Salinity Determination of Groundwater

by Electric Log Analysis

in the Lower Cretaceous (Cheyenne)

of Northwestern Kansas.

Electric well log curves have been successfully used to determine approximate equivalent salinities by Bryan (1950), Grynberg and Carlberg (1954), Jones and Buford (1951), Morris (1955), and Pryor (1956). However, only Tiddy (1955) and Pryor (1956) have published studies using these methods to determine regional groundwater quality.

The Cheyenne Sandstone contains interbedded shales, and porosity, permeability, and lithology of the unit vary greatly over the area of study. Data on groundwater quality in the Cheyenne Sandstone are so scarce that even imprecise results on this subject will be of value.

The study area extends from the State boundaries on the north and west. Southern and eastern limits of the area were determined by the existence of usable electric logs. Distribution of the oil wells having electric logs within the study area is not uniform. There are smaller areas with many wells and vast areas with only scattered wells. The Lower Cretaceous rocks dip to the south and west.

In the northern and eastern areas, the Lower Cretaceous rocks are often above the interval of the electrical survey. In the southernly areas few of the wells penetrate the

* References at end of paper

Cheyenne Sandstone and there are fewer sample logs to assist in determining the stratigraphic boundaries between formations and members south of Township 22.

Well Selection Procedure.

Many thousands of sample logs were examined and those having records of the Lower Cretaceous were noted. Electric logs of the same wells were compared to the sample logs to determine stratigraphic boundaries on the electric logs. In this manner, SP and resistivity curve characteristics of the Cheyenne Sandstone were obtained. One electric log per township was arbitrarily selected, near the center of each township. Using these logs and material published by Merriam (1957), electric logs not having corresponding sample logs were examined. Approximate NaCl-solution equivalents were obtained for all logs using the "Log Interpretation Charts" (Schlumberger, 1956).

Electrical surveys measure the resistivity of the fluids contained within the well bore and surrounding formation. Distribution and quantity of fluids held by subsurface formations are, to a great extent, controlled by characteristics of subsurface rocks. Theoretically, approximate equivalent salinity can be determined only for thick, homogeneous, shale free formations. Since formation waters contain several ions other than chloride, the results obtained from electric logs do not represent true salinity but an apparent salinity. Because resist-ivities of solutions of equal concentration of different

salts vary greatly, considerable error may be induced by
converting resistivity of water of unknown chemical
composition to NaCl-solution equivalents. Additional
sources of error may occur in estimation of formation
temperature or drilling fluid resistivity, inaccurate
reading of electric log records, inaccurate reading of
interpolation curves in the correction charts, or by
application of a theoretical method not strictly representing
real conditions. It may be expected that actual salinities
will differ from calculated apparent salinities, but some
relationship should exist between them. An example of
such a relationship has been given by Pryor (1956). For
an extensive survey of the theory and practice of electric
logging, refer to Lynch (1962).

According to Jones and Buford (1951), water quality
in granular aquifers of great extent is sufficiently
constant in quality and electrical resistivity to enable
preparation of a type curve for each aquifer or zone
of aquifers. An approximate hypothetical analysis using
this type curve can be derived from a single water-resist-
ivity value obtainable from an electric log and formation-
sample test.

Unfortunately, there are notchemical analyses available
from wells having electric logs which penetrate the Cheyenne
Sandstone in Kansas. Therefore, apparent salinities
calculated from electric logs could not be compared with
actual chemical analyses. Accuracy of the data obtained

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cannot be proved and a correction curve as given by Pryor (1956) could not be determined. To gain some approximation of the relationship between resistivities obtained from electric logs and actual analyses of water from an aquifer of similar age and geological position, data from the Dakota Formation in Colorado and Nebraska were examined. A curve was determined, based on fifteen chemical analyses of formation water from oil wells and on electric logs from the same or nearby wells. This curve, similar to that obtained by Pryor (1956) from almost 100 analyses, is used as a correction curve for the Cheyenne Formation. Using the curve, calculated NaCl-solution equivalents have been converted to approximate salinities, believed to be closer to actual salinities than uncorrected values.

Basic Information on the Electric Logging Method.

The spontaneous potential log of a well is a record of the electro-chemical potentials measured in the drilling fluid along one side of the well bore. Potentials are measured between an electrode lowered into the hole and another electrode at the surface and are related to an arbitrary constant. The SP log generally is flat opposite shales and shows positive or negative anomalies opposite permeable beds, so it is convenient to use the trace recorded through shales as a base line.

Spontaneous potentials in a bore hole primarily are due to the magnitude of electromotive forces generated by two different phenomena. The first and most important

of these, is the electrochemical cell fromed between the
drilling fluid and the fluid in the permeable rock. This
may be expressed for a thick, clean, permeable bed as:

$$E = -K \log_{10} \frac{R_{mf}}{R_w} \qquad (1)$$

where E=electromotive force of spontaneous potential

   R_{mf}=resistivity of the mud filtrate

   R_w=resistivity of the fluid in the permeable zone

   (formation water)

   K=factor dependent upon the character of the shale
   adjacent to the permeable bed and upon the char-
   acter of the two fluids

The second of these electromotive forces results
from filtration of the drilling fluid into a permeable
zone. The principle is a recognized phenomenon of elect-
rochemistry (streaming potential) and, if effective in
a well, may be expressed as:

$$E = \frac{M \times R_m \times P}{V} \qquad (2)$$

   E = electromotive force

   R_{fm} = resistivity of mud filtrate

   P = pressure differential between drilling fluid
   and formation

   V = viscosity of filtrating fluid

   M = complex factor dependent upon the nature of
   the permeable zone, the filtrate, and the mud
   cake

Although other factors may generate spontaneous
potential fields, the phenomena just described are assumed
to be most significant.

Description of Basic Data.

Reliability of calculations of resistivity and apparent
salinity made from logs range widely. Variations in
apparent salinity are due to three main factors; changes in
resistivity of formation waters, and differences in resist-
ivity of drilling fluids. All factors control the shape
and amplitude of the resistivity and SP curves. In favor-
able cases, deflections are distinct and no difficulties
are encountered in determining stratigraphic and lithologic
boundaries. In unfavorable cases, the curves are not
distinct and some are almost featureless. In such wells
the apparent resistivity and NaCl-solution equivalent were
determined only from resistivity curves.

Accuracy of data obtained from calculations depends
upon accuracy of reading the curves and some readings
may be in error. Those logs where resistivity of both
long normal and short normal curves is low and the ratio
of the resistivities is close to 1 are more likely to be
misinterpreted. In such cases, the thickness of the
resistivity curve represents a considerable percentage
of the total value of resistivity.

Apparent resistivity and NaCl-solution equivalent
for wells drilled with saline mud fluids. ranged from about
1 ohm-meter to about 25 ohm-meters for the short normal.

Ratios of the amplitude of the deflection of the long and short resistivity curves ranged from about 0.2 to about 3.0. The amplitudes of deflection of the SP curves ranged from about -70 milivolts to about +50 milivolts. Resistivities of mud varied from 0.1 ohm-meters to about 3.0 ohm-meters. Depths of the formation examined ranged from about 310 feet to less than four feet. Temperatures at formation depth ranged from $63^{\circ}F$ to $104^{\circ}F$.

According to the logs examined, thickness of the Cheyenne Sandstone ranges from 50 feet to 360 feet. In southwestern Kansas, no Cheyenne Sandstone exists and the Kiowa or Dakota Formations lie directly on rocks of Permian or Jurassic age.

Only the upper and the lower sandy layers in the Cheyenne Sandstone have been considered. The thickness of these layers is quite variable ranging between near 10 to about 50 feet.

Example for Calculation.

Fig. 1 represents a portion of an electric log of one of the wells examined. The electric logging was done by Schlumberger Well Surveying Corporation for the Banoff Oil Company in 1956 on the Bromfield No. 1 located in Graham County, Section 16, Township 6S, Range 22W. Elevations were as follows: D. F. 2372, K. B. 2375, G. L. 2370. Depth reached 3928. The temperature at the bottom of the hole (BHT) was $107^{\circ}F$. Aquagel mud fluid was used. Its resistivity was 1.14 ohmsm^{2}/m at temperature

80°R, and 9.85 ohms$/$m^2/m at BHT. The spacing of the electrodes were 16" for the short normal resistivity curve and 64" for the long normal resistivity curve.

In order to calculate the approximate equivalent NaCl concentration of the groundwater in the bed under consideration, according to Bryan (1950) and Pryor (1956), the following assumptions are made:

1. The mud filtrate has completely replaced formation water in the invaded zone.

2. The short normal curve measures only the portion of the formation which has been invaded.

3. The short normal is not being affected by the mud column.

These assumptions are never completely satisfied in practice. However, since the strata adjacent to the bore are more or less invaded by the drilling fluid, and according to Guyod (1944) the apparent resistivity given by the electrodes is largely affected by the true resistivity of materials within a distance from the center of the well bore equal the electrode spacing, it may be assumed that the short normal curve is essentially a measurement of the resistivity of the rock that is saturated with drilling fluid. Similarly, since the long normal curve is largely influenced by the resistivity of the material within 64" from the midpoint between the electrodes, and since much of this portion is relatively uncontaminated by drilling fluid, it may be assumed that the long normal curve is essentially a

measurement of the resistivity of the rock where it is filled with formation water.

According to this assumption the approximate resistivity of the formation water may be calculated from the equation:

$$\frac{Rw}{Rm} = \frac{R\ 64''}{R\ 16''}, \text{ hence } Rw = \frac{Rm \times RSP64''}{RSP16''} \qquad (2)$$

where R 16" – resistivity of that portion of the sand invaded by the mud filtrate (short normal curve reading)

R 64" – resistivity of the noninvaded zone of the sand (long normal curve reading)

Rw – resistivity of the formation water at formation temperature

Rm – resistivity of the mud fluid converted to the temperature encountered opposite the sand or sandstone under study.

The first step taken to calculate the NaCl-solution equivalent of the Cheyenne Sandstone is the ~~determination~~ of the bottom and top boundaries of the bed. Using existing sample logs and with the assistance of published materials D. F. Merriam (1955, 1957a, 1957b), these boundaries can be estimated with an accuracy sufficient for the purpose of this report. No attempt was made to estimate these boundaries closer that 5 feet. In many cases, because adjacent rocks have very similar electrical properties and sample logs were not available, estimated boundaries

may differ from the actual boundary much more than 5 feet.

In the well under consideration, top of the Cheyenne Sandstone has been estimated at 1230 feet and bottom at 1365 feet. Overlying the Cheyenne Sandstone is Kiowa shale and underlying are Morrison red beds. The Cheyenne Sandstone consists of two layers of sandy material separated by a layer of shale or sandy shale.

The reading of the resistivity curves are:

long normal, upper sandy layer 3.0 ohms, m^2/m

short normal "   "   "   6.5   "

long normal lower "   "   2.0   "

short normal "   "   "   5.0   "

Because the Cheyenne Sandstone lies between shale beds the base or shale line for the SP curve is very easily estimated. The deflection of the SP curve from the base line is

upper sandy layer -39 milivolts

lower "   "   -37   "

Using resistivity methods, the following steps must be taken to calculate the approximate NaCl-solution equivalent:

1. Determine the ratio of the apparent resistivity of the long normal curve to the resistivity of the short normal curve.

2. Convert the resistivity of the drilling fluid at the temperature given on the log heading to its resistivity at the formation temperature.

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3. Calculate for formation temperature knowing the bottom hole temperature (BHT), the depth of the formation, the depth of the bore holes and the average surface termperature.

4. Calculate the approximate resistivity of the formation water from the equation (2).

5. Convert the resistivity of the formation water at the formation temperature to the NaCl-solution equivalent concentration in ppm.

For all calculations and conversions the "Schlumberger Log Interpretation Charts" (~~25~~ Schlumberger, 1956) were used.

From Chart A-2 the temperature of the upper sandy layer was determined to be 75°F and for the lower layer 76°F. The resistivities of the mud fluid at corresponding temperatures were found by using the Resistivity-Salinity Chart A-6. By plotting the point corresponding to the temperature 80°F and resistivity of 1.14 ohms m^2/m given at the log heading on the chart, entering a point for the resistivity 1.14 ohms m^2/m and moving this point parallel to the diagonal lines to the new temperature we find that the resistivity of mud fluid at the temperature 75°F is 1.20 ohms m^2/m and @ 1.19 ohms m^2/m at the temperature 76°F.

The ratios of the apparent resistivities of the long and short normal curves are:

upper sandy layer $\dfrac{R64"}{R16"}$ = @ 0.46

lower   "   " $\dfrac{R64"}{R16"}$ = @ 0.40

Using formula 2 the approximate resistivities of the formation water were found:

upper sandy layer R_w = 0.55 ohms m^2/m

lower "   " R_w = 0.48   "

Using again chart A-6 the corresponding NaCl-solution equivalents were determined:

upper sandy layer @ 10,000 ppm

lower   "   "   @ 12,800 ppm

By using the empirical correction curve (fig. 3) it was estimated that the actual NaCl-concentration is:

upper sandy layer = 29,000 ppm

lower   "   "   = 40,000 ppm

The SP Method.

The procedure of calculation includes:

1. Correcting the observed SP when it is too low because of bed thickness.

2. Converting the resistivity of mud R_m at the formation temperature to the resistivity of mud filtrate R_{mf} at the same temperature.

3. Determining the equivalent water resistivity $(R_w)_e$ from the SP reading.

4. Converting $(R_w)_e$ to R_w.

5. Converting the resistivity of the formation water at the formation temperature to the NaCl-solution concentration in ppm.

6. Correcting the NaCl-solution equivalent concentration by means of the empirical curve.

Simple The thicknesses of both upper and lower sandy layer are 25 and 55 feet repectively, and the ratio of the resistivity of the invasion zone Ri to the resistivity of the mud is low; no correction for bed thickness is necessary. Using Chart A-4, the resistivity of mud at the formation temperature Rmf is estimated to be 1.05 *ohm-meters*. From the SP curve reading and from the Chart A-10 the equivalent water resistivity (Rw) is estimated.

Then using the SP curve readings and Chart A-10 it is been found that for both the upper and lower sandy layer the ratio Rmf/(Rw)e equals 3.4. Next from the formula

$$(Rw)e = \frac{Rmf}{Rmf/(Rw)e} \qquad (3)$$

it is been found that (Rw)e = 0.31 ohm-meters.

It should be mentioned that according to Chart A-9 the electrochemical component of the SP, E_C, is correlated to the activity of the formation water and of the mud filtrate, such that $E_C = -K \log a_w/amf$, where K varies with temperature.

According to Gonduin, M., Tixier, M. P., and Simard, G. L. (1956) a relation such as $E_C = -K \log Rmf/(Rw)e$ can also be used. The term (Rw)e (equivalent resistivity) is often nearly equal to the true Rw; but, when the formation waters are either very saline or quite fresh, large deviations may occur.

The next step, converting (Rw)e to Rw by using Chart A-12, determines that the Rw equals 0.34 *ohm-meters*.

The conversion of the Rw to NaCl-solutions equivalents has been done using the Chart A-6:

for the upper sandy layer 17,400 ppm NaCl

"   "   lower   "   "   16,900 ppm NaCl

The differences in the salinity found is due to the difference in formation temperature.

A considerable difference in the NaCl-solution equivalent determined using the SP and the long normal and short normal resistivity curves should be noted.

Results.

Table I and Figures 2, 3, 4, 5, and 6 show the results of the investigation. Resistivities and NaCl-solution equivalent salinities calculated from SP and resistivity curves for both the upper and lower sandy layer in the Cheyenne Sandstone are too voluminous to publish. However, the relationship between the resistivities obtained from SP and those received from long and short normal resistivity curves is shown (Fig.1). A theoretical line shown joining the points where the horizontal and vertical coordinates are the same is called the "zero variance line" (16).

The plotted data shows a high dispersion which points the inaccuracy of either one or both methods. However, it also indicates that a distinct relationship between the results obtained by these two methods. Figure 2 shows that for the resistivities less than 1.5 ohm-meters the resistivities obtained from the SP are lower than these calculated from the long and short normal resistivity curves.

Above the value 1.5 ohm-meters the resistivities computed
from SP curves are higher than these received from the
long and short normal.

On Figure 3 the apparent salinities calculated from
the SP curves are plotted against these computed from the
resistivity curves. Since the salinities vary inversely
to resistivities, Figure 3 is essentially an inverted
Figure 2.

Figure 2 shows that the data obtained do not fit
the "zero variance line" nor do they fit any distinct
curve, but are located inside of a belt of points. It
is significant that this belt shows a distinct trend,
and this trend represents the general rule, which for
the particular type of water and formation controls the
relationship between data received from the SP and the
resistivity curves. A line drawn among the points plotted
on Figure 2 crosses the "zero variance line" in the vicinity
of 4000 ppm. Above this value salinities computed from
the SP are higher than salinities calculated from the long
and short normal curves.

The ~~rate of~~ dispersion of points on both Figures 1
and 2 does not show any relationship to the values of
resistivity of salinity. The dispersion ~~rate~~ is nearly
constant for all areas of the data.

Table 1 lists actual salinities (chloride contents)
taken from chemical analyses from oil wells penetrating
the Dakota Sandstone in Colorado and Nebraska, and apparent

NaCl-solution equivalents computed ~~from~~ for the same formations ~~and~~ from the same or ~~close~~ nearby wells. These are plotted on Figure 4, with salinities along the vertical axis and the data derived from resistivity curves along the horizontal axis. A "zero variance line" is shown.

It may be seen from Figure 4 that the fifteen points do not fit the theoretical line but show wide dispersion. Although the dispersion is high the points seem to follow a certain curve. This curve is interpolated and drawn on Figure 2. Another curve, obtained by Pryor ~~(26)~~ (36) using almost one hundred analyses is also shown. The curves are almost parallel, the curve from the Dakota Formation being located above the curve from the Pennsylvanian in Illinois. They both are above the "zero variance line" in the zone of fresh waters.

The curve obtained by Pryor from the Pennsylvanian crosses the "zero variance line" at about 4000 ppm and the curve interpolated for data received from Dakota Formation crosses the theoretical line at about 1000 ppm.

Pryor's curve is based on many points located primarily below 2000 ppm, and the curve obtained by the authors is based on only fifteen points, the majority of which are located above 5000 ppm. It should be emphasized that the dispersion of the points in both cases is of the same order of magnitude in the zone where the majority of points are located.

As can be seen from Table 1, the values calculated from SP curves in some cases differ very much from the values taken from chemical analysis. Since this data does not follow any pattern it is not plotted on Figure 4.

The values calculated from long and short normal curves have been corrected by using the "empirical correction curve." These are shown on the map of north-western Kansas (Figs. 5 and 6) where corrected slainities have been divided into six water goups.

Fresh, approximately - less than 2000 ppm

brackish,   " - from 2000 ppm to 5000 ppm

low saline,   " - "   5000 " to 10000 ppm

high saline,   " - "   10000 " to 20000 "

very high saline, " - "   20000 " to 50000 "

brines,   " - more than 50000 ppm.

The groupings given above are arbitratily chosen and have only relative significance. Although Figures 5 and 6 differ in details, they show the same general picture. The highest salinities occur east from Range 26 in the lower section and east from Range 22 in the upper portion of the Cheyenne Sandstone. The area of high salinities is much more extensive in the lower part of the Cheyenne Sandstone.

To the west, along the northern portion of the Kansas-Colorado State line, the salinities begin increasing again.

Discussion of the Results and Conclusions.

The results of this investigation may be considered

as (1) the comparison of values obtained from SP and
resistivity curves, (2) the comparison of chemical analyses
and values computed form electric logs, and (3) the regional
distribution of relative salinity.

If all assumptions were satisfied, all measurements
perfect, and the curve reading and computations accurate,
one should obtain the same result for the groundwater
resistivity and thus the salinity using either the SP
or resistivity methods. Familiarity with the techniques
of measurement of temperature and mud fluid resistivity
as well as with the procedure of calculating resistivity
and salinity for rather thin sands and shaly sands alter-
nating with shales, however, forces realization that such
accurate coincidence of results is almost impossible.
The results obtained and plotted on Figures 2 and 3 show
a very great dispersion of points. The shape and width
of the belt created by the points, renders it possible
to assume that this dispersion may be the result of errors,
incidental as well as systematical. A great role is also
played by the discrepancies between the theoretical assump-
tions for which both the SP and resistivity method are
valid and the actual condition of an electric log penetrating
the Cheyenne, as well as simplifications made while cal-
culating the salinity values.

Both curves show a remarkable deflection from the
"zero variance line" in the zone corresponding to high
resistivities or low NaCl concentrations. As discussed

previously the equivalent formation water resistivity
$(Rw)e$ is converted to the Rw by means of Chart A-12
(Schlumberger 1956). The curves can be separated into
two parts where $(Rw)e < 0.1 < (Rw)e$ ohm-meters. ~~In the right
part, which corresponds~~ For high resistivities the Rw
increases in a much greater rate than the $(Rw)e$. These
parts of the conversion curves are plotted for average
fresh formation waters (where the Ca and Mg ions become
important) as reported by Gonduin, Tixier, and Simard,
(1957), and these curves can be in error. It is not out
of the question that the Cheyenne Sandstone waters represent
such a "special case". Until sufficient water analyses
are available this question remains open and no opinion
can be expressed as to which method has given results
closer to the actual salinities.

This question may be tentatively answered as far
as the results of fifteen analyses from the Dakota Form-
ation of Nebraska and Colorado are concerned. As Can
be seen from Table 1 the dispersion of values determined
the SP method is much higher than those calculated from
the resistivity curves. It may indicate that the resistivity
method in this particular case was more successful.
However, on the other hand some of the data received from
SP are much closer to the "zero variance line" than the
average curve interpolated amongt the data calculated from
the long and short normal curves. The small number of
analyses available do not allow firm opinion.

As to Figure 4, there is no doubt that the points
representing actual analyses tend to follow a curve,
however, there are many scattered points. This dispersion,
which is of the same order of magnitude as that received
by Pryor (1956) may be partly due to the analysis coming
from different geological and geographical regions.

There still remains the possibility, that the sample
of water taken for chemical analysis did not derive from
the same section which was used to calculate the salinity
from electric logs or that water taken for analysis was
contaminated.

Because of these uncertainties and the small number
of analysis, the results obtained in this investigation
cannot be considered as quantitative but only as qualitative.

Because the "correction curve" is uncertain the maps
(Figs. 5 and 6) of the "isochloride contours" may be
considered only as indicative of relative salinity.
They can show where there is nopossibility of encountering
fresh water in the Cheyenne Sandstone. This may be considered
as the most significant result of the investigation presented
in this preliminary report. Objections to the accuracy
of the method used do not affect the fact that there exist
striking differences in concentration of dissolved NaCl
between the southwestern and southeastern part of the
area investigated. It is also remarkable that the salinity
changes gradually. In many places, because of lack of
data the boundaries between the zones of different salinities

have been drawn somewhat arbitrarily. Moreover, in the southeastern part of the area investigated there are only few electric logs and for it no contour lines in this area may be drawn.

Even if the "correction curve" should be shifted downwards or upwards, according to new groundwater analyses which may be obtained in the future from the Cheyenne Sandstone, it should not affect the relative character of the location of areas with low and high slainity.

The fact that highly saline waters occupy greater area in the lower portions of the Cheyenne Sandstone than the upper portion is in accordance with the general observation that the concentration of dissolved solids increases with the depth of the formations.

The higher salinity at the bottom of the Cheyenne Sandstone and the distribution of high and low saline waters may be also of assistance in discussing the problem of the origin of salinity. It is commonly assumed that the Cheyenne Sandstone is a fresh or brackish water sediment. Thus, it should be expected that it originally contained fresh water. According to the results obtained from this investigation, we may assume that the initially fresh water was substituted or converted to saline waters.

There are three main sources of salt or brines that could cause this.

The overlying Kiowa shale is of marine origin.
It is possible that under the ~~acting of~~ weight of overlying
formations the sea water might be squeezed out and infiltrate
~~into~~ the Cheyenne Sandstone. In this case we rather should
expect more saline water immediately under the Kiowa
Formation, because the Cheyenne Sandstone contains shaly
sands and shales of low permeability alternating with
sandstone.

Secondly, during the deposition of the Cheyenne
Sandstone and afterwards, fresh water would dissolve
outcrops of the salt beds which are present in Permian
rocks. Groundwater movement might transport the saline
waters for some distance to the east (Refer to Groundwater
Geology of Northwestern Kansas). Nevertheless, we should
expect the maximum of salinity above or close to the outcrops
of salt beds. Figure 7 is a map of pre-Cretaceous formations
including those which are salt bearing (Merriam, 1955).
No distinct relationship between pre-Cretaceous salt exposures
shown in Figure 7, and saline water of the Cheyenne Sandstone
is evident.

If the above processes existed, they would act for
a very long time. The assumption can be made that, under the ~~according~~
influence of ~~to the~~ gravity ~~law~~, the saline waters would tend to occupy
the lowest portion of the permeable formation. Thus the brines
should occupy or their migration have been influenced
by the Cheyenne Sandstone fills of the pre-Cretaceous
stream channels, which represent the lowest portions of

the Cheyenne Sandstone.

Figure 8 shows the pre-Cretaceous surface by D. F.
Merriam (1955). No relationship between this map and
Figures 4 and 5 can be found.

Last of the three most possible sources of salinity
in the Cheyenne Sandstone are the oil field brines.
Two different ways of contamination ground water by such
brines may exist. J. M. Jewett (9) states that the Cheyenne
Sandstone is used for disposal of oil field brines in some
places. Another possible cause of contamination may be
the leaking of brines which occur under pressure in underlying
oil-productive formations. The invading brines may come
through corroded casing in old oil wells or even through
oil wells which were improperly abandoned. Figure 9 shows
the distribution of oil fields in the area investigated.

There exists in general an almost striking coincidence
between the location and concentration of oil fields
and the distribution of highly saline water. The unequal
dispersion of electric logs, and the arbitrarily assigned
"isochloride contours" on Figures 5 and 6 are basic reasons
for not expecting ideal coincidence. Further, the movement
of groundwater may produce considerable shifting of the
limits of the areas occupied by brines. Finally some
inaccuracy of calculation must be taken into account.

Nevertheless, the results of investigation presented
seems to indicate a noticeable relationship between the
oil fields and areas where Cheyenne Sandstone contains

high saline water.

These resultant indications require further investigations that take into consideration the location of brine disposal wells and oil production wells. They also should be more detailed and on smaller areas, using all available electric logs. The investigations should be supported by chemical analyses of the groundwater, and more accurate interpretation charts devised.

Without sufficient chemical analyses no quantitative results can be obtained, and few conclusions as to the original source of contamination can be drawn.

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Illustrations

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Illustrations

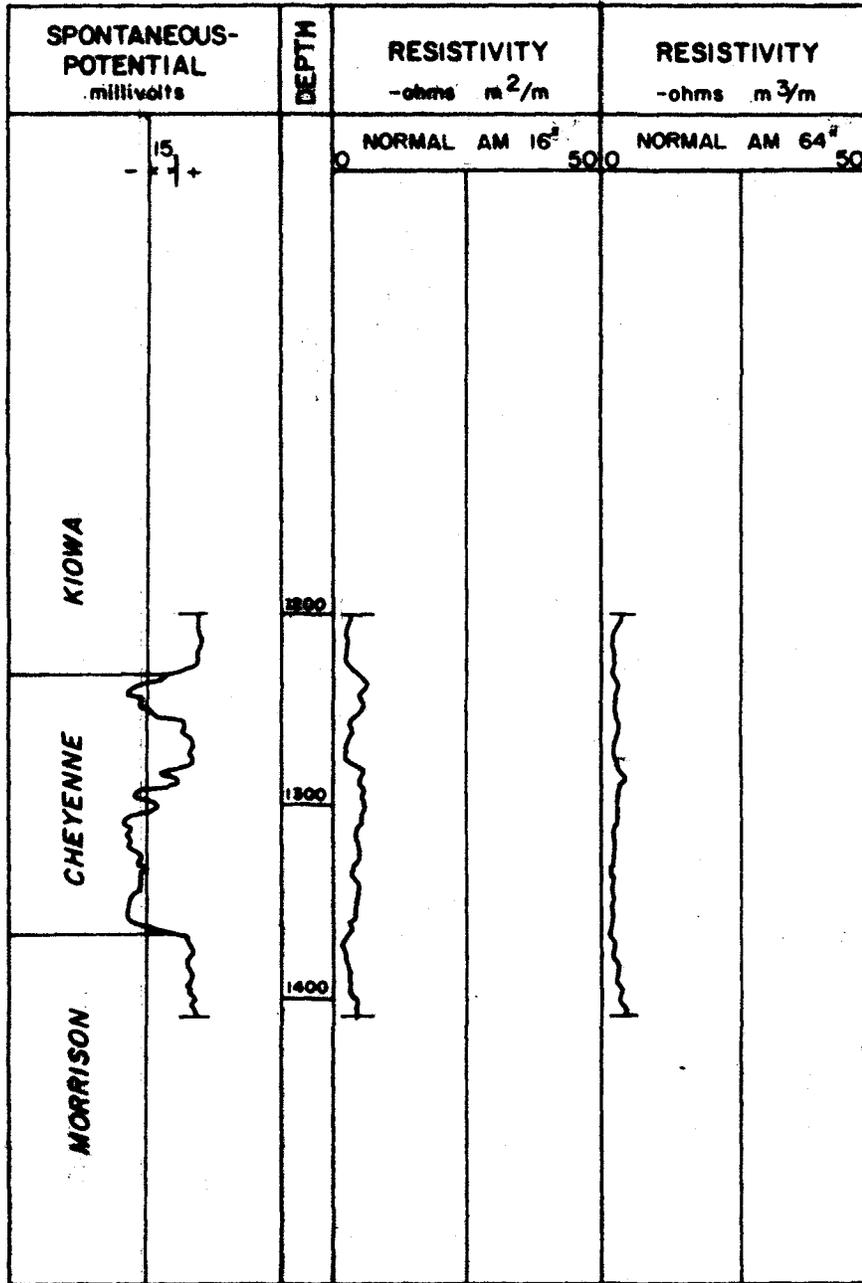# KGS OFR 60-6

NOTES AND ROUGH DRAFT CAN BE FOUND IN KGS LIBRARY OFR FILES

Kansas Geological Survey
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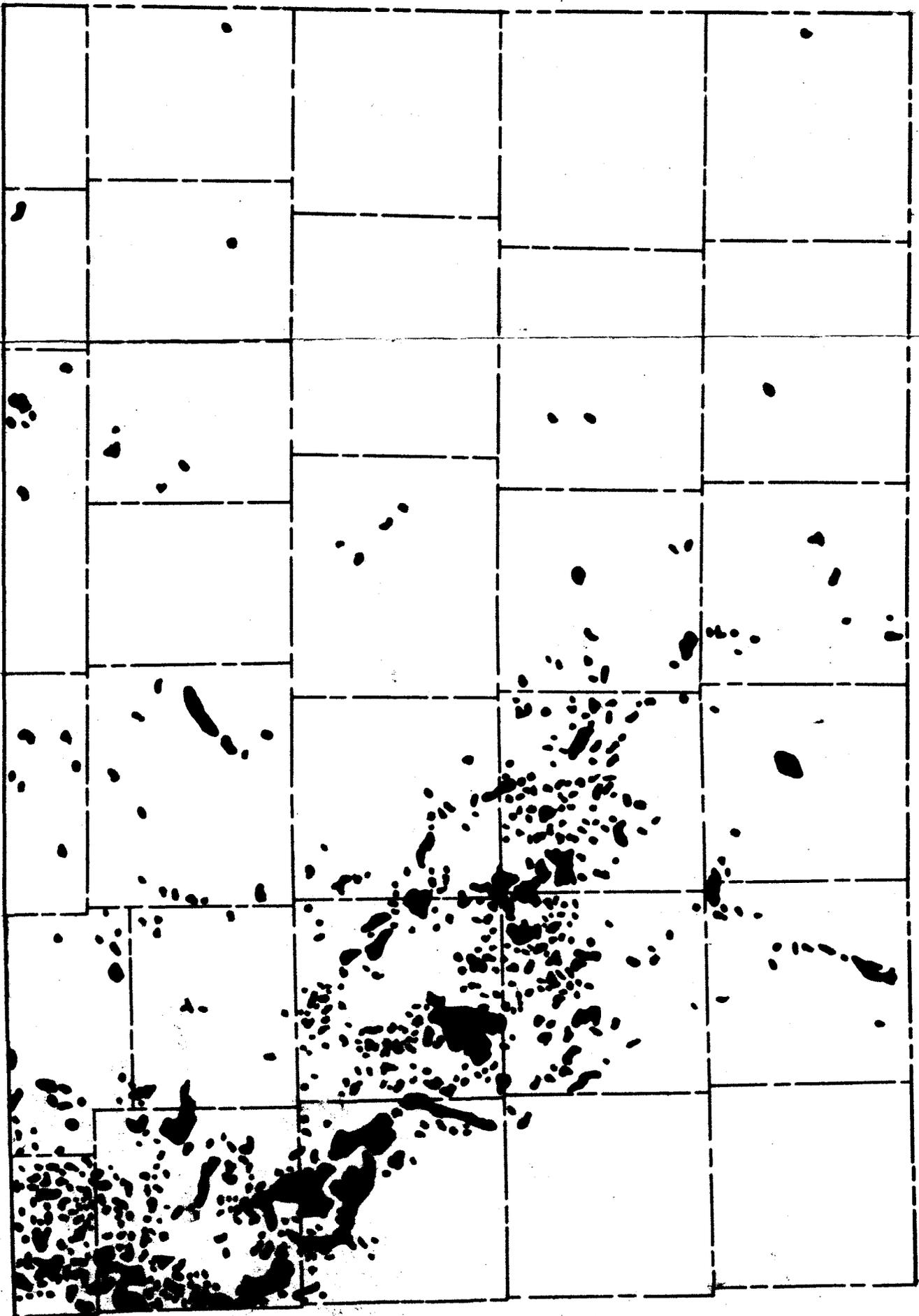
Fig 8
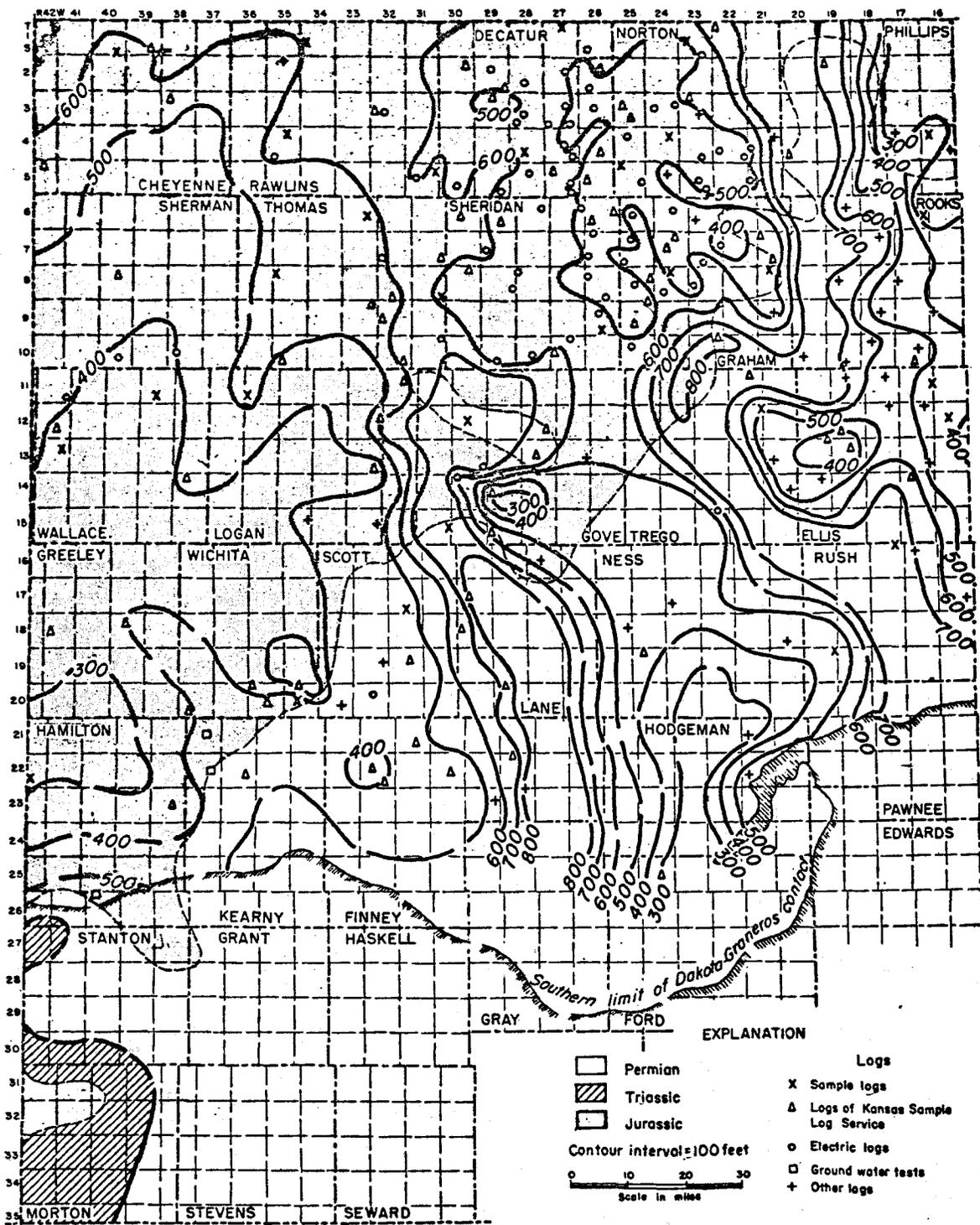
Fig. 8—Isopachous map between top of Dakota formation and base of Cretaceous. Map shows topographic relief on post-Morrison surface and reveals series of southerly trending valleys.

EXPLANATION

☐ Permian	Logs
▨ Triassic	X Sample logs
☐ Jurassic	△ Logs of Kansas Sample Log Service
Contour interval ± 100 feet	o Electric logs
	☐ Ground water tests
	+ Other logs

Scale in miles 0 10 20 30

Southern limit of Dakota-Graneros contact

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TABLE 1.

CALCULATED SALINITIES AND ACTUAL ANALYSES

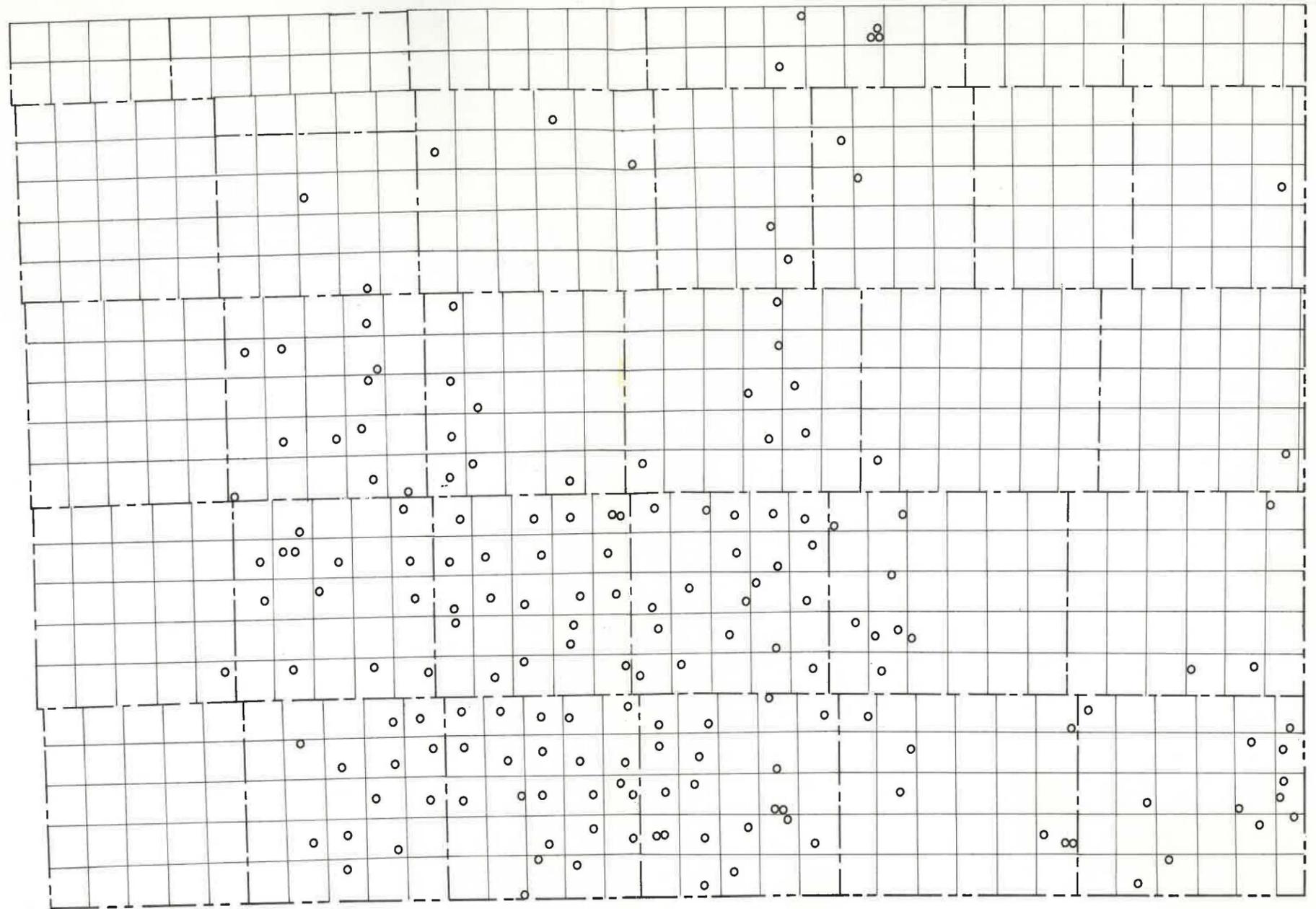| Well No.	Location				Depth, Feet	Geologic Source			Calculated Concentration of Chlorides from:		Data from Chemical Analyses	
						Dakota Formation	Resistivity calculated from:					
	T	R	S				Res. curve	SP curve	Res. curve ppm	SP curve ppm	Chlorides ppm	Total Solids ppm
D R Weaver #1	1N	58W	12	SE NW SW	5600 -5710	"T" sand	0.87	0.21	3800	16000	12520	15345
Ohman #2	1N	58W	12	SE SE SW	5645 -5670	"	0.71	0.12	4500	35000	12070	14442
Nagle #1	1N	58W	15	SE SE NE	5784 -5820	"D" "	0.53	0.2	6000	17000	14700	16981
J. E. Manning-Bamford #1	7N	54W	30	NE NW NW	5100		0.76	0.49	4000	6300	7300	8968
C. F. Green #1	9N	54W	25	NE NE NE	4900		0.9	0.17	3300	19000	9690	11250
Earl Vowers #3	14N	55W	22	C SE SW	6230 -6250	"T" "	2.1	0.18	1280	17200	3392	5597
Vowers #31	14N	55W	34	C NE SW	6334 -6352	"	2.7	0.07	970	51000	1354	3400
Durland Trust #1	14N	56W	15	SE SE SE	6490 -6510	"	0.86	0.12	3300	27000	5877	9123
State #2	14N	56W	36	NW SW NW	6350 -6390	"	1.42	0.29	2150	11000	5453	7489
Gehrke #7	14N	57W	7	C NW SE	6977 -6992	"	0.9	0.045	2800	90000	6354	8414
Ostgren #13	16N	55W	1	C NW SE	5890 -5910	"	0.77	0.35	3800	9000	8512	10587

N. S. Miller #1	[	12N	58W	7	C SW SW	7325 -7345	ʼʼ	0.45	0.23	5800	12500	8150	10200
Koehler #18-5		13N	42W	5	SW SW SW	3300 -3330	ʼʼ	3.3	1.8	980	1850	154	448
D. A. Mother #1		14N	50W	12	NW SE NW	4700 -4730	ʼʼ	0.37	0.12	9000	35000	20937	27702
Torgeson #1		14N	56W	23	SW NE NW	6475	ʼʼ	0.8	0.7	3100	3400	3665	5246

Note: First five wells are in Nebraska.
Remaining wells are in Colorado.

CHEYENNE | RAWLINS | DECATUR | NORTON | PHILLIPS | SMITH

HARPER

CEDAR HILLS SALT PLAIN

SHERMAN | THOMAS | SHERIDAN | GRAHAM | ROOKS | OSBORNE

FLOWERPOT

WALLACE | LOGAN | GOVE | TREGO | ELLIS | RUSSELL

BLAINE

DOG CREEK

GREELY | WICHITA | SCOTT | LANE | NESS | RUSH | BARTON

WHITEHORSE

PAWNEE

STAFFORD

HAMILTON | KEARNY | FINNEY | HODGEMAN

EDWARDS

TALOGA

DAY CREEK

GRAY

FORD

PRATT

STANTON | GRANT | HASKELL | KIOWA

BARBER

MEADE | CLARK

COMANCHE

MORTON | STEVENS | SEWARD

TRIASSIC

EXPLANATION

a – zero variance line (Theoretical)

b – empirical curve obtained by W. A. Pryor

c – empirical curve obtained by the authors

Relative salinity at the lower part of the Cheyenne.

	LESS THAN 5000
	5000 — 10000
	10000 — 20000
	20000 — 50000
	MORE THAN 50000

(Numbers in P.P.M.)

Relative salinity at the upper part of the Cheyenne.

	LESS THAN 5000
	5000 — 10000
	10000 — 20000
	20000 — 50000
	MORE THAN 50000

(Numbers in P.P.M.)