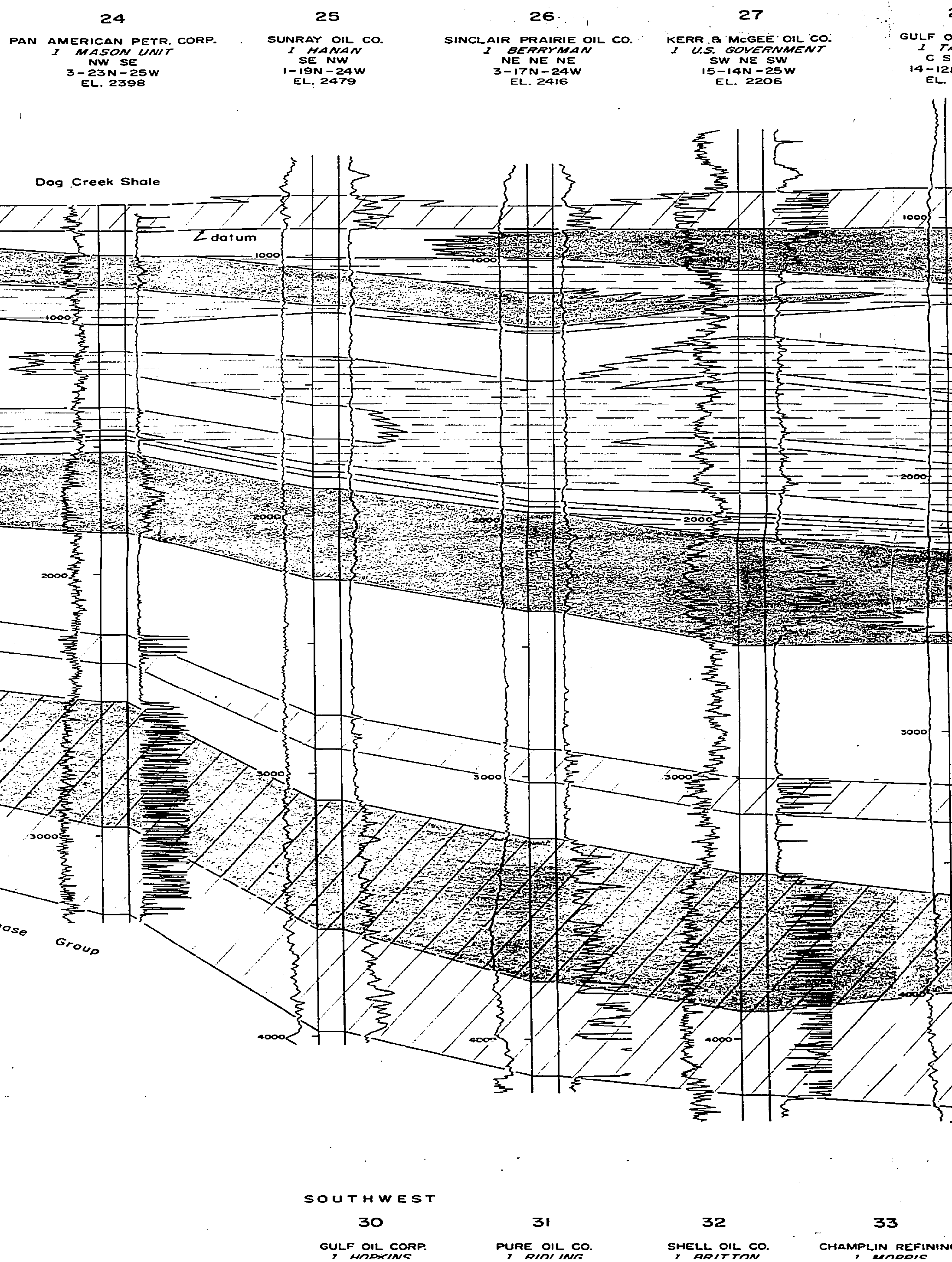


CROSS SECTION B-B'

ST

UNIT

EXPLANATION


24
PAN AMERICAN PETR. CORP.
1 MASON UNIT
NW SE
3-23N-25W
EL. 2398
25
SUNRAY OIL CO.
1 HANAN
SE NW
1-19N-24W
EL. 2479
26
SINCLAIR PRAIRIE OIL CO.
1 BERRYMAN
NE NE NE
3-17N-24W
EL. 2416
27
KERR & McGEE OIL CO.
1 U.S. GOVERNMENT
SW NE SW
15-14N-25W
EL. 2206
GULF O
1 TA
C S
14-12
EL.
Dog Creek Shale
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1000
1000
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2000
2000
2000
2000
2000
2000
3000
3000
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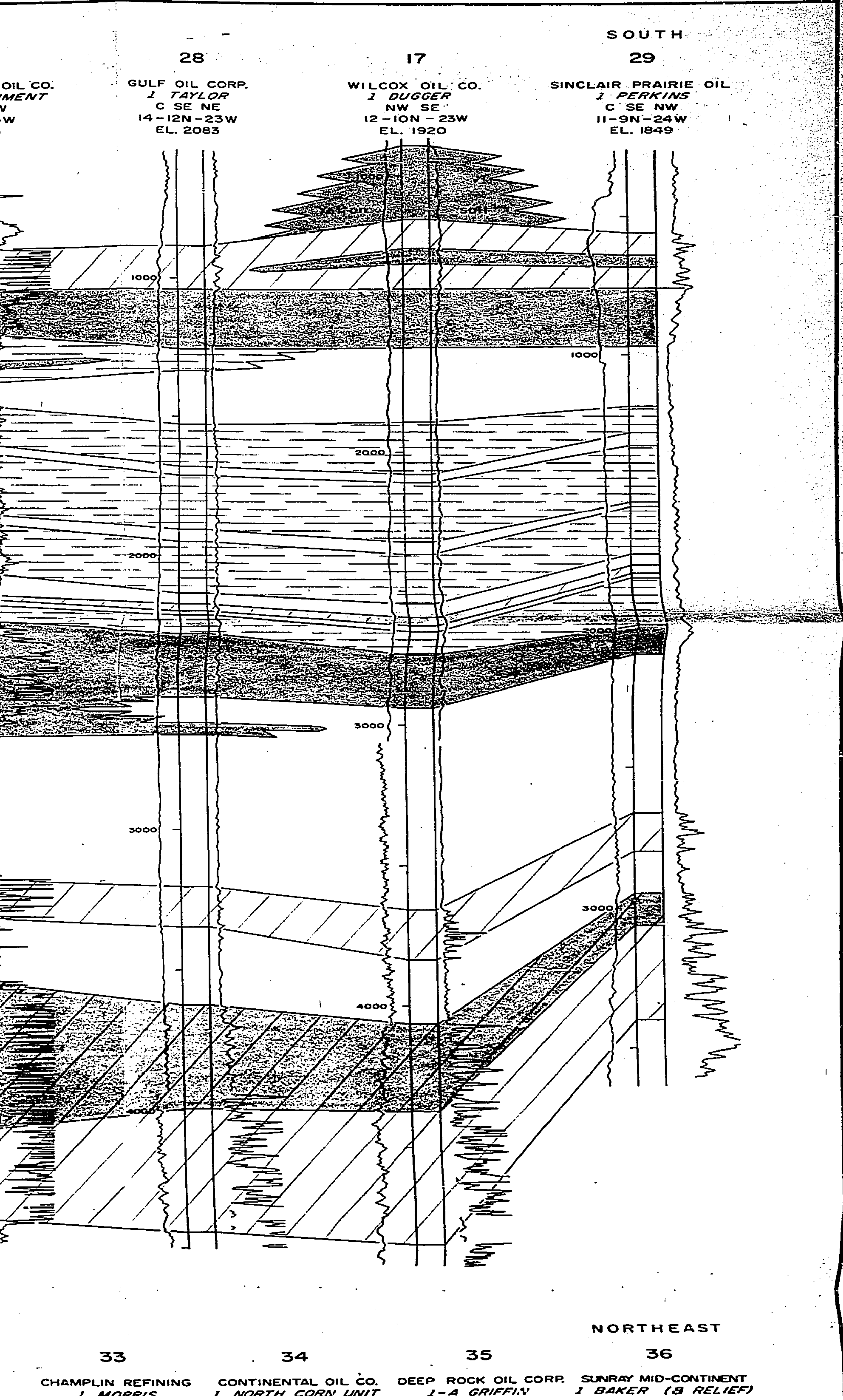
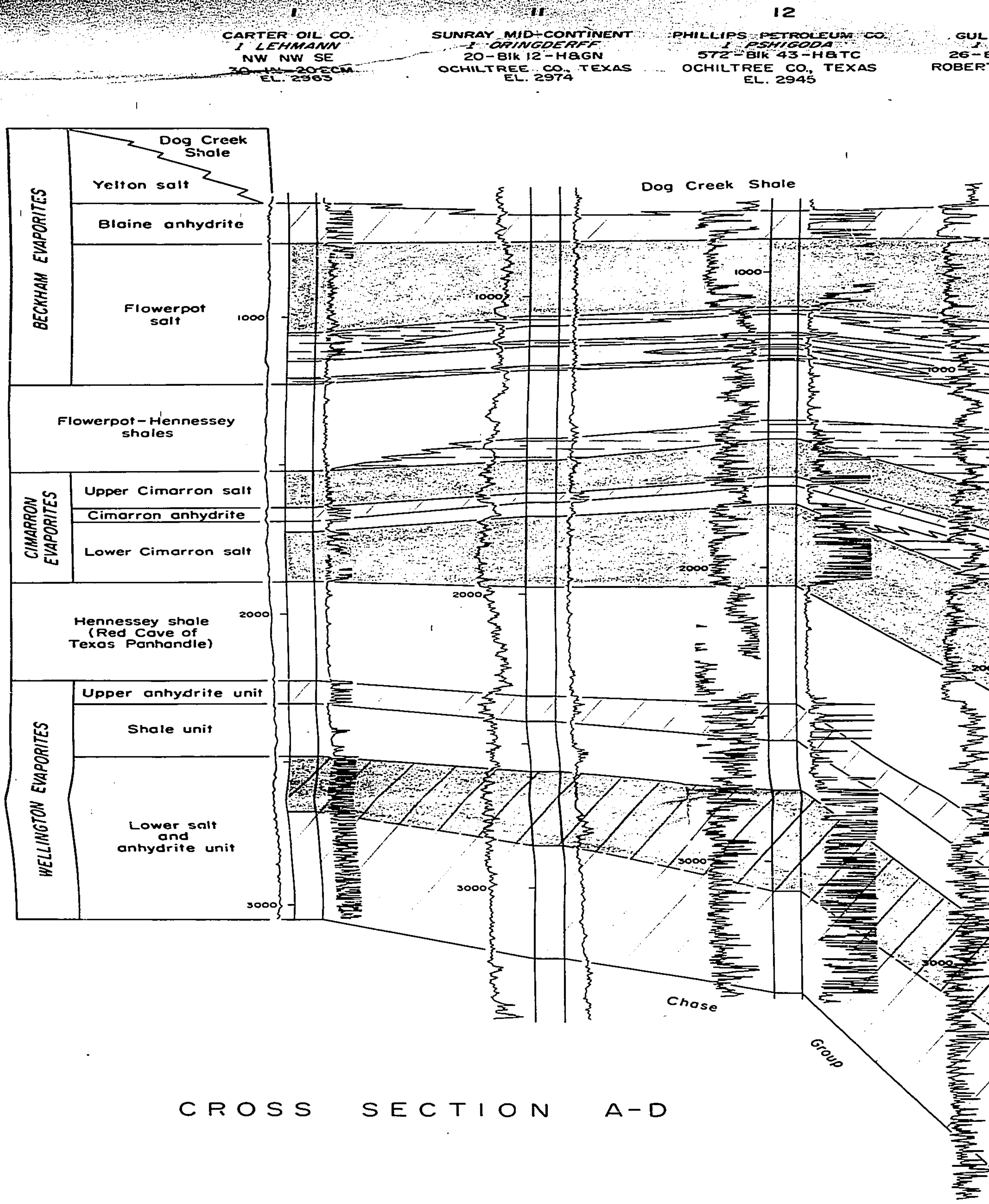
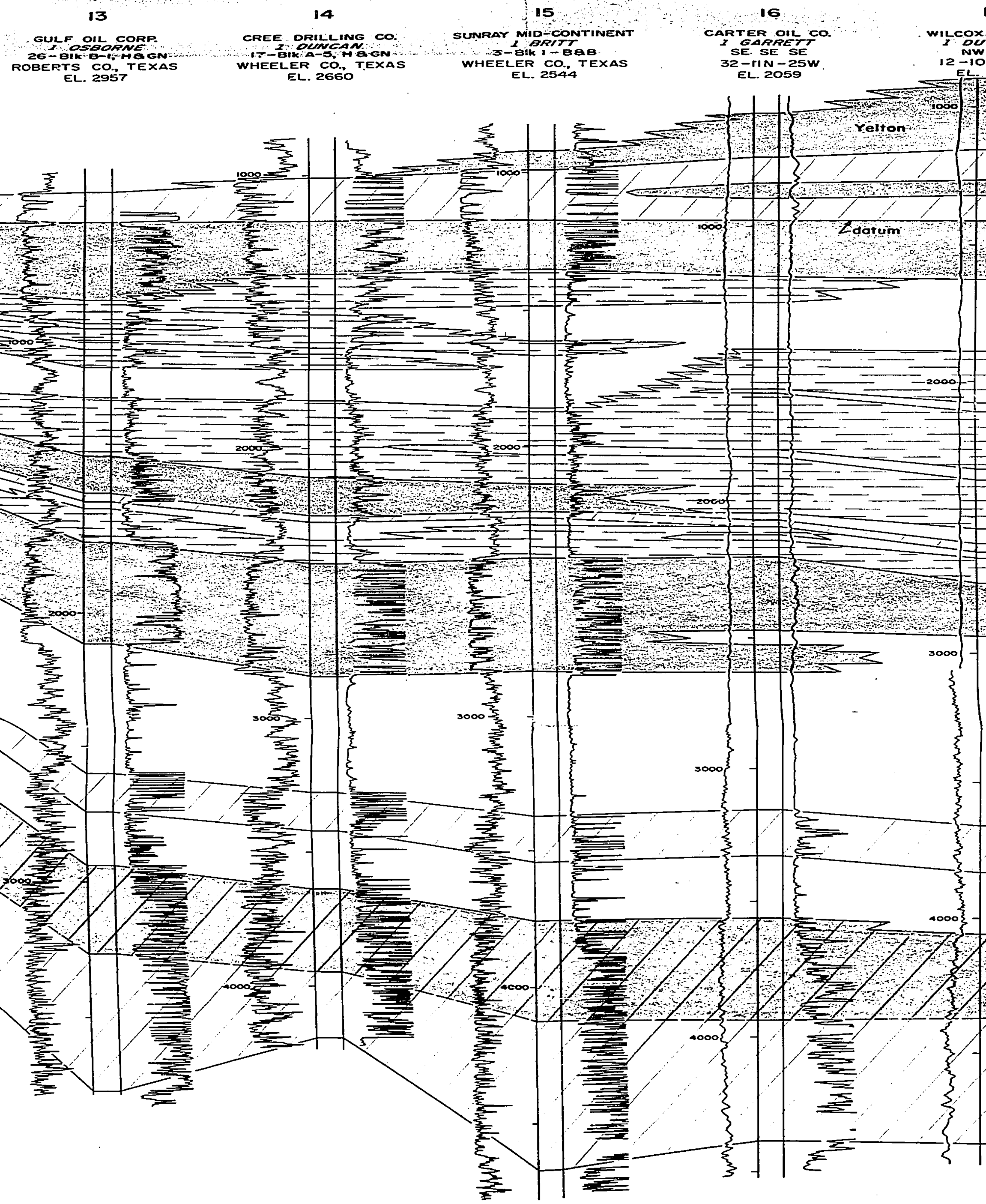
3000
3000
4000
4000
4000
4000
ase Group
SOUTHWEST
30
GULF OIL CORP.
1 HOPKINS
31
PURE OIL CO.
1 RIDLING
32
SHELL OIL CO.
1 BRITTON
33
CHAMPLIN REFININ
1 MORRIS

Plate II

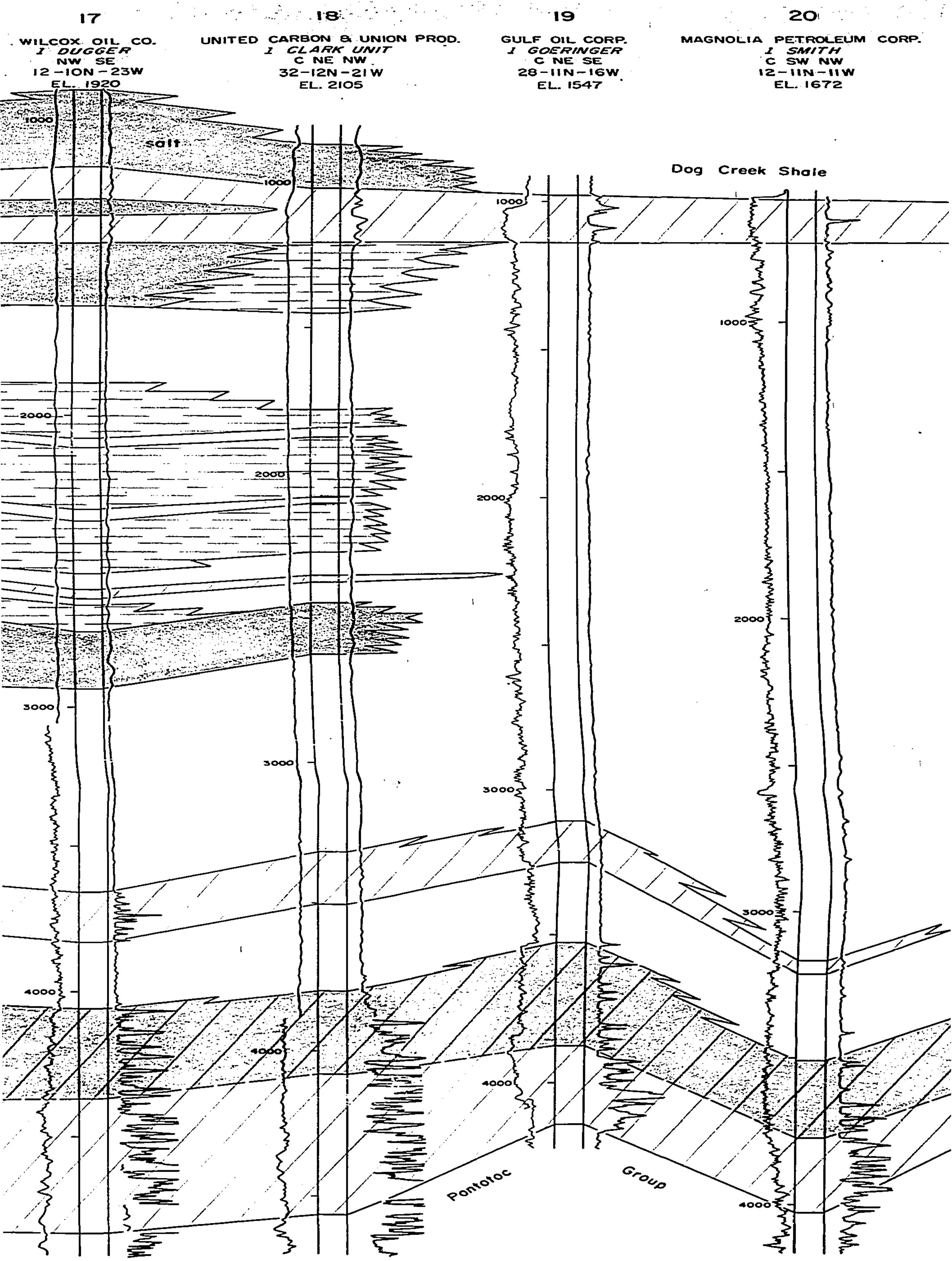

SOUTH
OIL CO.
MENT
W
W
28
GULF OIL CORP.
1 TAYLOR
C SE NE
14-12N-23W
EL. 2083
17
WILCOX OIL CO.
1 DUGGER
NW SE
12-10N-23W
EL. 1920
29
SINCLAIR PRAIRIE OIL
1 PERKINS
C SE NW
11-9N-24W
EL. 1849
salt
salt
1000
2000
3000
4000
NORTHEAST
33
CHAMPLIN REFINING
1 MORRIS
34
CONTINENTAL OIL CO.
1 NORTH CORN UNIT
35
DEEP ROCK OIL CORP.
1-A GRIFFIN
36
SUNRAY MID-CONTINENT
1 BAKER (8 RELIEF)



CROSS SECTION A-D

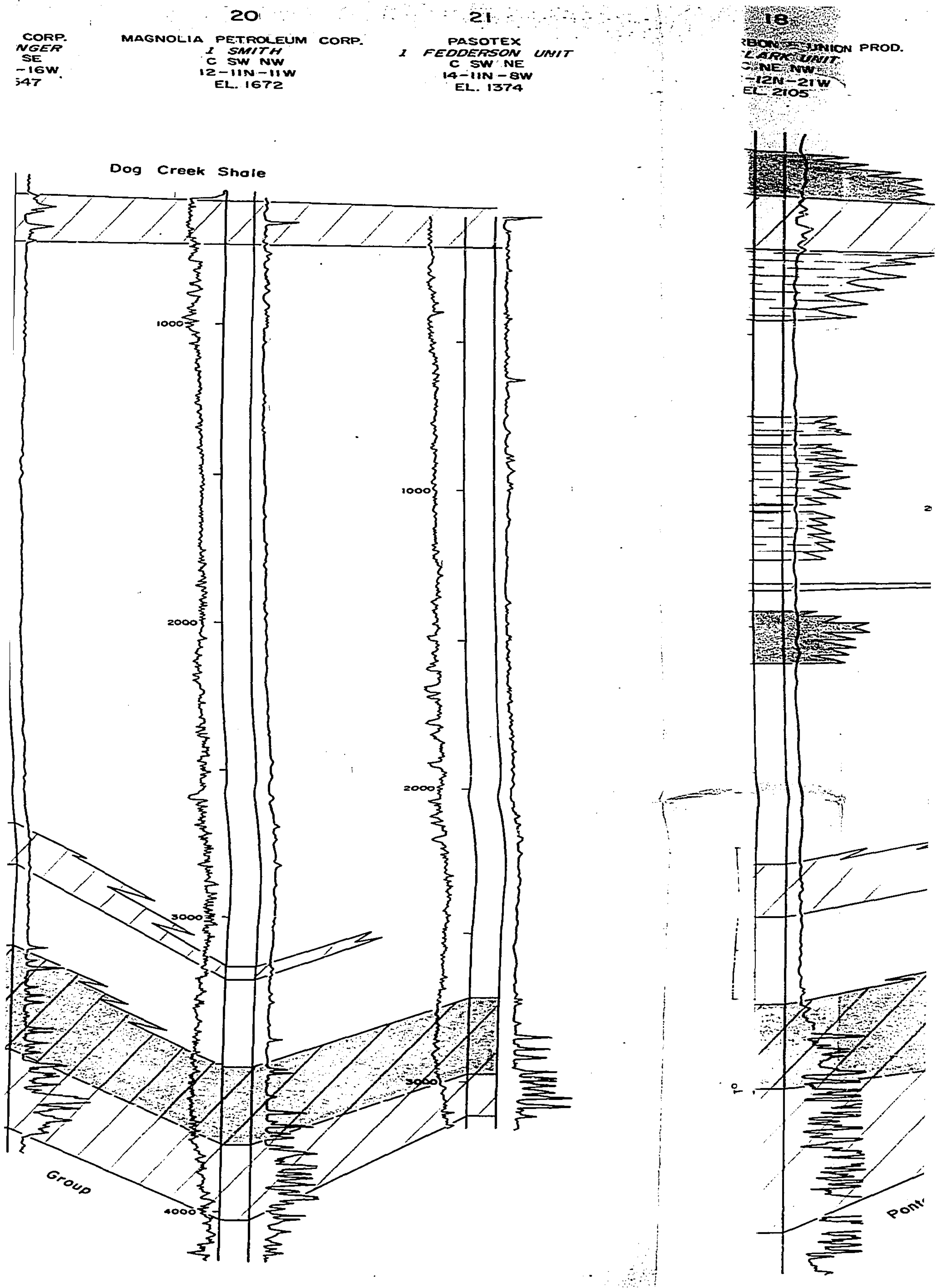


STRATIGRAPHIC CROSS SECTIONS



IS OF PERMIAN EVAPORITES IN

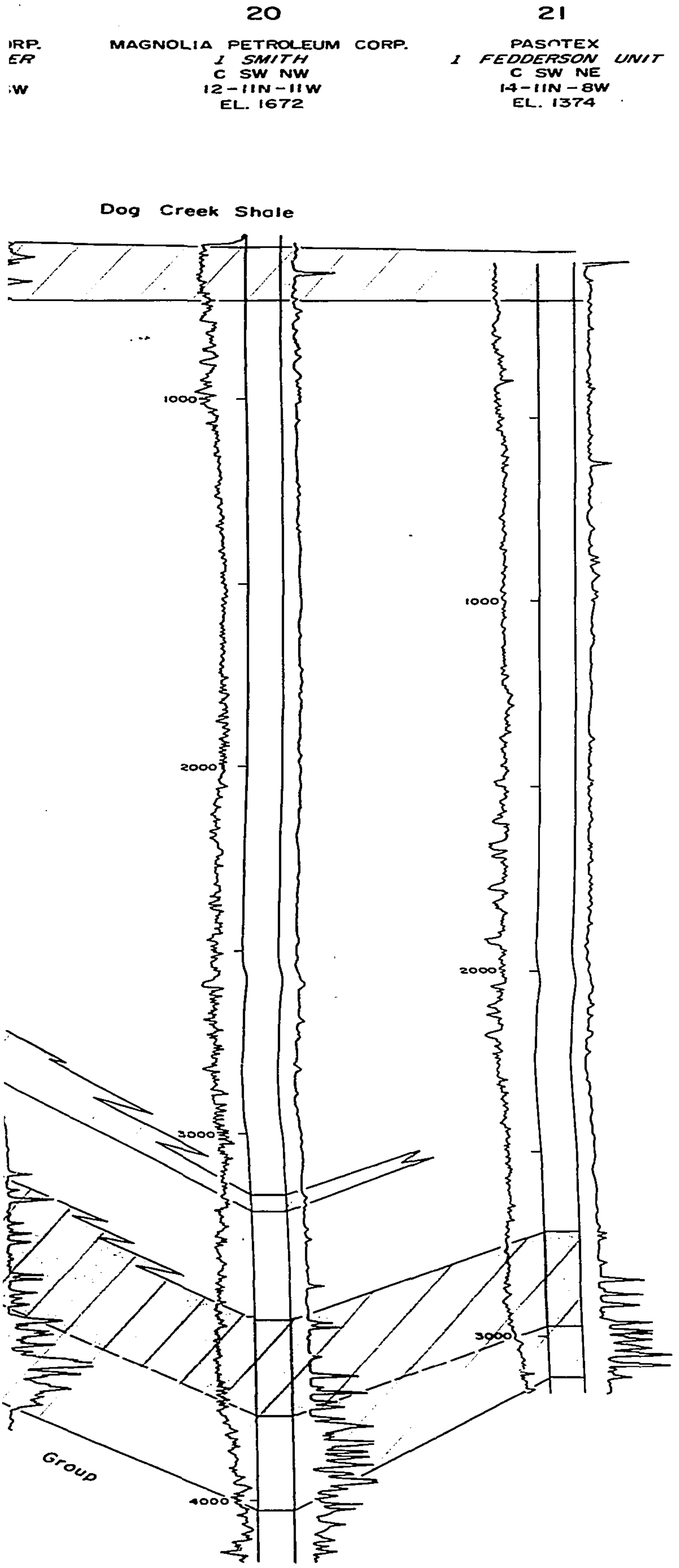
David L. Vosburg
1963



PORITES IN WESTERN OKLA MIAN

David L. Vosburg

1963



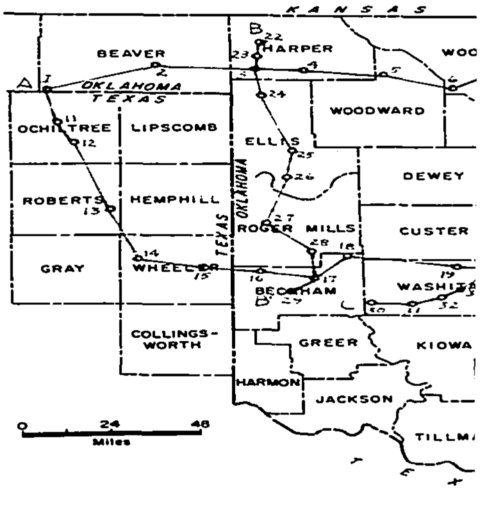
EXPLANATIO

░ Salt

☰ Salty shale and shaly

▨ Anhydrite

☐ Mainly shale



Index map of western Oklahoma and adjoi

ORITES IN WESTERN OKLAHOMA AND

David L. Vosburg

1963

ATION

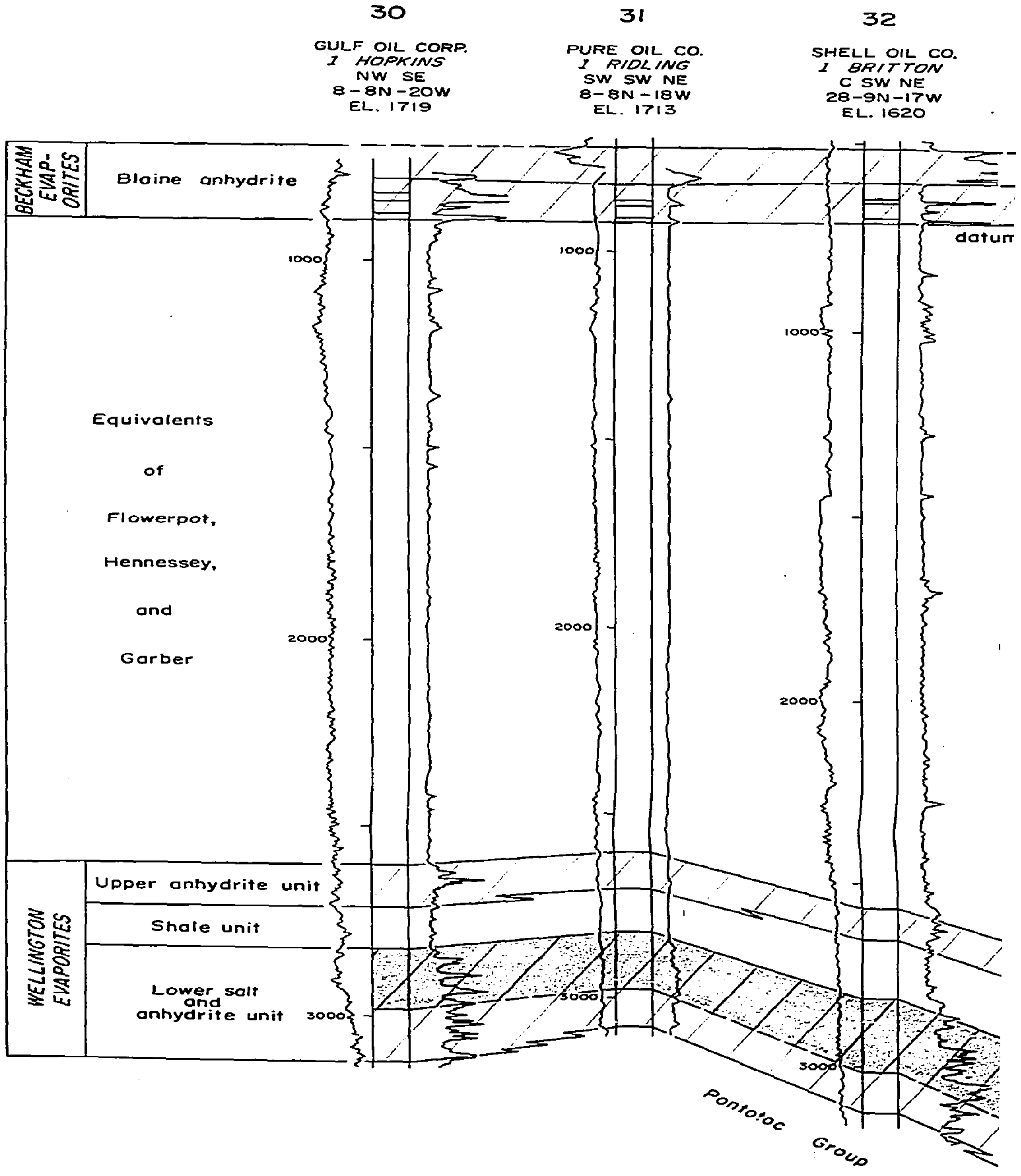
▨ lt

▤ nd shaly salt

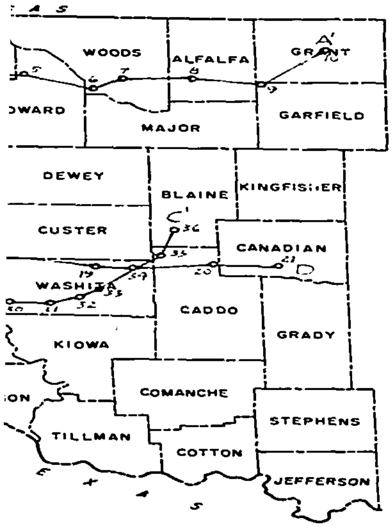
▧ drite

☐ shale

SOUTHWEST

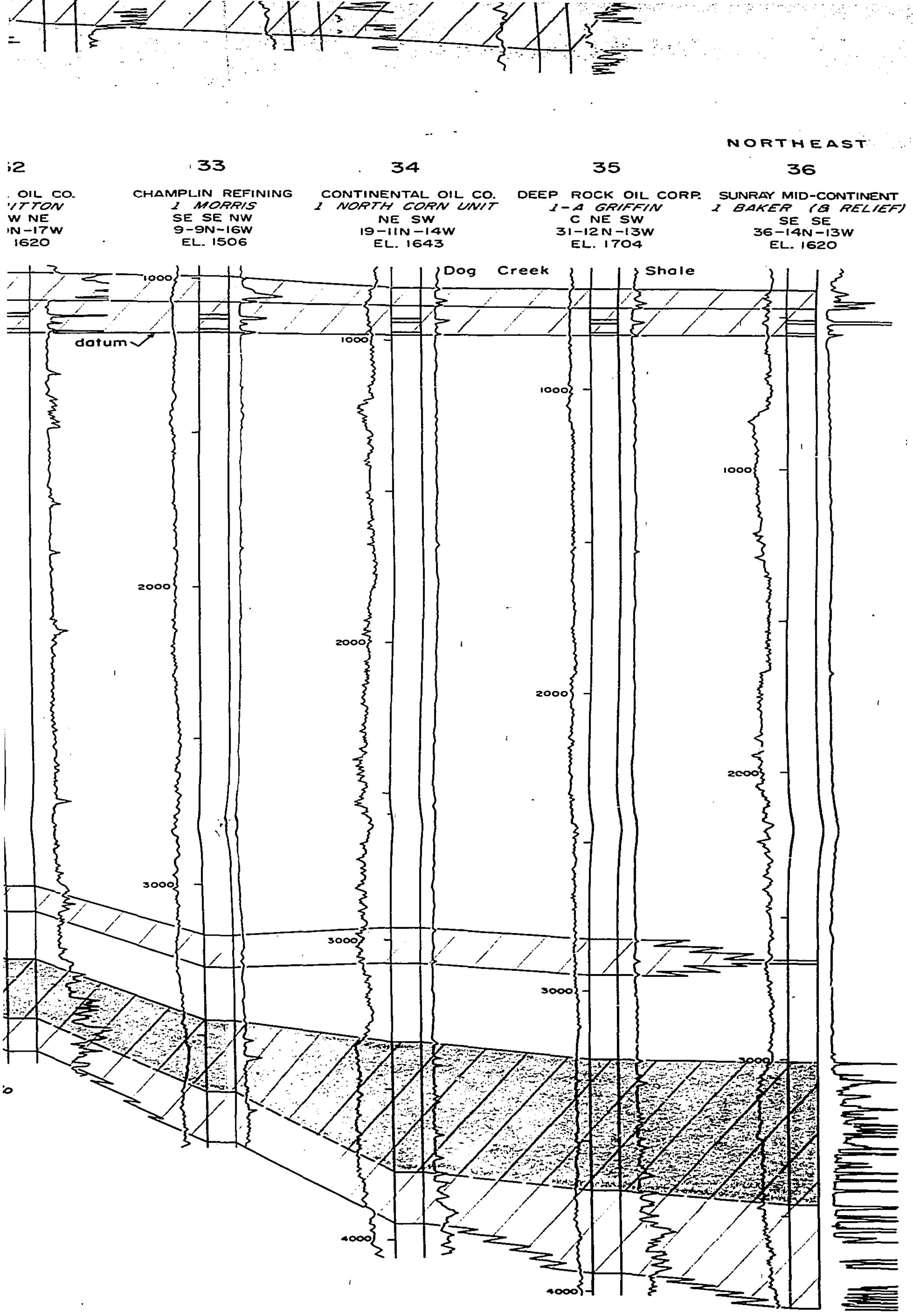


CROSS SECTION C-C'



and adjoining Texas Panhandle

ND ADJOINING TEXAS PANHANDLE


NORTHEAST
32
. OIL CO.
ITTON
W NE
N-17W
1620
33
CHAMPLIN REFINING
1 MORRIS
SE SE NW
9-9N-16W
EL. 1506
34
CONTINENTAL OIL CO.
1 NORTH CORN UNIT
NE SW
19-11N-14W
EL. 1643
35
DEEP ROCK OIL CORP.
1-A GRIFFIN
C NE SW
31-12N-13W
EL. 1704
36
SUNRAY MID-CONTINENT
1 BAKER (B RELIEF)
SE SE
36-14N-13W
EL. 1620
Dog Creek Shale
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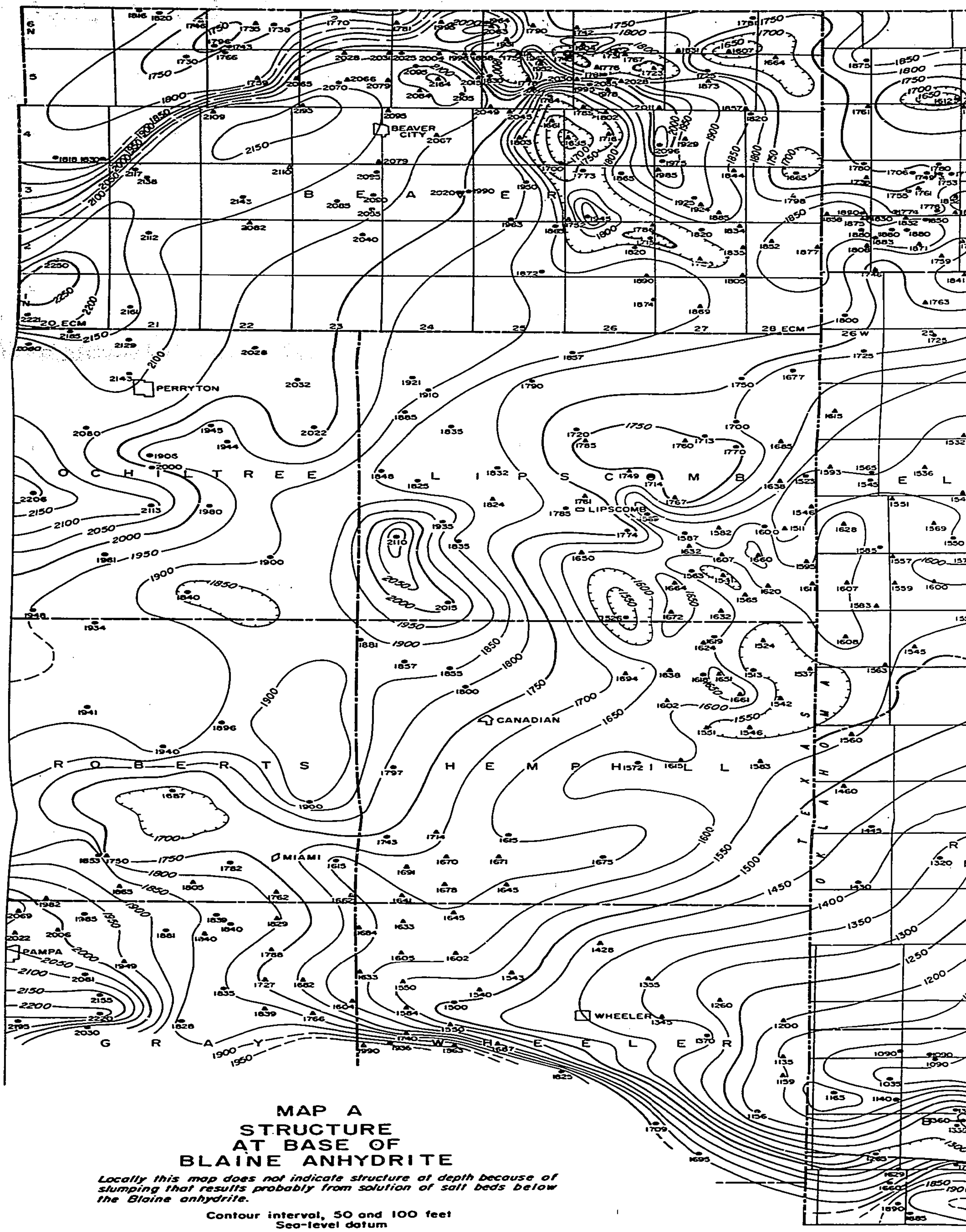
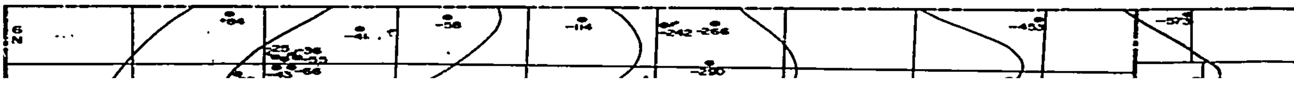
3000

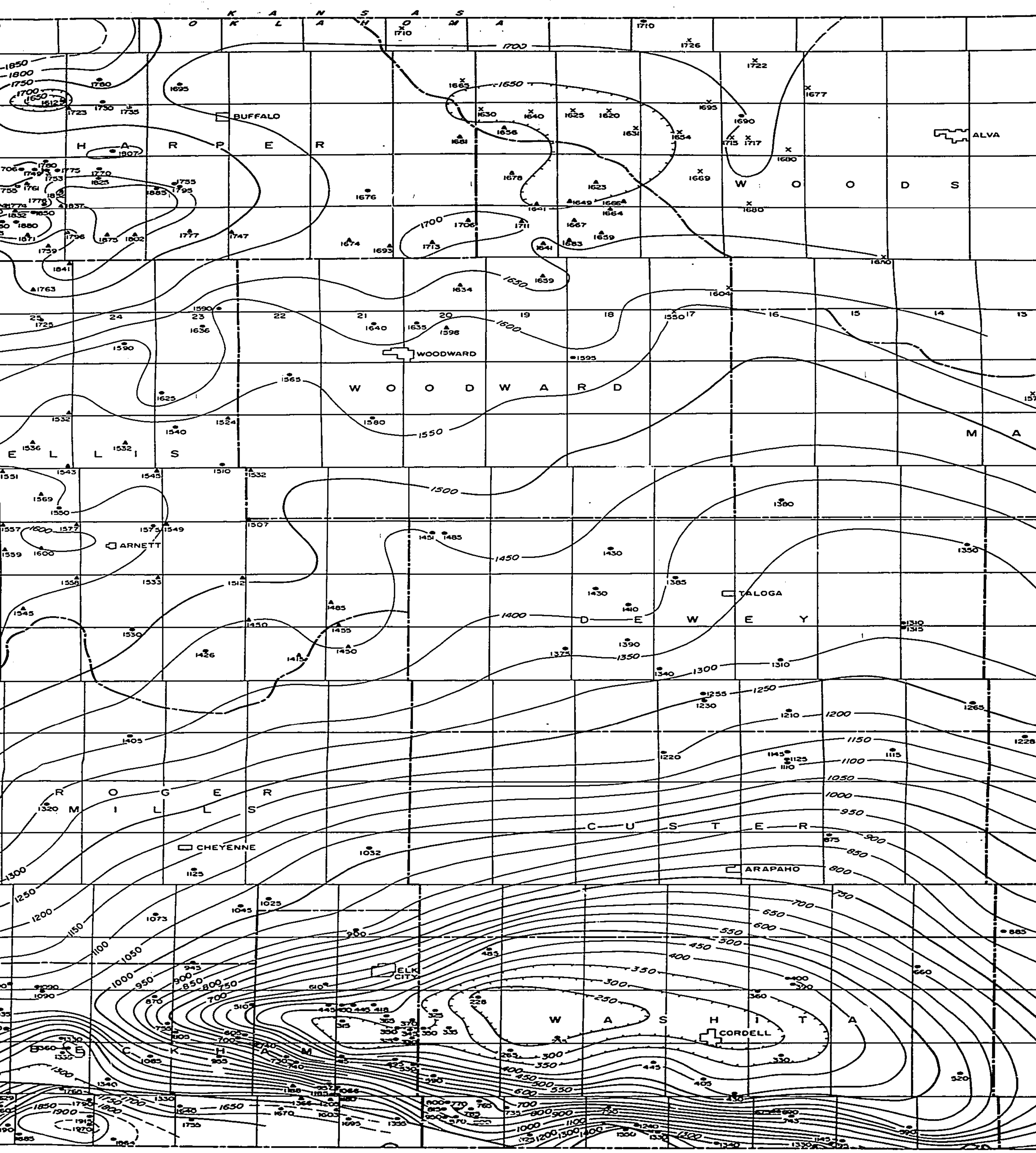


MAP A
STRUCTURE AT BASE OF BLAINE ANHYDRITE

Locally this map does not indicate structure at depth because of slumping that results probably from solution of salt beds below the Blaine anhydrite.

Contour interval, 50 and 100 feet
Sea-level datum




K A N S A S
O K L A H O M A
H A R P E R
BUFFALO
W O O D S
ALVA
W O O D W A R D
WOODWARD
E L L I S
ARNETT
D E W E Y
TALOGA
R O G E R M I L L S
CHEYENNE
C U S T E R
ARAPAHO
ELK CITY
W A S H I T A
CORDELL
B E C K H A M
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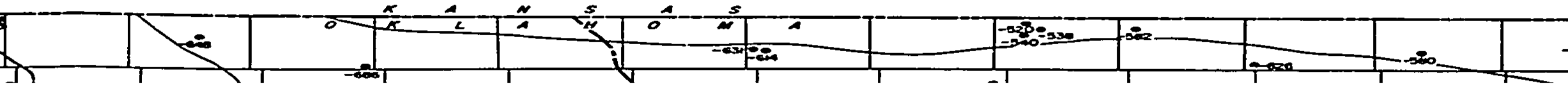
K A N S A S
O K L A H O M A
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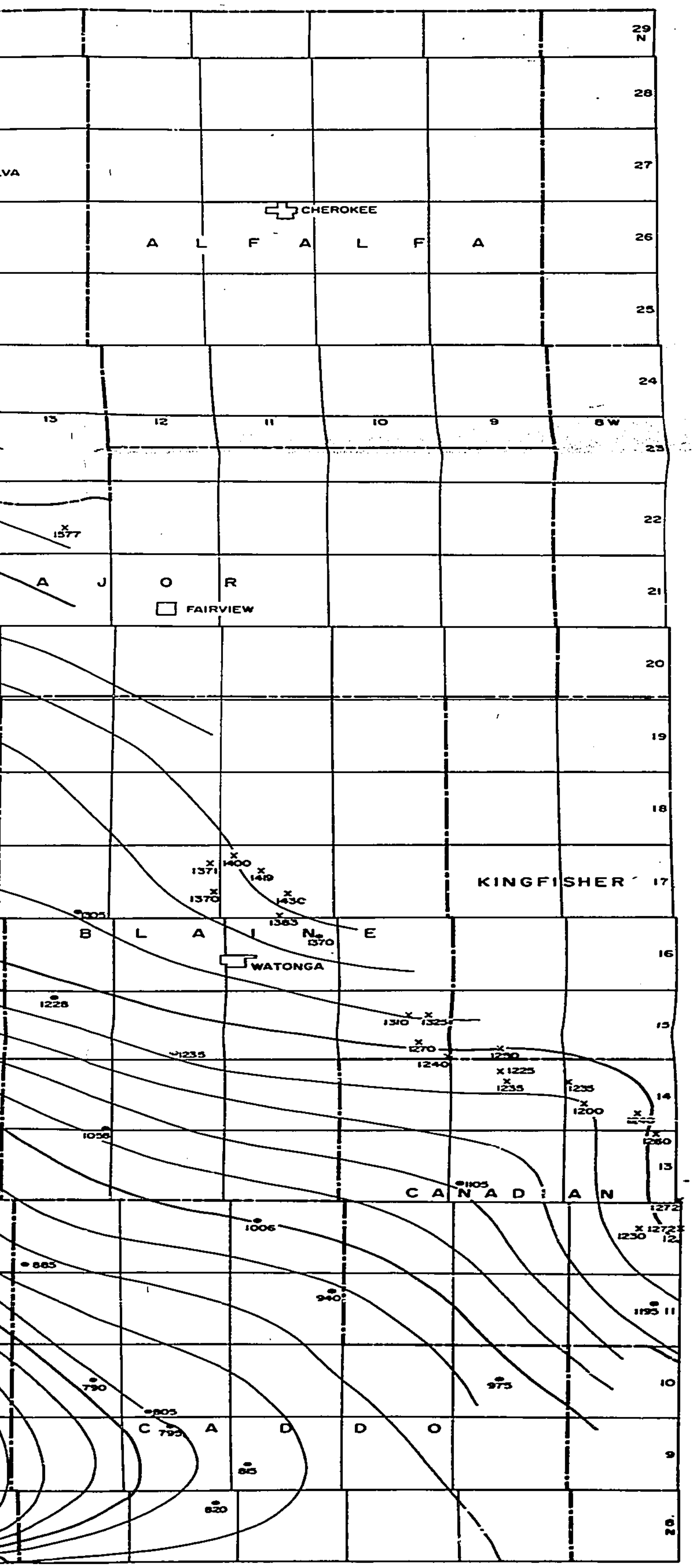
-686
-631
-614
-530
-540
-536
-562
-626
-580


ALFALFA
CHEROKEE
MAJOR
FAIRVIEW
BLAINE
WATONGA
KINGFISHER
CANADIAN
CADDO
29 N
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27
26
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8 N
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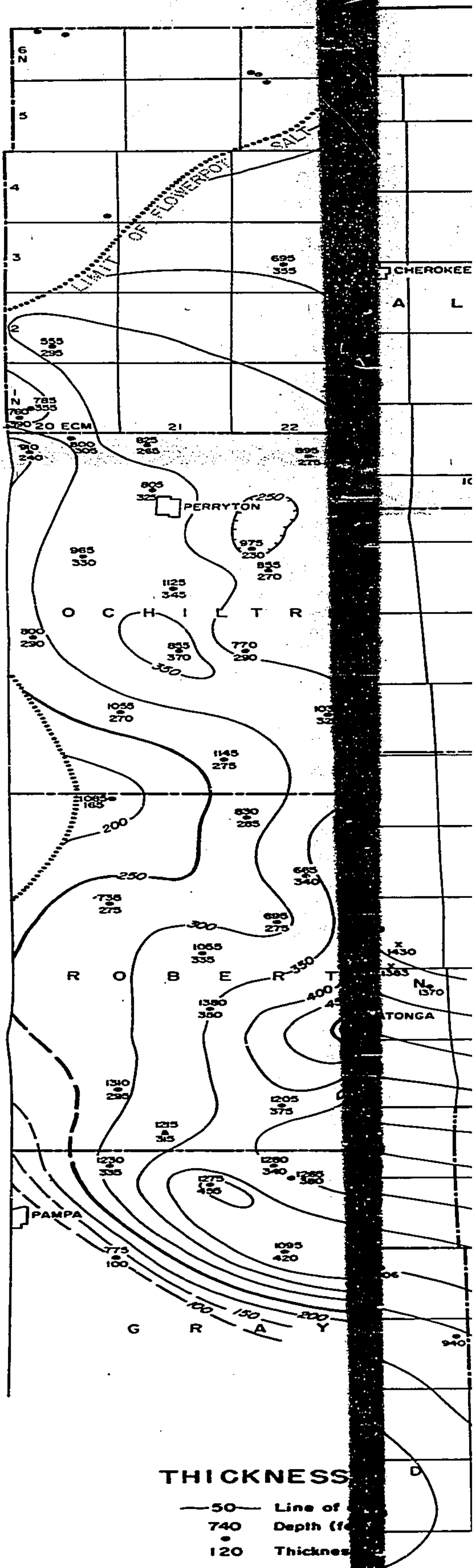
8 W


LIMIT OF FLOWERPOT SALT
CHEROKEE
PERRYTON
OCHILTREE
ROBERTS
WATONGA
PAMPA
GRAY
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22
6 N
5
4
3
2
1 N
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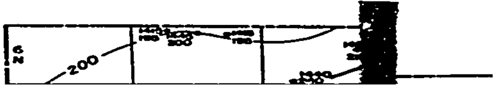
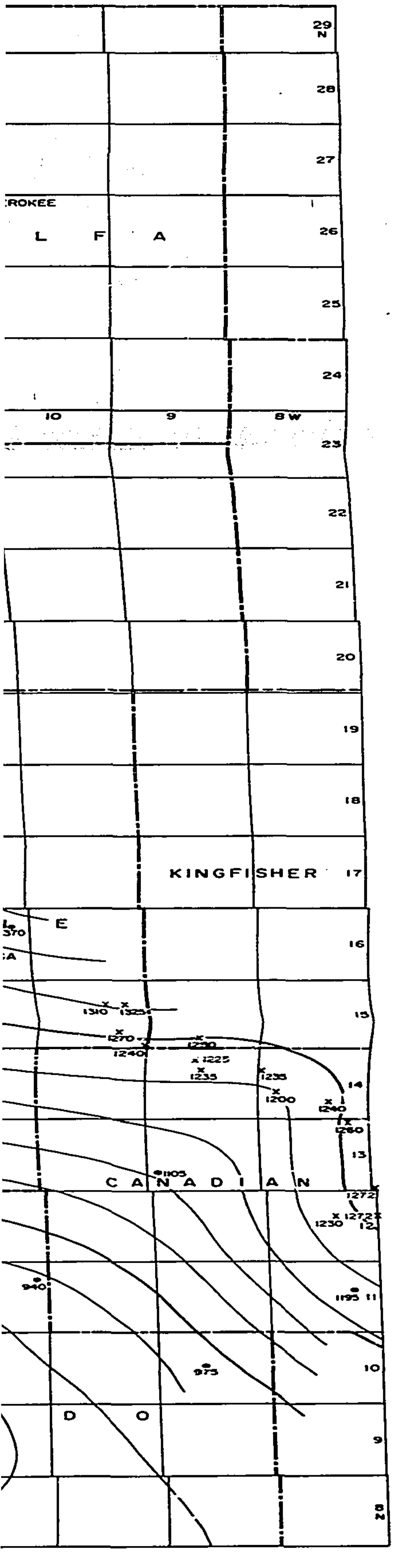
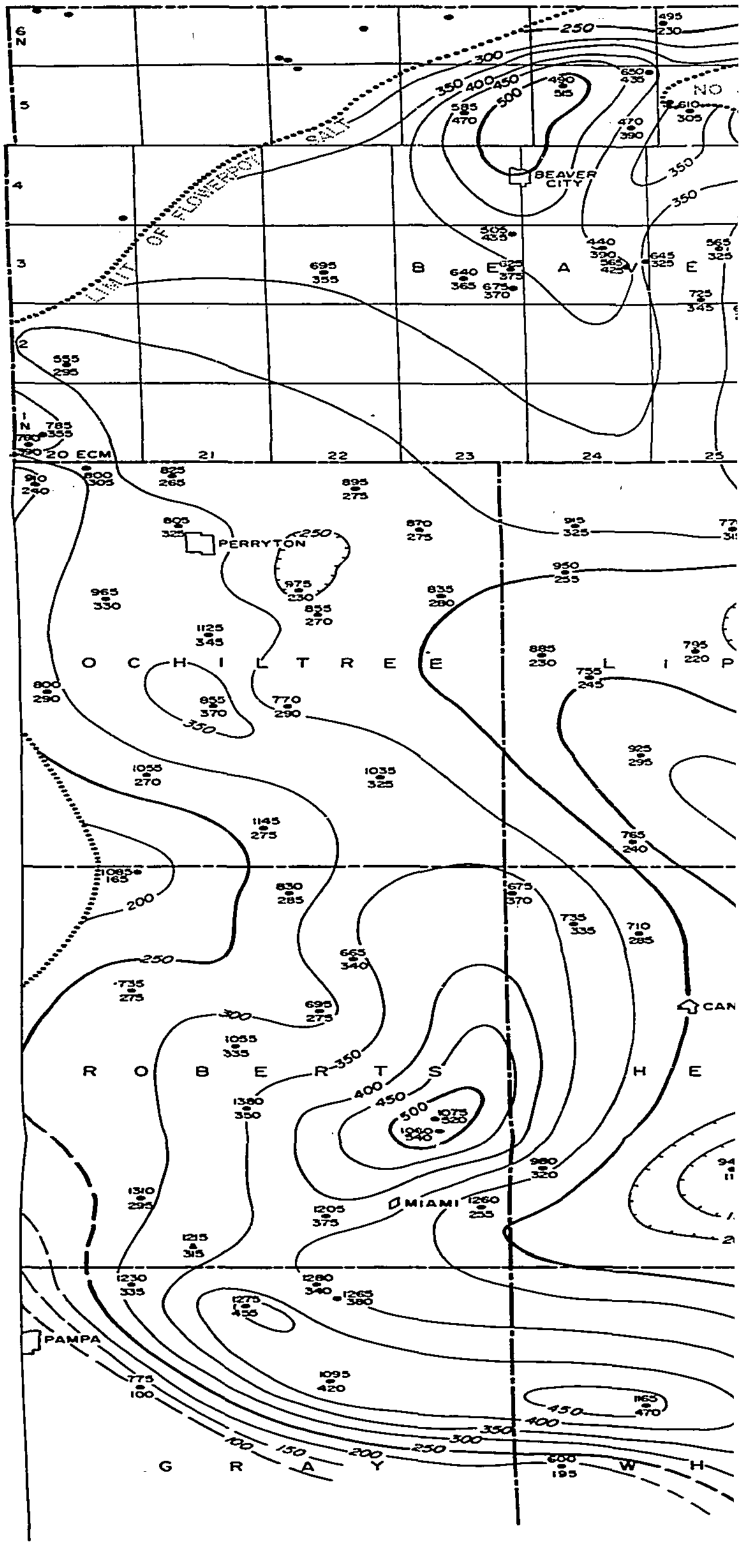
350
200
300
400
100
150
THICKNESS
—50— Line of
740 Depth (f
120 Thicknes


29 N


6 N
200



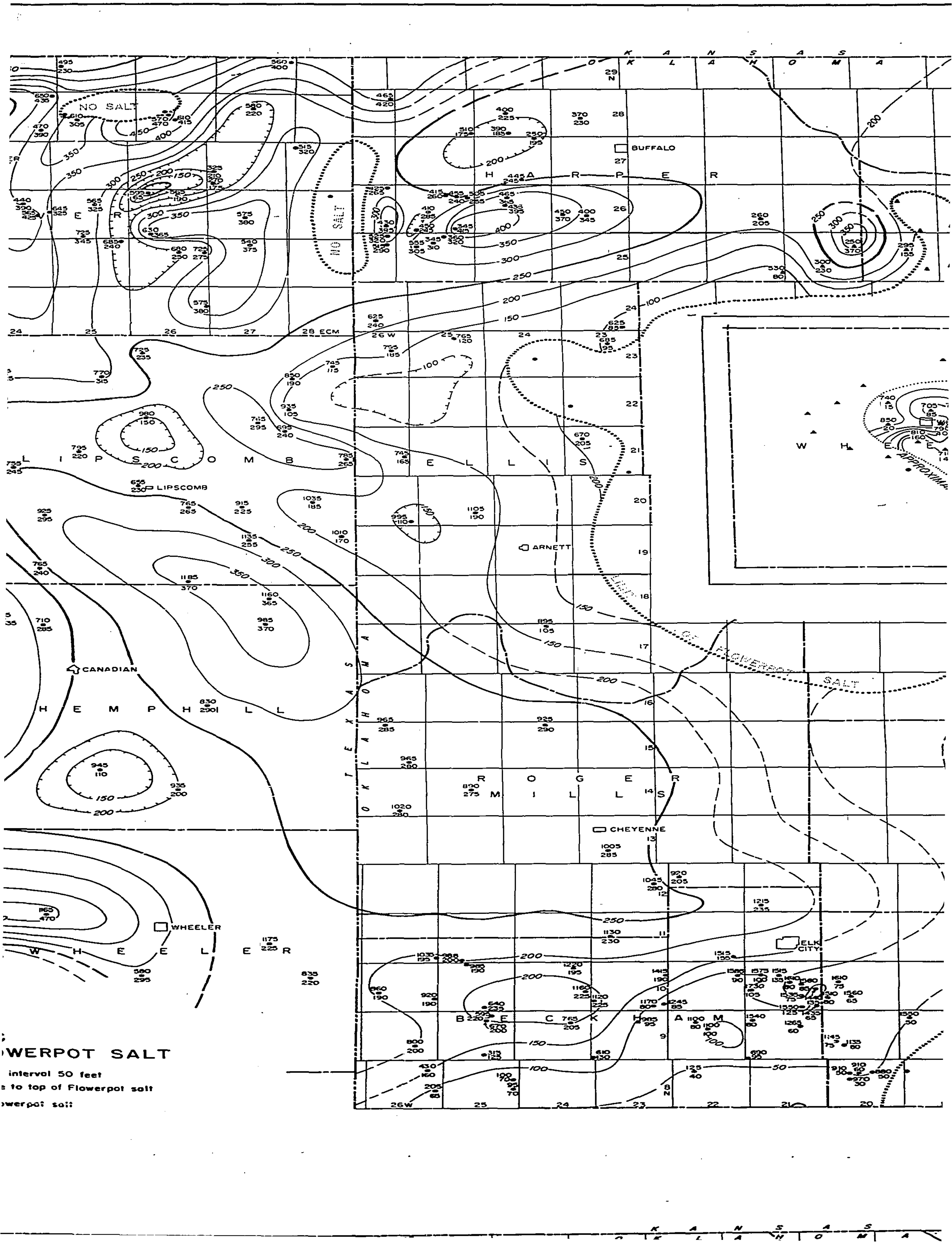


MAP C
THICKNESS OF FLOWERPOT

—50— Line of equal thickness, interval 50 fee

740 ● 120 Depth (feet) from surface to top of Flowe

120 Thickness (feet) of Flowerpot salt

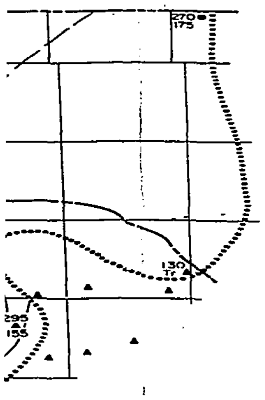


WERPOT SALT

interval 50 feet

e to top of Flowerpot salt

owerpot salt



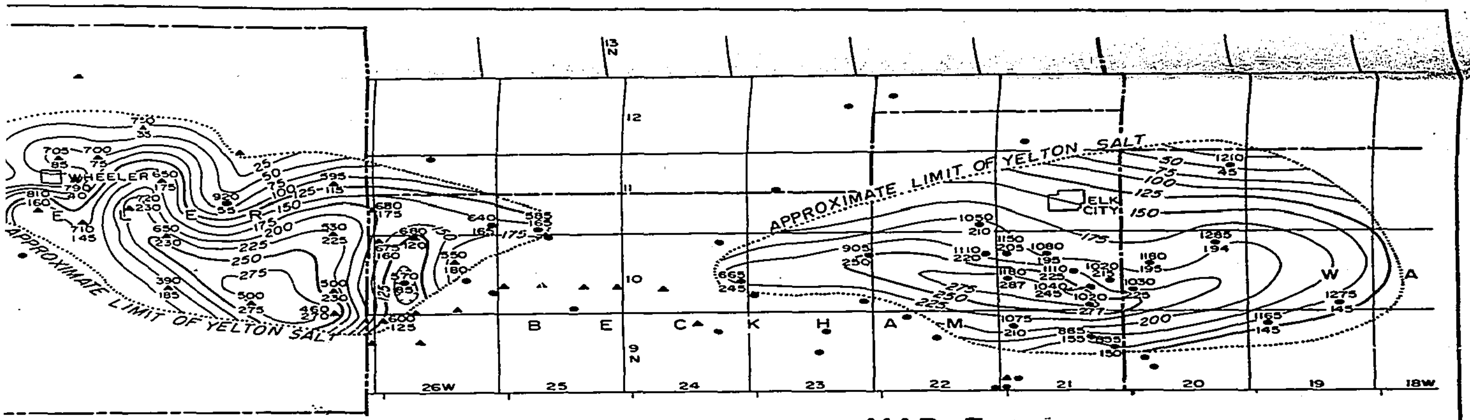
STRUCTURE AND THICKNESS MAPS OF PERMIAN EVAPORITES

WESTERN OKLAHOMA AND ADJOINING PARTS OF TEXAS PANHANDLE

David L. Vosburg
1963

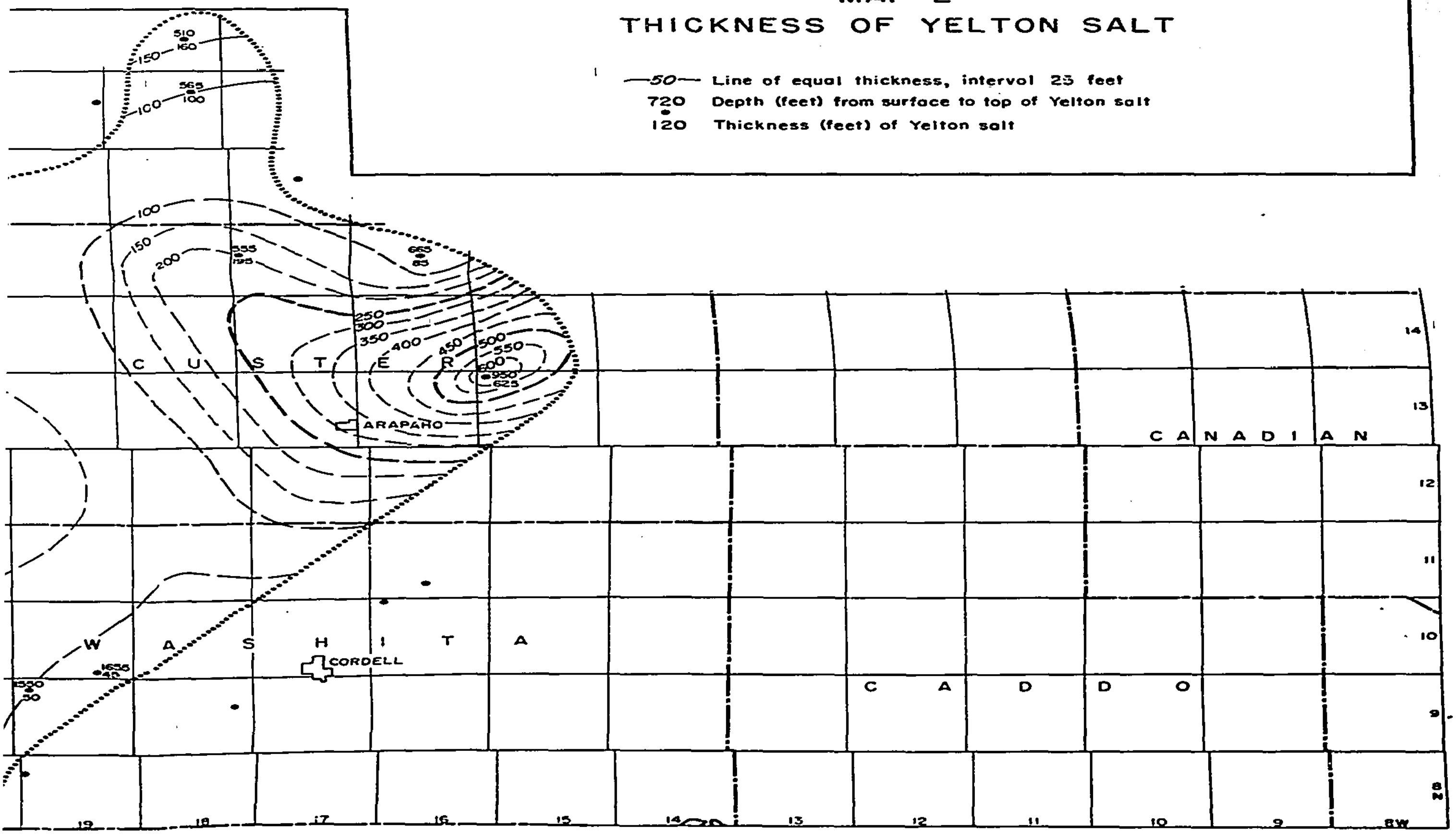
Control Points

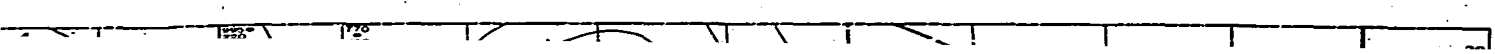
- ● Test for oil
- ▲ Stratigraphic test
- × Outcrop



MAP E
THICKNESS OF YELTON SALT

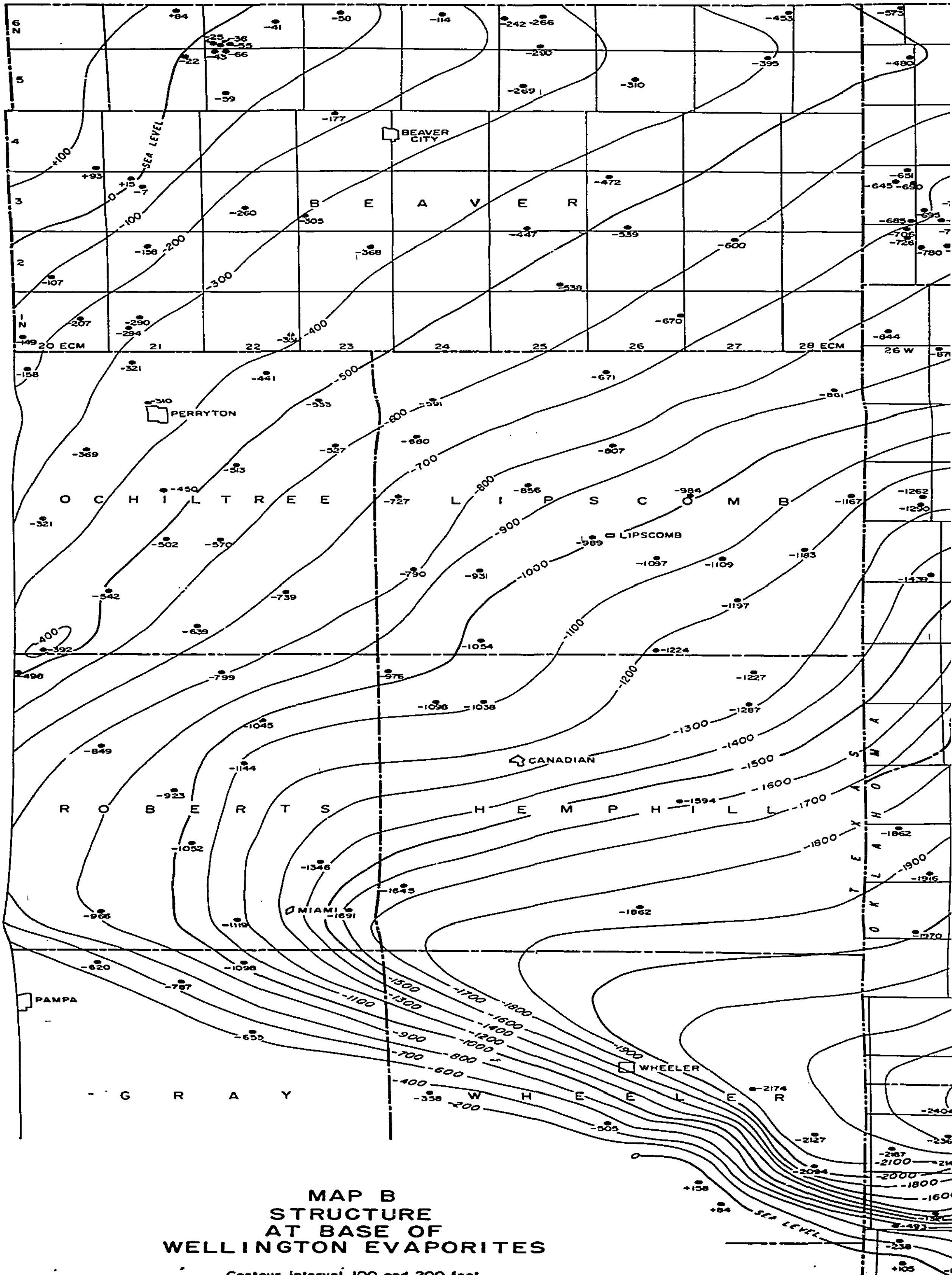
—*50*— Line of equal thickness, interval 25 feet
720 Depth (feet) from surface to top of Yelton salt
●
120 Thickness (feet) of Yelton salt





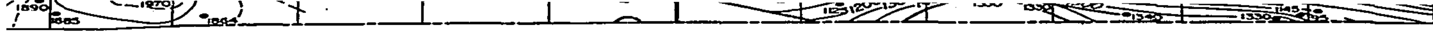
the Blaine anhydrite.

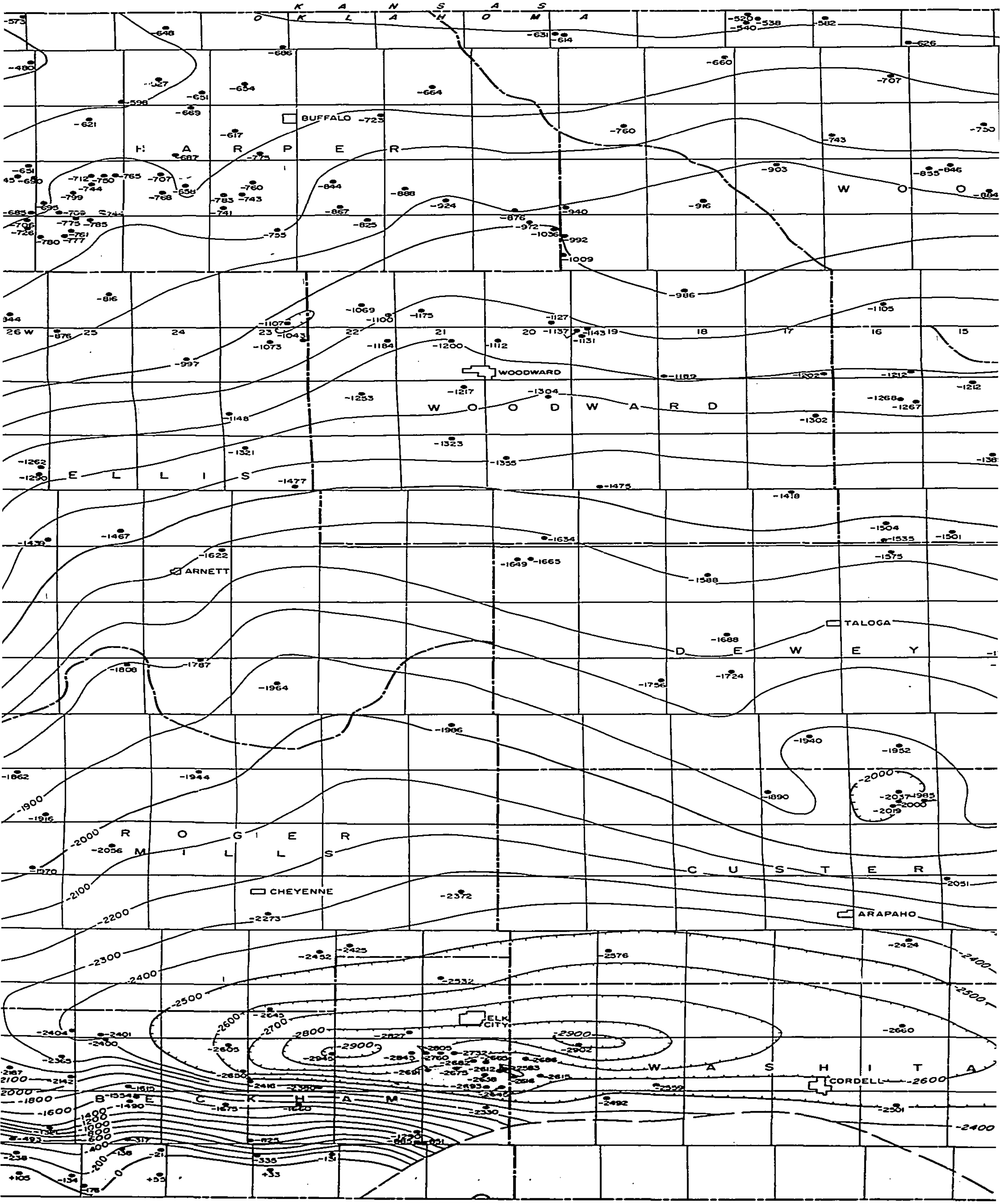
Contour interval, 50 and 100 feet
Sea-level datum



MAP B
STRUCTURE
AT BASE OF
WELLINGTON EVAPORITES

Contour interval, 100 and 200 feet
Sea-level datum




K A N S A S
O K L A H O M A
HARPER
BUFFALO
WOODS
WOODWARD
ELLIS
26 W
25
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16
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ARNETT
DEWEY
TALOGA
ROGER MILLS
CHEYENNE
CUSTER
ARAPAHO
ELK CITY
WASHITA
CORDELL
BECKHAM
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-2100
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-2500
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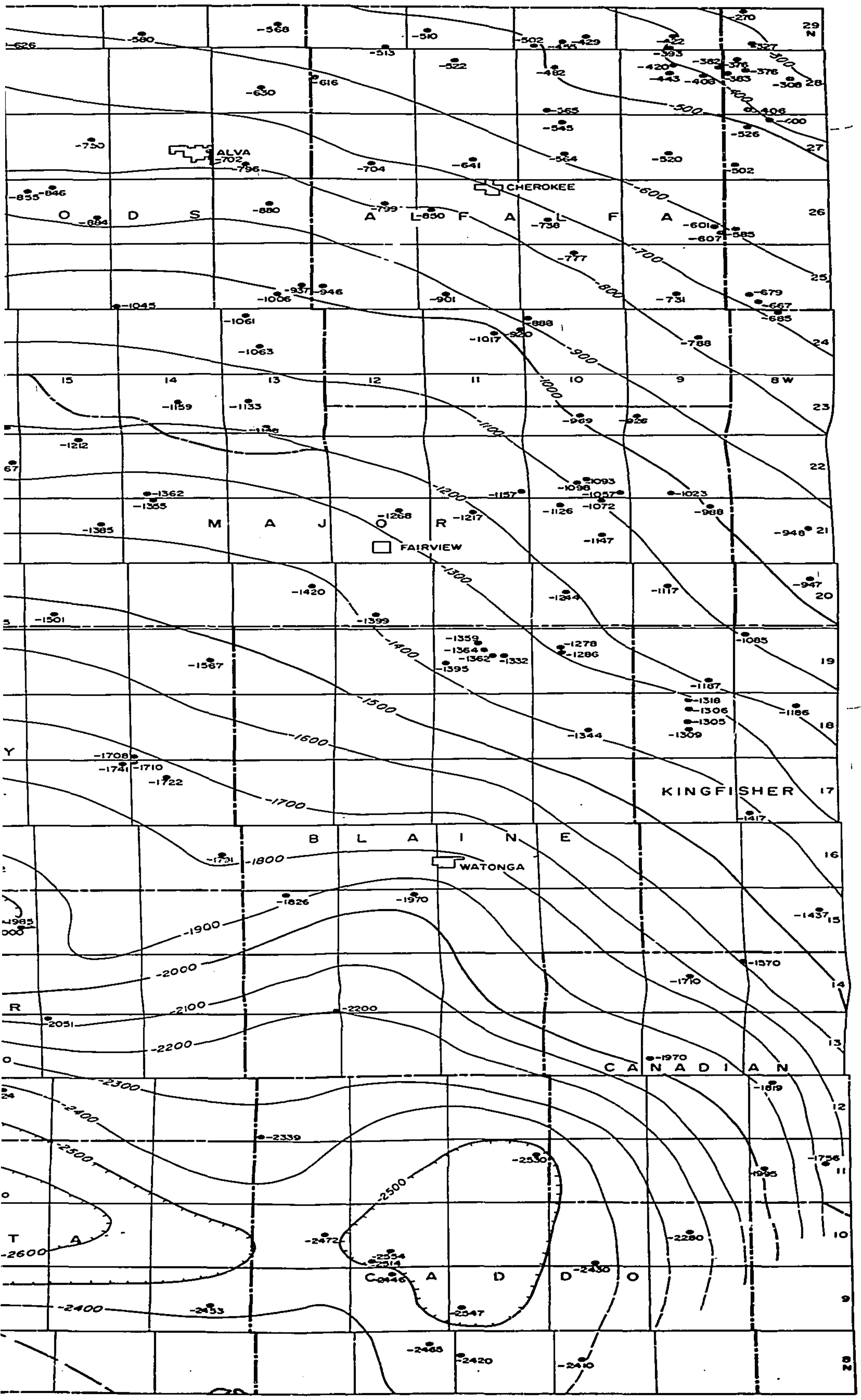
-2700
-2800
-2900



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FAIRVIEW
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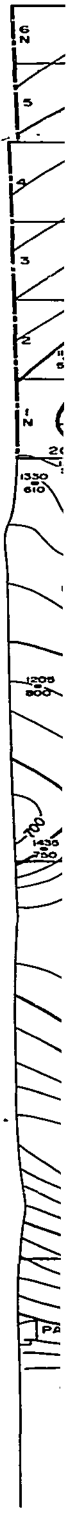

6 N
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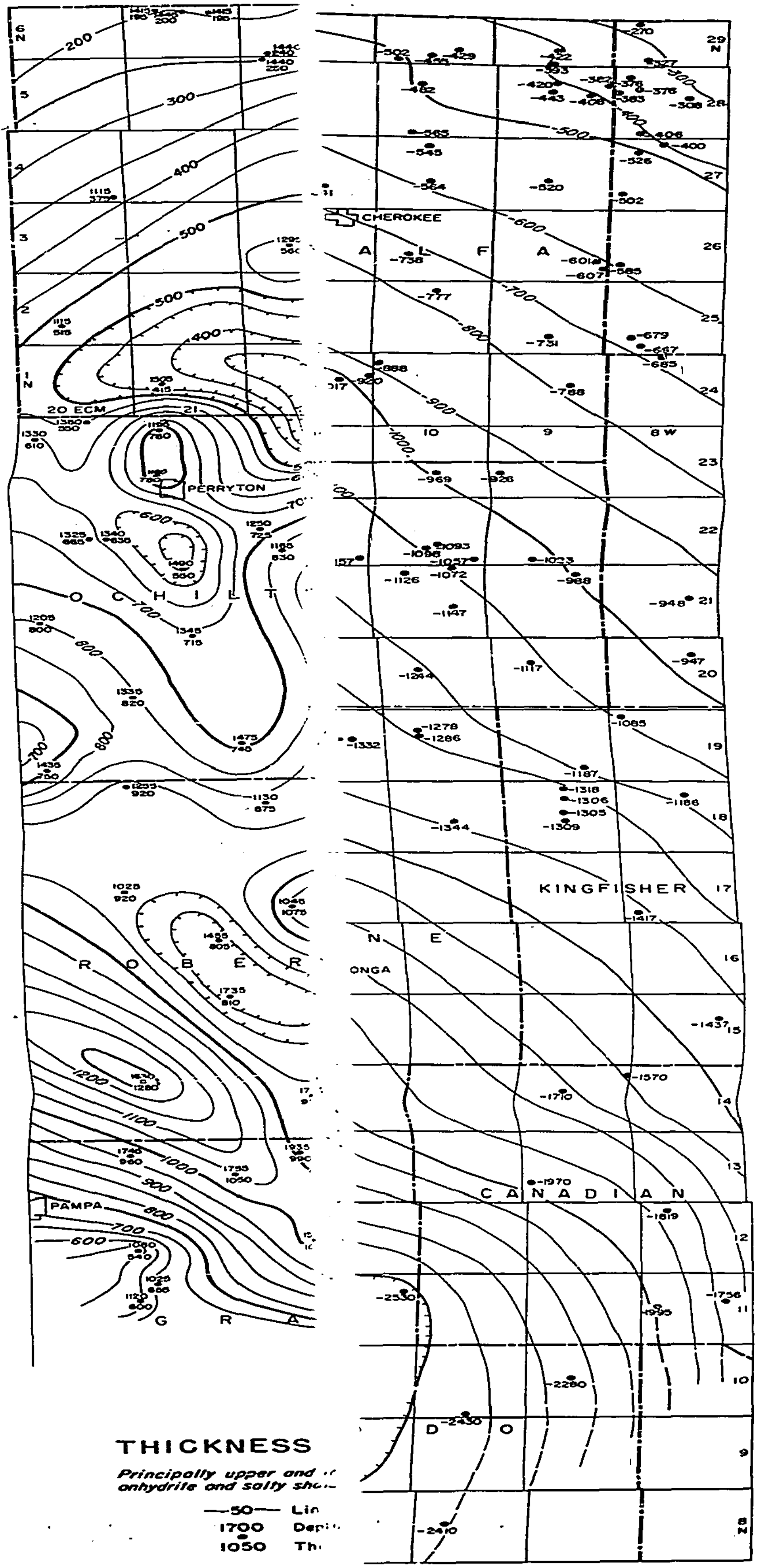


THICKNESS

Principally upper and ·· *anhydrite and salty sha*··

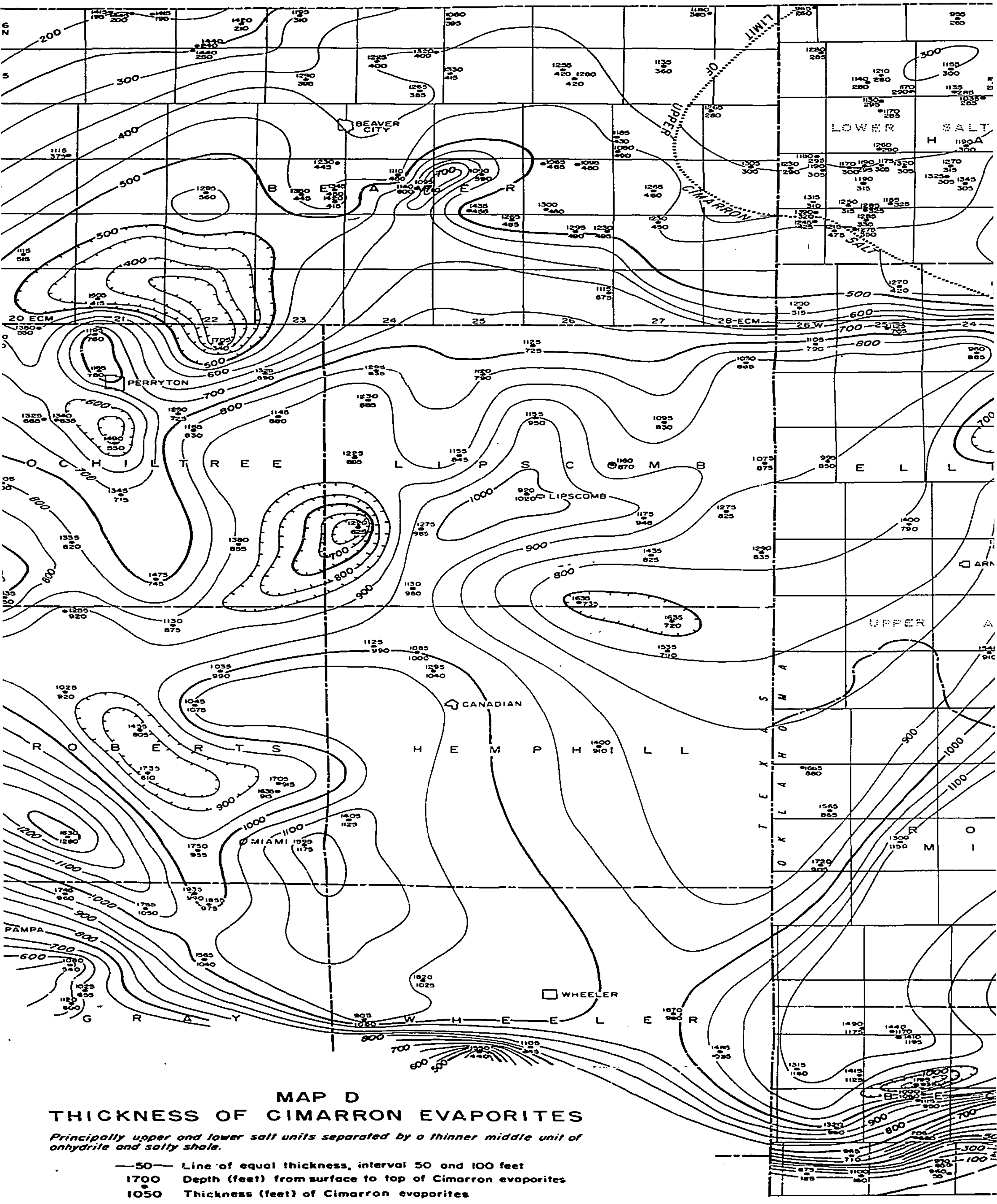
—50— Lin

1700 Dep··

1050 Th·

Depth (feet) from surface to top of Flowerpot salt

120 Thickness (feet) of Flowerpot salt



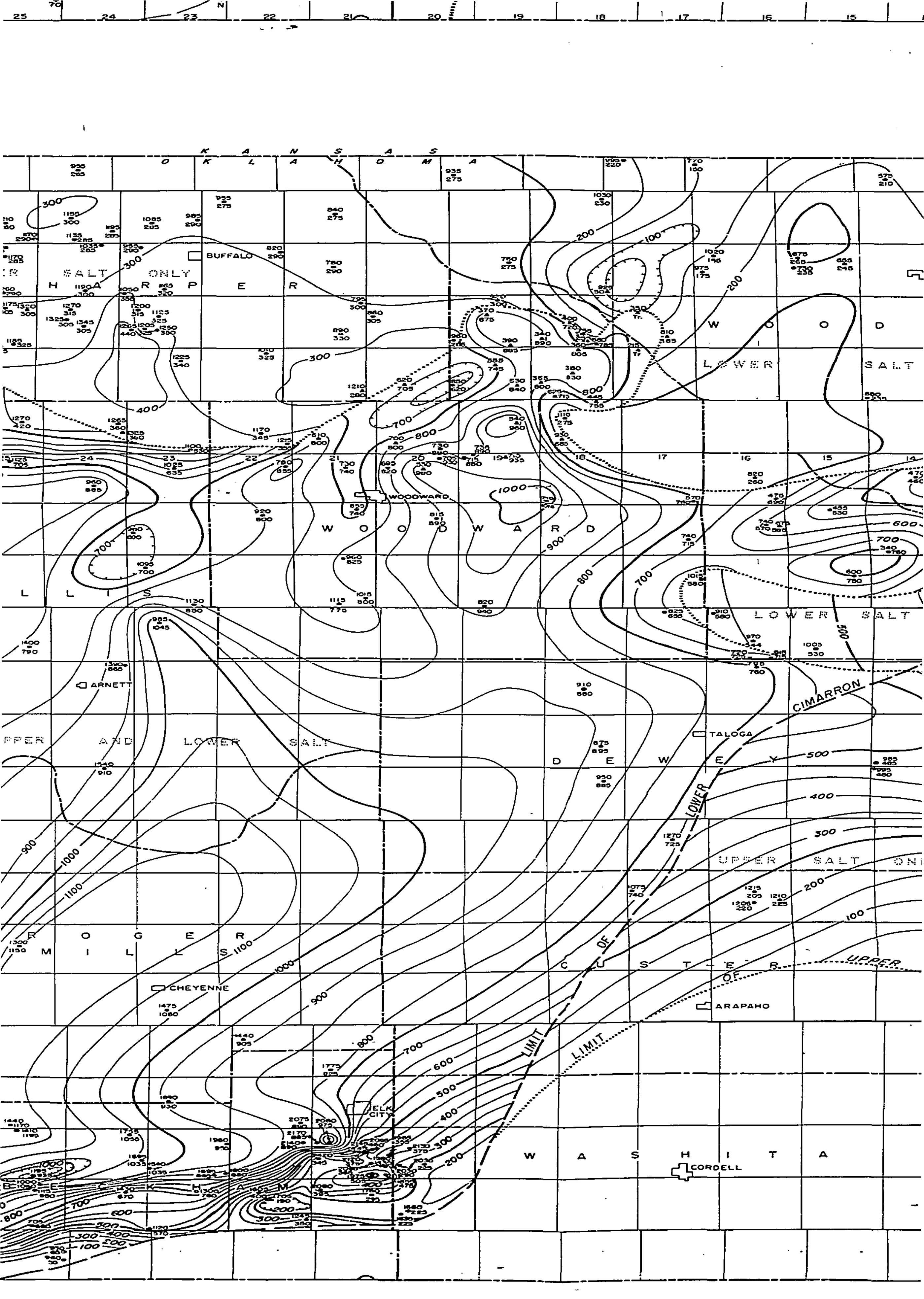
MAP D
THICKNESS OF CIMARRON EVAPORITES

Principally upper and lower salt units separated by a thinner middle unit of anhydrite and salty shale.

—50— Line of equal thickness, interval 50 and 100 feet

1700 Depth (feet) from surface to top of Cimarron evaporites

1050 Thickness (feet) of Cimarron evaporites


KANSAS
OKLAHOMA
HARPER
SALT ONLY
BUFFALO
WOODS
LOWER SALT
WOODWARD
ELLIS
ARNETT
UPPER AND LOWER SALT
DEWEY
TALOGA
CIMARRON
LOWER LIMIT OF
UPPER SALT ONLY
ROGER MILLS
CHEYENNE
CUSTER
ARAPAHO
UPPER LIMIT OF
ELK CITY
BECKHAM
WASHITA
CORDELL
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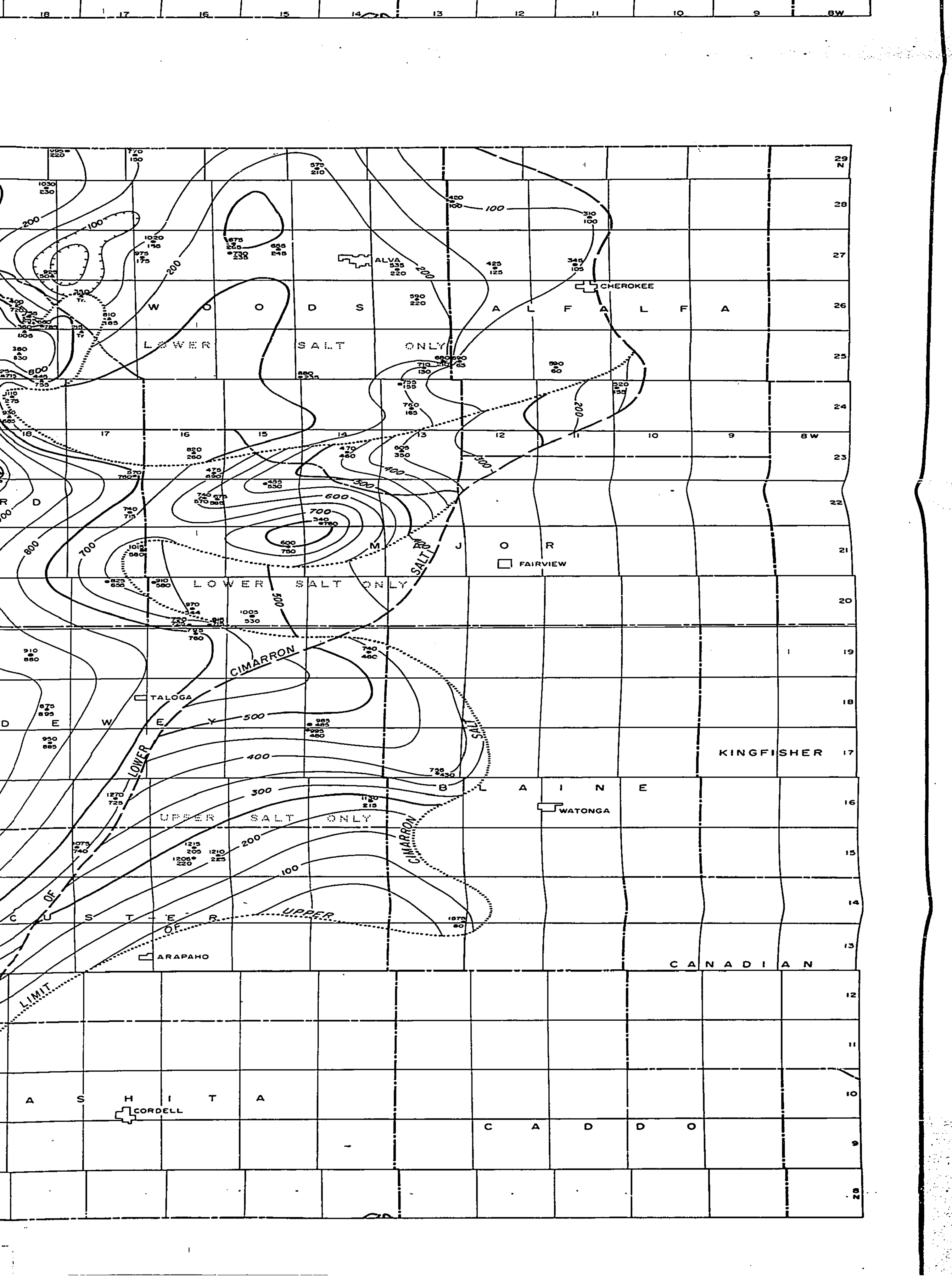

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W O O D S
A L F A L F A
LOWER SALT ONLY
ALVA
CHEROKEE
M A J O R
FAIRVIEW
LOWER SALT ONLY
D E W E Y
TALOGA
CIMARRON
LOWER SALT
B L A I N E
WATONGA
KINGFISHER
UPPER SALT ONLY
CIMARRON
C U S T E R
ARAPAHO
LIMIT OF LOWER
LIMIT OF UPPER SALT
C A N A D I A N
W A S H I T A
CORDELL
C A D D O
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700
800