CBRMarslandPEm Resource

From: Lancaster, Thomas
Sent: Friday, May 09, 2014 1:05 PM
To: John Schmuck
Subject: RE: Request for Document
Attachments: DeGraw_1969.pdf

Mr. Schmuck,

Attached is the paper I referred to when I was asking for clarification of the Marsland application.

Tom Lancaster
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Cc: Doug Pavlick; Larry Teahon; Sabrina Fox; Wade Beins
Subject: Request for Document

Tom - could you please provide Cameco a copy of the 1969 DeGraw paper? We have not been able to obtain a copy locally, and it should be considered in the context of Marland stratigraphy

Thanks. .john

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SUBSURFACE RELATIONS OF THE CRETACEOUS
AND TERTIARY IN WESTERN NEBRASKA

by

Harold Marlon DeGraw

An Open File Report
of the
Nebraska Geological Survey

A Preliminary and Unedited Report
from a Master of Science Thesis
January, 1969

Available from University of Nebraska
Conservation and Survey Division, Lincoln

SUBSURFACE RELATIONS OF THE CRETACEOUS AND TERTIARY IN WESTERN NEBRASKA

by

Harold Marlon DeGraw

A THESIS

Presented to the Faculty of

The Graduate College in the University of Nebraska

In Partial Fulfillment of Requirements

For the Degree of Master of Science

Department of Geology

Under the Supervision of Professor T. M. Stout

Lincoln, Nebraska

January, 1969

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ABSTRACT

After the discovery of oil and gas in commercial quantities in western Nebraska in 1949, there was an exploration "boom" that resulted in the drilling of more than eight thousand wells, mainly in the southwestern part of the Nebraska panhandle. Electric logs for most of these wells, together with some wells samples and information derived from supplementary subsurface and surface investigations, allow reasonable interpretations of the subsurface stratigraphy and structure. The paleotopography also has been reconstructed for selected horizons in the Tertiary and Pleistocene, but only generalized paleogeographic interpretations are presently possible for the upper part of the Cretaceous because of difficulties in evaluating the effects of structure.

Two paleotopographic maps, and a preliminary paleogeologic map, have been prepared for the truncated surface underlain by Cretaceous and some older rocks and overlain by Tertiary, principally Chadron (Early Oligocene). Special emphasis has been placed upon this Pre-Tertiary Surface and unconformity in the present investigation, and a reconstruction of the ancient drainages and divides has been attempted for the best-known area. The drainage net is interpreted as consisting mostly of subsequent patterns in that part of western Nebraska for which there is best control, but elsewhere there may be relics of superimposed-consequent patterns. In the southwestern part of the Nebraska panhandle,

it is to be noted that the drainage divides of the Pre-Tertiary Surface coincide with productive oil and gas trends of the "Dakota," whereas aquifers potentially useful in secondary-recovery operations occur axially along the ancient streams. Some reflection of the Pre-Chadron or Early Chadron landscape seems to occur even in the successional, overlying topographies from Chadron to Recent.

The sediments that overlie the Pre-Tertiary Surface may be classified at each successive horizon as either "valley" or "upland". The younger valley trends are commonly situated above earlier valleys, and coarse clastics are limited to these situations, whereas on the successive drainage divides the "upland" sediments seem to consist mostly of "draped" or "mantling" loessic-silt and sand. However, slopes may be expected to contain, in places at least, some colluvial aprons, and even sand dunes are expectable. The "upland" sediments of the Tertiary subsurface are thus suggestive of those areas in Nebraska where even today there are loess and sand blankets of considerable importance, but they seem to be more widespread in subsurface situations than one would expect from outcrop studies of the Tertiary in western Nebraska. This may be because the "valleys" of the Tertiary are what we see mainly today in outcrop, whereas the ancient divides are often buried beneath the present "uplands" and seldom glimpsed - or, when seen, not always fully appreciated.

INTRODUCTION

This report presents the results of a comprehensive study of the Pre-Tertiary Surface in western Nebraska and of the stratigraphic relations above and immediately below it. About eight thousand wells have been drilled in the region of investigation, particularly in the southwestern "Panhandle", and the logs for most of these have been utilized in preparing the maps and cross-sections, as well as in projecting the surface geology and structure into the subsurface. The method of approach is similar to that much used in the petroleum industry for investigation of the subsurface, but it has been seldom applied to continental sediments and is new in application to the Tertiary of western Nebraska.

In the more than ten years that have been devoted to the project, there has been much benefit from comments and constructive criticism of colleagues at the Nebraska Geological Survey, Conservation and Survey Division, the University of Nebraska. Professor E. C. Reed, the former Director, provided the opportunity to begin and carry on the study and established an environment allowing scholarly research. Mr. Vincent H. Dreeszen, the present Director, gave further encouragement and much assistance in developing techniques for determining and mapping the Tertiary-Cretaceous unconformity.

Special thanks are here expressed to Prof. T. M. Stout of the Department of Geology and State Museum, the University

of Nebraska, for continuous help. His exceptional knowledge of geologic literature and of Nebraska, as well as discussions during the course of development of new, basic concepts in comparative stratigraphy, have been particularly helpful. Other staff members of the Department of Geology, especially Drs. Russell Smith and Robert B. Nelson also have been most kind in discussing problems.

Additionally, mention must be made of aid from others. Mr. Ray Bentall, Geologist of the Water Resources Division, United States Geological Survey (Lincoln), has contributed greatly by discussing the problems encountered and the preparation of illustrations. Messrs. Harley Carr and Dennis Summers conscientiously drafted the maps and cross-sections, and Miss Doris Peabody ably typed the preliminary drafts as well as the final copy of text. Finally, the continuous help and encouragement from the author's wife, Mrs. Sara DeGraw, are most gratefully appreciated.

PREVIOUS WORK

The earliest important summary of the subsurface relations in western Nebraska was issued by the Nebraska Geological Survey nearly four decades ago (Condra, Schramm, and Lugn, 1931). Since the publication of that study of the "Deep Wells of Nebraska", many thousands of additional wells have been drilled and much more has been learned of the surface geology as a background for subsurface interpretations.

Prior to 1931, there had been only a few contributions relating subsurface to surface, and these now are considered too general to be of much value. In a series of masterly works, N. H. Darton (especially 1899, 1903a-c, partly revised in 1905) included some subsurface reconstructions that were also partly utilized by Barbour (1903). Only a short time later, O. A. Peterson (1906, p. 23; reprinted <u>in</u> Osborn and Matthew, 1909, p. 73, fig. 14) attempted reconstruction of the subsurface Tertiary in a north-south cross-section near the Wyoming boundary, in western Sioux County, Nebraska. An economic interest in the so-called "Agate Anticline", also situated in Sioux County, led to an investigation of the Tertiary geology and "structure" that was subsequently published privately by the Kanoka Oil Company (Schramm and Cook, 1921). There was a similar study made by these same authors and associates of the Chadron Arch, in northern Nebraska and adjacent part of South Dakota, but only preliminary maps were prepared. Many of these early maps have survived and have been preserved in the files of the late E. F. Schramm, in the Department of Geology and State Museum, The University of Nebraska.

Since 1931, the personnel of the Nebraska Geological Survey as well as of many oil companies have been engaged almost continuously in the study of the subsurface of western Nebraska. Many of the maps and cross-sections, particularly those prepared by E. C. Reed, have been published or placed on open-file with the Nebraska Geological Survey (see list following References at end of this report). Among the other maps and studies, the following require especial mention: maps of the Precambrian Surface (Lugn, 1934; and Carlson, 1966); isopachous and structural maps for Cretaceous rocks (Fuenning, 1942, also a thesis edition); maps and cross-sections showing principal structural features of western Nebraska, with interpretations of the subsurface stratigraphy along selected profiles (Condra, Reed, and Scherer, 1940; Condra and Reed, 1943, reprinted in 1959); geologic maps and well records (State map and others listed at end of this report; Lugn, 1939, Wenzel and Waite, 1941; Wenzel, Cady, and Waite, 1946; Cady and Scherer, 1946; Babcock and Visher, 1952; Bjorklund and Brown, 1957; Bjorklund, 1957); and generalized maps of Tertiary drainages (Lugn and Lugn, 1955).

There have been also several studies in States adjacent to the western part of Nebraska that must be considered. Sample descriptions have been published for certain deep wells in South Dakota (Baker, 1947, 1948). For eastern

Wyoming, especially the Goshen Hole, Schlaikjer (1935a-c) utilized driller's logs of three shallow wells to interpret the subsurface stratigraphy. Jenkins (log of ?1950) prepared a sample-description log and stratigraphic interpretation of an oil test-well in the Goshen Hole that was made available to personnel of the United States Geological Survey; it has been much utilized by many workers, particularly Laura McGrew (MS. of 1953, 1963). Rapp, Visher, and Littleton (1957) and Schultz and Stout (1955, fig. 10) have utilized available information to revise some of Schlaikjer's conclusions in this same Goshen Hole area. In northeastern Colorado, the subsurface studies of Mather, Gilluly, and Lusk (1928), Rankin (1933), and Blair (1951) should be mentioned. Of these, Rankin's paper was found to be the most useful because of the possibility of projecting his terminology for Cretaceous units into the western Nebraska subsurface.

The surface geology in western Nebraska and adjacent States obviously must be carefully considered likewise in any subsurface reconstructions, and on this subject there is a rich literature, many of the works being listed at the end of this report. For western Nebraska and adjacent regions, the Tertiary and Pleistocene relations have been adequately summarized by Lugn (1935, 1939), Schlaikjer (1935a-c), Schultz and Stout (1945, 1948, 1955, and 1961), Stout, Dreeszen, and Caldwell (1965), Schultz, Falkenbach, and Vondra (1967), and Schultz and Falkenbach (1968). In northeastern Colorado, the Cretaceous and Tertiary outcrops have been studied by Matthew (1901), Mather, Gilluly, and Lusk (1928), Lavington (1933), and more recently by Buffington (MS. of 1961) and Galbreath (1953; revised by Stout, 1960a, and unpublished chart). For South Dakota, particular attention should be given to the summary papers of Wanless (1922, 1923), Ward (1922), Clark (1937, 1954), Schultz and Stout (1945, 1948, 1955, 1961), Stout, Dreeszen, and Caldwell (1965), Clark, Beerbower, and Kietzke (1967), and Schultz and Falkenbach (1968).

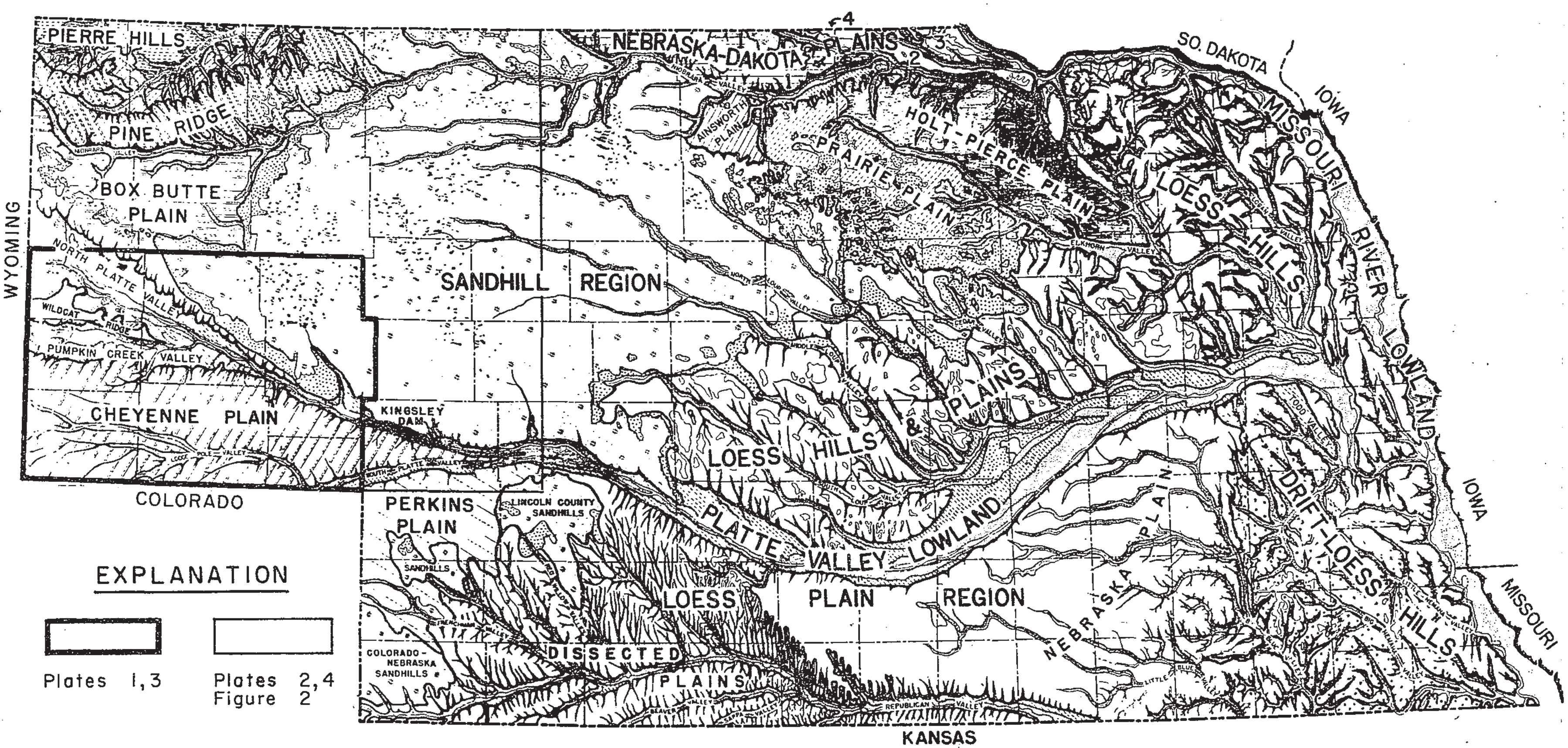
REGION OF STUDY

This investigation has been confined mostly to western Nebraska and includes a rectangular area (Figure 1) somewhat larger than the Nebraska panhandle, extending west from longitude 101° West to the Wyoming boundary (slightly west of longitude 104°02'30" West), and north from the Colorado border (approximately latitude 41° North) to the South Dakota State line (about latitude 43° North). This region comprises about 21,500 square miles, including all of Sioux, Scotts Bluff, Banner, Kimball, Dawes, Box Butte, Morrill, Cheyenne, Sheridan, Garden, Deuel, Grant, Arthur, and Keith Counties, the western parts of Cherry, Hooker, and McPherson Counties, and the northwestern corner of Lincoln County.

Map coverage varies from poor to excellent (see list of maps following the References, at end of text), but the sheets of the new 1:250,000 scale, that supplement the more-detailed new topographic maps of the United States Geological Survey, are very useful. Aerial photograph coverage is now complete, and there are county index-mosaics available. For general orientation, most workers rely upon highway maps of Nebraska, readily available at all gasoline stations, or upon the county maps of Nebraska prepared at two scales by the State Planning Board. Roads tend in some parts of the region to follow the usual mile-grid pattern, but the newer, paved highways, and many of the trails in the sparsely populated areas, often depart from this rectangular control.

Figure 1. Topographic divisions of Nebraska as recognized by G. E. Condra, and location of area studied.

FIGURE 1



Topographic regions of Nebraska (by G.E. Condra) and location of area studied.

The highest point in the region is near the southwestern corner of western Nebraska, southwest of Bushnell, in Kimball County, Nebraska, where the elevation is 5,424 feet, and the lowest point is along the Niobrara River, in Cherry County, Nebraska, with an elevation of about 2,640 feet. There is thus more than half a mile relief, or more precisely 2,784 feet.

The highest geomorphic surface in western Nebraska is the High Plains Surface, or top of the Ogallala (Kimball of Lugn, 1939). This was generally the summit of aggradation at the end of Ogallala time (Latest Pliocene), or the projection of this surface beveling older rocks, but it may have greater relief than is supposed.

The High Plains Surface appears to the eye to be rather flat, except where channeled by Early Pleistocene or younger valleys with associated loess-or-sand rims, but the present regional slope seems to be about 16 feet per mile east-northeast, compared with the southeasterly gradient of about seven feet per mile of the North Platte River. Structural contours have been constructed upon the High Plains Surface in western Kansas (Merriam, Guidebk Kans. geol. Soc., Conference 18), and it can be now approximated for much of western Nebraska by filling in the topography on sheets of the 1:250,000 scale to the elevation of the principal tablelands and other remnants.[1/] In any case, the

1/ Contours on the High Plains Surface are not available for eastern Colorado, but Cardwell (U.S. Geol. Surv., Circular 295, pl. 2, adapted by Malin, MS. of 1957, fig. 1) has contoured the base of the Ogallala for an area east and southeast of Limon, Colorado.

reconstruction of the High Plains Surface permits ready visualization of the probable appearance of much of western Nebraska at the end of the Tertiary, prior to the general dissection that began in the Earliest Pleistocene (Schultz and Stout, 1945, 1948, 1961; Stout, Dreeszen, and Caldwell, 1965).

The principal valleys in western Nebraska mostly drain in a general easterly direction today, but at the beginning of the Pleistocene much of the drainage was from northwest to southeast (Stout in Stout, Dreeszen, and Caldwell, p. 70, fig. 9-42a). Present rivers of importance are the White (but its former Hat Creek branch now flows to the Cheyenne), Niobrara ("Runningwater" or "L'eau qui court"), North Platte (with the Pumpkin /seed/ Creek, Lawrence Fork, and Blue Creek as major tributaries), and South Platte (with the Lodgepole Creek an important branch). Of these, the Niobrara River, Lodgepole Creek, and Lawrence Fork seem to be occupying shallower valleys, for reasons not readily explained.

The main "upland" areas consist principally of the Cheyenne Plain (or Tablelands), Perkins Plain (or Tableland), Wildcat Ridge, Box Butte Plain (or Tablelands), and Pine Ridge, all of which mostly represent remnants of the High Plains Surface and its extensions. This region constitutes, with the Sandhills areas, the main part of the "High Plains Section of the Great Plains Province" of Fenneman (1931, and map of physiographic provinces of the United States).

The northern boundary of the High Plains is usually taken, following Fenneman and D. W. Johnson, to be the north escarpment of the Pine Ridge, but this has been produced by differential erosion against the resistant sandstone concretions of Arikaree valley-fills (Monroe Creek and Harrison formations). Traced both westwardly into Wyoming and eastwardly into South Dakota, the Pine Ridge ceases to be a prominent topographic feature, but near its eastern terminus it is a slightly-modified fault escarpment (a true "State line fault").

North of the Pine Ridge in northwestern Nebraska, the present topography is wildly beautiful, being developed as the "Little Badlands" with intricate erosional forms upon the soft silt, clay, and sandstones of the White River Group, and farther north upon the still weaker Cretaceous shale and chalk. Fenneman (1931, and map) includes the dissected area north of the Pine Ridge in the "Unglaciated" portion of the "Missouri Plateau Section" of the Great Plains.

"Badlands" topography also characterizes three other districts in western Nebraska, but these are situated south of the Pine Ridge. The first occurs both east and west of the Scotts Bluff along the upper reaches of the North Platte, with westerly extension into the "Goshen Hole" of eastern Wyoming. The second is on the south side of the Wildcat Ridge along Pumpkin Creek, whereas the third is less prominent and situated near Sidney along the Lodgepole Creek. Other "Badlands" tracts occur in northeastern Colorado, south of Sidney, Nebraska, especially near New Raymer and Akron, Colorado.

SOURCES OF SUBSURFACE INFORMATION

Much of the information concerning the subsurface of western Nebraska must be derived from records of borings. More than eight thousand logs of oil-and-gas test-wells are presently on file with the Nebraska Geological Survey (Conservation and Survey Division, The University of Nebraska) in Lincoln for this region. About seven hundred of these records yield little information about the Pre-Tertiary Surface and Tertiary, usually because of depth of surface casing, but they can be used for Cretaceous and older rocks. Furthermore, distribution of the test-wells varies greatly (see Table 1 and Plates 2-4), with very dense concentration in areas of principal activity and wide spacing in districts of little exploration. Mapping in some detail is limited, therefore, to the main areas of exploitation, which occur in western Nebraska in the southwestern part of the panhandle region.

In this district of dense concentration of wells, only the number of wells per township is shown (Plate 3), but individual wells have been plotted outside it (Plates 2 and 4). Assuming reasonable skill and consistency, accuracy of interpretation must be considered to be largely dependent upon available logs, especially with respect to the configuration of the Pre-Tertiary Surface (Plate 2) and its paleogeology (Plate 4).

Although electric logs are preferred, other mechanical logs may be useful occasionally. Supporting data include sample-cuttings, rock cores or chips, and descriptions of

Table 1.-Distribution, by county, of the subsurface data for the Pre-Tertiary Surface in western Nebraska 1/

County	Number of wells	County	Number of wells
Kimball	2,784	Sheridan	25
Banner	1,764	Keith	20
Cheyenne	1,594	Cherry	14
Morrill	520	McPherson	13
Scotts Bluff . .	325	Arthur	9
Deuel	89	Grant	9
Sioux	75	Lincoln	6
Garden	75	Hooker	3
Box Butte	44	Total . . .	7,402
Dawes	33		

1/ See Figure 1 for area of study and Plate 3 for distribution, by township, of wells in Kimball, Banner, Cheyenne, Scotts Bluff, Morrill, and Deuel Counties.

samples and cores. Of these, the sample-cuttings provided by test-well operators must be used cautiously, for they are generally of poor quality and often contaminated. Also, they are seldom available for Tertiary and Late Cretaceous rocks. Since the "personal collection" of such samples for the younger rocks proved to be a necessary early step in evaluation and interpretation, a month in the summer of 1959 was devoted to collecting samples from wells then being drilled in the southwestern part of the Nebraska panhandle.

Additionally, the test-holes drilled as part of the State-Federal cooperative program of ground-water investigations have been most useful in supplying sample-cuttings, rock descriptions, and some point-electric logs. These records are excellent, for the most part, and the new ones are quite reliable because of the care taken in collection and description. Unfortunately, this coverage is available for only a part of western Nebraska. The drilling depth also is mostly restricted to the upper permeable intervals of the Tertiary, usually with penetration only into the upper part of the Brule (Oligocene). The few test-holes that have been drilled into the Cretaceous are thus of especial value.

METHOD OF APPROACH

All available subsurface information has been utilized as much as possible, but emphasis has been placed upon electric logs simply because they constitute the principal documentation. From these, an effort was made to pick the Cretaceous-Tertiary unconformity and as many traceable horizons below and above it as seemed practicable. In the preliminary work, nine electric-log cross-sections were constructed across the region, five from west to east and four from south to north.[1/]

1/ These cross-sections formed unwieldy work sheets, too large to be included in this report, but large size was necessary for detailed plotting (vertical scale is one inch equals fifty feet, which is full-scale, with horizontal scale of one inch equals one mile, thus vertically exaggerated 106 times). The full-scale logs were found to be superior for preliminary compilation because of the nature of these records and to insure greatest precision in correlation. One cross-section of this scale is included here as an example (see Plate 5, showing surface-subsurface relations of the White River Group in Scotts Bluff County, Nebraska). For contrast, Plate 6 (showing detailed electric-log characteristics from south to north along the 103°30' Meridian) illustrates the use of half-scale logs (vertical scale is one inch equals one hundred feet, with horizontal scale of one inch equals one mile, thus vertically exaggerated only 53 times). Such half-scale logs represent an excellent compromise with respect to scale, allowing horizontal and vertical relations to be evaluated more easily without extreme loss of log details. Greater reduction of logs for study is not recommended because of the loss of detail so necessary in establishing valid correlations and displaying regional subsurface relationships.

Sample cuttings have been also utilized, chiefly as a supplement to the electric logs and to verify lithologic characteristics at such critical contacts as the Cretaceous-Tertiary unconformity. These cuttings have come partly from oil test-wells and the remainder from wells of the State-Federal water-survey investigations; they were studied under a binocular microscope and calibrated with the proper electric-log intervals. The resulting logs were then incorporated into the network of electric log cross-sections.

Additional samples were studied upon occasion, especially those collected by the writer in 1959, and on numerous later field trips, from wells being drilled and from outcrops. The areas of concentration were at first mainly in the southwestern part of the Nebraska panhandle, but eventually most of western Nebraska was covered in such field reconnaissance and collecting from the Cretaceous and Tertiary. In the summer of 1963, the Cretaceous outcrops in the Goshen Hole of eastern Wyoming were studied in the field for several weeks, and ten days of reconnaissance were devoted also to northeastern Colorado. Only by such a combination approach and synthesis of subsurface and surface information can one hope to accomplish reasonable correlations and interpretations in the subsurface.

STRUCTURAL SETTING

Introductory Remarks

Previous Interpretations.--The recent marked increase in subsurface information allows progressively more-detailed interpretations of the geologic structure of Nebraska. Apparently the earliest structure map which shows the location of major Precambrian highs and lows, was made by G. E. Condra (*in* Condra, Schramm, and Lugn, 1931, p. 16, fig. 2). This map was sketchy, but five structurally-high areas and four basins were recognized. Using the subsurface data presented in the same publication, Lugn (1934) published the first contour map of the Precambrian surface. Next, Fuenning (1942) presented four structural maps on Cretaceous horizons. In addition to the well logs used by Lugn, logs of several wells drilled after publication of the report by Condra, Schramm, and Lugn (1931) were available to Fuenning.

The first really comprehensive map of the geologic structure of Nebraska was presented by Condra and Reed (1943, p. 2, fig. 2; revised by Reed in 1959). Included on this map is an interpretation of additional subsurface information resulting from the 1939 discovery and subsequent drilling for oil in the Forest City Basin. The 1949 discovery of oil in the Denver-Julesburg Basin made more subsurface information available and prompted Reed (1955) to compile a revised structural map of the State. Extension of oil and gas production into southwestern Nebraska in 1959 provided even more subsurface information, and this was utilized by Carlson and Reed (1961) in constructing a new structure map. Where present, the Greenhorn Limestone served as the datum for these two maps. In part of eastern Nebraska, where the Greenhorn is not present, a Pennsylvanian horizon (base of Missouri Series, Kansas City Group) was used as the datum. The latest structural contour map of the state is Carlson's (1966) "Configuration of the Precambrian Surface".

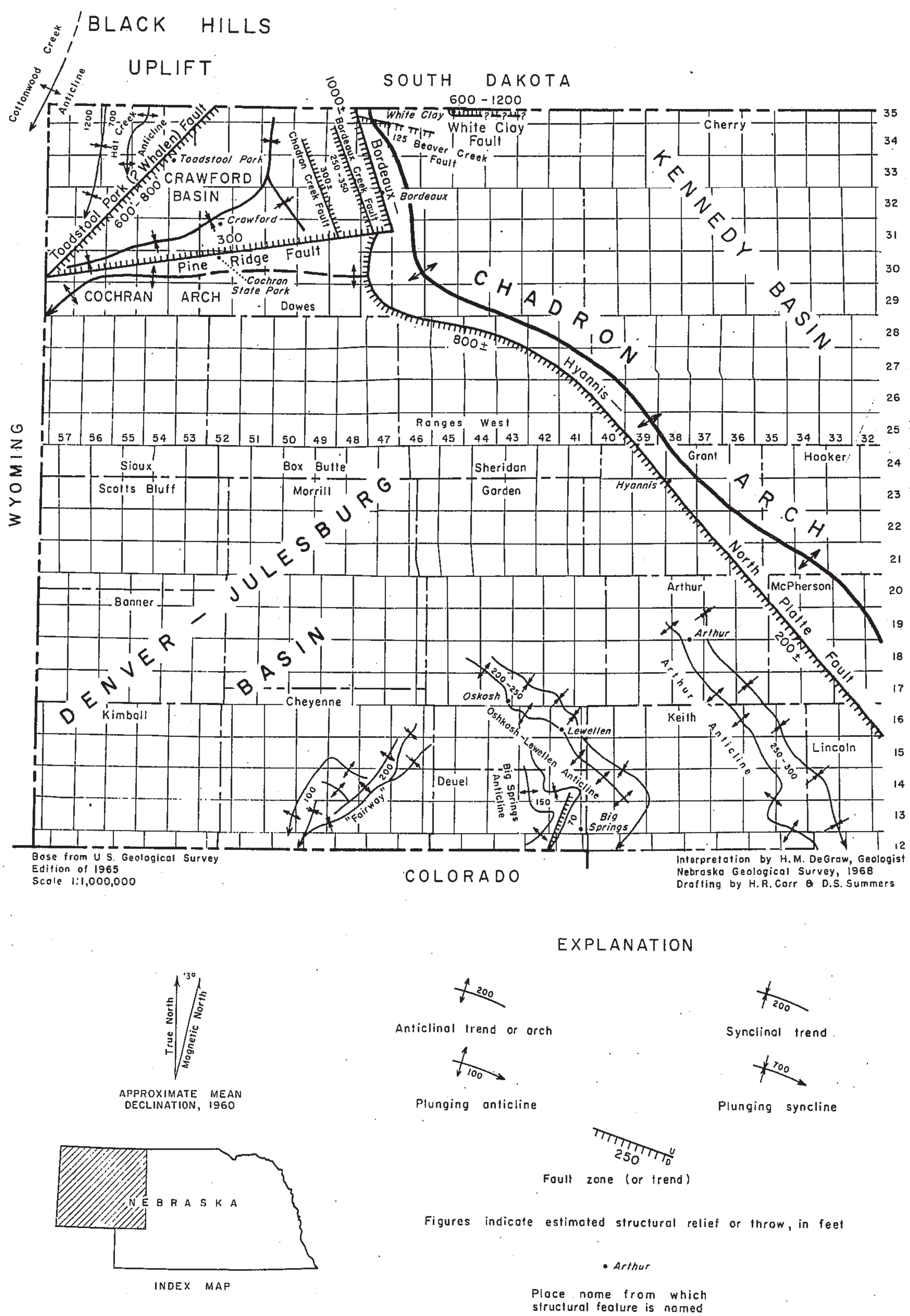
In nearly two decades of oil exploration in western Nebraska, a large number of both published and unpublished structural maps has been prepared, and these have allowed progressive refinement in delineation of structure. Even so, information for a large part of western Nebraska is so sparse that many of the maps showing geologic structure are highly interpretive.

General Relations.--The major structural features in western Nebraska are now fairly well known (Figure 2). The dominant structure is the Chadron Arch, which effectively separates the Denver-Julesburg Basin in the southwest from the Kennedy Basin to the northeast. Subsidiary structural features of the Black Hills Uplift also occur in the northwestern corner of the State.

Basis of Interpretation.--The following description of the structural features in western Nebraska is based not only on previous structural contour maps, but also considers an unpublished structural contour map of western Nebraska (DeGraw, MS.). On the latter, the datum used is the "X"

Figure 2. Structural features in western Nebraska. Based on an unpublished map of the author (Structure Contour Map--Top of "X" Bentonite, Western Nebraska). This is the revision of a map placed on open-file in 1962 at the Nebraska Geological Survey (Structural Contour Map--Top of Mowry Bentonite, Panhandle and Adjoining Parts of Western Nebraska).

FIGURE 2



STRUCTURAL FEATURES IN WESTERN NEBRASKA

(Interpreted from "X" Bentonite Datum of the "Graneros")

10 0 10 20 30 40

SCALE IN MILES

Bentonite, which is the lowest of four or five bentonites within the "Graneros Shale".[1]

1/ Because it is an easily-identified marker bed on electric logs, occurring throughout most of western Nebraska (except on part of the Chadron Arch) and much of the surrounding region, the "X" Bentonite is commonly used as a datum for contouring structure.

Use of Terms.--Two structural terms require definition. (1) Major structural features may be defined as those large-scaled folds and faults of regional extent. They are recognizable by relatively-large topographic expression, either surficial or buried, with a minimum amount of subsurface information. (2) Secondary structural features or subsidiary flexures may be defined as less-significant folds and faults associated with major ones. Because of smaller size, considerably more information is required for their recognition and delineation.[1/]

1/ Figure 2 is probably incomplete in this regard and because of scale some structural details that are known cannot be shown. In general, the secondary structures that have been delineated display 200-to 400-feet relief, but a few features with relief of 100 feet or less are included. Among the latter are certain positive and negative features in intrabasinal-low areas, as well as the most obvious domes, other anticlines, and synclines. Small flexures and faults are excluded as they require relatively-close control that is seldom available.

Fault Interpretation.--The faults shown on Figure 2 have been recognized from surface observations and maps, from subsurface data, or by combination. In surface studies, faulting in thick shales (the "Pierre", for example) may be obscure. In the subsurface, even under ideal conditions, it is difficult to establish fault trends, bifurcation, strike-and-dip relations, and throw. Subsurface control for most fault trends is usually poor, so details are mostly lacking, and interpretation is often subjective, susceptible to re-evaluation.

Chadron Arch

Surface Expression.--The Chadron Arch, a term used for the northern part of a structural ridge in Nebraska and South Dakota, is exposed only in a small area in the northeastern corner of Dawes County, the northwestern corner of Sheridan

County, and on northward into Shannon County, South Dakota. These exposed parts of the Arch, located about 16 miles northeast of Chadron, Nebraska, have been designated the Chadron Dome or Chadron Anticline. The total surface exposure within Nebraska aggregates about 35 square miles.[1/]

1/ Numerous manuscript maps showing the several domal features comprising the Chadron Anticline are preserved in the files of the University of Nebraska, Department of Geology Library, and other archives of the Department of Geology. In early years, Darton (1899, and later revisions) gave general descriptions and maps of this area. However, the late E. F. Schramm, A. L. Lugn, and many generations of students at the University of Nebraska revised this early work.

Rocks exposed on the Dome include the following: the upper part of the "Graneros Shale", the Greenhorn Limestone, the "Carlile Shale", and the "Niobrara Chalk", and the lower part of the "Pierre Shale", all of Late Cretaceous age; the Chadron and Brule formations of Tertiary age; and undifferentiated deposits of Quaternary age. The "Niobrara Chalk" is the most prominent formation there, owing to its resistance to weathering and characteristic, white to pale-orange color. Although the "Carlile Shale" crops out over several square miles, it is topographically low, and generally mantled by slope wash and alluvium. At only one presently-recognized outcrop, on the north side of the

White River, in sec. 33, T. 33 N., R. 47 W., Dawes County, Nebraska, is there exposure of the Greenhorn Limestone and "Graneros Shale" (Moore, MS. of 1954). It should be noted that, owing to the scale of the paleogeologic map (Plate 4) the outcrop and subcrop patterns for the Cretaceous formations of the Chadron Dome area are generalized.

Subsurface Extension.--The Chadron Arch is the northernmost part of a linear, sinuous ridge that extends southeastwardly from the Black Hills, across Nebraska and much of Kansas. It may be separated from the Black Hills by a structural sag. In Kansas, near its southern terminus, this structural ridge is appropriately called the Central Kansas Uplift, but the southern, poorly-defined extension is known as the Pratt Anticline (Merriam, 1963, p. 182). The Pratt Anticline has a northeasterly trend, whereas the Central Kansas Uplift is axially directed more nearly northwest. In northwestern Kansas and southwestern Nebraska, the ridge is named the Cambridge Arch, where the trend is north-south to slightly northeast-southwest.

In cross-section the Chadron Arch is apparently asymmetrical. Originally regarded as a simple fold with the steeper dip on the western or southwestern flank, the Arch now appears definitely to be faulted along its western and southwestern flanks. However, it may be faulted even along its eastern or northeastern flank.

Bordeaux-Hyannis-North Platte Fault Trend.--Along the western and southwestern flank of the Chadron Arch, the pronounced change in altitude of the Cretaceous formations is interpreted as due to faulting. In early years of study, and to some extent even now (Wulf, 1964) there was controversy among geologists as to whether this altitude difference was due to faulting or produced by steepening of dip. On the basis of structural and general mapping of the pre-Tertiary paleogeology and consideration of regional tectonic patterns, the fault-zone concept seems valid so is here accepted. The fault zone constitutes an excellent separation of the Chadron Arch from the Denver-Julesburg Basin.

This important fault zone is best designated the Bordeaux-Hyannis-North Platte Fault Trend, from the place names defining it (Figure 2)1/. The hyphenated name seems

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1/ Bordeaux is a siding along the Chicago and Northwestern Railroad, in the SE¼, sec. 3, T. 32 N., R. 47 W., eastern Dawes County, Nebraska. Hyannis, a county seat, is located along State Highway 2 in sec. 6, T. 23 N., R. 38 W., Grant County, Nebraska. North Platte is situated outside the study region, at the confluence of the South and North Platte Rivers, in Lincoln County, Nebraska.

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necessary because of length, change in strike, and probability that the trend consists of two or more faults. Alternatively, the trend could be considered as composed of separate faults, each individually named.

The strike of the Bordeaux segment of the fault trend is approximately N. 20° W. The amount of vertical displacement is difficult to determine, owing to confusion with other structures in the adjacent basin; it is estimated at this time as ranging from 300 to about 1,200 feet, but more likely 500 to 1,000 feet. The Bordeaux segment probably bifurcates to the north, near the Nebraska-South Dakota boundary. One fork maintains the established trend of the Bordeaux Fault segment but with a smaller displacement, probably of the order of 300 to 500 feet, whereas the west-northwest fork has a strike estimated as N. 50° W. to N. 70° W., with throw possibly as much as 1,000 feet.

It is likely that the southern part of the Bordeaux segment and northern part of the Hyannis segment of this fault trend is a fault-complex. As presently interpreted, the vertical displacement for this part of the fault zone is of the order of 300 to 600 feet.

The average strike of the Hyannis and North Platte segments is N. 40° W. To the north, the strike of the Hyannis segment becomes progressively more westerly, increasing to as much as N. 80° W. The vertical displacement along the fault is variable, but it ranges from 100 to 800 feet, perhaps from 500 to 800 feet in the northwest. The throw along the North Platte segment ranges from 100 to 300 feet.

White Clay Fault.--This is a major fault related to the northerly plunge of the Chadron Arch and the northwesterly margin of the Kennedy Basin. It is sometimes humorously referred to as the "State Line" Fault, because of its location and east-west strike in Nebraska, along the State boundary, but there is a shift to a northwesterly strike in South Dakota. It was named by field geologists working in the area for White Clay, Nebraska, southeast of which there seems to be a physiographic expression of the fault reflected in the north face of the Pine Ridge escarpment. That part of the Pine Ridge immediately southeast of White Clay and south of the State boundary may be a fault-line escarpment, for the Pine Ridge as a physiographic feature becomes obscure a few miles east of White Clay.

West and northwest of White Clay, the "Niobrara", and perhaps "Pierre", are margined by Brule and Chadron, so the structure must be inferred from the poorly-known surface as well as subsurface geology. The throw along the White Clay Fault is variously estimated to range between 600 and 2,000 feet, but the best estimate is 1,200 feet or less.

The southeastern or eastern extension of the White Clay Fault along the eastern flank of the Chadron Arch, or into the Kennedy Basin, is unknown. If marginal to the axis of the Arch, it would somewhat affect the mapping along the Arch (Plate 4). However, the interpretation of a fault subparallel to the Bordeaux-Hyannis-North Platte Trend, to produce an "anticlinal horst", seems to be the more expectable.

Related Faults.--Moore (MS. of 1954, p. 20) recognized two faults on the Chadron Dome, one of which is in South Dakota, each mapped with a strike of N. 75° W. and a throw estimated as 125 feet. The fault on the Nebraska side occurs along the southwestern side of the oldest outcropping formations on the Dome. As this fault has a strike that passes eastwardly into and is concealed by the alluvium of Beaver Creek, a tributary of White River, it is designated the Beaver Creek Fault. However, the most noticeable structural features on the Dome, according to Moore, were pseudo-structures produced by slump of the "Carlile Shale".

Kennedy Basin

Limits.--This basin was informally named by E. C. Reed some years ago, before 1949, after Kennedy, Nebraska, located in T. 30 N., R. 30 W., in Cherry County. It is defined here (Figure 2) as that structurally-negative portion of north-central Nebraska that is bounded on the southeast by the Sioux Ridge and on the southwest by the Chadron Arch. It is the southerly extension of the Williston Basin of North Dakota, traceable through central South Dakota, into Nebraska.

Only the southwestern flank of the Kennedy Basin is included in the mapped area (Figure 2; Plates 2, 4). The boundary between this basin and the Chadron Arch is arbitrary. Little is known about the structure of the basin, due to insufficient study and inadequate subsurface information. Consequently, secondary structural features have not been recognized. Even the possibility of a marginal fault along the eastern flank of the Chadron Arch is presently unverifiable.

Denver-Julesburg Basin

Limits.--The Denver-Julesburg Basin (Figure 2) is a large, asymmetrical structure that occurs in eastern Colorado, eastern Wyoming, western Nebraska, and northwestern Kansas, but extends northwardly a short distance into South Dakota. Its western flank is steeper, parallel to the Rocky Mountain Front, with a less prominent escarpment on the east side, next to the Chadron Arch. In general, the basin is bounded by the Front (Laramie) Range on the west, the Hartville Uplift to the northwest, the Black Hills Uplift on the north, the Chadron-Cambridge Arch on the northeast and east, the Las Animas Arch to the southeast, and the Apishapa Uplift at the south.

Additionally, these boundaries of the Denver-Julesburg may be more precisely defined by marginal fault systems, among which are: (1) the Golden Fault, next to the Front Range; (2) the Whalen Fault, in eastern Wyoming; (3) the Toadstool Park Fault (which may be an extension of the Whalen Fault), in northwestern Nebraska and southwestern South Dakota; and (4) the Bordeaux-Hyannis-North Platte Fault Trend along the Chadron Arch in western Nebraska.

For much of the southwestern part of the region studied (Figure 2), the structural features usually emphasized are of relatively small-scale, with less than 50 feet of structural closure, but they are economically important. Because of small size, they cannot be identified without detailed mapping of the data now available for the closely-spaced wells. Such small features have not been included in the following discussion.

Secondary Structures.--In the southeastern part of the region shown in Figure 2, secondary structures consist principally of four anticlinal-synclinal couplets, for three of which the synclines are on the northeastern or updip slope of the basin. There are two preferred orientations: a northwest-southeast trend that tends to parallel the Chadron Arch, and a northeast-southwest trend that is perpendicular to the Arch and subparallel to the Las Animas Arch on the southeast. These may be described in order from the basin toward the Chadron Arch (Figure 2), as the "Fairway", Big Springs, Oshkosh-Lewellen, and Arthur folds.

"Fairway" Folds.--A complex of additional anticlinal-synclinal couplets occurs in southeastern Cheyenne County. These are well known to geologists of the petroleum industry, who have called the district the "Fairway" of western Nebraska, because of associated oil and gas fields. It was in this "Fairway" that the first oil discovery was made in 1949, in the Nebraska portion of the Denver-Julesburg Basin. Both northeast-southwest and east-west trends occur, with the former predominant and characterized by anticlines and synclines that plunge southwesterly. Structural relief is of the order of 50 to 100 feet for the east-west trend, but 100 to 250 feet for the northeast-southwest trend.

Big Springs Fold.--In eastern Deuel County, and possibly extending into Logan County, Colorado, there is a small, less complex, anticlinal-synclinal couplet (Figure 2) that requires special mention. The positive element is at least 15 miles long in Nebraska, and it is named the Big Springs Anticline for the gas field located on its southeastern crest.1/ Structural relief between the anticline and syncline ranges from 100 to 150 feet, part of which is due to faulting. As can be seen in Figure 2, the anticlinal and synclinal axes have sinuous traces, the southern element trending N. 21° E.

Oshkosh-Lewellen Fold.--This is a prominent anticlinal-synclinal couplet with a northwest-southeast trend subparallel to the Chadron Arch (Figure 2). It is named the Oshkosh-Lewellen Anticline for two villages along the North Platte River that are located near its crest.2/ The "Lisco Anticline", a surface structure northeast of Lisco (personal communication from T. M. Stout, 1968), may represent the supplementary northeast-southwest trend for this couplet, rather than a continuation of the Oshkosh-Lewellen Fold.

1/ This gas field was named for Big Springs, Nebraska, situated along the South Platte River, in the southeastern part of T. 13 N., R. 42 W., Deuel County.

2/ Oshkosh is located in the southeastern part of T. 17 N., R. 44 W., and Lewellen is in sec. 22, T. 16 N., R. 42 W., both in Garden County.

However, subsurface data for this county are still insufficient for adequate interpretation. The Oshkosh-Lewellen anticlinal axis extends for at least 40 miles and coincides with the modern river course between Oshkosh and Lewellen, where it strikes N. 65° W. It has an average trend of N. 52° W. northwest of Oshkosh. This fold axis has a strike of N. 42° W. southeast of Lewellen, and it extends into western Keith County. The synclinal trend is generally parallel to that of the Oshkosh-Lewellen Anticline, with the distance between the axes varying from three to six miles. The structural relief is of the order of 200 to 250 feet. To the south, the strike of the syncline appears to change abruptly, to about N. 35° E.

Arthur Fold.--The easternmost anticlinal-synclinal couplet, in that part of the Denver-Julesburg Basin considered here (Figure 2), is named for Arthur, Nebraska.1/ The fold has

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1/ Arthur is located on the northeastern flank of the anticline, in sec. 34, T. 19 N., R. 38 W., central Arthur County.

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a length of more than 50 miles and an average strike of about N. 36° W., nearly parallel to the Hyannis-North Platte segment of the main fault trend. The anticlinal and synclinal axes are about four to six miles apart and the structural relief is of the order of 250 to 300 feet.

Related Faults.--Few faults have been recognized in the southwestern part of the Denver-Julesburg Basin (Figure

2). However, small-scale faults occur locally in at least three areas: in the northeastern part of Kimball County, along the "Fairway" trend in eastern Cheyenne County, and along the eastern flank of the Big Springs Anticline in Deuel County. The latter is generally known as the Big Springs Fault.1/ These faults are not considered further

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1/ The other anticlinal-synclinal couplets of this region (Figure 2) may also have associated faults, but these have not been recognized, if indeed present.

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in the present study, even though they have significant economic importance.

Near the northern margin of the Denver-Julesburg Basin, in the transitional area between that basin and the Powder River Basin, there are additional folds and faults that require separate discussion. Some of these are near the rim of the Powder River Basin (see map of Pierce, Girard, and Zapp, 1952) and others are associated with the Black Hills and related uplifts. These are considered in following sections.

Cochran Arch

Definition and Limits.--This is a structural feature (Figure 2), here recognized for the first time to occur in the northwestern part of Nebraska and southwesterly into eastern Wyoming. It is situated near the northern margin of the Denver-Julesburg Basin, with its name derived from

Cochran State Park, near Crawford, Nebraska.[1/] The Arch,

1/ The Cochran State Park is situated on the Arch along Highway 2 south of Crawford, in sec. 3, T. 30 N., R. 52 W., southwestern Dawes County.

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which separates the main Denver-Julesburg Basin from its northernmost subsidiary basin (Crawford Basin, defined later), has a general east-west trend, and plunges west. Near its western limit, its trend shifts southwesterly, with S. 50° W. strike, probably subparallel to the Whalen Fault trend. This Arch is best developed in Sioux County, Nebraska, where the maximum relief of the structure above the adjacent depressions is of the order of 200 to 400 feet.

Related Faults.--An east-west fault, here designated the Pine Ridge Fault, occurs on the northern flank of the Cochran Arch (Figure 2). It is a gravity fault, downthrown to the north with throw of about 300 feet and strike of N. 82° E. This fault is limited on the east by the Bordeaux segment of the Bordeaux-Hyannis-North Platte Fault Trend and on the west by the Toadstool Park Fault (defined later, possibly an extension of the complex Whalen Fault Zone). A small fault cuts at least part of the Gering Formation, along Highway 2 south of Crawford, Nebraska; it was illustrated by Darton (1899, pl. 93; reprinted later) and by Schultz and Stout (1961, p. 27, Fig. 15).

Crawford Basin

Definition and Limits.--This basin is here named and defined for Crawford, Nebraska.1/ It occurs (Figure 2) in an area

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1/ Crawford is located at the junction of Highways 2 and 20, in secs. 3 and 10, T. 31 N., R. 52 W., in western Dawes County, Nebraska.

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of about 33 townships in northwestern Nebraska, with perhaps four adjacent townships in South Dakota. It is bounded on all sides by faults: by the Toadstool Park Fault (? Whalen Fault) to the northwest, the Bordeaux segment of the Bordeaux-Hyannis-North Platte Fault Trend on the northeast and east, and by the Pine Ridge Fault to the south.

Secondary Structures.--The Crawford Basin is probably the most complex structural area for its size presently recognized in western Nebraska. Subsurface and surface information is insufficient to delineate fully all of the secondary structures present, but there appear to be two intrabasinal lows and at least two local highs. The deepest part of the main basin is in T. 30 N., R. 57 W., Sioux County, Nebraska, near the intersection of the Toadstool Park and Pine Ridge Faults.

A secondary basin occurs in the vicinity of the South Dakota-Nebraska boundary, near Wayside, Nebraska. A domal area occurs in the southeastern part of T. 33 N., R. 52 W., and adjacent townships in western Dawes County. The second high is located mainly in T. 32 N., R. 49 W., near the center of Dawes County.

Related Faults.--Two intrabasinal faults that margin a small graben have been identified in the eastern part of Dawes County, Nebraska: the Chadron Creek and Bordeaux Creek Faults. Although trends and extent cannot be accurately determined, an anlysis of subsurface data and present topography suggests that they both strike about N. 20° W. This is subparallel to the trend of the Bordeaux segment of the regional fault trend. Both faults probably project southward to intersect the Pine Ridge Fault, but their northerly extensions have not been determined. It is suggested also that the two faults may extend across the basin, to the northwest bifurcation of the Bordeaux segment of the regional fault zone.

The faults are named for Chadron Creek and Bordeaux Creek, since the lower courses of these streams appear to coincide with the strike. Each is a normal fault, with the former showing about 300 feet of throw, downthrown east, and the latter 250 to 350 feet of throw, downthrown west.

Black Hills Uplift

Surface Expression.--The Black Hills Uplift is a major structural feature that occurs mainly north of the region shown in Figure 2, in southwestern South Dakota and adjacent part of Wyoming. Its surface expression is that of an elliptical dome or brachy-anticline, approximately 125 miles long by 65 miles wide. The generally-accepted limits of the Uplift are the outermost hogback ridges formed by the basal sandstones of the Dakota Group (Cretaceous).

Subsurface Extension.--Cretaceous strata marginal to the Black Hills become progressively younger outwardly. However, the domal structure is peripherally obscure, since: (1) resistant beds become scarcer outwardly; (2) there are some subsidiary structures; and (3) there has been planation and also deposition in relation to the Tertiary and Pleistocene episodes on the flanks of the uplift.

Secondary Structures.--South from the Black Hills, in Fall River County, South Dakota, Rothrock (1931a, 1931b, 1938, 1949, and 1955) recognized three plunging anticlines with axes in a fan-like arrangement: (1) the Chilson or Hat Creek Anticline,[1] extending southward along Hat Creek into

1/ Apparently named by Rothrock (1931) for Hat Creek, a southerly tributary to the Cheyenne River, in eastern Wyoming, northwestern Nebraska, and southwestern South Dakota.

northwestern Nebraska; (2) the Cascade Anticline,[2] the

2/ Named by Rothrock (1931) for Cascade Springs, in southwestern South Dakota, which lies at the northern end of the structure.

eastern fold; and (3) the Cottonwood Creek Anticline,[3] the

3/ Named by Rothrock (1949, p. 43) for Cottonwood Creek, in southwestern South Dakota.

western fold.

Of these three folds, only the Hat Creek Anticline extends into Nebraska, but its axis cannot be confidently defined at present.[1/] Both the Hat Creek and Cascade Anticlines are

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1/ The anticlinal axis surely extends along Hat Creek to a point at least three miles south of the South Dakota-Nebraska boundary, where it may turn southwesterly, perhaps coincident to the present course of Hat Creek.

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truncated by the Toadstool Park Fault, the former in northwestern Nebraska and the latter in Fall River County, South Dakota. The Cottonwood Creek Anticline extends into Wyoming just north of the Nebraska-South Dakota boundary. The east flank of the Cottonwood Creek Anticline and the west flank of the Hat Creek Anticline rim an unnamed, southward-plunging syncline.

Related Faults.--A major fault zone, the Toadstool Park

(?Whalen) Fault Trend,[1/] extends across the northwestern

1/ Toadstool Park is a well-known tourist and geological attraction (Darton, 1899; Schultz and Stout, 1955, 1961) situated northwest of Crawford, in sec. 8, T. 33 N., R. 34 W., Sioux County, Nebraska. The fault is long-recognized and an obvious feature, despite recent comment (Clark, 1968) concerning it. The fault, which bifurcates in several places and has numerous related subsidiary faults, was mapped by E. F. Sabatka (MS. of 1953) and in the period 1933-1940 by T. M. Stout (personal communication, 1968). The surface throw, according to Sabatka, is between 64 and 50 feet, and the strike at Toadstool Park is N. 58° E., with an angle of dip of 78° SE.

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corner of Nebraska, and effectively defines the Crawford Basin from the Black Hills Uplift. The subsurface fault trend has an average strike of about N. 45° E., and a throw of the order of 600 to 800 feet.

The Toadstool Park Fault is here suggested to be probably the northeastern extension of the Whalen Fault, named and defined by Schlaikjer (1935, p. 121) from the Goshen Hole, Goshen County, Wyoming. He described the Whalen Fault as a prominent, normal fault with a strike of N. 70° E. and a dip of 61° S-SE. The Arikaree (Miocene) sediments are brought down against White River (Brule Formation, Oligocene). Later workers (*see* map by Rapp, *in* Rapp, Visher and Littleton, 1957, pl. 1) have recognized a number of surface faults northeast of the Whalen Fault in eastern Wyoming; these have a considerable range in strike, from N. 30° E. to N. 50° E.

Topography and Structure

Principles.--The relationship between present topography and structure is especially pronounced in northwestern Nebraska, and five examples may be cited. (1) Present Hat Creek[1/] is entrenched at least partly along the axis of the Hat Creek Anticline. (2) Farther east, the White River flows approximately along the synclinal axis of the Crawford Basin, near Whitney, Dawes County, Nebraska. (3) South of this, the Cochran Arch and Pine Ridge Fault seem to coincide with portions of the Pine Ridge Escarpment and drainage divide, near Belmont and Glen, in central Sioux County and southwestern Dawes County, Nebraska. (4) Chadron Creek and Bordeaux Creek, also in Dawes County, Nebraska, flow along faults. (5) Still farther east, displacement along the

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1/ Hat Creek presently is a principal southerly tributary for the Cheyenne River, but as MacClintock, Barbour, Schultz, and Lugn (1936), Schultz (1938), and Schultz and Stout (1945, pl. 2, fig. 3; 1948, p. 559; 1963) have shown, it was in the Late Pleistocene a branch of the White River. Wanless (1923, p. 264-269, fig. 10) has called attention to the elbow of piracy, in the southern part of the Big Badlands, South Dakota.

White Clay Fault may account, in part, for the coincidence of its trend with that part of the Pine Ridge Escarpment southeast of White Clay, just south of South Dakota-Nebraska boundary.

"Agate Anticline." Named for Agate, Sioux County, Nebraska, this is a much-publicized "structure" that has been mapped and discussed since the early 1900's. It was probably first recognized by Harold J. Cook, but many geologists have accepted its validity. As described and mapped by Schramm and Cook (1921), the "anticlinal trend" is approximately N. 70° E., with two areas of closure. The larger closure occurs in sec. 15, T. 28 N., R. 55 W., and the smaller is located in sec. 3, T. 28 N., R. 54 W., both in east-central Sioux County. Structural closure was interpreted to be of the order of 200 to 240 feet. Two unsuccessful deep well tests, one in 1920 and one in 1938, were made on the principal "structure".

Structural contouring on the "X"-Bentonite datum fails to show an anticlinal subsurface structure in this area. However, the "Agate Anticline" is located approximately on a pre-Tertiary paleotopographic ridge with a trend of about N. 78° E. (Plates 2, 4). Thus, the "Agate Anticline" may be at least partly a reflection of ancient topography controlling Arikaree (Miocene) sedimentation, hence a "pseudo-anticline."

STRATIGRAPHIC CONSIDERATIONS

Emphasis here is given to the subsurface data and to the relation between subsurface and surface geology. An abundance of evidence from the subsurface, including more than 7000 well logs that yield information on the pre-Tertiary unconformity (Table 1), makes possible the projection of many units from exposed to concealed situations. The basic geologic column for Sundance and overlying strata in western Nebraska is shown as Table 2; all of the post-"Dakota" units, except possibly the "Lance" and "Transition zone" of the "Pierre", are exposed there, whereas the "Dakota", Morrison, and Sundance are known only from the subsurface.

Thirteen reference horizons ("a" through "m" from the oldest to youngest), shown in the legend for Plates 6, 7 and 8 (all in pocket), were used in preparation of the geologic cross sections and maps. Of these horizons, twelve were contoured as part of this study, and the present topography (the modern-day surface "m") has been contoured by the United States Geological Survey. These datum surfaces warrant special discussion. The Pre-Tertiary Surface is discussed first and in greater detail because it is considered to be the key stratigraphic horizon. The other horizons are considered in order from the modern surface downward.

Pre-Tertiary Surface and Interior Paleosol Complex

The unconformity and weathered surface at the base of the Tertiary section (Table 2, identified as horizon "e"

Table 2.-Sundance and overlying strata in western Nebraska

		Stratigraphic Units (Exposed units indicated by asterisk,*)	Thickness 1/ (feet)
QUATERNARY		*Undifferentiated 2/	0-560
TERTIARY	PLIOCENE	*Ogallala 3/	0-543±
	MIOCENE	*Hemingford 4/	0-520
		*Arikaree 5/	0-626
	OLIGOCENE	*White River 6/	0-687
CRETACEOUS	"LARAMIE"	"Lance"	0-368
		*"Fox Hills"	0-274
	"PIERRE"	"Transition"	0-1,205
		"Undifferentiated"	0-4,600
	"NIOBRARA"	*Niobrara (and *Codell)	270-475
	"BENTON"	*"Carlile"	140-225
		*Greenhorn	15-35
		*"Graneros"	185-355
	"DAKOTA"	"Upper Dakota" (Omadi; D, G, and J Sands)	190-410
		"Middle Dakota" (Skull Creek)	30-265
		"Lower Dakota" (Fall River-Lakota)	260-425
JURASSIC	MORRISON		135±
	SUNDANCE		160±
	(Pre-Sundance not included in this study)		

See following page for footnotes.

Footnotes for Table 2

1/ Thicknesses for Oligocene and younger units are composites from surface exposures in study area (oral communication, T. M. Stout, 1968); for "Pierre" and "Laramie" units from oil test-wells in southwestern part of Nebraska panhandle; and for units older than "Pierre" from oil test-wells in Chadron Arch area (Pre-Tertiary erosion not considered).

2/ Includes Broadwater and younger sediments.

3/ Includes Kimball, Ash Hollow, and Valentine, from youngest to oldest.

4/ Includes Sheep Creek and Marsland, from youngest to oldest.

5/ Includes Harrison, Monroe Creek, and Gering, from youngest to oldest.

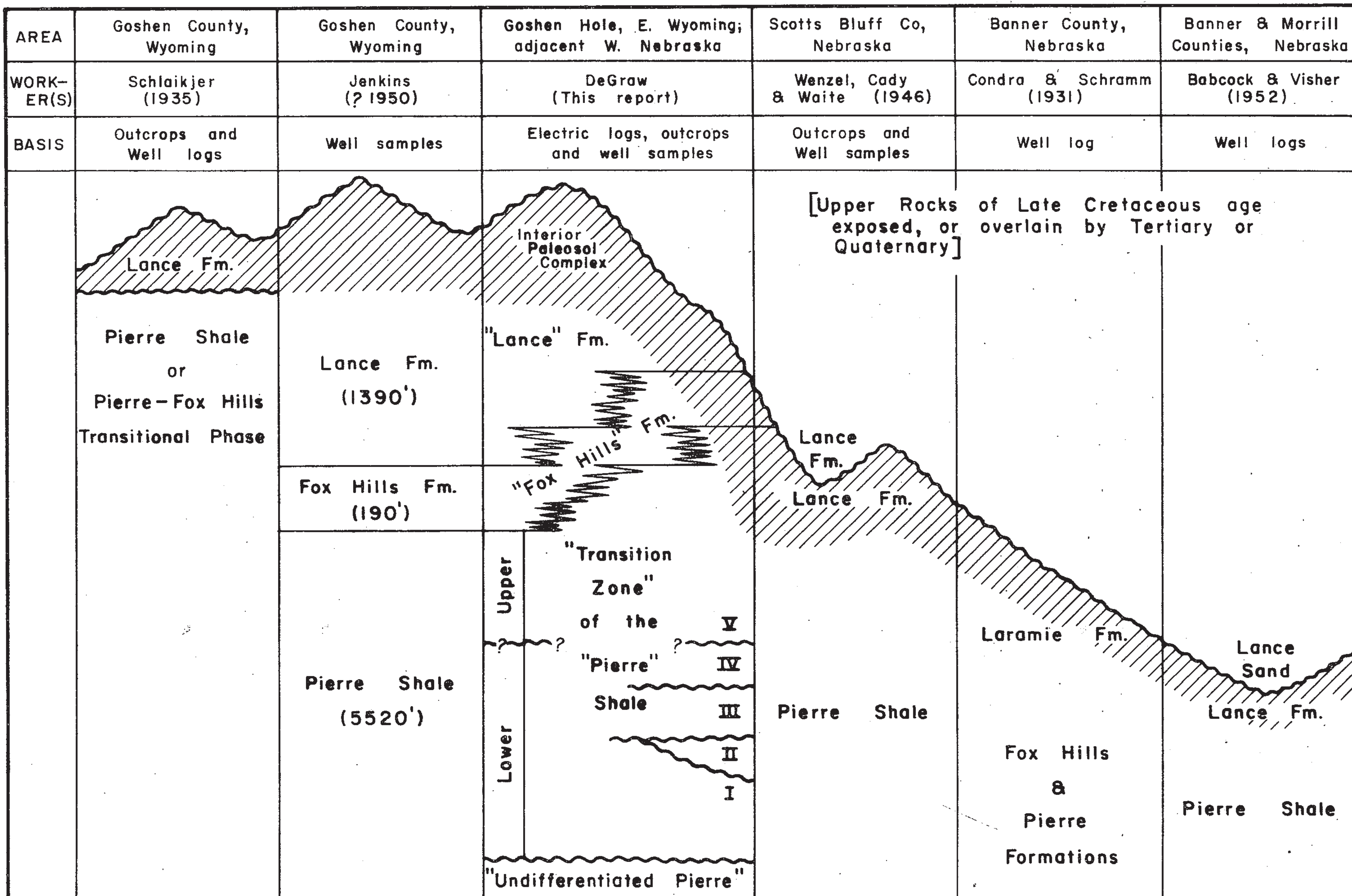
6/ Includes Brulo (Whitney above, Orella below) and Chadron from youngest to oldest.

on the cross sections) is of paramount importance in interpreting the subsurface relations in western Nebraska (see especially Plates 1-2, 4, 6-8; Figures 4-5). Where the Chadron sediments overlie it, this unconformity is clearly a Pre-Chadron Surface. However, along the west margin of central Sioux County, Nebraska, several hundred feet of fine-grained sediments underlie unquestioned White River. These sediments may be older White River or possibly of Eocene, Paleocene, or even Late Cretaceous age.

The Chadron is known to rest on rocks as old as "Dakota" in Sheridan County, Nebraska, where, according to E. C. Reed (in Schultz and Stout, 1955, p. 22) the top of the Morrison is separated from the base of the Chadron by only 25 feet of "Dakota" beds. In part of Dawes and Grant Counties, probably Cherry County also, the Chadron is interpreted as resting on "Dakota", but in at least one place in Sheridan County (a well in sec. 14, T. 30 N., R. 45 W.) there is reason to conclude that the Chadron rests directly on the Morrison (see Plate 4). Moreover, the possibility of Chadron directly on Sundance in the same general vicinity should not be excluded. Elsewhere, in Wyoming and Colorado, the Chadron may rest on rocks as

Figure 3. Stratigraphic correlation chart, rocks of Late Cretaceous age in part of western Nebraska and eastern Wyoming, comparing terminology of this report with that of earlier workers.

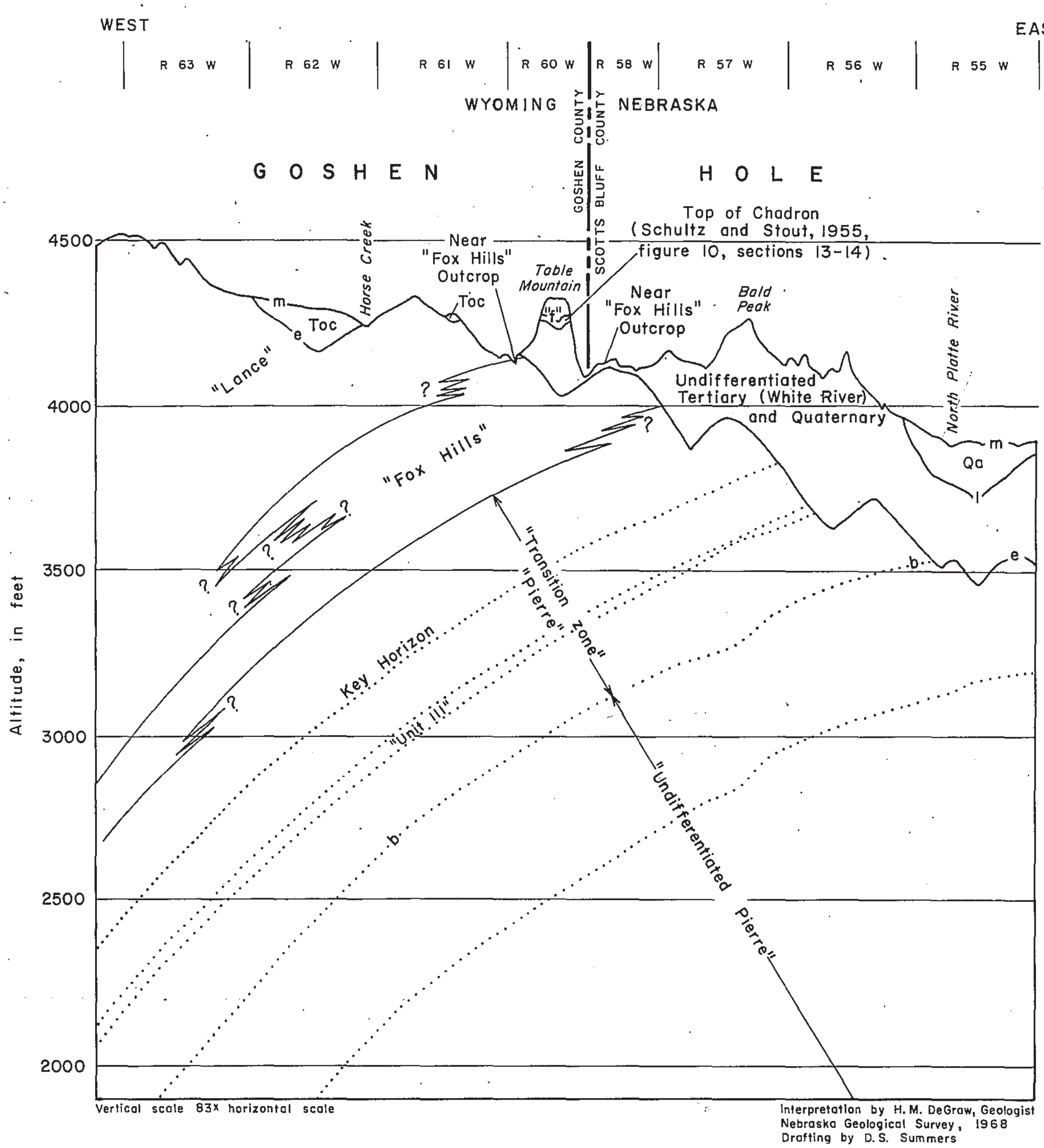
FIGURE 3



Stratigraphic correlation chart, rocks of Late Cretaceous age in part of Western Nebraska and Eastern Wyoming, comparing terminology used in this report with that of earlier workers.

Figure 4. Diagrammatic profile section of the Goshen Hole in eastern Wyoming and western Nebraska (approximately nine miles south of the 42° parallel), showing surface-subsurface relations of Late Cretaceous strata.

FIGURE 4



EXPLANATION

Bedding surfaces or unconformities within the "Pierre" (inferred time lines)

Contacts questioned where correlation is uncertain.

Letter symbols explained in text and in legend for Plates 6, 7, and 8 (in pocket)

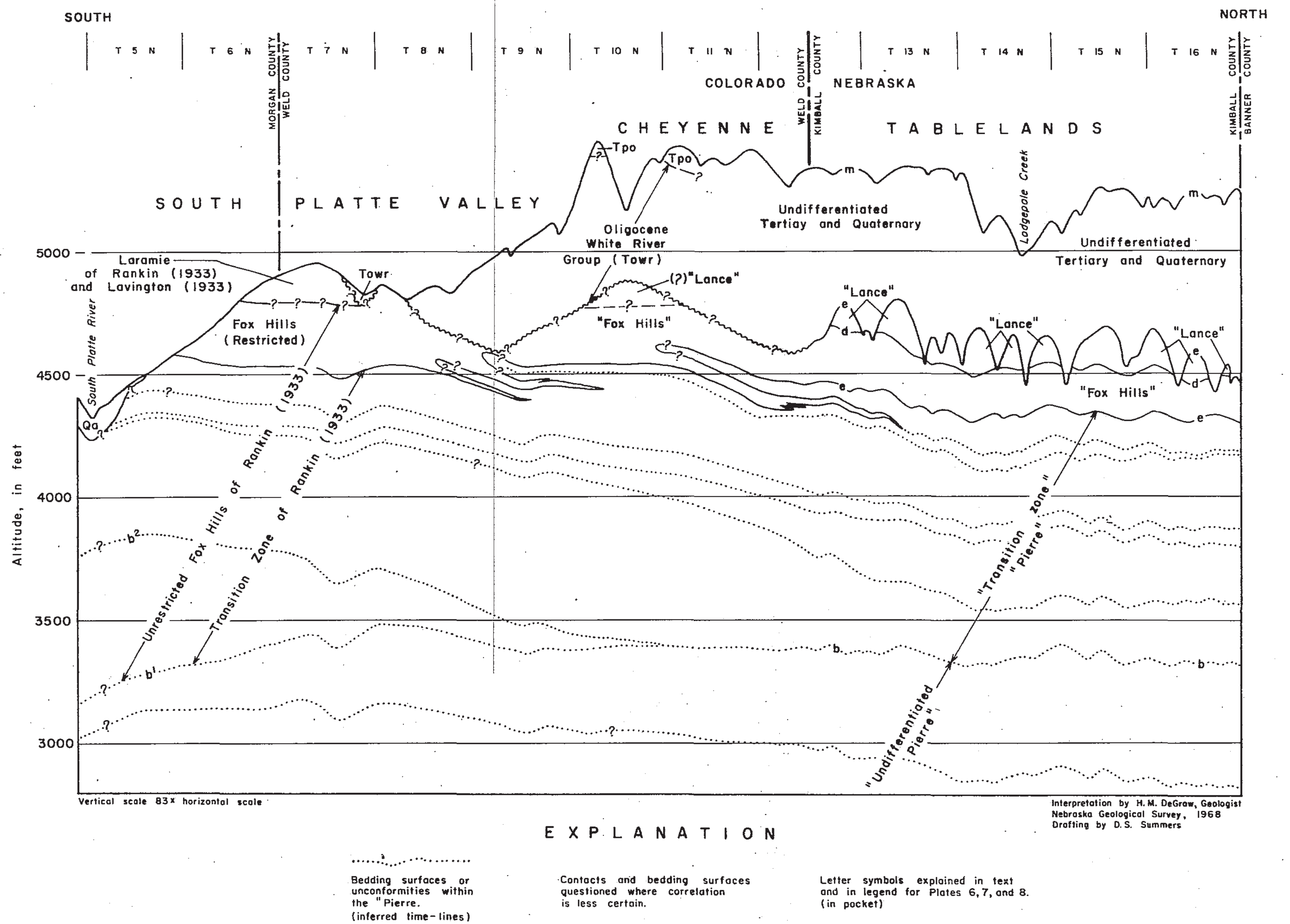
DIAGRAMMATIC PROFILE SECTION OF THE GOSHEN HOLE IN EASTERN WYOMING AND WESTERN NEBRASKA (APPROXIMATELY NINE MILES SOUTH OF THE 42° PARALLEL) SHOWING SURFACE-SUBSURFACE RELATIONS OF LATE CRETACEOUS STRATA

5 0 5 10

SCALE IN MILES

Figure 5. Diagrammatic profile section of northeastern Colorado and western Nebraska (near the 104° meridian) showing surface-subsurface relations of Late Cretaceous strata.

FIGURE 5



DIAGRAMMATIC PROFILE SECTION OF NORTHEASTERN COLORADO AND WESTERN NEBRASKA (NEAR THE 104° MERIDIAN) SHOWING SURFACE-SUBSURFACE RELATIONS OF LATE CRETACEOUS STRATA old as Precambrian[1/] to as young as latest Eocene

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1/ One locality where Chadron fossils occur commonly on granite is at the north entrance to North Park, near the Wyoming-Colorado boundary, just south of Mountain Home, Wyoming (personal communication from T. M. Stout, 1968).

(Schultz and Stout, 1955, p. 22).

In one area of western Nebraska the Pre-Tertiary Surface is overlain by probable Arikaree sediments: this subsurface occurrence is in four townships, T. 16-17 N., and R. 55-56 W., in Kimball and Banner Counties, Nebraska (see Plate 4).

The relief of the pre-Tertiary surface below a cover of Chadron or Arikaree sediments is considerable in western Nebraska, as well as in the immediately adjacent region. As is shown in Plates 1, 2, 4, 7 and 8, it commonly exceeds 200 feet in the subsurface, locally approximating 500 feet.

Outcrops show similar relief on the Pre-Chadron Surface. In northeastern Colorado, this surface is exposed near Sterling and New Raymer (Schultz and Stout, 1955, p. 32; Mather, Gilluly, and Lusk, 1928, p. 99; Lavington, 1933, p. 408; Galbreath, 1953, p. 12; and F. E. Moore, 1963, p. 162). Farther south, near Akron, Colorado, the Chadron rests unconformably with noticeable relief on Cretaceous (personal communication from T. M. Stout, 1968). In the Goshen Hole of eastern Wyoming, the Chadron likewise rests with moderate relief upon Cretaceous, principally "Lance" (Schlaikjer, 1935a-c; Schultz and Stout, 1955, fig. 10;

Wenzel, Cady, and Waite, 1946, p. 53; and Rapp, Visher, and Littleton, 1953, p. 25). Similarly, in southwestern South Dakota, the Chadron valleys were deeply incised in the "Pierre" through the Big Badlands, which can be seen especially well southwest of Interior (Schultz and Stout, 1955, pp. 24-25, 32-33; Clark, 1937, 1968), a situation interpreted somewhat differently by Pettyjohn (1966, pp. C64-C65).

In most places the rocks truncated by the Pre-Tertiary Surface show evidence of deep weathering prior to burial (Figure 3; Plates 4, 7-8). These beds constitute the Interior Paleosol Complex, which are strikingly varicolored in a generally regular sequence. Where developed upon "Undifferentiated Pierre" and the soil profile is complete, red shale normally occurs at the top of the alteration complex. Below it, the profile is characterized by color bands that change progressively downward from lavender, brown, yellow, grayish black with limonitic streaks, to the primary black or medium to dark-gray coloration characteristic of the unaltered "Pierre" (Schultz and Stout, 1955, fig. 3; Pettyjohn, 1966). Where developed upon "Lance", as in and near the outcrops of the Goshen Hole, Wyoming (Schlaikjer, 1935a-c; Schultz and Stout, 1955, p. 24, fig. 10), special studies have been made of this relation (Figures 3-4; Plates 7-8; DeGraw, 1966.[1/]

1/ Marginal to the Chadron valleys in several areas of both "Pierre" and "Lance" exposures (personal communication from T. M. Stout, 1968) groundwater movements in Chadron as well as other times seemingly resulted in migration of iron compounds, thus disturbing or even reversing the regularity of the normal sequence of color bands. Similar color zonation also has been observed in the present study to occur at the top of weathered "Fox Hills" and "Transition Pierre."

In the eastern extension of the Goshen Hole, the Nebraska subsurface (Figure 3) shows beds above this altered Pre-Tertiary Surface that are actually Chadron but were assigned to "Lance" by Wenzel, Cady, and Waite (1946, pp. 53-59), and by Babcock and Visher (1952, pp. 7-8).

In the Goshen Hole proper, in Goshen County, Wyoming, the base of the weathered interval was considered by Schlaikjer (1935-a-c) to be the Lance-Pierre contact, whereas the view presented here (Figures 3-4) is that no unconformity exists at this horizon, such as Schlaikjer assumed. This so-called "contact" actually transgresses several hundred feet of Cretaceous section.

Following the development of the Interior Paleosol Complex, perhaps inadvisedly termed the "Eocene Paleosol" by Pettyjohn (1966), there was incision of Chadron valleys and reworking of this supposed laterite or sublaterite (Schultz and Stout, 1955; Vondra, MS. of 1958; Pettyjohn, 1966). Such relations, clear in outcrops, are subject to several interpretations when encountered in the subsurface.

Quaternary and Younger Tertiary Surfaces

Eight reference horizons younger than the base of the Tertiary (Pre-Tertiary Surface) are used in several of the illustrations (see especially Plates 6-8) to show the relations of the subsurface Tertiary and Pleistocene strata to the present-day land surface. These horizons are discussed below, in reverse order from "m", the Modern Surface, downward to "e", the Base of the Tertiary.

Modern Surface ("m").--This horizon is the present-day topographic surface. Part of this surface, formed at the end of Ogallala aggradation, may be termed the High Plains Surface or End-Tertiary Surface[1/]; an equivalent pediment on older rocks has been described by Buffington (MS. of 1961). The younger surfaces included in the present-day topography are those of loess-mantled Pleistocene and Recent valley-fills or of colluvium along slopes. All are lower topographically

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1/ The top of the Kimball marks the end of Ogallala as well as end of Tertiary sedimentation, and its capping caliche is mantled by a thin cover of loess and soils, progressively modified at least in part by later soil-forming processes (calichification). Early Pleistocene drainages were incised below this High Plains Surface, and there were numerous cut-and-fill episodes and piracies throughout the Pleistocene (Stout, Dreeszen, and Caldwell, 1965, figs. 3-7, 9-41A, 9-42a).

than the High Plains Surface because the base levels that controlled erosion during the cut-and-fill episodes of the Pleistocene and Recent generally were progressively lowered.

Base of Alluvium ("1").--This, for the most part, is taken to be the base of recognized alluvial-fills in modern valley situations. It is, therefore, an unconformity and undoubtedly a composite surface of at least several of the younger, more deeply-incised Pleistocene valley-fills (Lugn, 1935; Schultz and Stout, 1945, 1948; Stout, Dreeszen, and Caldwell, 1965). Included on the profile of this surface, as shown on Plate 7, is a segment that possibly represents the "Assumed Base of Ogallala" Surface. ("k") The segment in question is that underlying the northernmost of the two deep channel-fills within the North Platte Valley. According to V. H. Dreeszen (personal communication, 1968), the lower part of this channel-fill may be a fluviatile sequence of Ogallala age even though located beneath a prominent Pleistocene terrace (the "third terrace" of Wenzel, Cady, and Waite, 1946, pp. 38-41). If this is the case, the "Base of Alluvium" Surface should be shown somewhat higher within the channel-fill at a position not now determinable from available evidence. T. M. Stout (personal communication, 1968) reports a similar deep Ogallala channel cut into the Brule nearly to the level of the present-day floodplain of the North Platte River at a location about six miles east of Broadwater in Garden County. Farther east, the present-day

Rush Creek in northeastern Cheyenne and southwestern Garden County coincides with the trace of a deeply-incised Ogallala channel and an underlying, prominent Chadron channel (see Plates 1-2).

Assumed Base of Ogallala ("k").--This horizon is an unconformity at the assumed base of the Ogallala. Although the Cheyenne Tablelands are mainly underlain by Ogallala sediments, most oil and gas test-wells have their surface casings set below this contact,[1/] thereby considerably reducing the amount of potential control. This is the situation for the western part of the study area (Plate 8), where the Ogallala is commonly thin. Consequently, it is impossible to contour this horizon and to delineate its profile. This is also the situation along the 103° 30' Meridian (Plates 6-7), in the northern part of the Cheyenne Tablelands of southern Banner County, Nebraska. However, there is a sufficient number of wells in the eastern part of Kimball County showing this contact to allow construction of a

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1/ Although the surface casing of a well may conceal a stratigraphic contact, the base of the casing may be useful in establishing the lower limit of elevation for a key horizon. If there is unusual complication in the rock succession, as along the 104° Meridian where there may be two or more unconformities in such a hidden interval, this information does not allow contouring of the concealed horizons.

reasonably accurate profile.

Base of Arikaree or top of definite White River ("j").--This horizon, as shown in the cross sections along the 103° 30' Meridian (Plates 6-7), is an unconformity interpreted in most places as the approximate White River-Arikaree contact.1/

1/ This contact has been much studied in outcrop in the Wildcat Ridge of western Nebraska, where the Arikaree is subdivided into three formations, the Gering, Monroe Creek, and Harrison, from oldest to youngest. The Gering in some areas is deeply incised into the Whitney Member of the Brule Formation, and the Harrison may be in part a conglomeratic channel cut into older Arikaree (see summaries in Vondra, MS. of 1962; Schultz, Falkenbach, and Vondra, 1967; Vondra, Schultz, and Stout, in press; Schultz and Stout, 1955, 1961). No attempt at subdivision of the Arikaree in the subsurface is made at this time, and indeed no accuracy can be claimed for this profile in the northern part of the Cheyenne Tablelands (Plate 7) because of poor control.

However, in the profile along the 104° Meridian, this horizon is surely a composite, as shown in Plate 8, of at least three situations; (1) of Arikaree valley sediments unconformable on White River (Brule and assumed Chadron upland sediments); (2) of younger Brule valley sediments on older Brule upland sediments (both probably Orella, but possibly Whitney on Orella or even a complex); and (3) of Ogallala valley sediments unconformable on Brule (Orella and possibly

Whitney) upland sediments. The unconformities in the latter two situations, where more clearly differentiable, are designated horizons "g" and "k".

Bases of Ash Beds in White River ("i", "h").--These reference horizons are bedding planes correlated as the bases of the Upper and Lower Ash Beds in the Whitney Member of the Brule (Schultz and Stout, 1955, figs. 3, 10; 1961). These two ash beds occur extensively in western Nebraska and adjacent areas, cropping out in the region of study in four principal situations: (1) locally along the north escarpment[1] of the Cheyenne Tablelands; (2) along

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1/ An ash bed occurs in the Whitney also in the Lodgepole Valley southwest and west of Sidney, Nebraska (personal communication from T. M. Stout, 1968), but there is at present no reliable correlation of it. Both ash beds have been identified, however, south of Sidney, in outcrops along the escarpment southwest of Peetz, in Logan County, northeastern Colorado (Stout, 1960a). In the subsurface of the northern part of the Cheyenne Tablelands, truncation by both pre-Arikaree and pre-Ogallala erosion limits the distribution of these ash beds (Plates 6, 7-8). The Upper Ash horizon ("i") is mostly restricted to the southern part of Banner County, the Wildcat Ridge, and the uplands north of the North Platte Valley. The Lower Ash horizon ("h") is somewhat more extensive, occurring in the areas just mentioned as well as in northern Kimball County and beneath the Pumpkin Creek Valley. However, only a few wells show its presence along the 104° Meridian (Plate 8), at the south side of the Pumpkin Creek Valley.

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both sides of the Wildcat Ridge; (3) along the north wall of the North Platte River Valley; and (4) in northwestern Nebraska, along the Pine Ridge Escarpment. Because of this wide distribution and ease of recognition, together with considerable consistency in a given area for the interval of separation, they have become key horizons for correlation of White River and Arikaree strata (Darton, 1899, 1903; Schultz and Stout, 1955, 1961; Vondra, MS. of 1962, Leonard, MS. of 1957; Luebke, MS. of 1964) as well as the basis for subdivision of the Whitney (Schultz and Stout, 1955).

Base of Unconformity in White River ("g").--This important datum is also considered to be a composite of an intraformational complex of unconformities, contained within the Brule. The valley-fills above this horizon are easily recognized from electric logs (see Plates 5-6), provided that the fine-textured upland sediments (silts) of certain Brule underlie and overlie the variable, intermediate lithology (clay, silt, sand, and gravel). However, in those places where valley sequences are missing, the assumed unconformity in the upland sediments on divides is difficult to ascertain without extremely-close subsurface control. In most valley situations, this horizon is tentatively correlated with the base of the Middle Channels, which include the Toadstool Park Channel, of Schultz and Stout (1955, figs. 3, 10). In upland situations, it appears to be equivalent to the "White Bed" of Schultz and Stout (1955, fig. 3), the base of which they relate as the top of the Upper Channels.[1/]

1/ Several paleosol complexes, as well as two or more unconformities occur in this stratigraphic interval in outcrops (Schultz and Stout, 1955, 1961; Schultz, Tanner, and Harvey, 1955). This complex stratigraphic relationship is also reflected in subsurface data which require horizon "g" to be considered a composite surface. Several other problems in determination of this horizon are also present. For instance, in the southern part of the Cheyenne Tablelands, along the 104° Meridian (Plate 8), there is a deep valley-fill in T. 12 N. of Kimball County, where the horizon shown to be "j" may be horizon "g" instead. Similarly, there can be no real certainty that the deeply-incised and low-lying valley-fill below the Pumpkin Creek Valley (also shown on Plate 8) is intraformational-Brule as indicated, but the problem there is one of interpretation because of casing into these valley sediments. In such a situation, with only scattered well control, the possibility of younger Tertiary or even Pleistocene dating must be considered. Also, in the southern part of the Cheyenne Tablelands, along the 103° 30' Meridian (see Plates 6-7) there has been undoubted truncation of this horizon due to pre-Ogallala erosion. Even with the large number of wells there, the contouring is most difficult because the surface casings are usually set below this stratigraphic contact.

Base of Marker Bed in White River ("f").--This is a bedding plane at the base of a pronounced marker bed, assumed to be a volcanic ash, that has electric log characteristics similar to those for the Whitney ash beds ("h" and "i" of Plates 5-6). Its stratigraphic position fits best the Second Volcanic Ash Bed, at the contact between Orella A and Orella B of Schultz and Stout (1955, fig. 10). This is a very thin but distinctive ash bed in outcrops, and it is now recognized not only in the upper part of the North Platte Valley (near Lyman, in Scotts Bluff County, Figure 4), but also just north of Chadron, in Dawes County, Nebraska (personal communication from T. M. Stout, 1968). Although there is a limited number of pertinent test wells for which both electric logs and rock samples are available, the lithology characteristic of the Chadron occurs consistently below this contoured horizon. Therefore, the "f" horizon is correlated as marking a datum just above the Chadron-Brule contact,[1/] and, in most situations, considerably above that

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1/ With the exception of the Pre-Tertiary Surface ("e"), this marker bed and corresponding datum has the widest distribution and the best subsurface control of the contoured horizons. It occurs as an identifiable contact in more than 75 percent of the electric logs for the area. Where absent or not identifiable, the explanation may be one of several: (1) truncation and removal in episodes of later erosion; (2) concealment by surface casing, a situation commonly encountered in the North Platte Valley; (3) indefinite electric log characteristics due to poor logging conditions or to lateral changes in lithology, most prevalent in the North Platte Valley wells; or (4) nondeposition or penecontemporaneous removal. Examples of local absence are furnished by wells situated near the Kimball-Banner County line (Plate 8), and in Kimball County at the boundary of Townships 14 and 15 North (Plate 7), where the "f" horizon projects very close to or nearly upon the Pre-Tertiary Surface ("e"). No attempt is made here to explain this relationship.

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at the base of the Tertiary ("e").

"Fox Hills"-"Lance" Contact

The assumed contact between the "Fox Hills" (below) and the "Lance" (above) has been contoured as horizon "d" (Plate 8). It may be defined here as that horizon which separates an underlying, commonly thick sequence of sandstones and interbedded shales from an overlying sequence of beds characterized by variable lithology with rapid lateral and vertical changes. Although at a higher time-stratigraphic position, it conforms to the definition given for the top of "Fox Hills" by Lovering, Aurand, Lavington and Wilson (1932, p. 703) and applied by Lavington (1933, p. 406) in northeastern Colorado. In Figures 3, 4, and 5 the difference between the usage adopted here for these terms is contrasted with that employed by other workers, particularly from the outcrops and subsurface of northeastern Colorado and the Goshen Hole of eastern Wyoming to the subsurface of western Nebraska.

Throughout most of the study area, the "Lance" appears to conformably overlie the "Fox Hills." However, in the area of T. 12 N., R. 58 W., Kimball County, Nebraska (near trace of Figure 5; Plate 6) where the sandstones and interbedded shales of the "Fox Hills" are thickest, the two units are in part time-stratigraphic equivalents and apparently intertongue.

As redefined, the areal extent of the "Lance" in western Nebraska is greatly reduced (see Plate 4; Figure 4) from that suggested by earlier workers (Condra and Reed, 1943, pp. 15-16, reprinted 1959; Wenzel, Cady and Waite 1946, pp. 53-59).

"Transition Pierre"-"Fox Hills" Contact

Another contoured datum (designated horizon "c" on Plate 8 and Figure 5) is the assumed contact in the subsurface between "Transition Pierre" and overlying "Fox Hills".1/ This horizon, which is coextensive with the "Fox Hills" in western Nebraska, underlies an area of about 715 square miles in western Kimball and Banner Counties and southwestern Scottsbluff County (see Plate 4; Figures 4-5). Along the Wyoming-Nebraska boundary (Figure 4) the strata below and above horizon "c" differ in lithology: the "Transitional Pierre" is predominantly silty and sandy shale, interbedded with sandstone, whereas the "Fox Hills" consists chiefly of sandstone, interbedded with shale.

Eastwardly, the two units become progressively similar, eventually indistinguishable. However, horizon "c" still may be identified in electric logs until one reaches those problematical areas where the horizons "c" and "e" converge

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1/ As defined and used in this report, the "Fox Hills" is the stratigraphic equivalent of the "restricted Fox Hills" in northeastern Colorado as defined by Lovering, Aurand, Lavington and Wilson (1932) and as used by Lavington (1933) and Rankin (1933). However, correlations established during this study indicate that the "Fox Hills" in western Nebraska is not an exact time equivalent of the "restricted Fox Hills" in northeastern Colorado.

or where the older "c" is removed by pre-Tertiary erosion "e".

At least one sequence of sandstones occurs from northeastern Colorado into western Nebraska within the "restricted Fox Hills" of Colorado usage, and it now seems clear that the "restricted Fox Hills" is partly a facies of "Unit V" of the "Transitional Pierre" of this report (Figure 5).

From its lateral relations to the predominantly brackish-water and continental deposits that constitute the "Lance" and to the marine deposits of the upper part of "Transitional Pierre," the "Fox Hills" of both western Nebraska and northeastern Colorado is regarded as a nearshore time-transgressive facies of both the upper "Transitional Pierre" and the "Lance". The former is definitely lower in the stratigraphic sequence than the latter. The time-transgressive character of the "Fox Hills" was recognized previously by Lovering, Aurand, Lavington, and Wilson (1932, p. 703), Lavington (1933, p. 406), Weimer (1961), and Waage (1961, p. 229).

So far as can be determined, horizon "c" is a bedding plane, but it may be a disconformity throughout its extent in western Nebraska (Figure 5). Regionally, however, the lithologic change that occurs at this horizon in western Nebraska crosses time planes to occur at lower stratigraphic horizons in northeastern Colorado and also southeastern

Wyoming (Figures 4-5). The thickness of the "Fox Hills" in western Nebraska differs from place to place, ranging from a minimum of 26 feet in sec. 2, T. 13 N., R. 59 W. (the same location where the "Lance" is thickest), to 275 feet in sec. 3, T. 12 N., R. 58 W., both in Kimball County, Nebraska. Although "Lance" overlies "Fox Hills" where the latter is thinnest, the differences in thickness of the "Fox Hills" is due largely to pre-Tertiary erosion and to regional truncation of the Late Cretaceous sequence.

Base of "Transition Zone" ("Pierre")

As shown in the cross sections along the 103° 30' Meridian (Plates 6-7), two contouring horizons for the base of the "Transition zone" of the "Pierre" have been recognized on electric-log characteristics; these horizons have been assigned the letters "a" (older) and "b" (younger). The older datum ("a") is the assumed base of the "Transition zone" of the "Pierre" to the north, seemingly an unconformity there, and it probably becomes a bedding-plane projection into "Undifferentiated Pierre" in a southerly direction.1/

1/ Plates 6 and 7 should be consulted as to the approximate area of change from the assumed unconformity to a bedding-plane relation, in the vicinity of T. 17 N., R. 53 W., Banner County, Nebraska.

This horizon has not been recognized along the 104° Meridian to the west. The younger horizon "b" is interpreted as an unconformity across much of the southwestern part of the study area (Plates 6-8; Figures 4-5). To the south and also to the west, it marks the base of the electric-log characteristics usually considered as "Transition zone" lithology.[1/] Neither datum ~~can be distinguished~~

1/ Rankin's (1933, p. 423, fig. 1) "Base of Unrestricted Fox Hills", which he elsewhere (pp. 425-426) labels the "Transition zone" of the "Upper Pierre" in northeastern Colorado, is the younger horizon ("b") of the present report (Figure 4).

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can be distinguished eastwardly in much of Cheyenne County, Nebraska, presumably because of the deep dissection at the base of "Unit II" but possibly, in part, due to nondeposition of "Unit I" and older intervals (see Plate 6) of the "Transition zone" of the "Pierre" (not illustrated for eastern Cheyenne County).[2/]

2/ As also shown on Plate 6, several other unconformities or horizons have been identified within the "Transition zone", but they have not been included in the geologic profiles (Plates 7-8) because of incomplete contouring. However, these horizons form the basis for subdividing the "Transition" into "Pre-Unit I" and "Units I through V" (see Figure 3 and Plate 6).

The maximum known thickness of the "Transition zone" in western Nebraska is 1205 feet. This thickness occurs in sec. 14, T. 12 N., R. 57 W., in Kimball County. Of it, 400 feet belongs to the "Upper" part ("Unit V") and 805 feet belongs to the "Lower" part ("Units I through IV"). The thickness of the "Lower" part is distributed as follows: "Unit I", 340 feet; "Unit II", 185 feet; "Unit III", 45 feet; and "Unit IV", 235 feet.

As is best demonstrated in Plates 6 and 7, the relation between the "Transition zone" and the "Undifferentiated" subdivisions of the "Pierre" is not the same throughout western Nebraska and the adjacent area. Two situations occur: (1) In the northern part of the area, the "Transition zone" unconformably overlies the "Undifferentiated Pierre"; and (2) to the south, at least "Pre-Unit I" of the "Transition zone" is a lateral facies of the "Undifferentiated Pierre". Farther south, in Colorado, "Units I through IV" also may be facies of the "Undifferentiated Pierre". The lower part of the "Transition zone" ("Pre-Unit I" through "Unit IV") is, therefore, interpreted to be the northern, near-shore sediments of a part of the "Undifferentiated Pierre" off-shore deposits to the south (DeGraw, 1967).

It should probably be stressed here that, although time-stratigraphic intervals of the "Fox Hills" and the "Undifferentiated Pierre" can be correlated into the "Transition zone", at no place in western Nebraska and adjacent area can a relation be established in which the same time-stratigraphic interval of the "Transition zone" is equivalent to both. Furthermore, it appears to be definite that a time-stratigraphic equivalency of the "Fox Hills" in northeastern Colorado is restricted to the "Upper" part ("Unit V") of the "Transition zone" in western Nebraska. Likewise, the time-stratigraphic equivalent of the "Undifferentiated Pierre" (in northeastern Colorado) is restricted to the "Lower" part of the "Transition zone" ("Pre-Unit I" through "Unit IV") in western Nebraska.

Possible Older Contouring Horizons

Several older horizons can be similarly contoured. Among these are the bases of the following: "Pierre", "Niobrara", "Dakota", Morrison, Sundance, and some subdivisions of these units (see Table 2). Some maps have been prepared for all of these, together with a few isopachous maps, but perhaps the best horizons for contouring are: (1) the top or base of the thin "X" Bentonite,[1/] which is the most prominent of several bentonites in the shales of the "Graneros" below the Greenhorn Limestone; and (2) the top or base of the Greenhorn Limestone. All of the contourable horizons reflect the same regional structural features, as long ago demonstrated by Fuenning (1942).

The horizons preferred for contouring are easily

1/ The contour map for the "X" Bentonite has been the subject of special study, and constitutes the background for the structural interpretation discussed earlier. This is not included in this report, and will be issued separately.

recognized, areally extensive time-surfaces. But, even the best horizons for contouring have their limitations. For example, the Greenhorn Limestone loses its normal electric-log characteristics in the southwestern part of the study area, probably owing to lateral facies change. Also, the "X" Bentonite is not present everywhere in the southeastern part of the study area, presumably because of nondeposition or merging with other bentonites on an unconformity, but possibly due to facies change and loss of its normal electric log expression. Older horizons, including the base of the "Dakota" and pre-"Dakota" units, are generally unsatisfactory for contouring as reference points are far less numerous.

DISCUSSION OF CERTAIN INTERPRETATIONS

Plates 7 and 8 include profiles for certain Tertiary contouring horizons, "f" through "k", which require some discussion at this point. At least two of these surfaces, "j" in Plate 8 and probably "g" in Plates 7 and 8, are composite, hence do not represent correctly either an ancient land surface or a time "plane". Other contouring horizons of those same illustrations however, do approximate reconstruction in profile of buried topography and thus of time.[1/] The reconstructed topographies for these contouring horizons cannot now be developed as precisely as for the Pre-Tertiary Surface (Plates 1-2, 4, 6-8), but do not show the coincidence with modern drainage to the degree that some workers (Lugn and Lugn, 1955, fig. 1) have inferred. Also, the subsurface information suggests that the divides between major drainages throughout the Tertiary may have received considerable eolian sedimentation, mainly loess

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1/ The Tertiary profiles display considerable relief, especially at unconformities, so such contouring horizons may be rather confidently interpreted in such situations to express chiefly ancient topography. By contrast, underlying Cretaceous horizons shown in the profiles commonly exhibit low relief; therefore, Tertiary relief is not due to structure.

and ash (DeGraw, 1965).[1/]

1/ The widespread occurrence today of the Pleistocene loesses, such as the Peorian and Loveland, in the Great Plains and Central Lowlands, affords a ready example of dominantly-eolian sedimentation. In the past, the Whitney member of the Brule, and parts of the Orella, constitute another clear example of eolian sedimentation of remarkable similar character (Schultz and Stout, 1955, pp. 45-46; Matthew, 1899, 1901). The present writer would invoke a similar eolian origin for the thick mantling of some of the divides ("uplands") during the later Tertiary, presently known principally in the subsurface. The high percentage of shards in certain Arikaree and White River samples (Howard, 1932; Wenzel, Cady, and Waite, 1946, pp. 61 and 67; Denson and Bergendahl, 1961; Sato and Denson, 1967; Denson, MS. of 1968, and Izett, MS. of 1968) further emphasizes the importance of eolian contributions even in valleys.

ECONOMIC CONSIDERATIONS

The principal natural resources of interest here are groundwater and oil and gas; eventually, however, other natural resources may prove to be much more important than at present. Soils, of course, are not involved in the present subsurface investigation, even though the economy of the region is based to a large extent upon ranching and farming.

Groundwater Potential

The occurrence of groundwater in sufficient and predictable quantities for specific purposes, and of acceptable quality as well as at a reasonable cost, is the principal concern of many subsurface investigations. Permeability and porosity factors, also possible migration and recharge, must all be considered from the standpoint of the geologist as well as from the view of the hydrologist or engineer. All potential aquifers require study, documentation, and evaluation to determine usefulness and to meet domestic and municipal requirements, and also those of agriculture and industry. In recent years there has been a marked increase in demand for each of these categories.

Aquifers may be broadly treated as either primary or secondary. Primary or principal aquifers are capable of yielding large quantities of good-quality water from a reasonable depth over a considerable area at minimal cost. Secondary aquifers are regionally less important because they are deficient in one or more of these respects. They are potentially more important for small-scale use, provided that the requirements of quality, quantity, cost, and depth are satisfied. The latter are especially important where there is no primary aquifer, an insufficient quantity of recoverable water within the primary aquifer, or conflict in water use. Unusual demand or conflict of interest occasionally may require the development of secondary aquifers at somewhat higher cost. An example is the exploitation at considerable depth of the "Transition Pierre" in western Nebraska where previous exploration had not shown a readily available primary source.

Quality-of-water determinations at a single test site often must be taken as a guide to water quality for the total aquifer. If conditions are reasonably uniform throughout the aquifer with hydrologic continuity, and provided the relation between aquifer and overlying and underlying strata remains constant, this premise may be considered reasonably valid. However, once an aquifer has been tapped, equilibrium is likely disturbed, and some important changes in quality of water may be expected.

Primary Sources.--Two principal aquifers, Quaternary channel-fills and Ogallala valley-fills, are considered here to be the principal aquifers in western Nebraska. Although the trends of both may partly reflect valleys and aquifers of the underlying Pre-Tertiary Surface, or some other older unconformity (*see* Plates 7-8), the relations are imperfect.

Most of the Quaternary aquifers underlie or are marginal to present drainages and so generally are easy to locate from observations at the surface and from map studies. Even so, some Quaternary channel-fills may be discordant in trend with respect to modern valleys, or are concealed by dune cappings, so they can be found only by test drilling and geomorphic analysis. Examples of aquifers related to modern valleys are the channel-fills of the North and South Platte Rivers, which may be as much as 200 feet thick, and the Lodgepole Creek channel-fill, as much as 70 feet thick (Bjorklund, 1957). For an example of the other situation, attention is directed to Plate 7, where another valley-fill is shown just north of the present channel-fill of the North Platte River. Although this ancient valley-fill has some surface expression, its size, configuration, trend, and water-yield potential could only be determined by evaluation of subsurface data.

The Ogallala, the second primary aquifer, is rapidly becoming an acknowledged economic asset to agriculture on the Cheyenne Tablelands. As yet, its trends and water-producing capabilities are imperfectly known, but recent collaborative test-drilling and evaluation of samples by the State-Federal Cooperative Water-Survey Program of Nebraska (Nebraska Geological Survey and the United States Geological Survey) have tremendously increased predictability of production. Good-quality water has been recently developed with yields of more than 2,000 gallons-per-minute, from depths of 300 to 500 feet.

Secondary Sources.--Other aquifers in the study area must be considered secondary, but such a term is always relative. Generally, they are as good or better aquifers than many considered as primary elsewhere in the United States, and they have become important in some areas where there are no "primary" aquifers in the usual sense. Such is the situation in some parts of western Nebraska, as discussed below.

Hemingford and Arikaree (Miocene).--Deposits of this age are among the least known of the Tertiary in the subsurface of western Nebraska, and their water-yielding capacities have been evaluated in only a few places. Undoubtedly, much of this sequence of fine to very fine sand, coarse silt, and silty, fine sand is capable of yielding water. Where primary aquifers are absent, as on the Box Butte Tablelands, they have become, in practice, the principal aquifers there.

As another example, the test well for the Agate Fossil Beds National Monument, developed in 1967 in west-central Sioux County, Nebraska, yielded more than 165 gallons-per-minute from the Monroe Creek Formation (Arikaree). Furthermore, irrigation wells in southeastern Dawes County and west-central Sheridan County commonly yield 400 to 900 gallons-per-minute from a thick sequence of very fine, sandy siltstone and silty, fine sandstone. This sequence is probably of Hemingford age. In both areas, the water quality is quite good.

On the Cheyenne Tablelands, in the southern part of

T. 16-17 N., R. 56-57 W. of Kimball and Banner Counties, Nebraska (Plates 4, 8), thick channel-fills of probable Arikaree age occur.[1/] Little is really known about these

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1/ A tentative Arikaree assignment has been given to these deposits because of stratigraphic position and apparent compatibility with the known trend of Arikaree outcrops in northeastern Colorado, as well as parallelism with the escarpment (chiefly Ogallala) separating the Cheyenne Tablelands and the Pumpkin Creek Valley. Such a narrow, deep Arikaree valley-fill, but seemingly of a different drainage system in the writer's reconstruction, is mostly exposed a few miles west of Harrisburg, Banner County, (personal communication from T. M. Stout, 1968).

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channel-fills, other than their probable age. This stratigraphic unit should be a good aquifer in parts of western Kimball and southwestern Banner Counties. Although the quality of water has not been determined by laboratory analysis, it should be nearly as good as that for the overlying Ogallala. But such possible reduction in quality may be expected, due to probable hydrologic continuity with underlying White River, "Lance", and "Fox Hills" aquifers.[1/]

1/ As a general rule the older reservoirs in the southwestern part of the Nebraska panhandle, appear to contain water of poorer quality. However, Man's disturbance of younger reservoirs, by withdrawal of large quantities of groundwater and resulting recharge problems, is such as to require conservatism in any such generalization. Thus, judgment of water-quality requires a full assessment of all geologic factors, including hydrologic data, together with full consideration of the results of previous disturbance by Man.

Brule (Oligocene).--The Brule contains an intraformational sequence of valley-fill sediments that seems to have been developed as inner valley-fills with partly independent paleotopography. The trends of some of the major channels appear to coincide with those of underlying channel-fills of the basal Chadron.

However, these relations, like those of the Ogallala, can only be imperfectly perceived. This inner valley-fill sequence of clay and sand probably includes some reworked older Brule in the Cheyenne Tablelands (Plates 7-8). It is best developed in the eastern part of the Cheyenne Tablelands, especially in Cheyenne County, but at least one principal channel has been tentatively identified also in T. 12 N. of Kimball County (Plate 8). These valley-fills are especially important as aquifers where primary sources are absent or are not well developed. According to Durum (*in* Babcock and Visher, 1952), water from the Brule is of good quality but tends to be high in sodium bicarbonate.

The Brule is perhaps the best secondary aquifer underlying the Cheyenne Tablelands where it is permeable to open fractures or to "piping" within the formation (*see* Lowry, 1966, for discussion). It has many of the qualifications for consideration as a primary source, but it is here relegated to secondary rank because of: (1) limited areal extent; (2) dependent relation to overlying Ogallala or Quaternary deposits; and (3) difficulty in detecting the trends of permeable zones. Two test wells penetrating this aquifer were drilled in 1965 as part of the state-federal cooperative water-survey program on the Cheyenne Tablelands; one was in Deuel County and the other in Cheyenne County. Evidence such as rapid loss of drilling fluid near the top of the Brule, depth of water table, and difficulties encountered during the drilling of an oil test-well in the vicinity of the Deuel County water-survey test-well (oral communication by a local farmer, 1965) indicates that water wells with high yields could probably be developed at these sites.

The identification of this aquifer at other sites is not certain, for there may be some confusion locally with younger channel-fills that contain basal gravels of Brule that has been locally derived. Quality of water in the Brule aquifer should be similar to that of overlying channel-fills of Ogallala or Quaternary age, inasmuch as they probably are interconnected.

<u>Basal Sand or Gravel of Chadron (Oligocene)</u>.--The basal Chadron clastics in western Nebraska directly overlie the surface developed on Cretaceous and older rocks, and mostly occur axially in principal valleys and tributaries of the drainage system of that time (Plate 3). The thickness of this aquifer is variable, as may be expected, both across channels and along valley trends. For example, in the western part of the Cheyenne Tablelands (Kimball County), this aquifer is poorly developed, being limited to only a few principal tributaries that generally extend eastwardly from the subcropping "Fox Hills."[1/]

1/ For this reason, the sandstones of the upper part of the "Transition zone", the "Fox Hills", and overlying "Lance", are considered to be a principal source for Chadron basal sands in most of the Early Oligocene tributaries underlying the Cheyenne Tablelands. However, in eastern Cheyenne County, other sources to the southwest also may have contributed to these coarse clastics.

The basal clastics become progressively thicker and better sorted downstream. In such ancient valleys as that crossing the Pine Ridge Fault in northeastern Sioux County, they may be as much as 200 feet thick.[1/] Owing to the relation of the

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1/ In the oil test-well, Russell "C" No. 1, drilled by Miami Petroleum Co. Inc., in the center of NW¼, NW¼, sec. 28, T. 31 N., R. 54 W., there is present at least 190 feet of "basal Chadron" sand and gravel. This unit may include here sand that in outcrop would be placed in the middle part of the Chadron (Schultz and Stout, 1955).

Chadron valleys to the Pre-Tertiary Surface, the predictability of this aquifer is excellent for the area shown in Plates 1 and 3. For much of the area west of the Chadron Arch and Bordeaux Fault Trend, predictability is also good, but not as accurately defined. To the east, there is insufficient control for reliable prediction.

The water in the basal Chadron is under artesian pressure and will rise in a well that penetrates this aquifer. This is especially noticeable in the North Platte Valley, as exampled by the well-known flowing well southwest of Broadwater, Nebraska, and others near the Nebraska-Wyoming border (Wenzel, Cady and Waite, 1946), where Chadron water flows at the present surface.[1/] The water is of poor quality

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1/ The relation of the confined, basal Chadron sands to the Pre-Tertiary Surface "e", and higher elevation of the Chadron tributary valleys underlying the Cheyenne Tablelands compared with elevation of the present North Platte Valley surface (see Plates 7-8), adequately explain this hydrologic phenomenon.

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commonly containing more than 1,000 parts-per-million of total solids, and is high in sodium. This rather high mineralization probably reflects hydrologic continuity with underlying Cretaceous aquifers.[2/] Because of poor quality, this Chadron

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2/ See W. H. Durum, in Babcock and Visher (1952). Although attributed to the "Lance", the water is actually from the basal Chadron.

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water is not desirable for some uses although acceptable for domestic purposes; it is not recommended for irrigation. Even so, it becomes important locally, where it is the only available aquifer. Examples of this situation are certain districts in southeastern Deuel County, and the Toadstool Park in northwestern Sioux County, Nebraska.

Cretaceous Sands.--In general, the paleogeologic map for the base of the Tertiary in western Nebraska (Plate 4) shows the location of these older and essentially undeveloped secondary water sources. Among these, the "Fox Hills" requires especial mention, and likewise the "Lance".

However, as the lithology of the "Lance" is more variable than that of the "Fox Hills", it is not as promising an aquifer. The "Transition zone" of the "Pierre" is more widespread than the "Fox Hills", and it contains a number of permeable zones, each with its own trend. For all practical purposes, now and in the forseeable future, the top of the "Undifferentiated Pierre" may be considered a depth limit for aquifers in western Nebraska. This is due to the regional characteristics of the "Pierre": excessive thickness over a large area, general impermeability, and poor water quality.

Older Cretaceous and Jurassic rocks, subcropping or cropping out along the Chadron Arch, are not considered here, but permeable intervals observed appear to be dry or under-saturated. South of the Chadron Dome, however, it should be remarked that good-quality water usually is available in the overlying Tertiary at reasonable depths.

Sandstones of "Lance" age undoubtedly are potential aquifers, but they seem not to have been tested in their subcrop belt in western Nebraska, probably owing to depth and availability of shallower aquifers. In the Goshen Hole of eastern Wyoming, and probably also in northeastern Colorado, the "Lance" is locally an important source of water. The quality of this water seems similar to that of the basal sands of the Chadron, being of sodium-bicarbonate type and usually with about 1,000 parts-per-million of total dissolved solids.[1]

1/ *See* W. H. Durum, *in* Rapp, Visher, and Littleton (1957, p. 84).

The "Fox Hills" is considered to be potentially the best Cretaceous aquifer in western Nebraska, particularly in westernmost districts where the "Lance" is truncated by the unconformity at the base of the Tertiary. It is in these areas that the "Fox Hills" is predominantly sandstone, is of greatest thickness, and has best-developed permeability. The quality of water contained in the "Fox Hills" is probably somewhere between that of the "Lance" (1,000± parts-per-million) and that in the "Transition zone" of the "Pierre" (1,720 parts-per-million). Although no water wells are presently known to produce from the "Fox Hills" aquifer, an analysis of a report on the Johnson No. 1 well supports the possibility of eventual high-yield production.[1/] It was

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1/ The report stated that a four-inch stream of water (estimated to be a million gallons-per-day) came from a depth of 2200 to 2300 feet. This was the depth being drilled by the contractor before he started pulling the drill stem to change bits. Analysis of the electric log shows that the indicated interval is within "Undifferentiated Pierre", and that the base of the "Transition zone" is at 1861 feet. Only two possible high-yield aquifers had been penetrated in this oil test-well: (1) the upper one, based at 300± feet, which is probably the Ogallala; and (2) the "Fox Hills", measuring 230 feet for the interval between depths of 650 and 880 feet. The Ogallala would be the more likely producer of such a large quantity of water, but as artesian pressure in this aquifer usually is absent, or seldom encountered, the most logical sources for water are the "Fox Hills" sandstones.

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drilled by S. D. Johnson and is located in the SW corner of sec. 2, T. 13 N., R. 58 W., Kimball County, Nebraska.

The capacity of permeable intervals within the "Transition zone" to yield water has now been well established, as operators of two fields in southeastern Kimball County rely wholly on permeable zones in this stratigraphic unit as a source of supply for secondary-recovery operations. The quality of water is generally poor, yields are relatively low, and depth is considered to be excessive in comparison with most water wells in Nebraska. However, this aquifer has proved to be an economic asset for these two fields.[1/]

1/ In 1953, the Rock Hill Oil Company became interested in attempting a secondary oil-recovery program for the Enders Field, located mostly in sec. 15, T. 13 N., R. 55 W., Kimball County, Nebraska. An inquiry by the Rock Hill Oil Company to the Nebraska Conservation and Survey Division (Nebraska Geological Survey) requested information concerning a possible aquifer there. Due to limited possibilities presented by the Ogallala, a shallow aquifer, and to the higher priorities of domestic and agricultural requirements above industrial use, it was recommended by E. C. Reed that they investigate the sandy intervals in the upper part of the Cretaceous.

A test well was then drilled, from which sample cuttings were collected, supplemented by coring of selected intervals. The "Transition zone" was found to consist primarily of laminated, gray, silty shale, with interbedded, gray, silty, fine sand in thin laminations, and also beds up to 1.5 feet thick, with occasional partings of brown, carbonaceous shale. The most-permeable interval was found to be "Unit II", which at this location is about 120 feet thick. It contains a sand-shale ratio ranging from about 50/50 to 70/30. The initial production was of the order of 600 barrels-per-day, but development by water-fractionation ("hydro-frac") increased the yield to between 1250 and 1550 barrels-per-day. The water here is under artesion pressure, as it rises about

450 feet above the producing interval.

In 1957, the Vaughey and Vaughey Oil Producers also began a search for a water source for use in secondary oil-recovery operations in the Goodwin Field, located about five miles east of the Enders Field, in secs. 9 and 16, T. 13 N., R. 54 W., Kimball County, Nebraska. They followed recommendations of the Rock Hill Oil Company and likewise investigated the "Transition zone." Two permeable intervals were found, and in both, the lithology is thinly-laminated, gray shale and sand. The upper production interval is about 90 feet thick; it is the "Unit II", the same aquifer utilized by the Rock Hill Company. The lower permeable interval is 40 feet thick and is easily identifiable as a marker horizon in the upper part of "Unit I." Initial production of water from these two aquifers varied from 700 to 850 barrels-per-day, a rate of approximately 20 to 25 gallons-per-minute. The quality was found to be about 1720 parts-per-million of total dissolved soilds, predominantly sodium chloride.

Other potential sandstone aquifers occur to the west in the "Transitional Pierre", and these are stratigraphically higher, principally in "Unit V." Three of these are sandstones, fine- to very fine-grained, one of which is correlated here with the "Fox Hills" in northeastern Colorado (Figure 5). The other two have a general northerly to northwesterly trend, similar to that of the overlying "Fox Hills", but they are likewise included within the

"Transition zone" since the overlying beds seem to be sandy and silty, gray shale.

Oil and Gas Potential

Commercial quantities of oil and gas have been found in western Nebraska only since 1949, and these are still limited to the deep portion of the Denver-Julesburg Basin. Future exploration and development must consider the prospects for such accumulations also in other parts of western Nebraska. Both sedimentary and structural traps should be evaluated in the light of available paleogeographic, stratigraphic, and hydrologic information. Since these data have accumulated only as a result of preliminary drilling programs, no definite limitations can be imposed. Discussion is restricted, however, to the possibilities of Cretaceous and Jurassic production.

Sedimentary Traps.--Most of the stratigraphic units shown in Table 2 (pp. 46-47) do contain oil and gas and could, under certain favorable situations, yield them in commercial quantities. The "Dakota" is presently being actively investigated in this regard, and the "Benton" and Sundance produce just outside the western Nebraska area of study. Particular attention needs to be given to possible commercial production also from the "Niobrara", "Undifferentiated Pierre", "Transition Pierre", "Fox Hills" and "Lance". Unconformities are common within and between these units. Also, there are numerous sand bodies in which updip migration or structural modifications would allow commercial accumulations somewhere in this large region, at almost any horizon. However, unconformities should be thought of as possible horizons of leakage and loss of hydrocarbons, under certain conditions, even though elsewhere they might be levels of concentration of oil and gas in commercial amounts.[1/] Leakage could occur

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1/ The "basal Chadron" cannot be completely disregarded in this respect for a gas show has been reported at Crawford, Dawes County, Nebraska (Condra, Schramm, and Lugn, 1931, pp. 268-271). This is discussed on the following page.

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downwardly, as along fractures or in karstified situations, as well as laterally.

Structural Traps.--The Chadron-Cambridge Arch has been long considered as a possible favorable structure for oil and gas accumulation, but any of the other folds or faults shown on Figure 2 (p. 23) are likewise possible areas of concentration. However, attention must be given to the dating of the various important episodes of folding and faulting as well as to any later rejuvenations, for migration and leakage of hydrocarbons may reflect these movements, at least in part. Also, they may be significant in establishing hydrologic or other pressure conditions in reservoirs.

Unconformities similarly, in many situations, may reflect tectonism, and the resulting coarse clastics from uplift or (and) climatic change would be limited to axial positions in the valley systems produced by such erosion. Truncation and consequent escape from reservoirs of the hydrocarbon contents may be expected also occasionally to occur. For example, the "basal Chadron" sand has yielded a small amount of gas in the vicinity of Crawford, Dawes County, Nebraska (Schramm and

Cook, 1921, p. 16; Condra, Schramm, and Lugn, 1931, pp. 268-271) that has been interpreted, probably correctly, as leakage from the underlying "Undifferentiated Pierre" of present classification. But the "basal Chadron" elsewhere cannot be seriously considered as an important potentially-productive reservoir, on the basis of any available information. However, there is always the possibility of encountering a low-pressure "gas pocket" in drilling into this horizon, and even some hazards in such drilling operations must be presumed as present.

Paleotopography and Structure.--A somewhat-unexpected relation obviously exists between the drainage patterns established just before or at the beginning of Chadron deposition and the distribution of many oil and gas fields in the Denver-Julesburg Basin of western Nebraska (Plate 3). This coincidence of production trends with drainage divides of both major and minor pre-Chadron valleys,[1] considered in

1/ Which is to say that Chadron drainages avoided those areas underlain by oil and gas accumulations of commercial value.

relation to what has been known previously,[2] suggests the

2/ See particularly: Blackstone, 1946; Schultz and Stout, 1948, 1955; and unpublished theses of Buffington, Leonard, Luebke, Horton, and Malin at The University of Nebraska.

following sequence of events between the deposition of the middle part of the "Pierre" and the beginning of Chadron sedimentation:

(1) Development of structural patterns for the Medial and Late "Pierre", perhaps beginning in the middle of "Pierre" ("Hygiene") sedimentation in western Nebraska.[1/]

1/ The Chadron Arch and some related structures is a case in point: see Lavington, 1933; Rankin, 1933; Griffiths, 1949; Blair, 1955; Dunn, 1959; Scott and Cobban, 1959; and DeGraw, 1967.

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(2) At least partial planation (truncation or pedimentation) of many or most of these structural features, accompanied by deposition of a mantle or thicker cover of sediments so that a consequent drainage system (dominantly dendritic pattern), could develop that was largely independent of structural position and hardness or permeability of rock.

(3) Rejuvenation of some structures, accompanied by possible initiation of others, at the beginning of Chadron time, so that superimposition of many of the drainages occurred, closely followed by piracy and readjustment of streams (subsequent pattern) to structure, hardness, and permeability.

(4) Sedimentation of oldest Chadron, with basal conglomerate and sand confined chiefly to the axial trends of those principal Chadron valleys that drained the major uplifts. The divides and other inter-stream remnants in many situations then would be expected to reflect structure and harder rock; some of these eventually would have been buried as the valley walls were mantled (or, less-plausibly, the valleys over-filled).

In any case, a general "rule" may be formulated: A striking correspondence exists between ancient stream divides (subsequent drainages) and certain deeply-buried production trends in western Nebraska. This should prove useful in delineating new areas for commercial exploration for oil and gas in the region. It may have general application also as a new tool in oil exploration in similar situations elsewhere, as for example, in relating certain pre-"Dakota" drainage divides to deeper productive trends (Pennsylvanian) in southwestern Nebraska.

Discussion and Some Possible Exceptions.--The above-stated "rule" is but the subsurface extension of an old and well-established practice in oil and gas exploration--to search for and to drill topographic "highs" of the present surface in a known or suspected oil province. However, like any generalization, it probably has its limitations, and there are several possible exceptions now known in western Nebraska.

One would expect that stratigraphic traps, as a class, would be exceptional and not have reflections in younger, buried topography. However, surprisingly enough, some in western Nebraska do have such expression. In southeastern Banner County, Nebraska, for example, two oil fields that are well-known stratigraphic traps have been supposed to be independent of structure: these are the Willson Ranch Field (Exum and Harms, 1968) and the Singleton Field, both shown on Plate 3 (T. 17 N., R. 53 W.). The former occurs along a major drainage divide of the Pre-Tertiary Surface, and the other underlies upland topography of this surface, with only minor tributaries heading into the field. Thus, some stratigraphic traps do have reflection,[1/] even though one might expect paleotopography to express only structural or combination traps.

Although combination traps characterize most of the productive oil and gas fields in that part of the Denver-Julesburg Basin considered in the present investigation, both structural and stratigraphic traps occur commonly also. For each to have expression as drainage divides of the pre-Chadron topography, as seems to be generally the case, there must be inheritance of successive topographies. Some exceptions are expectable.

Paleotopography and Secondary Recovery.--The buried topography, it now appears, also may serve as a guide in locating adequate water sources for implementation of secondary recovery of oil and gas, accompanying or following

1/ A third example requires mention in this connection. In central Kimball County, Nebraska, there is a sprawling production area known as the Sloss Field (T. 14 N., R. 55 W.; Plate 3), in which oil is obtained from three separate "J" sands, each almost completely oil-saturated, representing two stratigraphic horizons. Even here, the Early Chadron drainages that cross this field are rather narrow and shallow channels; they could be mapped only because of close control due to field development.

primary production in a field. Two principles are of importance in this regard: (1) many of the younger, overlying, valley-fills, such as those developed on the Pre-Ogallala Surface, occupy positions generally coincident with valley-fills on the Pre-Chadron Surface; and (2) the best aquifers do not have trends coincident with production trends for oil and gas, but instead, are offset from them, following the trends of valleys on the Pre-Chadron Surface rather than along the divides. Therefore, the most promising post-Cretaceous water sources are not to be expected in an oil field, but marginal to it: this serves as a corollary to the "rule" expressed above.[1/]

1/ A case in point is the large Jacinto-Travis Field, in Kimball County, Nebraska (Plate 3, in secs. 15 and 16, T. 16 N., R. 54 W.; shown also in the profile directly through the field, Plate 7). The oil occurs in a combination structural-stratigraphic trap, where a subdued structural "high" is reflected at the horizons "a" and "b" and is overlain by a much-more prominent topographic "high", expressed at horizons "e", "f", "g", and "k". Illustrating the corollary, the best-available water source for this field is a deeply-incised channel-fill of Ogallala age that lies along the northern flank of the productive trend.

Timing of Oil Migration and Structural Movements.--An important but often-ignored factor in oil and gas exploration is the dating of oil movements,[1/] that is, whether the

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1/ This is of especial importance with regard to evaluating the oil and gas possibilities of the structurally-complex Crawford Basin and adjacent Cochran Arch. The former now appears to be a graben or "collapse basin" that is, at least in part, post-Brule and pre-Gering (post-Oligocene and pre-Miocene) in age. Any structural traps of this late date and geologic setting might be expected to be "geologic successes" but "economic failures", insofar as oil and gas accumulations may have occurred in different situations, but only at an earlier time than when this particular structure was formed and only to the extent that reservoir beds of proper geometry were available. In any case, the stratigraphic and structural history, in addition to reservoir form, should be given consideration in the economic exploration of the Crawford Basin or Cochran Arch. In general, these structures seem to be too young for successful prospecting, if present thinking has validity. The "gas pocket" at Crawford might be thought to be an exception, but it seems local, and is discussed elsewhere in this report; it occurs in an older geologic situation.

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structural movements involving the reservoir and its capping bed were penecontemporaneous with oil accumulation or occurred later. However, the stratigraphic information that would allow an opinion concerning this is usually not available.

The geometry of the reservoir bed may be the truly-significant control, for many reservoir beds, when greatly permeable, tend to operate as transmitters or "pipelines". They would constitute the avenues (or boulevards) along which migrating oil and gas would be channeled in response to early structural movements, but it is conceivable, and even likely, that later structural episodes would have little or no effect upon the reservoir.[2/]

2/ However, an exception must be noted: "Upper Dakota" production from the "J" and "D" sand bodies in the Denver-Julesburg Basin, in areas other than along the "Fairway" and Big Springs Anticline, where there seems to have been very little or no lateral migration. In such districts, the field limits commonly reflect the geometry of the reservoirs, and these usually appear to show little or no relation to local structures.

The history of the major structural features adjacent to western Nebraska, like the Front Range, Hartville, and Black Hills, may be expected to have begun long ago, even in Precambrian time. It is likely that the Chadron Arch and Denver-Julesburg Basin were, to some extent at least, involved in the history of the "Ancestral Rockies", even though these structures were in a "foreland" position, far inland from regions affected most severely in those tectonic movements.

However, it is the Cretaceous ("Dakota") and later history of the structures that seems to be most significant in present exploration for oil and gas in western Nebraska. For example, the "modern" Chadron Arch, apparently now essentially a horst, probably began to form along a hinge-line fold that later became a high-angle thrust fault along its northeast side. This particular fault seems to have occurred sometime in the midst of "Pierre" sedimentation, insofar as this movement now can be dated. At any rate, the development of the Chadron Arch seems to antedate the formation of the more-complex Crawford Basin, which is more of a graben or "collapse basin".1/

1/ See discussion above, in footnote 1, p. 98.

The smaller structural features of the Denver-Julesburg and Crawford Basins appear to be mostly pre-Chadron, but some are later or experienced principal rejuvenation. Some faults may have been rejuvenated: Toadstool Park and Whalen Faults, among others, which are, at least, post-White River and pre-Arikaree. Also two faults, the White Clay and Pine Ridge Faults, appear to have been at least post-Arikaree or post-Hemingford features, but this movement, too, may have been rejuvenation.

Thus, the development of western Nebraska structures surely took place over a very long period of time, but oil and gas migration probably was affected most by those movements that occurred during, or slightly after, the main accumulation of these hydrocarbons, and progressively less-affected (or perhaps, even not affected at all) by later movements.

Other Structural and Hydrologic Factors.--It would appear, from the data presently available, that hydrologic conditions are essentially "normal", or what one would expect in given situations, for most of the known or potential producing intervals for oil and gas in western Nebraska. However, in the vicinity of the Chadron Arch, unusual hydrologic conditions seem to occur for permeable Cretaceous and basal Chadron, as well as perhaps for the permeable beds of the Jurassic. The data presented in Table 3 and Figure 6 suggest that most or all of these permeable sediments, along at least parts of the Chadron Arch, are unsaturated or undersaturated, (that is, partly or entirely dry with respect to all fluids). These anomalous situations are very important economically, and future exploration must give serious consideration to the implication that in some places along the Chadron Arch these conditions would have much to do with obtaining significant production of oil and gas, or even water, from these permeable beds.

The principal data documenting the above conclusion are summarized in Table 3. The documentation reflects the type

Table 3.--Anomalous hydrologic relations reported for permeable stratigraphic units penetrated by oil test-wells on and near the Chadron Arch in Western Nebraska.

Reference datum: KB, Kelly bushing; DF, drilling floor; GL, ground level.
Hydrologic and other pertinent information: BP, back pressure; HP, hydrostatic pressure; IFP, initial flowing pressure; FFP, final flowing pressure; FP, flowing pressure; SIP, shut-in pressure; Rec., recovered; E-log, electric log; DST, drill-stem test.

Well No. (Fig. 6)	Name (A), operator (B), and location (C) of well	Year drilled	Reference datum, in feet	Total depth, in feet	Permeable stratigraphic unit (A); depth interval (B) and thickness (C) given in feet	Hydrologic and other pertinent information regarding permeable stratigraphic unit1/ (all indicated pressures in pounds per square inch.
					CABLE-TOOL METHOD OF DRILLING	
1.	(A) Beaver Creek Well (B) M. J. Miller (C) NE¼ sec. 18, T. 34 N., R. 46 W.	1903	3400± GL	800-900	(A) Probably "Upper Dakota" Sandstones	"A strong current of air poured out of the well."
2.	(A) Braddock No. 1 (Jones No. 1) (B) Clear Oil Co. (C) NW¼ sec. 33, T. 35 N., R. 47 W.	1919	3050± GL	1300	(A) "Upper Dakota" Sandstones (B) 600±-800± (C) 200±	"At a depth of about 600-700 feet, he /the drilling superintendent/ first noticed the suction; now at a depth of about 800 feet, the suction is strong enough to be heard 50 or 60 feet away from the well. It is not a breathing well but one of continuous suction. A sack placed over the top would be drawn in immediately."
3.	(A) Duthie No. 1 (B) Nebraska Oil Corp. (C) CNLNE¼NW¼NE¼ sec. 33, T. 35 N., R. 47 W.	1926	3115 GL	2947	(A) "Lower Dakota" Sandstones 2/ (B) 945-1250 (C) 305	Operator reported that sandstone interval 945-1025 feet is water-bearing near base.
4.	(A) F. M. Conn No. 1 (B) H. T. Osborn (C) SE¼NE¼ sec. 7, T. 34 N., R. 46 W.	(?)	3244 GL	900	(A) Probably "Upper Dakota" Sandstones (B) 510± 610± (C) 100±	Operator reported that depth interval 510-610 feet consisted of sand and that water had not been encountered down to a depth of 830 feet.
5.	(A) Murray No. 1 (B) A. F. Adams (C) SW¼NE¼SW¼ sec. 24, T. 32 N., R. 46 W.	1962	3960 GL	1600	(A) Probably Basal Chadron and "Lower Dakota" Sandstones 3/ (B) 1368-1524 (C) 156	"No fluid was found other than fresh potable water in any of the formations4/ encountered. The Dakota formation was absolutely barren containing neither water, gas, or oil. The hole was bailed dry before topping the Dakota and it remained that way through the entire interval."5/
					ROTARY METHOD OF DRILLING	
6.	(A) Murray No. 17-24 (B) Superior Oil Co. (C) NW¼SW¼SW¼ sec. 24, T. 32 N., R. 46 W.	1950	3990 KB	3041	(A) Probably Basal Chadron (B) 1222-1278± (C) 56± (A) "Lower Dakota" Sandstones (B) 1278±-1458 (C) 180±	E-log intervals 1250-1270 and 1304-1316 feet had very high resistivities. E-log intervals 1411-1446 and 1450-1458 feet had extremely high resistivities. DST--interval 1412-1432 feet: Rec. 7 feet drilling mud; FP 0, HP 700, SIP 0.
7.	(A) State No. 1 (B) S. D. Johnson (C) SE¼SE¼SE¼ sec. 16, T. 32 N., R. 45 W.	1951	3920 GL	3051	(A) Probably Basal Chadron (B) 1180-1220± (C) 40± (A) "Lower Dakota" Sandstones (B) 1220± 1630 (C) 410±	E-log intervals 1180-1206, 1254-1280, 1346-1460, and 1508-1600 feet had high to very high resistivities.

(Continued)

Table 3.--Anomalous hydrologic relations reported for permeable stratigraphic units penetrated by oil test-wells on and near the Chadron Arch in Western Nebraska--Continued.

8.	(A) Serbousek No. 72-28 (B) Superior Oil Co. (C) SW¼NE¼NE¼ sec. 28, T. 33 N., R. 46 W.	1951	3618 DF	3700	(A) Probably Basal Chadron (B) 578-620± (C) 42± (A) "Upper Dakota" Sandstones (B) 620±-802 (C) 182± (A) "Lower Dakota" Sandstones (B) 1036-1439 (C) 403	E-log intervals 588-614, 732-752, 1038-1048, and 1078-1092 feet had very high resistivities. E-log interval 1178-1239 feet had extremely high resistivity. DST #1--interval 558-574 feet: Rec. 120 feet drilling mud; FP 0, HP 260, SIP 0. DST #2--interval 598-635 feet: Rec. 130 feet slightly water-cut drilling mud; FP 0, HP 300, SIP 0. DST #3--interval 1035-1062 feet: Rec. 35 feet slightly water-cut drilling mud; FP 0, HP 550, SIP 0. DST #4--interval 1213-1240 feet: Rec. 10 feet very slightly water-cut drilling mud; FP 0, HP 650, SIP 0.
9.	(A) Max Theis No. 1 (B) Amerada Petroleum Co. (C) CSW¼SW¼SE¼ sec. 22, T. 31 N., R. 47 W.	1954	3969 KB	1901	(A) "Upper Dakota" Sandstones (B) 1366-1646 (C) 280 (A) "Lower Dakota" Sandstones (B) 1830-1901± (C) 71+	E-log intervals 1370-1379, 1386-1392, 1534-1538, and 1578-1602 feet had very high resistivities. DST #1--interval 1366-1380 feet: Rec. 1 foot drilling mud; FP 0, SIP 0. DST #2--interval 1367-1380 feet: Rec. 3 feet drilling mud; FP 0, SIP 0. DST #3--interval 1368-1380 feet: Rec. 4 feet drilling mud; FP 0.
10.	(A) Jaggers No. 2 (B) Shell Oil Co. (C) SE¼SE¼SE¼ sec. 22, T. 28 N., R. 46 W.	1952	3871 KB	2764	(A) "Upper Dakota" Sandstones (B) 1702-1992 (C) 290 (A) "Lower Dakota" Sandstones (B) 2162-2500 (C) 338	DST #1--interval 1753-1768 feet: IFP and FFP 0, HP 900, SIP 0. DST #2--interval 1817-1879 feet: Rec. 280 feet drilling mud; IFP 240, FFP 240, HP 875, SIP 425. DST #4--interval 1703-1709 feet;: Rec. 18 feet drilling mud; IFP 0, FFP 0, HP 920. DST #5--interval 1705-1710 feet: IFP 0, FFP 0, HP 900.
11.	(A) Sandoz No. 47-18 (B) Superior Oil Co. (C) CNE¼SE¼SW¼ sec. 18, T. 28 N., R. 42 W.	1951	3904 KB	2815	(A) Basal Chadron (?) (B) 1812-1837 (C) 25 (A) "Upper Dakota" Sandstones (B) 1837-2000 (C) 167 (A) "Lower Dakota" Sandstones (B) 2180-2570 (C) 390	DST #1--interval 1825-1851 feet: Rec. 60 feet drilling mud; FP 0, BP 975, SIP 0.

1/ Information from driller's logs, operator's reports and related documents on open-file at the Nebraska Geological Survey, Lincoln, Nebr.

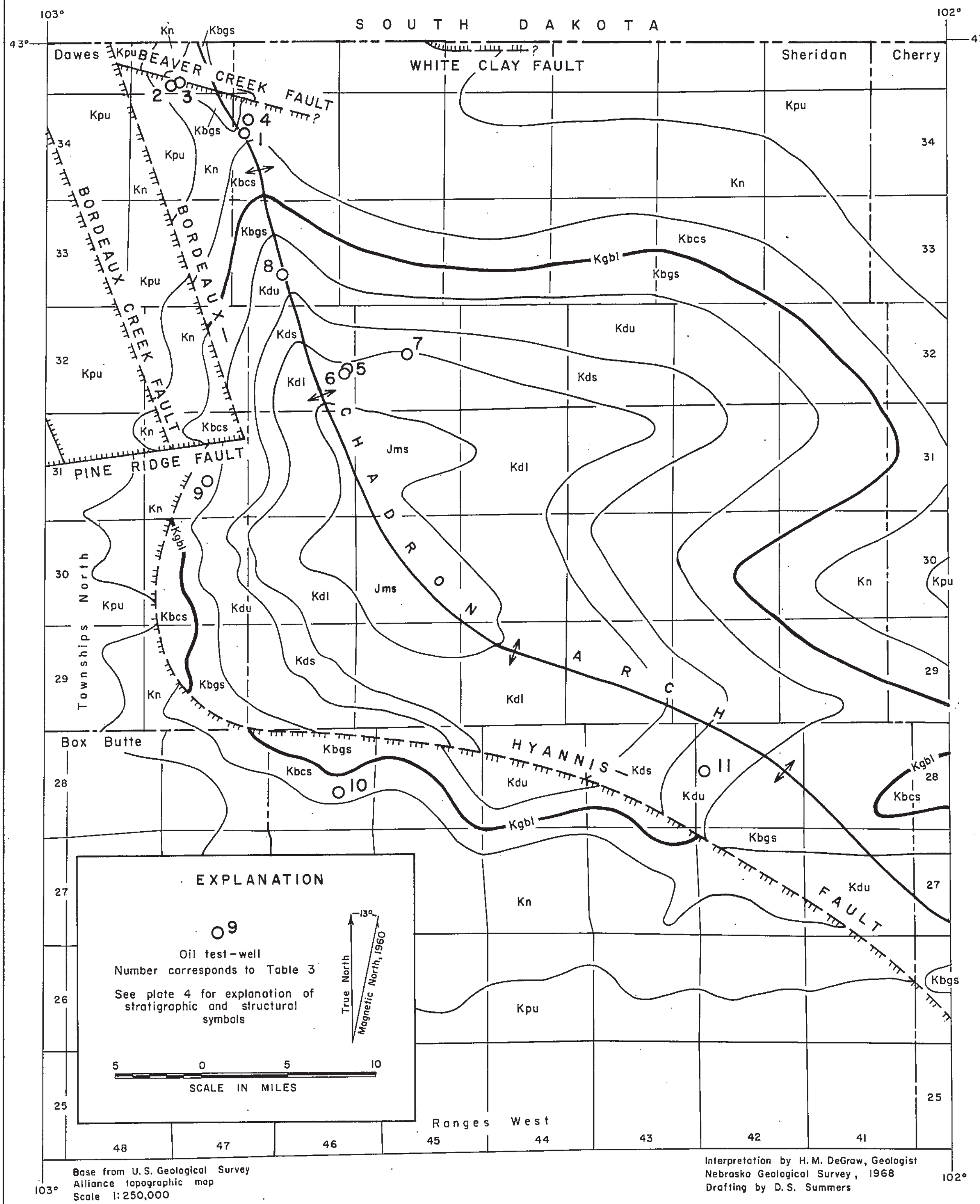
2/ Note: "Upper Dakota" Sandstones are missing or were not recognized in this well. Although it is possible that they are not developed at this location, it is more reasonable to assume, in the light of supporting data, that they were not recognized or were not reported because they did not contain water.

3/ "Upper Dakota" Sandstones missing owing to pre-Tertiary erosion.

4/ Probably thick Miocene deposits, the principal aquifer in this part of western Nebraska.

5/ The validity of this report was reinforced by Mr. William Garber of Sidney, Nebr., the well-site geologist for this well (oral communication, 1963).

Figure 6. Location of oil test-wells on and near the Chadron Arch in relation to the structure and subcropping stratigraphic units on the Pre-Tertiary Surface.



Location of oil test-wells on and near the Chadron Arch in relation to the structure and subcropping stratigraphic units on the Pre-Tertiary Surface.

of drilling equipment used, whether cable-tool[1/] or rotary[2/];

1/ Cable-tool wells are documented with significant observations by drilling personnel; these statements are often very useful for the geologist. Such information is contained in the right column of Table 3. For example, notice the following comments on the table: Well No. 1 was strongly "blowing"; No. 2 had continuous suction; No. 3 contained sandstone that was water-bearing near the base of a recorded interval; No. 4 penetrated 100 feet of dry sand; and No. 5 was water-bearing in the Tertiary but completely dry of any fluid in the basal Chadron-"Dakota" interval that was drilled.

2/ With respect to rotary-drilled holes, the records may be expected to contain less-direct but equally-pertinent information, such as is given farther down in the right column of Table 3. For instance, they would allow recognition by drill-stem tests of permeable sandstone in wells containing no or extremely-low pressure (such as IFP--initial flowing pressure, FFP--final flowing pressure, FP--flowing pressure, and SIP--shut-in pressure) and characterized by electric-log resistivities that are high to extremely high.

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generally the older wells were drilled with cable-tools, whereas the new ones utilized rotary equipment. However, cable-tools were used in one well more recently: this is the Murray No. 1 gas test, drilled in this exceptional manner in 1962. Interest in this one well must be especially expressed because it proves most definitely that the "Dakota" here contained no fluids at all for the section drilled, even though the Tertiary above contained at least four water-bearing horizons (personal communication, Mr. William Garber, 1968; Table 3, Well No. 5; location shown on Figure 6).

Such a "dry" interval cannot be adequately explained at present, but in this case, the following factors must be considered: (1) presence and elevation of the pre-Chadron unconformity considered in relation to the "dry" basal Chadron here, whereas farther west the basal Chadron is an aquifer; (2) "Dakota" at relatively-high elevation; and (3) relation of the major faults associated with both sides of the Chadron Arch. However, it seems reasonable to postulate that the present fluid level in each of the several "Dakota" horizons may be the normal piezometric surface for each confined unit of the "Dakota". Further, one must take into account the possibility of different conditions having obtained in Early Chadron time: there may have been a somewhat lower water table before Chadron sedimentation was completed, and all this may have been modified in later tectonic movements. Finally, restoration of past conditions become exceedingly difficult once drilling has penetrated these several horizons; the variables introduced become only rough approximations.

OTHER POSSIBLE RESOURCES

In addition to oil, gas, and water, the following materials exist or may exist in western Nebraska in commercial quantities: (1) sand and gravel; (2) volcanic ash (pumicite); (3) diatomaceous earth (diatomite); (4) potash and perhaps other salts; (5) gypsum; (6) bentonitic clay (bentonite); (7) expandable shale, for light-weight aggregates; (8) refractory clay and possibly "Fuller's Earth"; (9) uranium minerals; (10) agates and opals; and (11) chalcedony and other quartz minerals.

SUMMARY

The subsurface stratigraphy, structure, and paleotopography of western Nebraska have been investigated in as much detail as present information allows for sediments of Late Cretaceous, Tertiary, and Pleistocene age, and the Pre-Tertiary Surface was given special emphasis. The logs of about eight thousand wells have been considered in preparing the maps and profiles. Additionally, numerous well samples were collected and examined, and more than three months of field studies were devoted to the project since it began in 1958.

The drainages and drainage divides developed upon the Cretaceous and older rocks before the deposition of the Chadron (Early Oligocene) have been reconstructed as a first step in preparing contour maps (both structural and paleotopographic) of successive horizons beginning with the base of the "Transition zone" of the "Pierre" and ending with the base of the Quaternary. The pre-Chadron paleotopography is of unusual interest, for the ancient drainage divides seem to be mostly coincident in some areas with production trends of oil and gas fields yielding from "Dakota" traps. Similarly, the pre-Chadron drainages are of importance in the delineation of possible aquifers that can be utilized in secondary recovery operations, marginal to certain productive oil and gas fields. Apparently younger aquifers in the Tertiary-Quaternary sequence bear interesting relations, also largely reflective, to this Pre-Tertiary Surface as well as to other contouring horizons.

The economic utilization of such a study of successional topographies, possibly reflecting structural and stratigraphic conditions at depth, may be significant in locating oil and gas accumulations and thus important in future exploration. Perhaps it illustrates how a purely-scientific investigation may occasionally yield unpredictable economic rewards. However, both maps and cross-sections are required to document the regional relations.

The illustrations include: paleotopographic reconstructions for the Pre-Tertiary Surface; a map of the structural features in western Nebraska; a paleogeologic map for the Pre-Tertiary Surface, on a base with paleotopographic contours for this same surface; and cross-sections near the western margin of Nebraska. These are further discussed below.

Paleotopographic Maps.--The Pre-Tertiary Surface, which is principally the Pre-Chadron Surface, is shown by two maps at different scales reconstructing the ancient topography of much of western Nebraska. The greatest concentration of control points in the southwestern part of the region allowed the most detailed reconstruction (Plate 1), whereas only general information was available for the remainder (Plate 2). The pre-Chadron drainages and divides known with best control and which have the interesting economic relations discussed above, are shown as Plate 3.

Structural Map.--The regional structure of western Nebraska is portrayed in Figure 2. Although the principal structures have been previously recognized, additional faults and folds have been identified. The important structural elements are: (1) the Chadron Arch: (2) the Kennedy Basin; (3) the Denver-Julesburg Basin, including the newly-defined Cochran Arch and Crawford Basin near its northern margin; and (4) the Black Hills Uplift.

Paleogeologic Map.--Plate 4 shows the paleogeology below the Tertiary; this subcrop map for the Pre-Tertiary Surface is in part inferential, but it involves units of Jurassic and Cretaceous age in the region of study. Closest control is available above the "Undifferentiated Pierre", that is, for the "Transition zone" of the "Pierre", "Fox Hills", and "Lance". Dispersed control and structural complications lessen the accuracy of identification within the "Undifferentiated Pierre" and older sediments.

Cross-Sections.--Of the six cross-sections presented, two (figures 4 and 5) are concerned with Late Cretaceous correlations in northeastern Colorado, western Nebraska, and eastern Wyoming; and with correction of certain discrepancies and errors in previous work. The problems of time-stratigraphy are particularly involved in the "Pierre" and younger Cretaceous (Figures 4 and 5; Plate 6), and five horizons, probably disconformities, that have been established in the "Transition zone" allow recognition of six subunits within it alone. The tracing of any subsurface unit into the surface presents problems, as is shown by the electric logs for the Tertiary White River Group in Scotts Bluff County, Nebraska (Plate 5). Similarly, the relations to other successional horizons from the Late Cretaceous to the present (Plates 6, 7, and 8) permit reciprocal adjustments as to "limits-of-error".

Finally, hydrologic problems also have been studied. On and in the vicinity of the Chadron Arch, anomalous and presently-unpredictable hydrologic conditions occur with respect to basal Chadron sands and underlying of the permeable horizons of the Cretaceous. However, in parts of western Nebraska, water evidently occurs in an important economic relation to oil and gas. Both present and prospective aquifers eventually must be evaluated in terms of the patterns produced by the successive valley-fills and reflections in the Tertiary and Quaternary, and by Late Cretaceous paleogeography. The preferential position of oil and gas fields with respect to ancient drainage divides already has been shown to be important, and Tertiary aquifers possibly usable in secondary recovery, as well as for irrigation, are commonly marginal to productive oil and gas fields. The economic future of western Nebraska seems to be linked to an adequate study of the subsurface; this can be said just to have begun.

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MAPS, CROSS-SECTIONS, AND WELL RECORDS

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Sample log: Unpublished sample log of the Lloyd Blunt No. 1 well drilled by C. W. Toster, located in SE.¼ NE.¼ NE.¼, sec. 32, T. 22 N., R. 63 W., Goshen County, Wyoming. Sample description and correlation by Page T. Jenkins of Jenkins and Hand, Consulting Geologists, Denver, Colorado.

Legend for Plates 6, 7 and 8
(All in pocket)

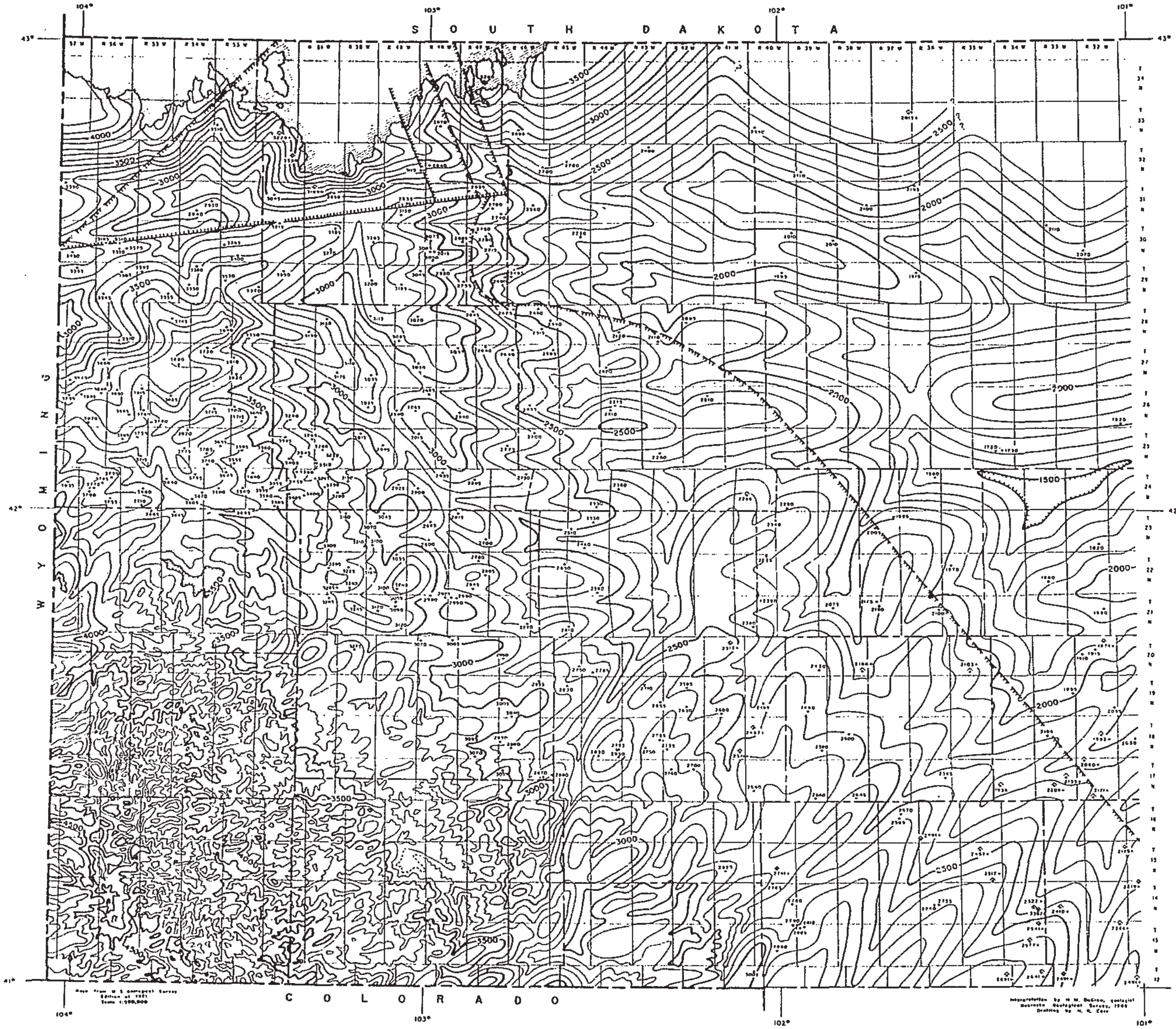
Symbol	Datum Horizon
m	Modern topographic surface; a composite including remnants of thinly mantled High Plains Surface (End Tertiary).
l	Unconformity at base of Quaternary alluvium in valley situations; probably a composite surface.
k	Unconformity at assumed base of Ogallala.
j	In places, unconformity at assumed base of Arikaree; in other places, a composite surface separating overlying valley deposits (probably Ogallala, Arikaree, and Brule) from underlying upland phase of White River.
i	Base of Upper Ash Bed in Whitney.
h	Base of Lower Ash Bed in Whitney.
g	A composite surface at base of intraformational valley deposits of Brule and assumed upland equivalent; in upland situations, an unconformity (paleosol) separating overlying Whitney from underlying Orella; in valley situations, an unconformity at base of Middle Channels and Toadstool Park Channels of Schultz and Stout (1955); in places, possibly at base of higher channel deposits.
f	Base of an excellent marker bed assumed to be just above true Chadron-Brule contact; possibly the Second Volcanic Ash Bed of Schultz and Stout (1955) and considered by them to be the contact between Orella A and Orella B.
e	Major unconformity at base of Tertiary; in most places, the weathered Pre-Tertiary Surface, but in at least one place, the Pre-Arikaree Surface; top of the Interior Paleosol Complex.
d	Assumed contact between overlying "Lance" and underlying "Fox Hills".
c	Assumed contact between overlying "Fox Hills" and underlying "Transition zone" of "Pierre".
b	In places, unconformity separating overlying "Transition zone" of "Pierre" from underlying "Undifferentiated Pierre"; in other places, unconformity within lower part of "Transition zone" of "Pierre". Equivalent to base of "Transition zone" of Rankin

(1933) in northeastern Colorado.

a In places, unconformity separating overlying "Transition zone" of "Pierre" from underlying "Undifferentiated Pierre"; in other places, bedding surface within upper part of "Undifferentiated Pierre".

Symbol	Stratigraphic Unit
Qa	Quaternary alluvium
Tpo	Ogallala of Pliocene age; includes both upland and valley depositional phases (undifferentiated)
Tma	Arikaree of Miocene age; includes both upland and valley depositional phases (undifferentiated)
Tmav	Assumed Arikaree of Miocene age; valley depositional phase
Tv	Tertiary valley deposits of indeterminate age (may be Ogallala, Arikaree, or Brule)
Tob	Brule of Oligocene age; includes both upland and valley depositional phases (undifferentiated). Actual base assumed to be slightly below "f" datum.
Tobwu	Upper Whitney of Brule; upland deposits
Tobwm	Middle Whitney of Brule; upland deposits; base defined by Schultz and Stout (1955) is top of Lower Ash Bed
Tobwl	Lower Whitney of Brule; top defined by Schultz and Stout (1955) is top of Lower Ash Bed
Tobv	Intraformational Brule valley phase; in part, considered to be equivalent to the Middle Channels (Orella C and D) of Schultz and Stout (1955)
Tobo	Orella Member of Brule; upland phase; considered to be at least in part equivalent to Orella B and in places, Orella C and D, of Schultz and Stout (1955)
Toc	Chadron of Oligocene age; predominantly valley deposits but upper part, in places, is upland depositional phase; uppermost part may be equivalent to Orella A of Schultz and Stout (1955)
Kl	"Lance" redefined
Kfh	"Fox Hills" redefined
Kpt	"Transition zone" of " Pierre"
Kpu	"Undifferentiated Pierre"

PLATE 2



EXPLANATION

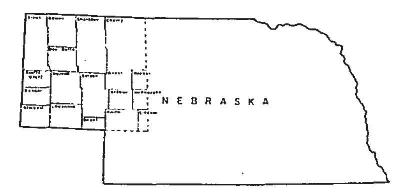
Outcrop of pre-Tertiary surface

Contours on pre-Tertiary surface
Contour interval 100 feet
Datum is mean sea level

Fault Trend
Solid line, movement principally post "White River"; broken line, movement principally pre-"White River" or undetermined

Altitude, in feet, of pre-Tertiary surface in well
Datum is mean sea level

Casing elevation below pre-Tertiary surface in well

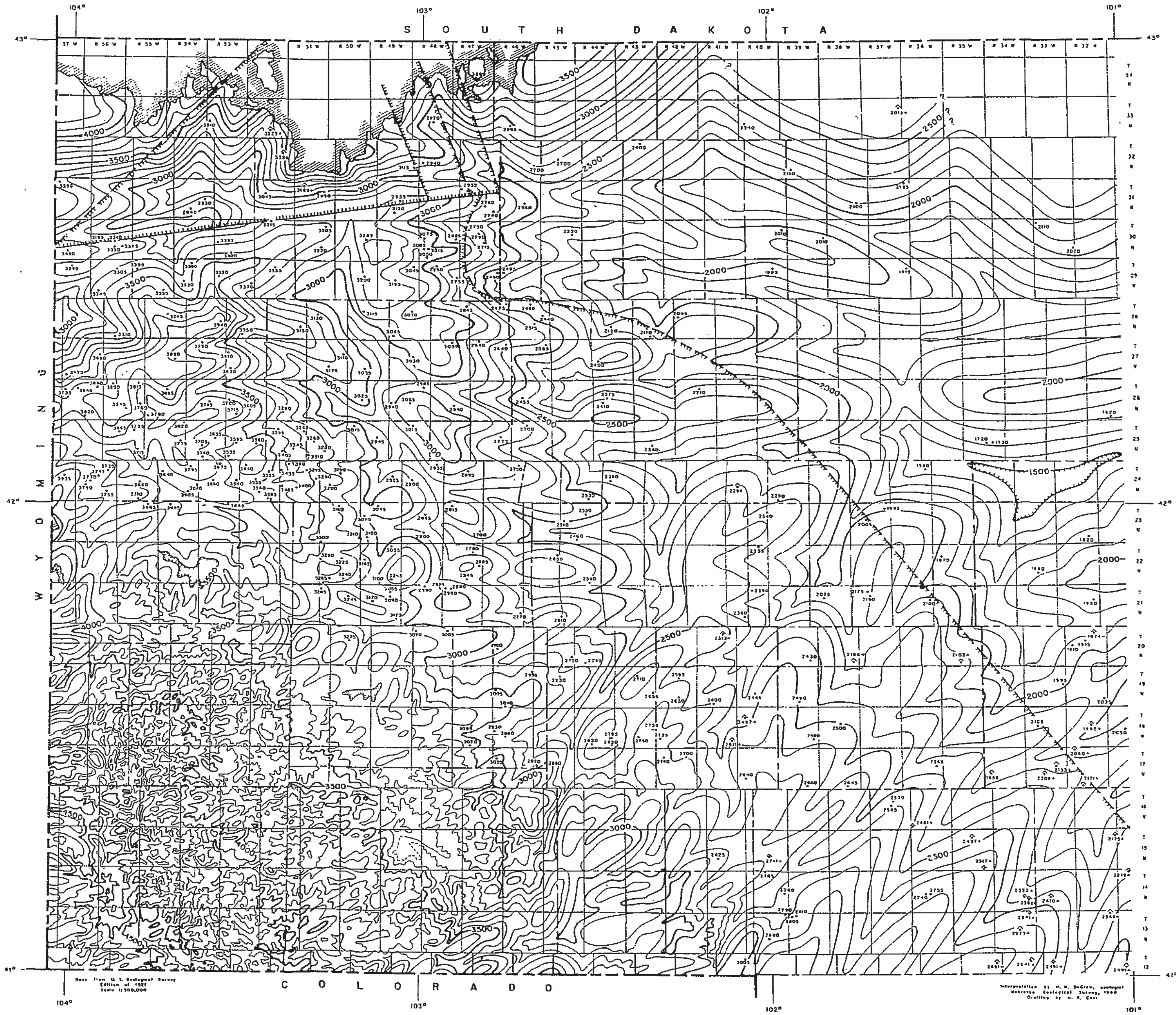


INDEX MAP

APPROXIMATE MEAN DECLINATION, 1960

CONFIGURATION OF THE PRE-TERTIARY (PRINCIPALLY PRE-CHADRON) SURFACE IN WESTERN NEBRASKA

10 0 10 20 30 40
SCALE IN MILES



EXPLANATION

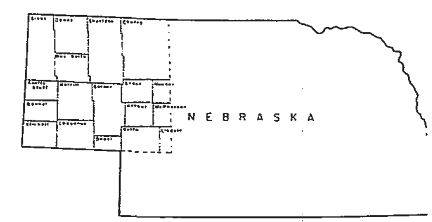
Outcrop of pre-Tertiary surface

Contours on pre-Tertiary surface
Contour interval 100 feet
Datum is mean sea level

Fault Trend
Solid line, movement principally post "White River"; broken line, movement principally pre-"White River" or undetermined

Altitude, in feet, of pre-Tertiary surface in well
Datum is mean sea level

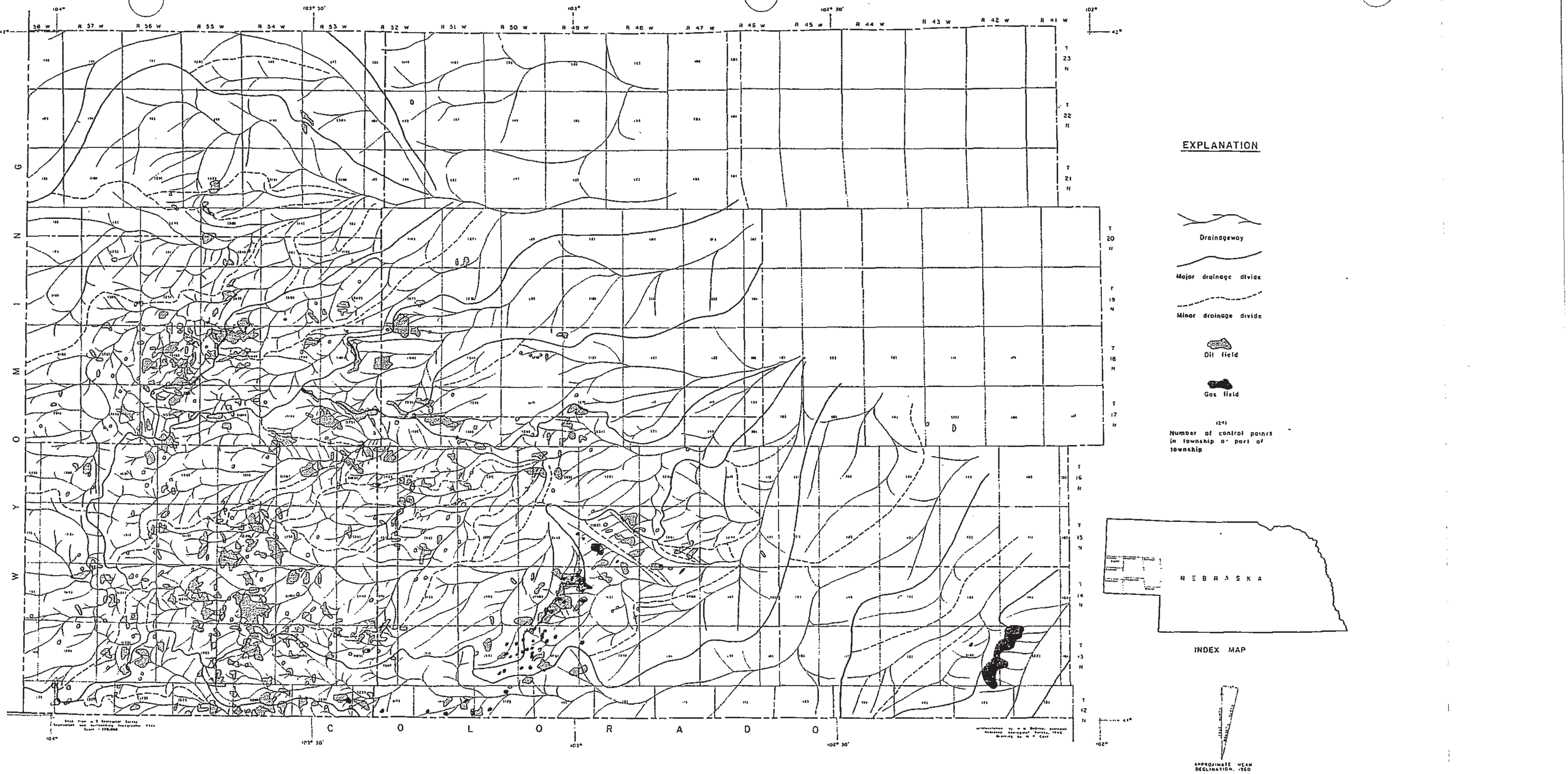
Casing elevation below pre-Tertiary surface in well



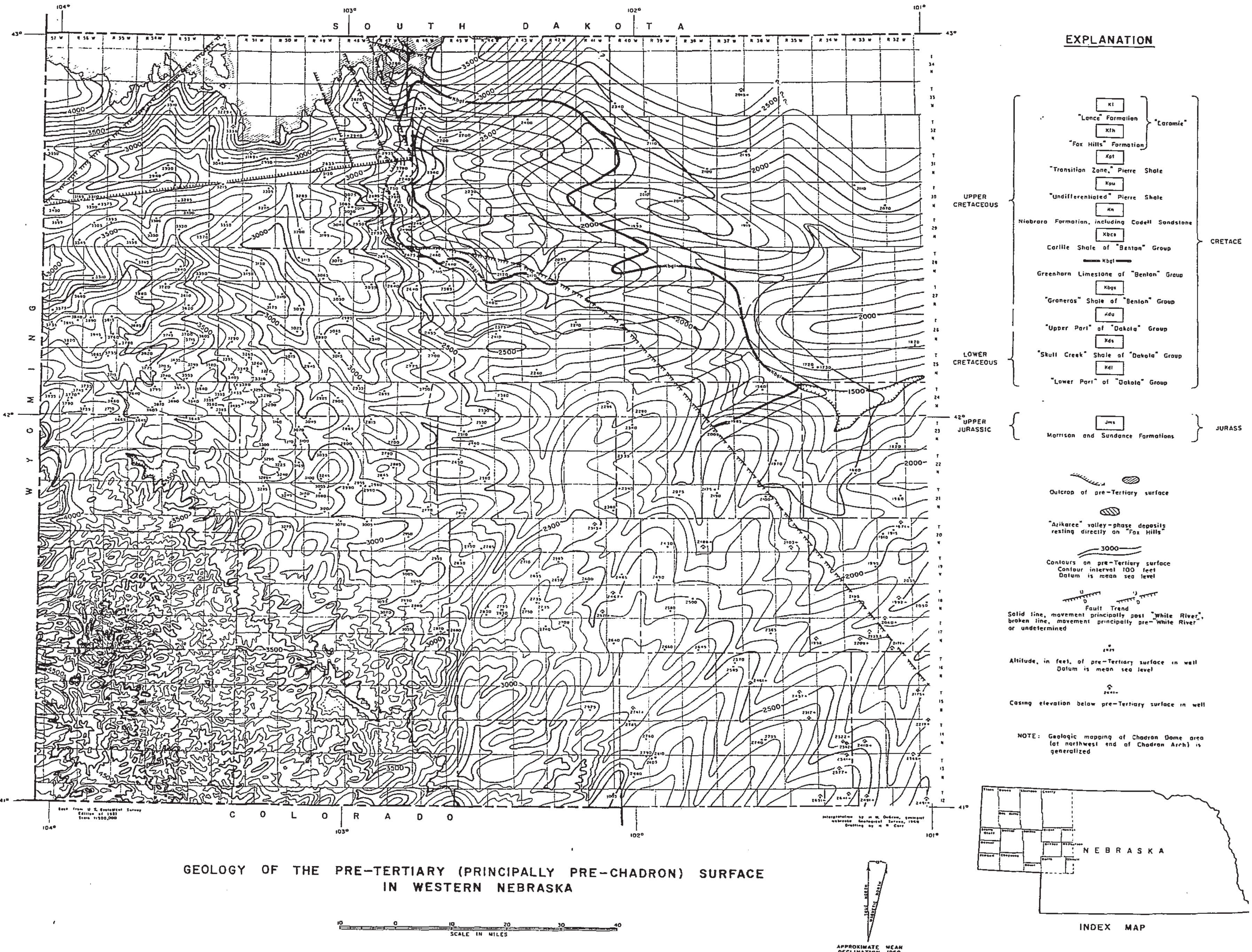
INDEX MAP

APPROXIMATE MEAN DECLINATION, 1960

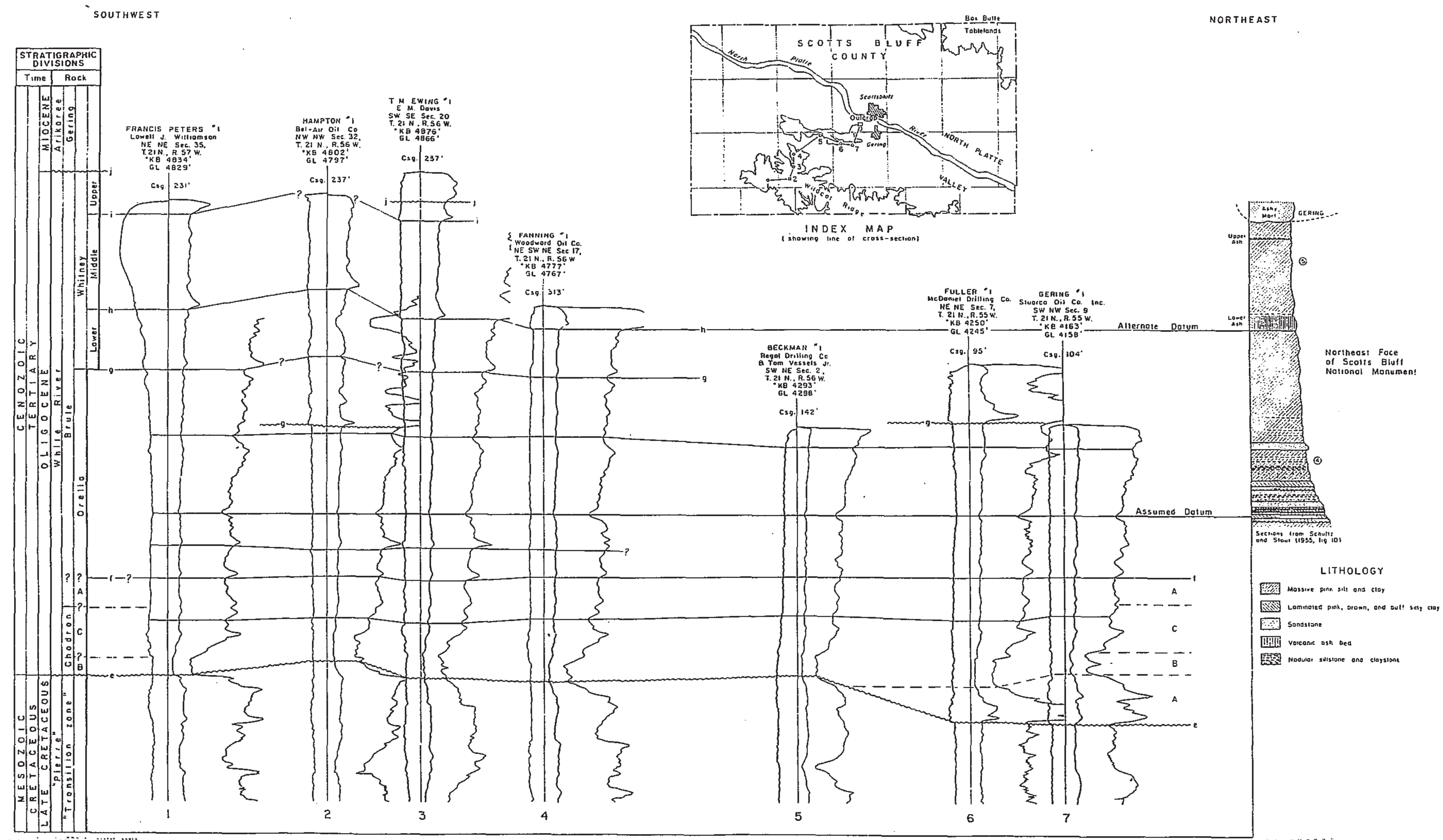
CONFIGURATION OF THE PRE-TERTIARY (PRINCIPALLY PRE-CHADRON) SURFACE IN WESTERN NEBRASKA



EARLY TERTIARY (PRINCIPALLY PRE-CHADRON) DRAINAGES AND DIVIDES, WITH LOCATIONS OF OIL AND GAS FIELDS, IN PART OF WESTERN NEBRASKA



GEOLOGY OF THE PRE-TERTIARY (PRINCIPALLY PRE-CHADRON) SURFACE IN WESTERN NEBRASKA



Interpretation by H M DeGraw, Geologist
Nebraska Geological Survey, 1968
Drilling by H R Carr and D S Summers

EXPLANATION

XB—Kelly bushing (Asterisk indicates reference datum log is measured from)
GL—Ground level
Csg.—Base of surface casing

The assumed datum is used to demonstrate uniformity of thickness and to show ease of tracing electric-log characteristics.

The alternate datum is the key horizon for relating electric-logs to outcrop.

Subdivisions of White River Group are those of Schultz and Stout (1955).

Correlation line (assumed time horizon)

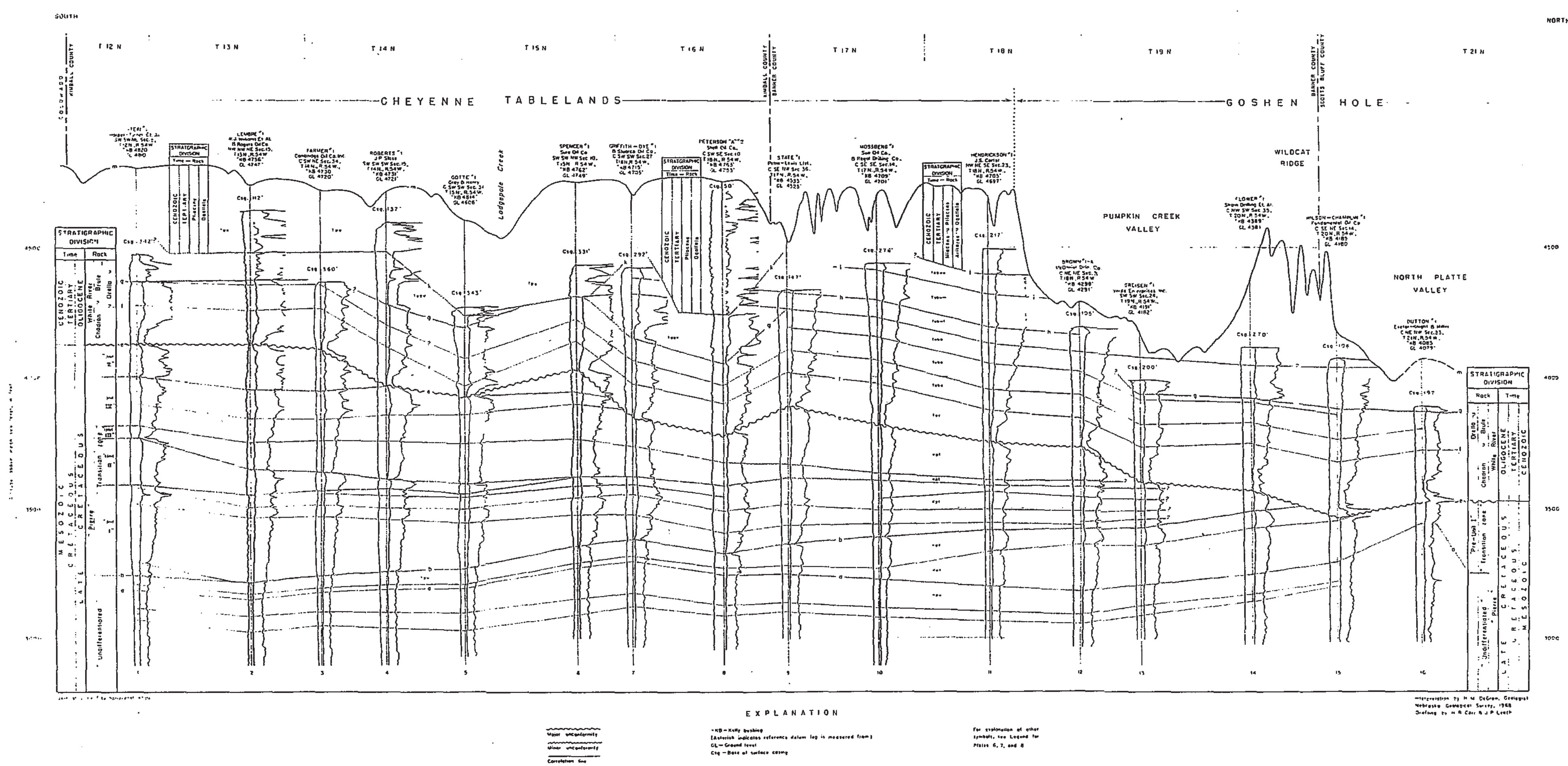
Unconformity

For explanation of other symbols, see Legend for Plates 6, 7, and 8.

ELECTRIC-LOG CORRELATION AND SUBSURFACE-SURFACE RELATIONS OF WHITE RIVER GROUP IN SCOTTS BLUFF COUNTY, NEBRASKA

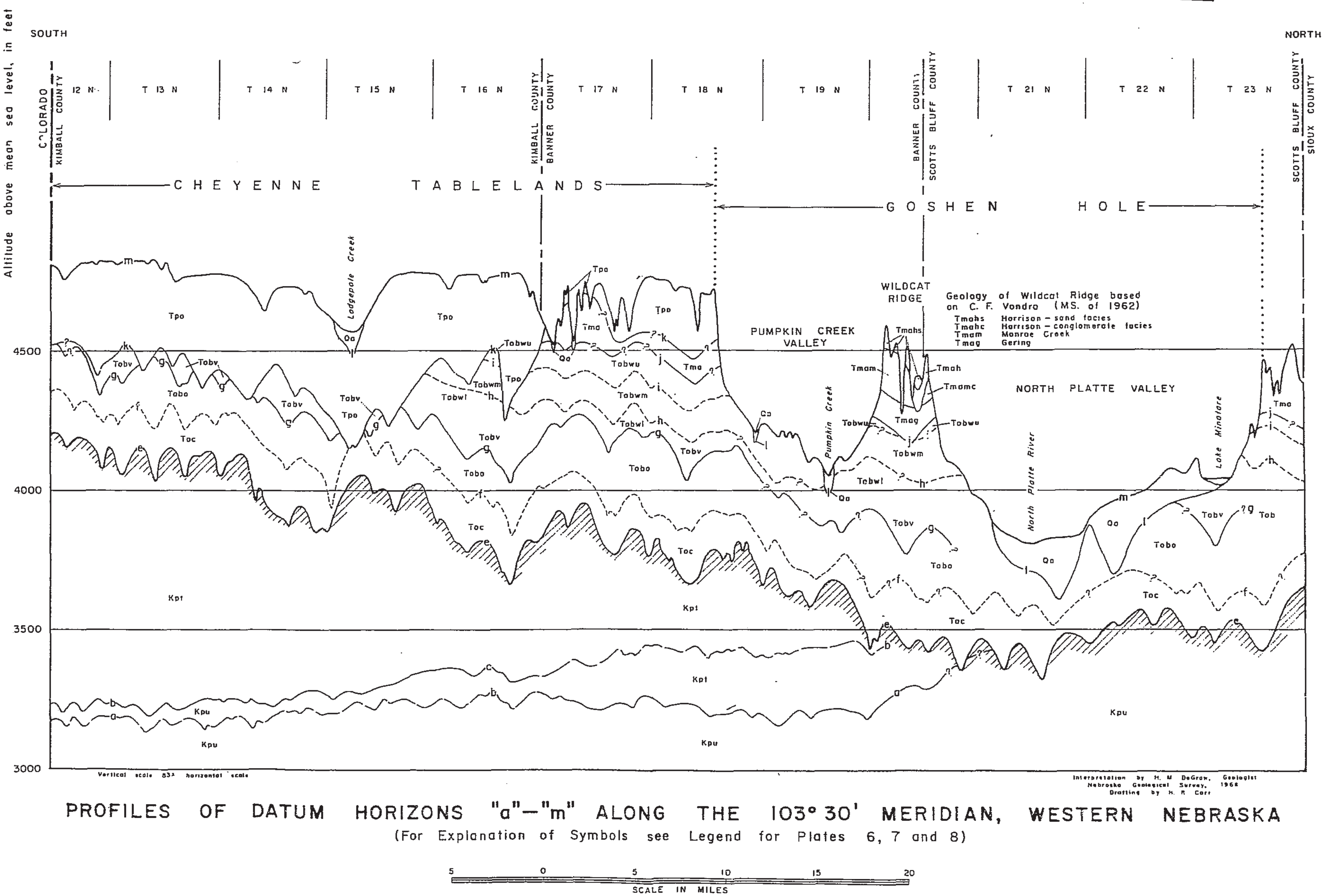
1 0 1 2 3
SCALE IN MILES

VI-EF-7



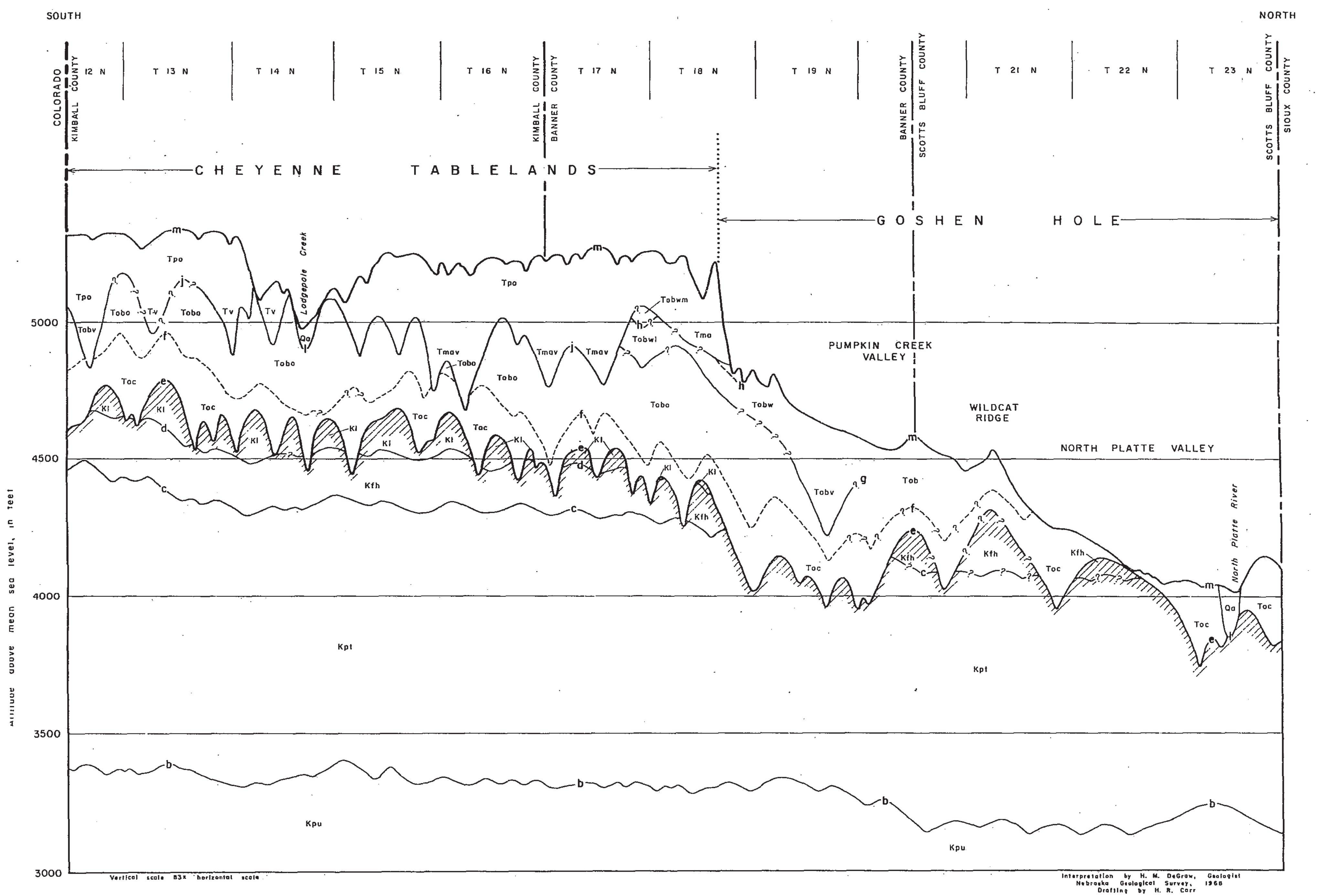
ELECTRIC LOG CROSS-SECTION ALONG THE 103° 30' MERIDIAN, WESTERN NEBRASKA

PLATE 7



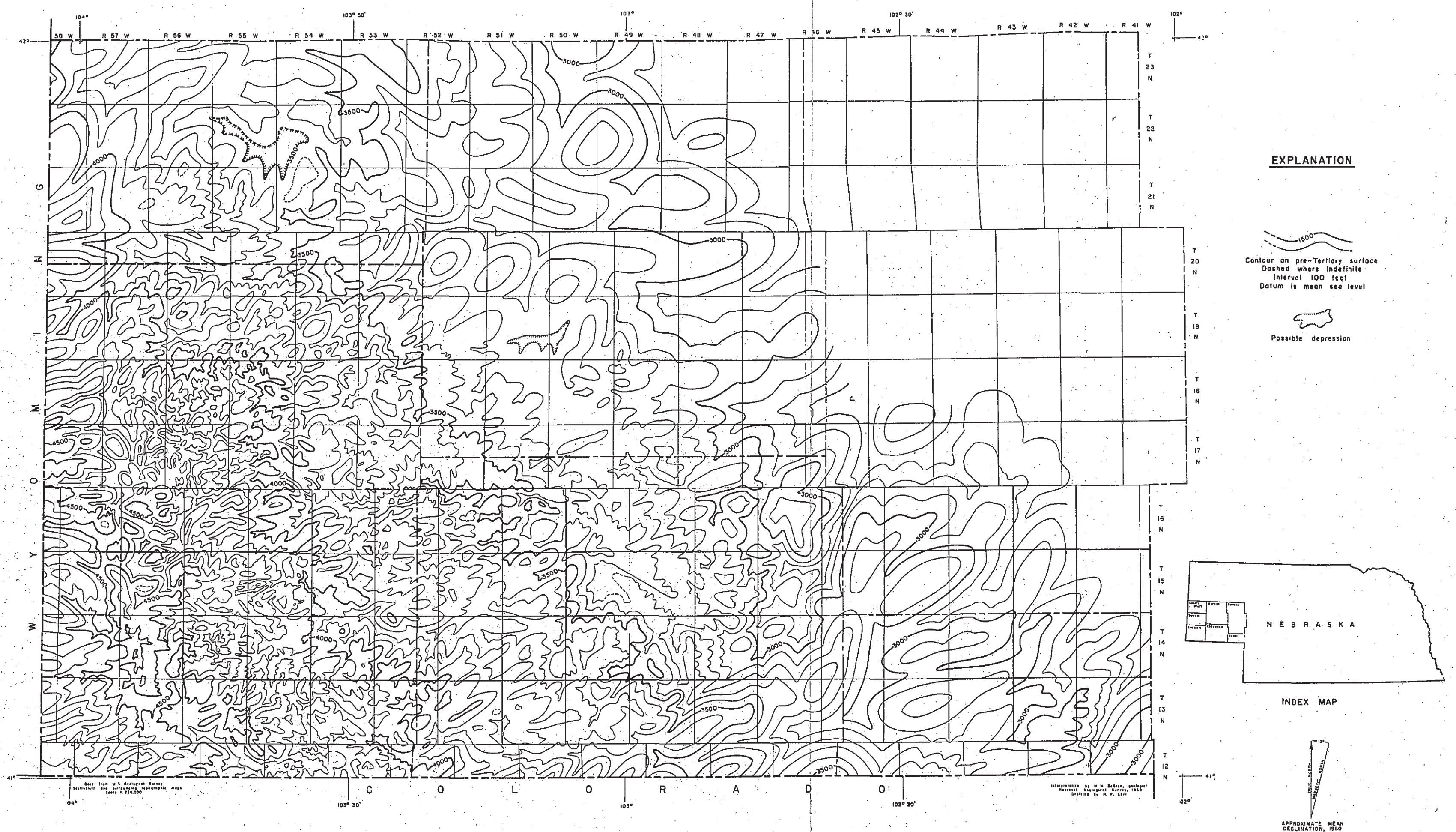
PROFILES OF DATUM HORIZONS "a"—"m" ALONG THE 103° 30' MERIDIAN, WESTERN NEBRASKA

(For Explanation of Symbols see Legend for Plates 6, 7 and 8)



PROFILES OF DATUM HORIZONS "b"—"m" ALONG THE 104° MERIDIAN, WESTERN NEBRASKA

(For Explanation of Symbols see Legend for Plates 6, 7 and 8)



CONFIGURATION OF THE PRE-TERTIARY (PRINCIPALLY PRE-CHADRON) SURFACE
IN PART OF WESTERN NEBRASKA

Table 3.--Anomalous hydrologic relations reported for permeable stratigraphic units penetrated by oil test-wells on and near the Chadron Arch in Western Nebraska.

Reference datum: KB, Kelly bushing; DF, drilling floor; GL, ground level.
Hydrologic and other pertinent information: BP, back pressure; HP, hydrostatic pressure; IFP, initial flowing pressure; FFP, final flowing pressure; FP, flowing pressure; SIP, shut-in pressure; Rec., recovered; E-log, electric log; DST, drill-stem test.

Well No. (Fig. 6)	Name (A), operator (B), and location (C) of well	Year drilled	Reference datum, in feet	Total depth, in feet	Permeable stratigraphic unit (A); depth interval (B) and thickness (C) given in feet	Hydrologic and other pertinent information regarding permeable stratigraphic unit1/ (all indicated pressures in pounds per square inch.
					CABLE-TOOL METHOD OF DRILLING	
1.	(A) Beaver Creek Well (B) M. J. Miller (C) NE¼ sec. 18, T. 34 N., R. 46 W.	1903	3400± GL	800-900	(A) Probably "Upper Dakota" Sandstones	"A strong current of air poured out of the well."
2.	(A) Braddock No. 1 (Jones No. 1) (B) Clear Oil Co. (C) NW¼ sec. 33, T. 35 N., R. 47 W.	1919	3050± GL	1300	(A) "Upper Dakota" Sandstones (B) 600±-800± (C) 200±	"At a depth of about 600-700 feet, he [the drilling superintendent] first noticed the suction; now at a depth of about 800 feet, the suction is strong enough to be heard 50 or 60 feet away from the well. It is not a breathing well but one of continuous suction. A sack placed over the top would be drawn in immediately."
3.	(A) Duthie No. 1 (B) Nebraska Oil Corp. (C) CNLNE¼NW¼NE¼ sec. 33, T. 35 N., R. 47 W.	1926	3115 GL	2947	(A) "Lower Dakota" Sandstones 2/ (B) 945-1250 (C) 305	Operator reported that sandstone interval 945-1025 feet is water-bearing near base.
4.	(A) F. M. Conn No. 1 (B) H. T. Osborn (C) SE¼NE¼ sec. 7, T. 34 N., R. 46 W.	(?)	3244 GL	900	(A) Probably "Upper Dakota" Sandstones (B) 510± 610± (C) 100±	Operator reported that depth interval 510-610 feet consisted of sand and that water had not been encountered down to a depth of 830 feet.
5.	(A) Murray No. 1 (B) A. F. Adams (C) SW¼NE¼SW¼ sec. 24, T. 32 N., R. 46 W.	1962	3960 GL	1600	(A) Probably Basal Chadron and "Lower Dakota" Sandstones 3/ (B) 1368-1524 (C) 156	"No fluid was found other than fresh potable water in any of the formations4/ encountered. The Dakota formation was absolutely barren containing neither water, gas, or oil. The hole was bailed dry before topping the Dakota and it remained that way through the entire interval."5/
					ROTARY METHOD OF DRILLING	
6.	(A) Murray No. 17-24 (B) Superior Oil Co. (C) NW¼SW¼SW¼ sec. 24, T. 32 N., R. 46 W.	1950	3990 KB	3041	(A) Probably Basal Chadron (B) 1222-1278± (C) 56± (A) "Lower Dakota" Sandstones (B) 1278±-1458 (C) 180±	E-log intervals 1250-1270 and 1304-1316 feet had very high resistivities. E-log intervals 1411-1446 and 1450-1458 feet had extremely high resistivities. DST--interval 1412-1432 feet: Rec. 7 feet drilling mud; FP 0, HP 700, SIP 0.
7.	(A) State No. 1 (B) S. D. Johnson (C) SE¼SE¼SE¼ sec. 16, T. 32 N., R. 45 W.	1951	3920 GL	3051	(A) Probably Basal Chadron (B) 1180-1220± (C) 40± (A) "Lower Dakota" Sandstones (B) 1220± 1630 (C) 410±	E-log intervals 1180-1206, 1254-1280, 1346-1460, and 1508-1600 feet had high to very high resistivities.

(Continued)

Table 3.--Anomalous hydrologic relations reported for permeable stratigraphic units penetrated by oil test-wells on and near the Chadron Arch in Western Nebraska--Continued.

8.	(A) Serbousek No. 72-28 (B) Superior Oil Co. (C) SW¼NE¼NE¼ sec. 28, T. 33 N., R. 46 W.	1951	3618 DF	3700	(A) Probably Basal Chadron (B) 578-620± (C) 42± (A) "Upper Dakota" Sandstones (B) 620±-802 (C) 182± (A) "Lower Dakota" Sandstones (B) 1036-1439 (C) 403	E-log intervals 588-614, 732-752, 1038-1048, and 1078-1092 feet had very high resistivities. E-log interval 1178-1239 feet had extremely high resistivity. DST #1--interval 558-574 feet: Rec. 120 feet drilling mud; FP 0, HP 260, SIP 0. DST #2--interval 598-635 feet: Rec. 130 feet slightly water-cut drilling mud; FP 0, HP 300, SIP 0. DST #3--interval 1035-1062 feet: Rec. 35 feet slightly water-cut drilling mud; FP 0, HP 550, SIP 0. DST #4--interval 1213-1240 feet: Rec. 10 feet very slightly water-cut drilling mud; FP 0, HP 650, SIP 0.
9.	(A) Max Theis No. 1 (B) Amerada Petroleum Co. (C) CSW¼SW¼SE¼ sec. 22, T. 31 N., R. 47 W.	1954	3969 KB	1901	(A) "Upper Dakota" Sandstones (B) 1366-1646 (C) 280 (A) "Lower Dakota" Sandstones (B) 1830-1901± (C) 71+	E-log intervals 1370-1379, 1386-1392, 1534-1538, and 1578-1602 feet had very high resistivities. DST #1--interval 1366-1380 feet: Rec. 1 foot drilling mud; FP 0, SIP 0. DST #2--interval 1367-1380 feet: Rec. 3 feet drilling mud; FP 0, SIP 0. DST #3--interval 1368-1380 feet: Rec. 4 feet drilling mud; FP 0.
10.	(A) Jaggers No. 2 (B) Shell Oil Co. (C) SE¼SE¼SE¼ sec. 22, T. 28 N., R. 46 W.	1952	3871 KB	2764	(A) "Upper Dakota" Sandstones (B) 1702-1992 (C) 290 (A) "Lower Dakota" Sandstones (B) 2162-2500 (C) 338	DST #1--interval 1753-1768 feet: IFP and FFP 0, HP 900, SIP 0. DST #2--interval 1817-1879 feet: Rec. 280 feet drilling mud; IFP 240, FFP 240, HP 875, SIP 425. DST #4--interval 1703-1709 feet;: Rec. 18 feet drilling mud; IFP 0, FFP 0, HP 920. DST #5--interval 1705-1710 feet: IFP 0, FFP 0, HP 900.
11.	(A) Sandoz No. 47-18 (B) Superior Oil Co. (C) CNE¼SE¼SW¼ sec. 18, T. 28 N., R. 42 W.	1951	3904 KB	2815	(A) Basal Chadron (?) (B) 1812-1837 (C) 25 (A) "Upper Dakota" Sandstones (B) 1837-2000 (C) 167 (A) "Lower Dakota" Sandstones (B) 2180-2570 (C) 390	DST #1--interval 1825-1851 feet: Rec. 60 feet drilling mud; FP 0, BP 975, SIP 0.

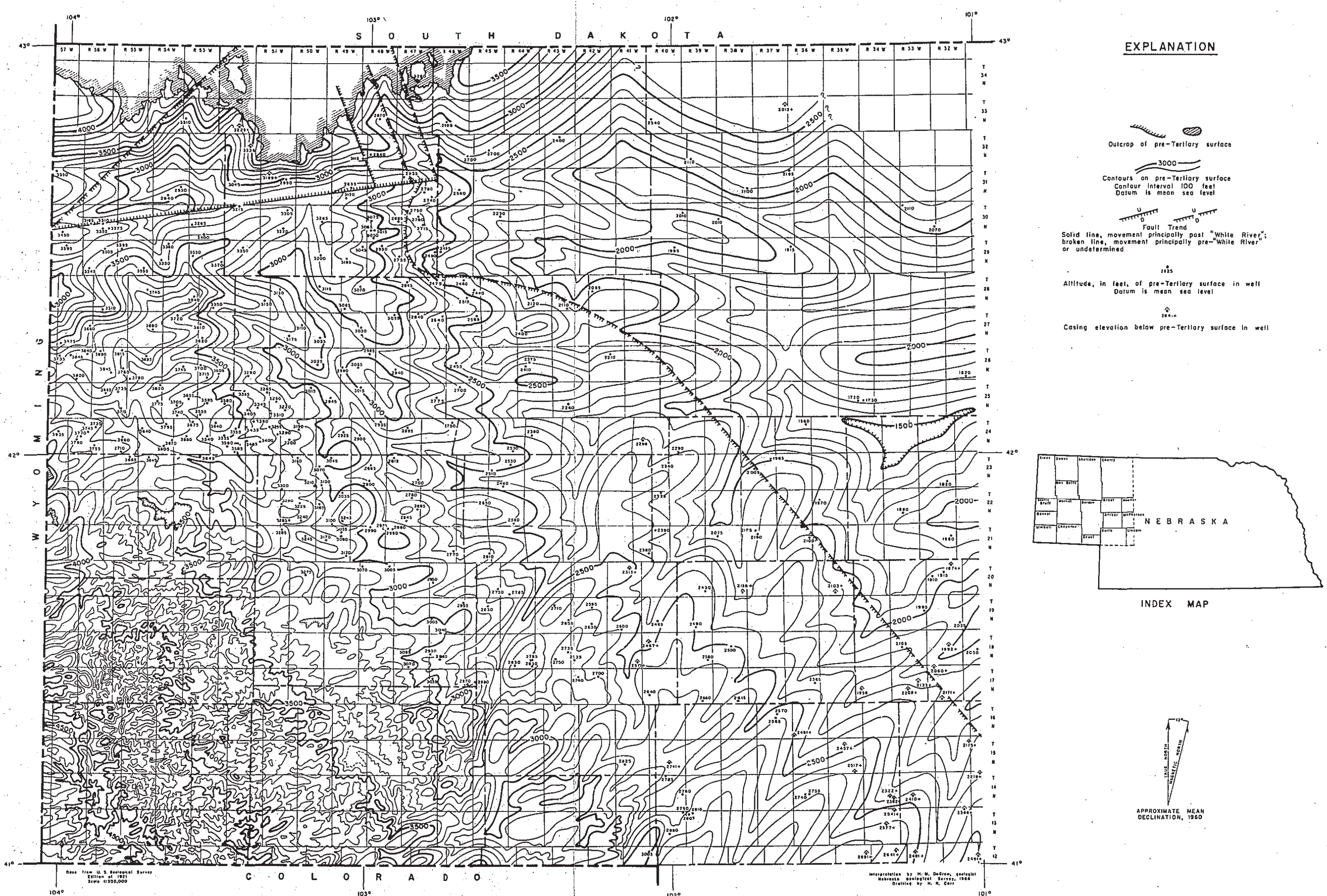
1/ Information from driller's logs, operator's reports and related documents on open-file at the Nebraska Geological Survey, Lincoln, Nebr.

2/ Note: "Upper Dakota" Sandstones are missing or were not recognized in this well. Although it is possible that they are not developed at this location, it is more reasonable to assume, in the light of supporting data, that they were not recognized or were not reported because they did not contain water.

3/ "Upper Dakota" Sandstones missing owing to pre-Tertiary erosion.

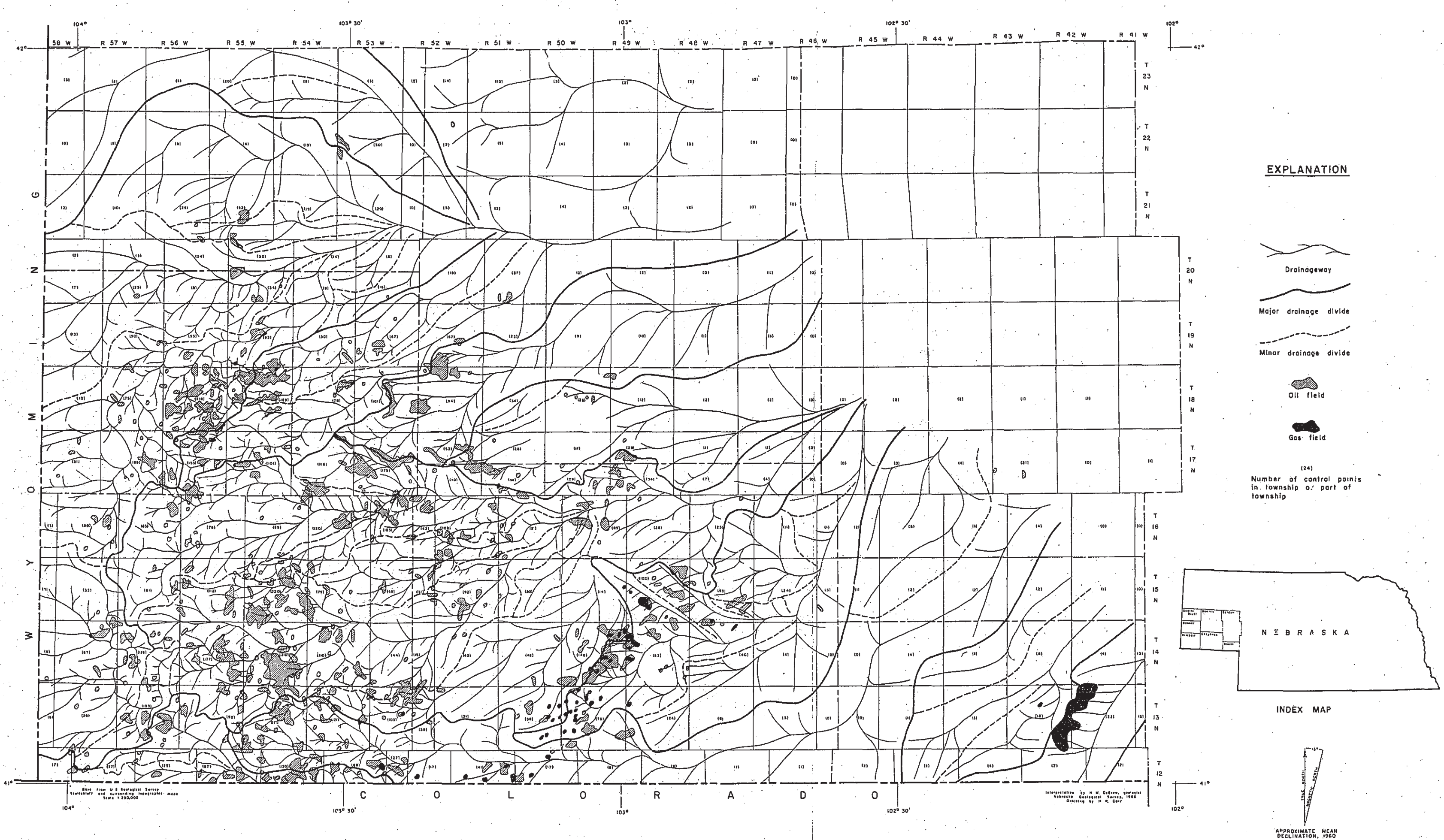
4/ Probably thick Miocene deposits, the principal aquifer in this part of western Nebraska.

5/ The validity of this report was reinforced by Mr. William Garber of Sidney, Nebr., the well-site geologist for this well (oral communication, 1963).

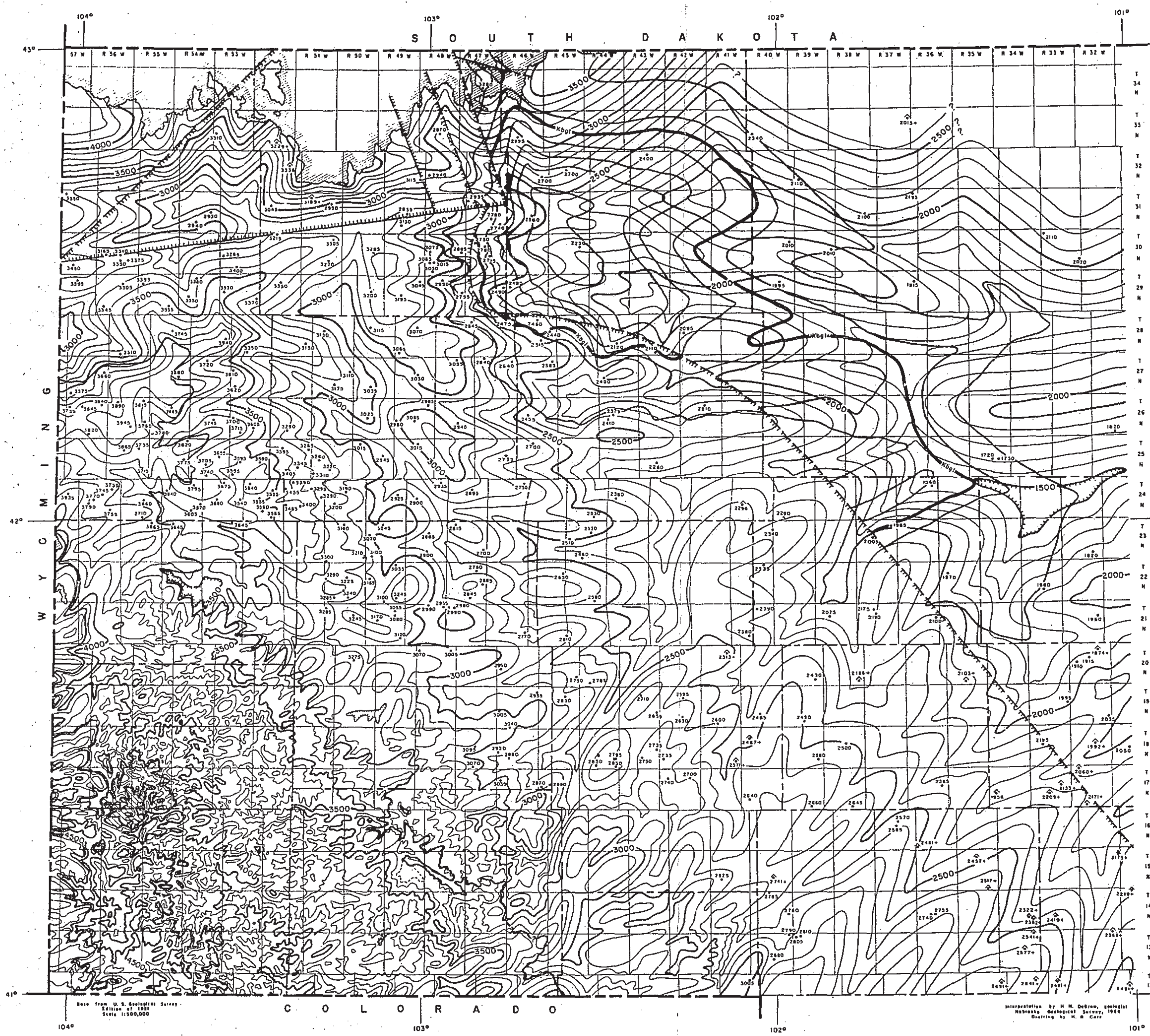


CONFIGURATION OF THE PRE-TERTIARY (PRINCIPALLY PRE-CHADRON) SURFACE IN WESTERN NEBRASKA

10 0 10 20 30 40
SCALE IN MILES



EARLY TERTIARY (PRINCIPALLY PRE-CHADRON) DRAINAGES AND DIVIDES, WITH LOCATIONS OF OIL AND GAS FIELDS, IN PART OF WESTERN NEBRASKA



GEOLOGY OF THE PRE-TERTIARY (PRINCIPALLY PRE-CHADRON) SURFACE IN WESTERN NEBRASKA

10 0 10 20 30 40
SCALE IN MILES

APPROXIMATE MEAN DECLINATION, 1960

EXPLANATION

CRETACEOUS

UPPER CRETACEOUS

- Kl — "Lance" Formation ("Laramie")
- Kfh — "Fox Hills" Formation ("Laramie")
- Kpt — "Transition Zone," Pierre Shale
- Kpu — "Undifferentiated" Pierre Shale
- Kn — Niobrara Formation, including Codell Sandstone
- Kbcs — Carlile Shale of "Benton" Group
- Kbgl — Greenhorn Limestone of "Benton" Group
- Kbgs — "Graneros" Shale of "Benton" Group

LOWER CRETACEOUS

- Kdu — "Upper Part" of "Dakota" Group
- Kds — "Skull Creek" Shale of "Dakota" Group
- Kdl — "Lower Part" of "Dakota" Group

JURASSIC

UPPER JURASSIC

- Jms — Morrison and Sundance Formations

Outcrop of pre-Tertiary surface

"Arikaree" valley-phase deposits resting directly on "Fox Hills"

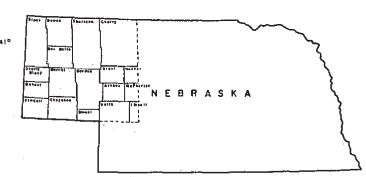
3000 — Contours on pre-Tertiary surface. Contour interval 100 feet. Datum is mean sea level

Fault Trend — Solid line, movement principally post "White River"; broken line, movement principally pre-"White River" or undetermined

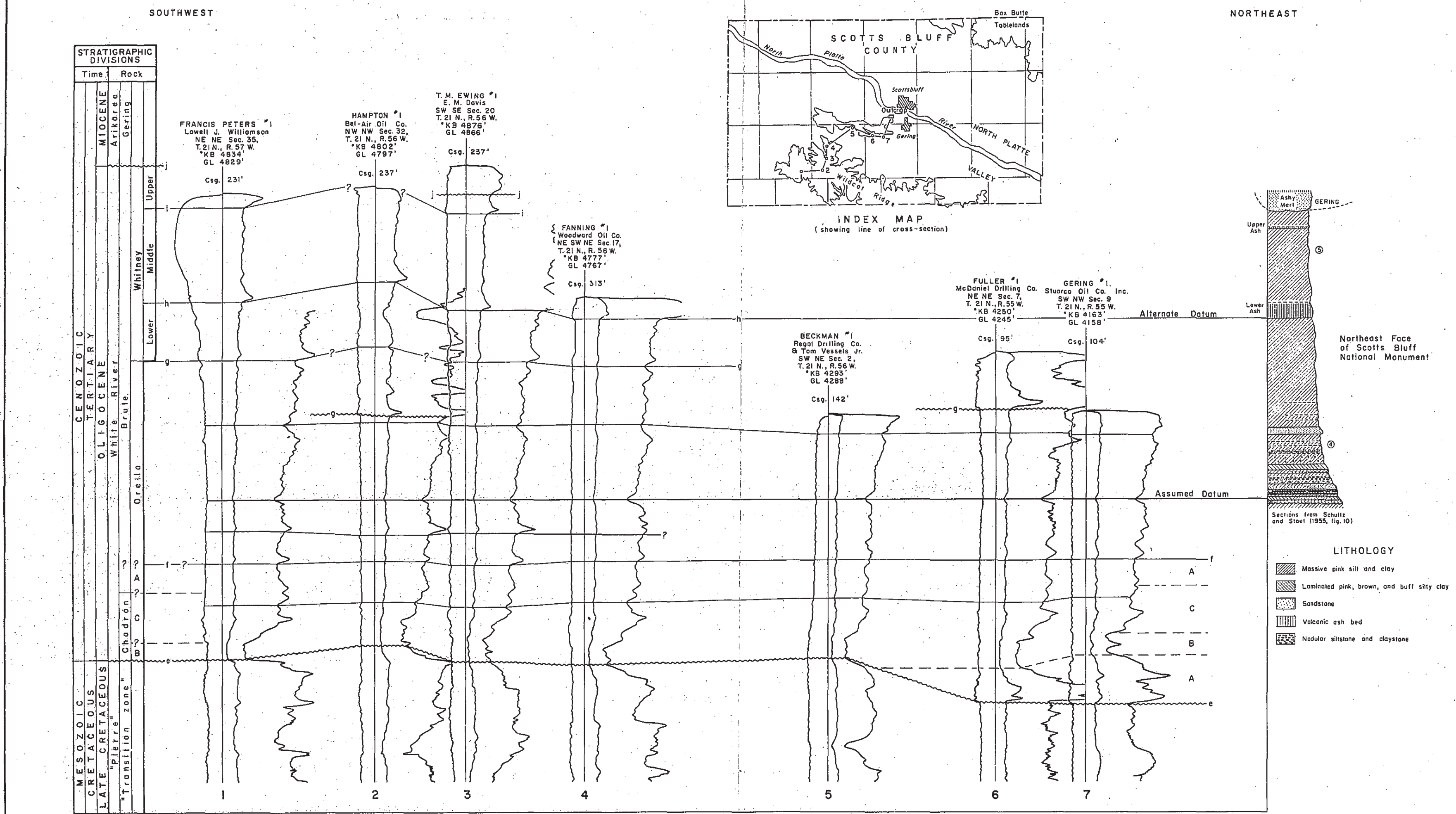
Altitude, in feet, of pre-Tertiary surface in well. Datum is mean sea level

Casing elevation below pre-Tertiary surface in well

NOTE: Geologic mapping of Chadron Dome area (at northwest end of Chadron Arch) is generalized



INDEX MAP



Interpretation by H.M. DeGraw, Geologist
Nebraska Geological Survey, 1968
Drafting by H.R. Carr and D.S. Summers

EXPLANATION

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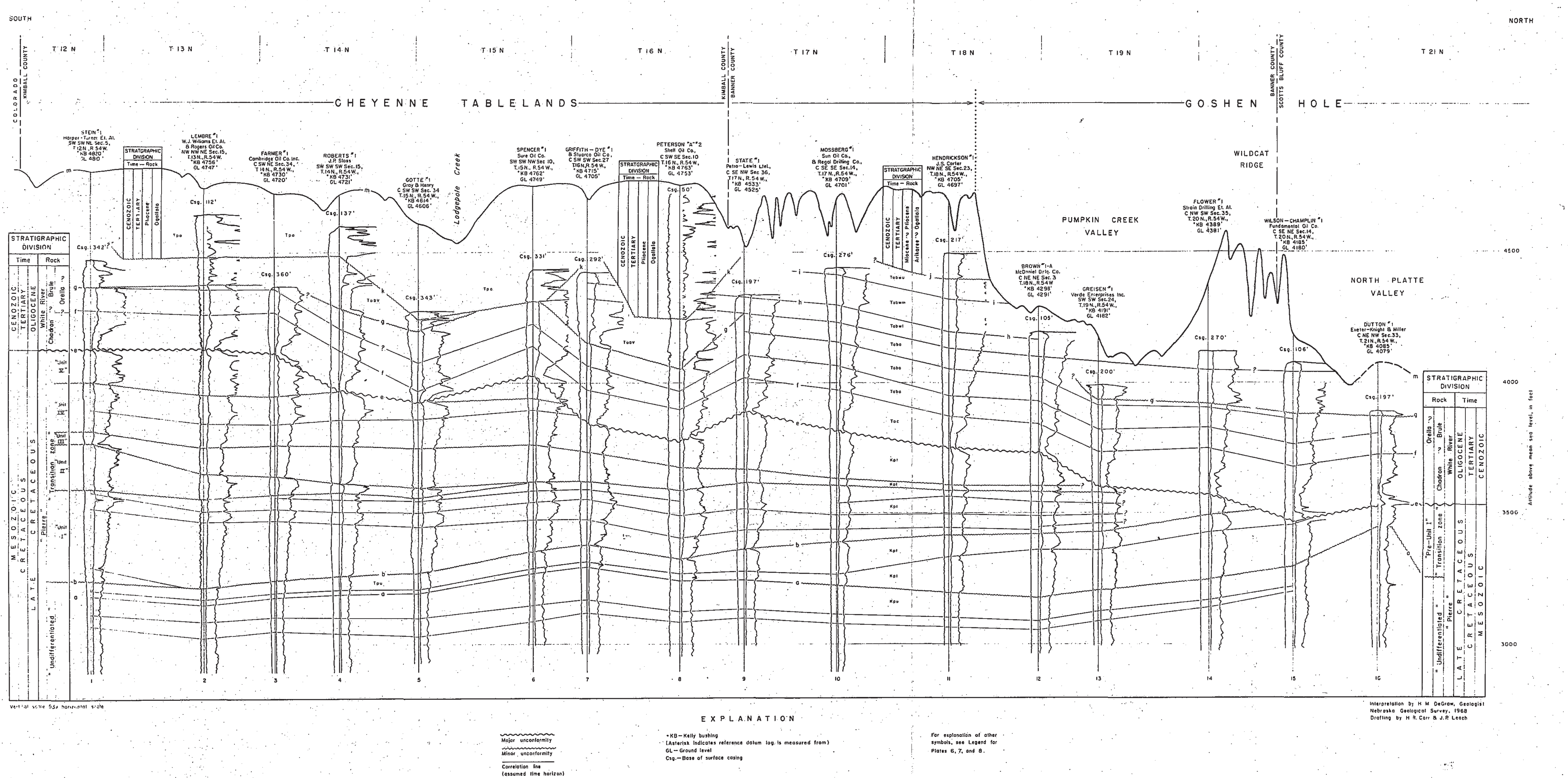
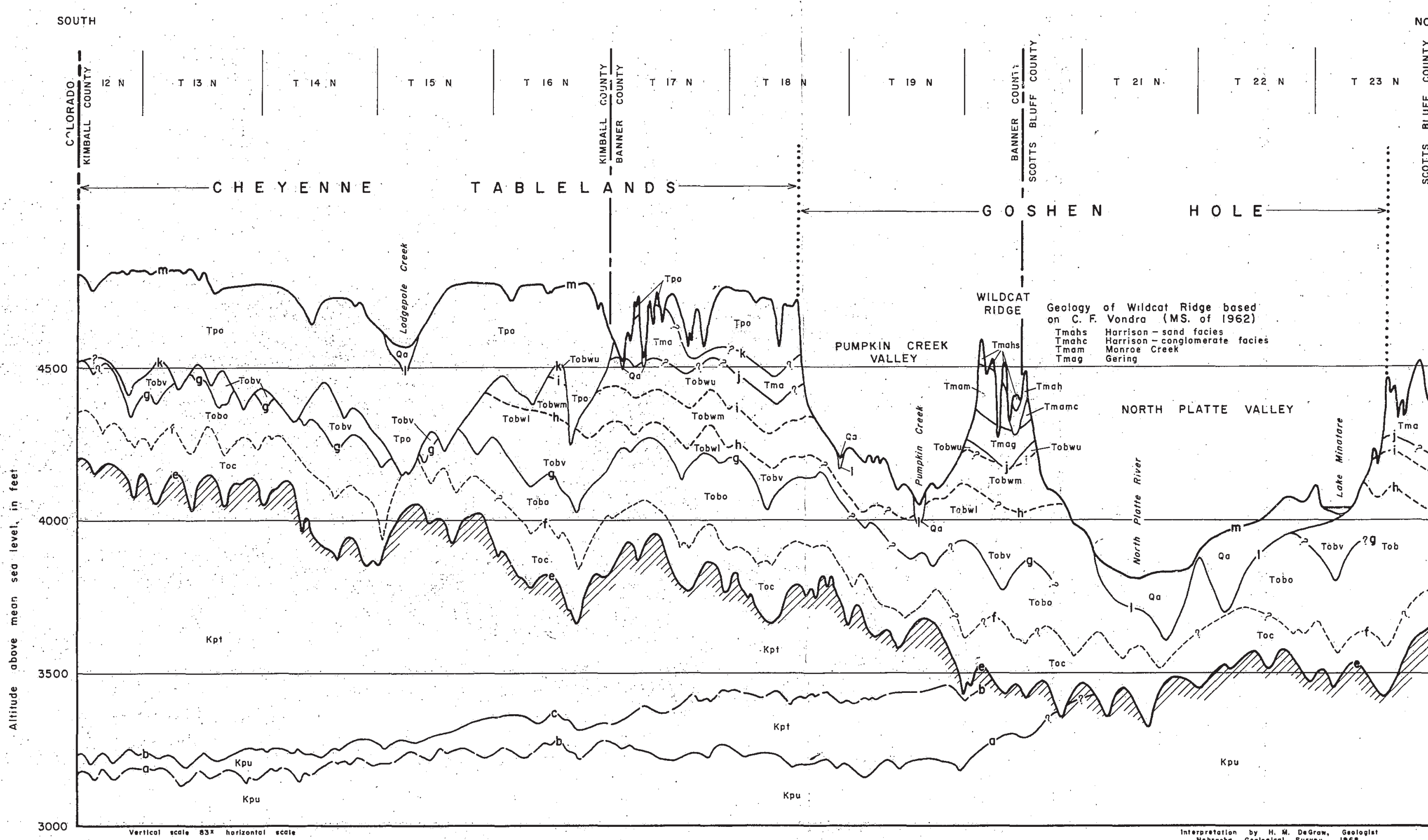
1 0 1 2 3
SCALE IN MILES



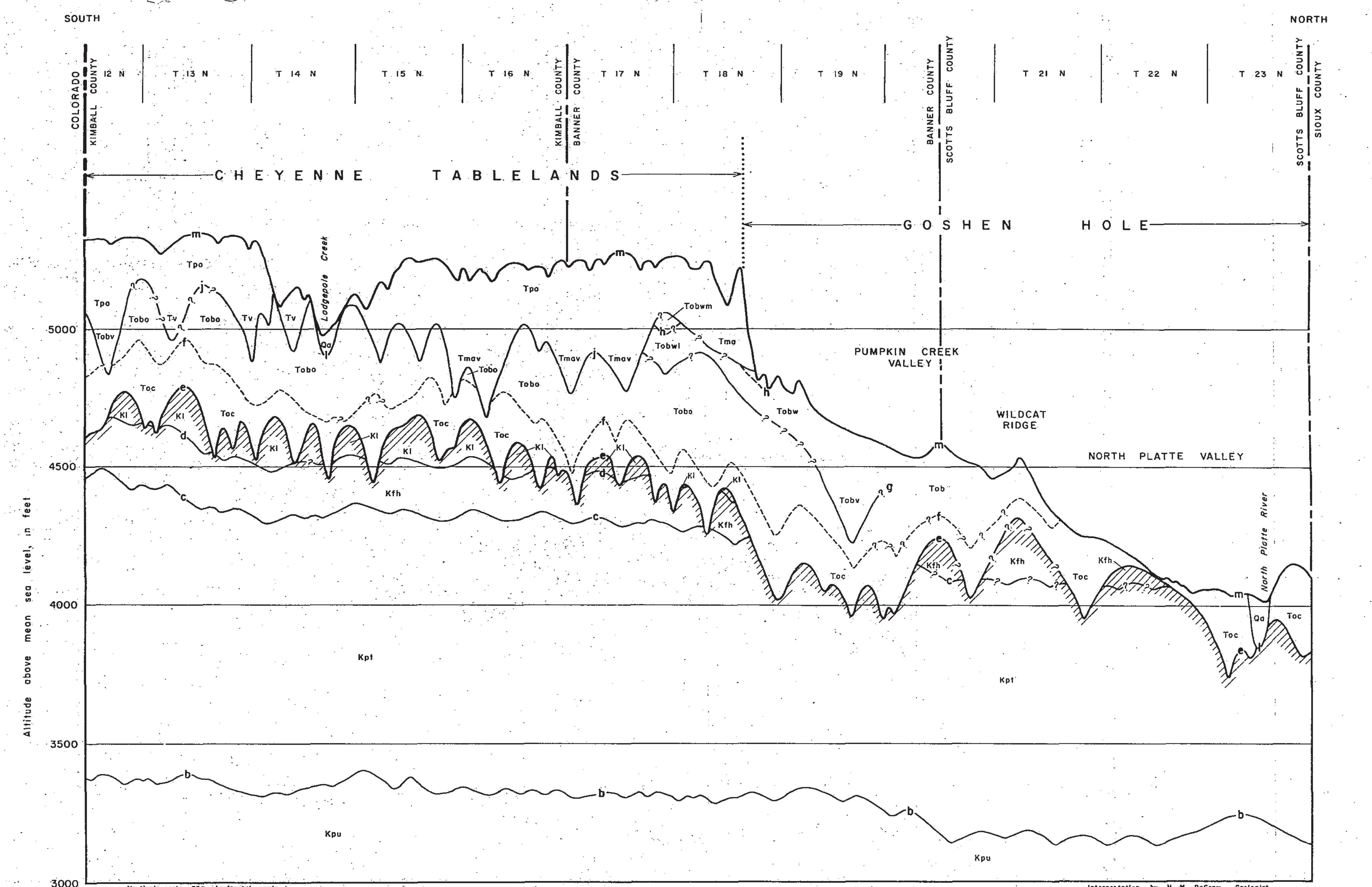
ELECTRIC LOG CROSS-SECTION ALONG THE 103° 30' MERIDIAN, WESTERN NEBRASKA



PROFILES OF DATUM HORIZONS "a"—"m" ALONG THE 103° 30' MERIDIAN, WESTERN NEBRASKA

(For Explanation of Symbols see Legend for Plates 6, 7 and 8)

5 0 5 10 15 20
SCALE IN MILES



PROFILES OF DATUM HORIZONS "b"—"m" ALONG THE 104° MERIDIAN, WESTERN NEBRASKA

(For Explanation of Symbols see Legend for Plates 6, 7 and 8)