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SEISMIC INTERPRETATION OF PERMIAN SALT DISSOLUTION FEATURES, NORTHEASTERN COLORADO

by

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T-3203

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ABSTRACT

Recent well control shows that, locally, a significant portion of salt within the Permian Leonardian interval of the Sterling basin of northeastern Colorado has been removed by salt dissolution. Well log cross sections through the study area indicate that dissolution may have started as early as Jurassic time and continued spasmodically through the Cretaceous. The largest percentage of salt dissolution and associated collapse of the overlying section is suggested to have occurred during the Laramide Orogeny of Late Cretaceous-Early Tertiary. Rejuvination of Precambrian faults may have controlled Permian salt dissolution as indicated by the spatial distribution and orientation of the dissolution features within the study area. Modeling of the salt dissolution indicates that seismic data is capable of defining salt dissolution within the upper Leonard. A seismic isochron map of this interval delineates dominate northeast-southwest trending thins.

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INTRODUCTION

This thesis examines the seismic definition of salt dissolution features in the Permian of Leonard Age. Seismic data from portions of Logan, Phillips, Sedgewick and Yuma counties, Colorado are used in this study. A Permian evaporite basin has long been recognized in northeastern Colorado. Isopachous variations in the rocks of the Permian Leonard are associated with areas of salt presence and absence due to dissolution (Momper, 1963, Sonnenberg and Weimer, 1981).

Recent deep drilling within the study area has provided additional well control that gives clear evidence of dissolution and a better understanding of its timing. Seismic models of the Leonard salt section are used in conjunction with seismic data and available well control to interpret the present extent of dissolution, timing of dissolution, and the relationship of dissolution cause and effect on the overlying stratigraphic section. For salts above an objective, interval thickness variations in the salt can induce false structure on a seismic time-structure map due to the replacement of lower velocity shales by higher velocity salts. Thickness variations of the salt must be mapped to allow for accurate depth conversion of pre-salt horizons. Sedimentary strata above the salt may be influenced by the underlying salt dissolution. Salt dissolution events can affect deposition and can change structural position after deposition influencing water and hydrocarbon movement and hydrocarbon entrapment. Fracturing of brittle sedimentary units can occur over salt dissolution edges thereby enhancing permeability of otherwise tight reservoir strata.

GEOLOGIC BACKGROUND

Regional Setting

The study area is located in northeastern Colorado and covers portions of Logan, Phillips, Sedgewick, and Yuma counties, Colorado. The area lies on the eastern flank of the Denver Basin, north of the Yuma County high (an extension of the Las Animas Arch), and southwest of the Chadron-Cambridge Arch of Nebraska (Fig. 1, Plate 1).

Regional Stratigraphy

A generalized stratigraphic column for the study area is indicated in Fig. 2. Rocks of the Pennsylvanian Morrow unconformably overly Precambrian rocks in the study area. Morrowan strata, 100 - 150 thick, are generally comprised of an unnamed sequence of interbedded marine black to green shales; tan to light gray, glauconitic, skeletal limestones; and white, glauconitic, quartz sandstones (Maher, 1953a, 1953b; Maher and Collins, 1952).

Above the Morrow, rocks of the Atoka, up to 100 feet in thickness, are present in the western portion of the study area. These strata are dominated by marine, dark gray to black shales and dark gray, argillaceous, cherty lime mudstones to wackestones. Marine sedimentation continued throughout the Des Moinesian, Missourian, and Virgilian adding about 800 feet of sediments. During the

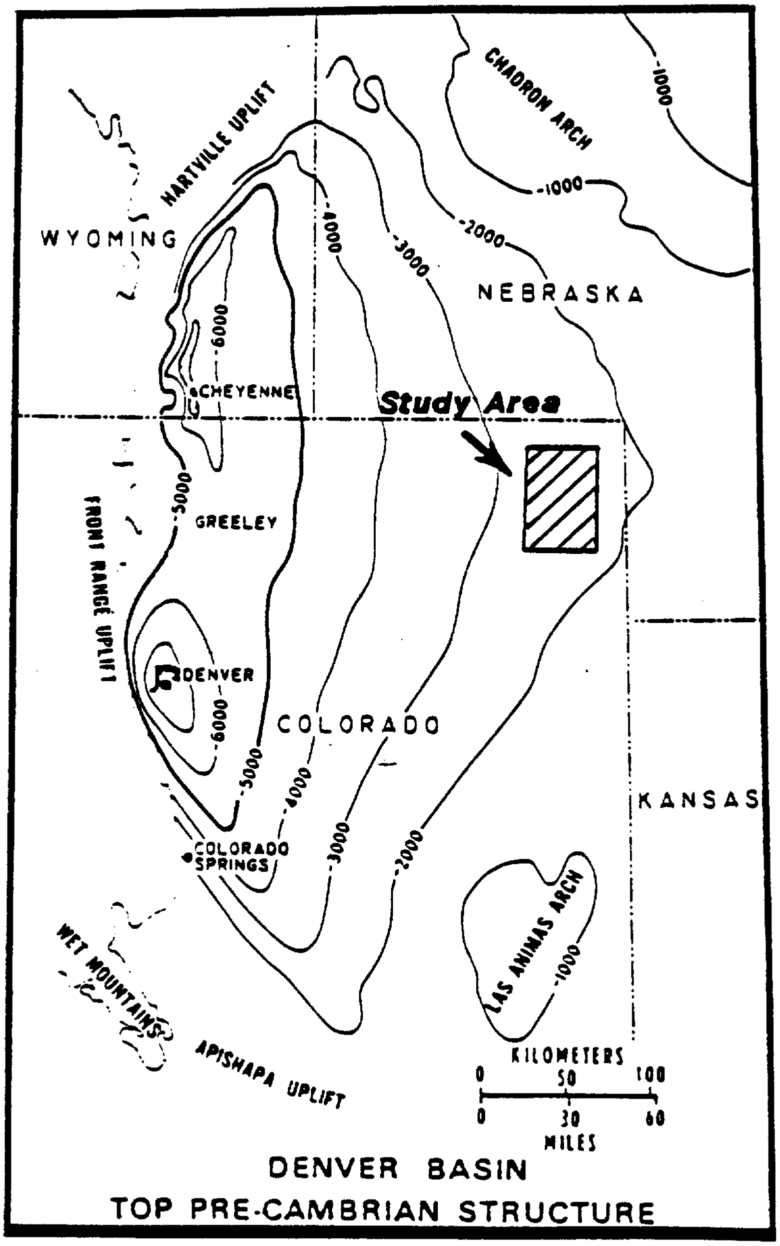

Fig. 1 Index map of the study area. C.I.: 1000 ft. (after Matuszczak, 1973)

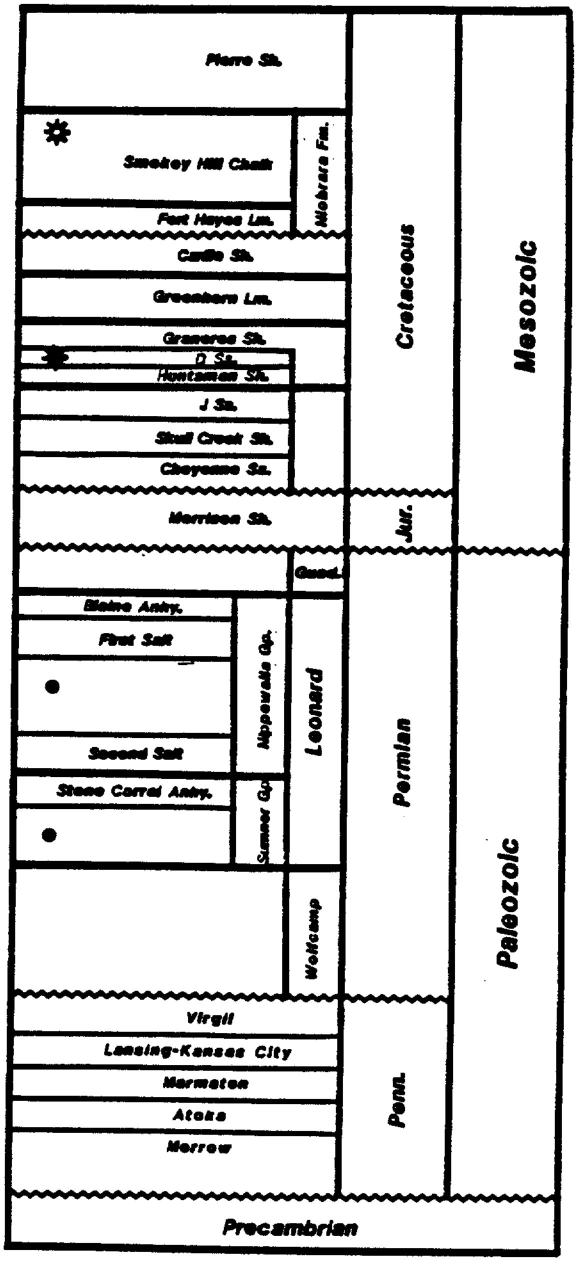

Fig. 2 Generalized Stratigraphic Column over the study area. (after Sonnenberg and Weimer, 1981 and Rascoe, 1972)

Pennsylvanian, carbonate sedimentation reached a maximum during the Marmaton in this area. The rocks here are comprised dominately of gray, cherty, mixed skeletal, oolitic lime packstones, wackestones, and mudstones with some interbedded gray, green, and black shales (Maher, 1953a, 1953b, Maher and Collins, 1952, DeVoto, 1980).

Approximately 1,000 feet of Permian rocks exist in the study area according to the Permian isopach of Sonnenberg and Weimer (1981) (Fig. 3). The Permian here consists of rocks of the Wolfcamp, Leonard, and Guadalupe Series. The Wolfcamp is predominately white and pink anhydrite and light colored dolomite (Hoyt, 1963). These rocks approach 400 feet of thickness in the study area. Leonardian rocks range from 250 to 550 feet thick in the study area and are the primary focus of this study. The Guadalupe interval consists of carbonates and anhydrites interbedded with red shales and is approximately 100 feet thick in the study area (Rascoe, 1972).

Triassic rocks are not present in the study area (Maughan, 1980).

The Jurassic Morrison Formation in the study area is comprised of approximately 100 feet of varigated claystones, siltstones, sandstones, and dense limestones (Imlay, 1952).

Cretaceous rocks make up the majority of the

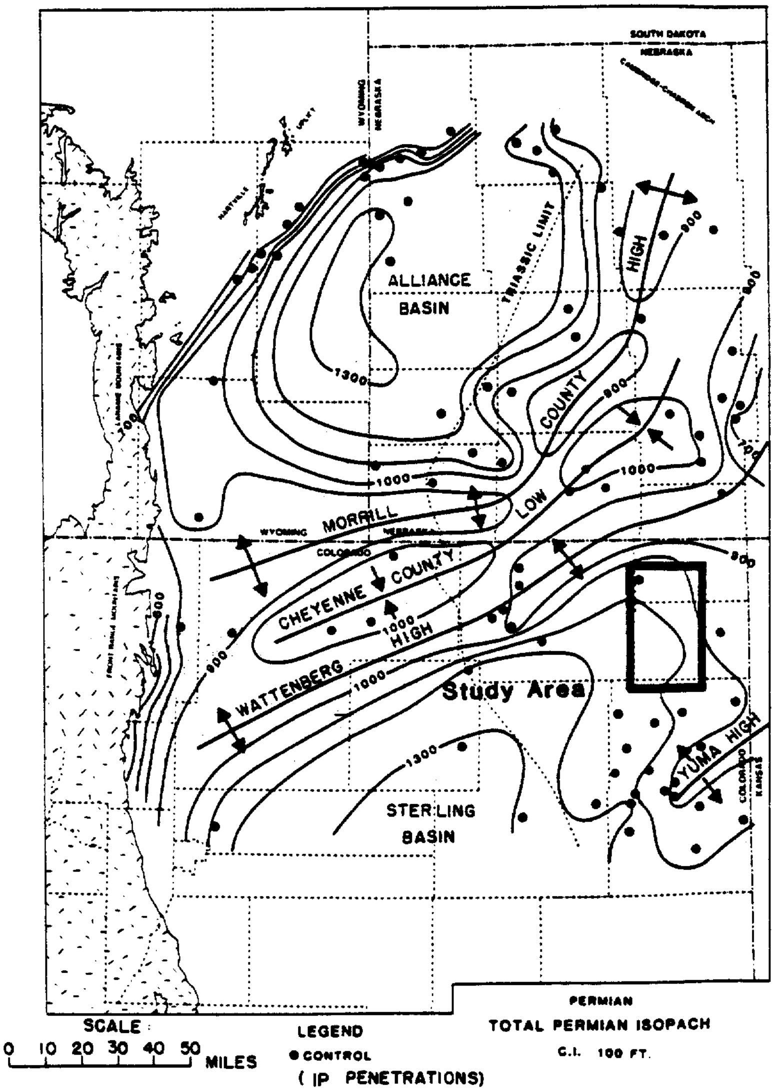

Fig. 3 Isopach map of total Permian, northern Denver Basin. (after Sonnenberg and Weimer, 1981)

stratigraphic section in the study area with approximately 3,500 feet of sediments. These sediments were deposited as the inland Cretaceous sea rose and fell, and consist of sandstones, shales, limestones, and chalks (Haun, 1959, Weimer, 1959).

Tertiary/Quaternary deposits cap the sedimentary sequence and consist of sandstones and shales.

Leonardian Stratigraphy

The majority of the thickening in rocks of Permian Age occurs in the Upper Permian Leonardian. The outline of the Permian Sterling Basin described by Momper (1963) is still apparent in the Upper Permian isopach of Sonnenberg and Weimer, (1981) (Fig. 4). Incorporating recent well data, an isopachous thin appears in the middle of this basinal thick in the Upper Permian (Leonardian) Age rocks (Fig. 5). This thin is interpreted to be the result of dissolution of salts within the rocks of Leonard Age.

In describing the Leonardian rocks of the study area, nomenclature from the Midcontinent region, the Black Hills Region, or the Denver Basin may be used. In their study of the Northern Denver Basin Sonnenberg and Weimer (1981) utilized the later two and described these sediments as the Goose Egg Formation or the Santanka and Lyons Formations. I have chosen to use terminology from the Midcontinent for

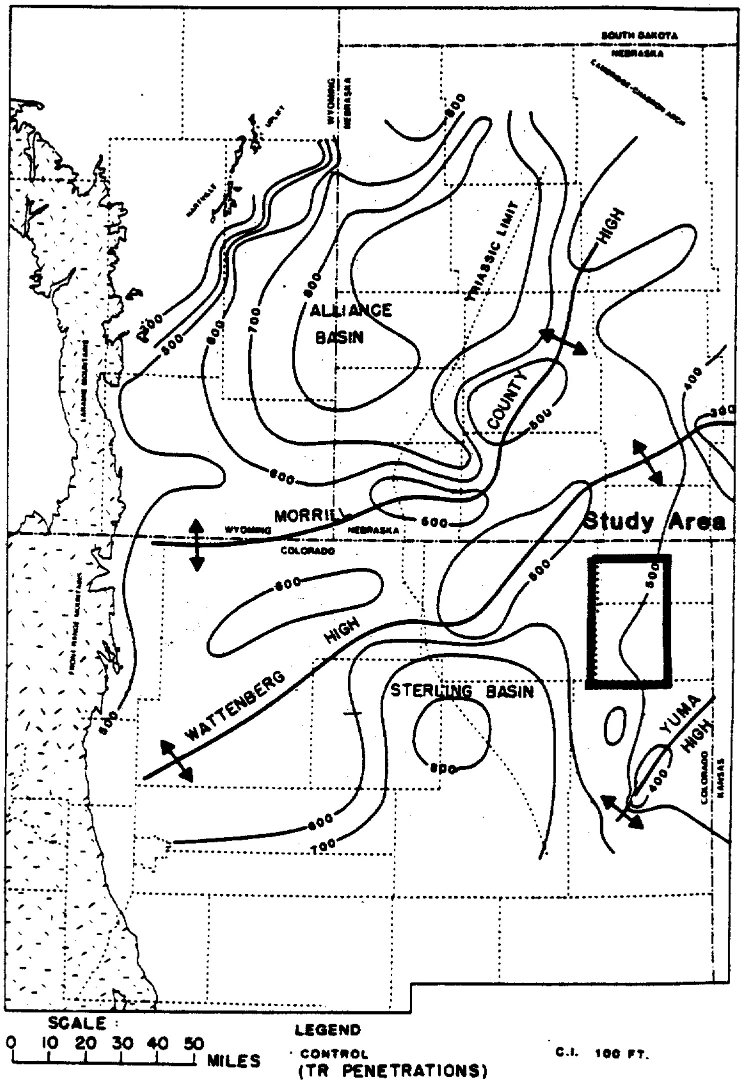

Fig. 4 Isopach map of upper Permian, northern Denver Basin. (after Sonnenberg and Weimer, 1981)

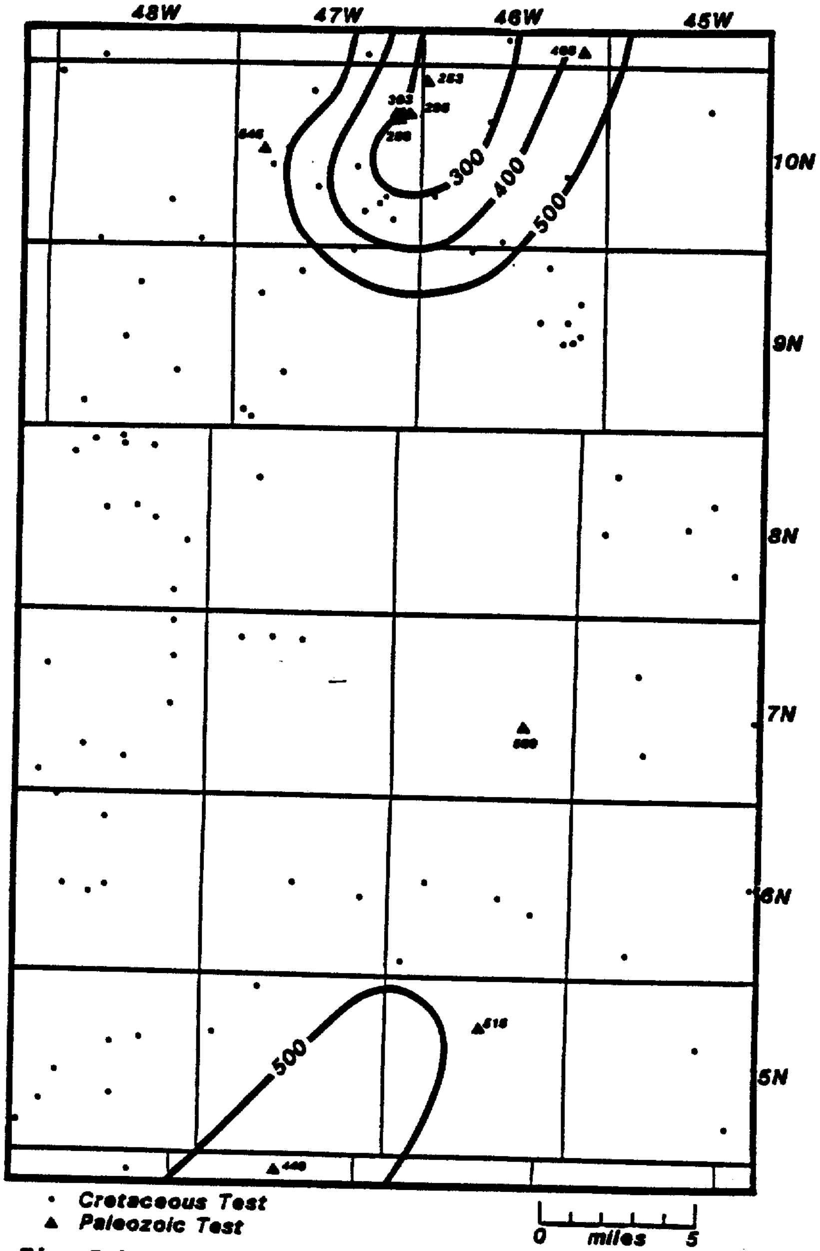

Fig. 5 Isopach of total Leonard over study area. C.I.:100 ft.

this study because the rock units being investigated are more clearly defined. In the Midcontinent terminology the Leonard is divided into two rock units, the Nippewalla Group and the Sumner Group (Fig. 2 and Plate 2). The Nippewalla Group is bounded by the Blaine Anhydrite at the top and the Stone Corral Anhydrite at the base (Rascoe, 1972). Both are present in the study area, however the Stone Corral Anhydrite is thin and grades to a shale to the northeast (Plate 2). An isopach of the Nippewalla Group is shown in Fig. 6. The Sumner Group is bounded at the top by the Stone Corral Anhydrite and at the base by an unnamed anhydrite at the top of the Wolfcamp. An isopach of this interval is shown in Fig. 7. A comparison of these two intervals shows that although both show thinning to the northwest, greater thinning occurs in the Nippewalla Group. In reviewing sonic, density, caliper, and neutron log data from wells within the study area salts have been located within both groups of Leonard Age rocks. Salts in the Sumner Group attain a maximum thickness of approximately 70 feet (Fig. 8) while 250 feet of salt occurs in the Nippewalla Group (Figs. 9 and 10). The rest of the Upper Leonard is comprised primarily of red shales and siltstones. A comparison of the Nippewalla isopach and the isopachs of the two Nippewalla salts shows that the

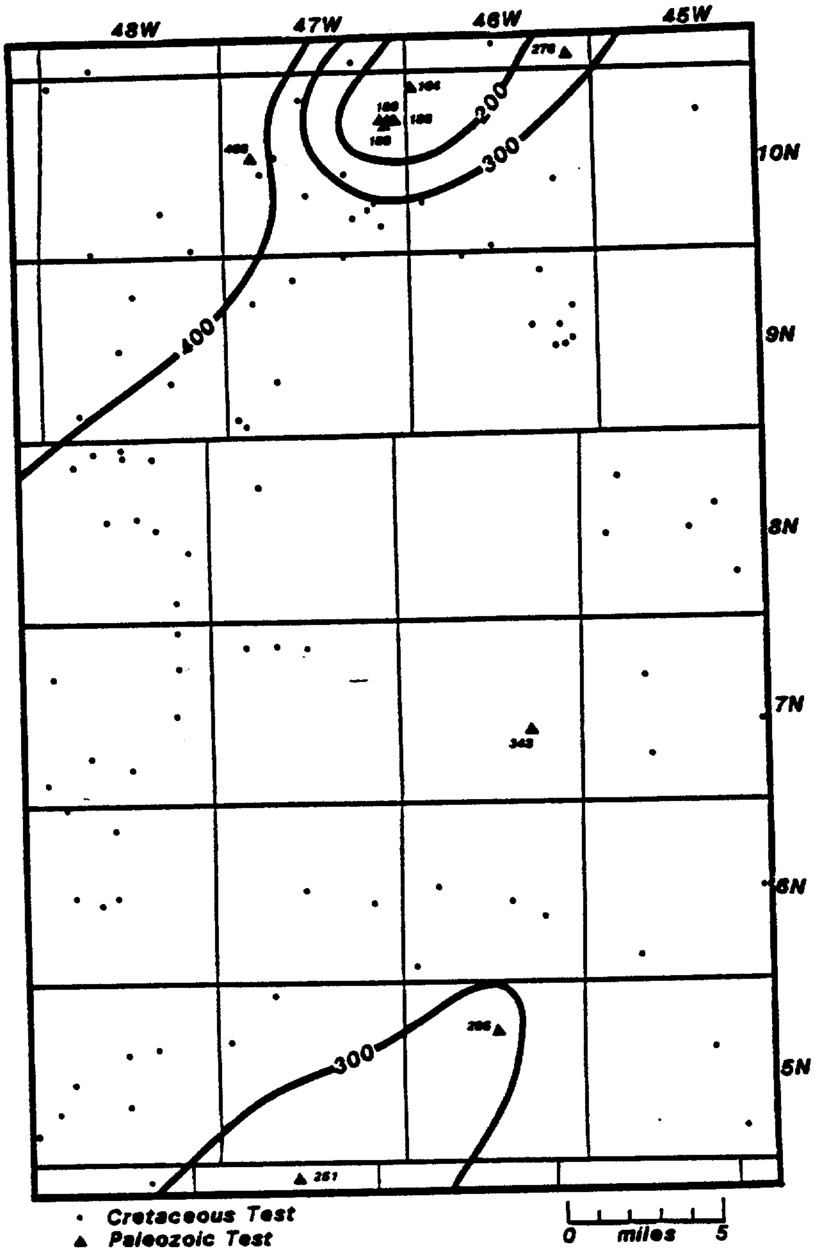

Fig. 6 Isopach of total Nippewalla Group over study area. C.I.: 100 ft.

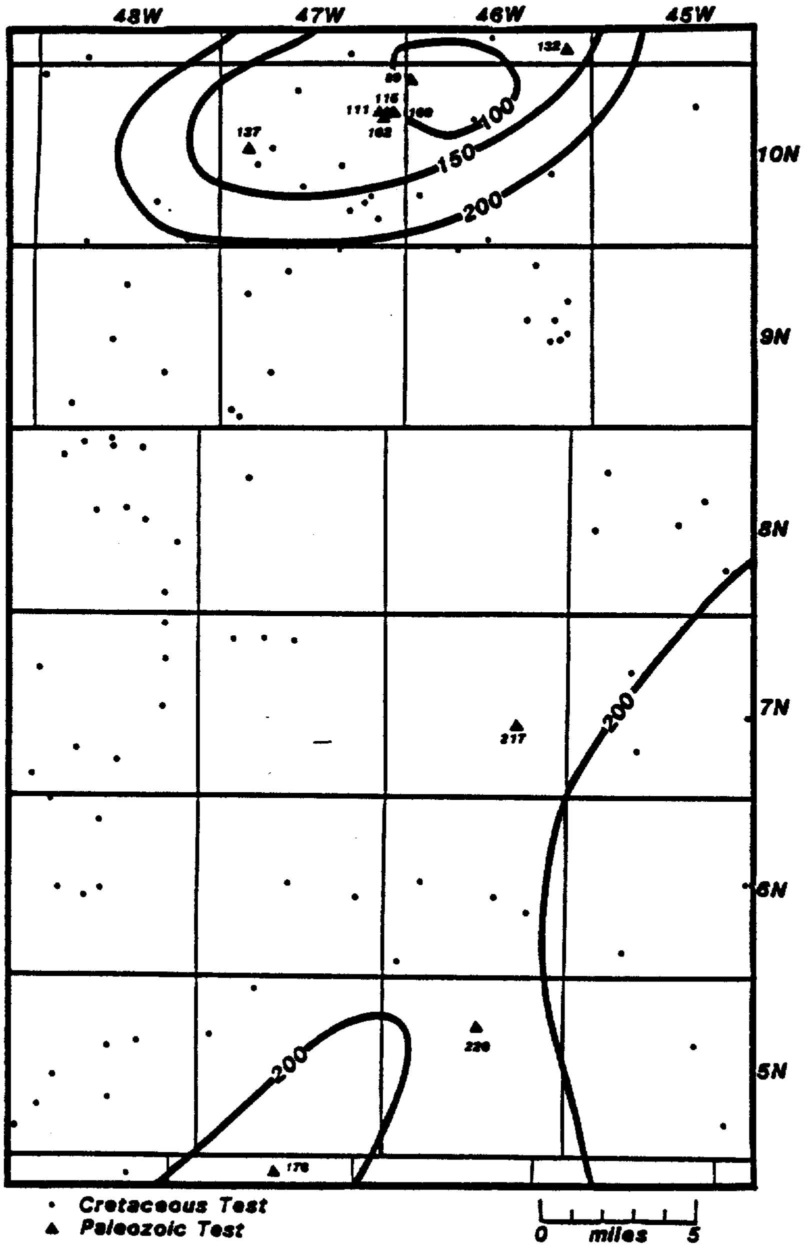

Fig. 7 Isopach of Sumner Group rocks over study area. C.I.: 50 ft.

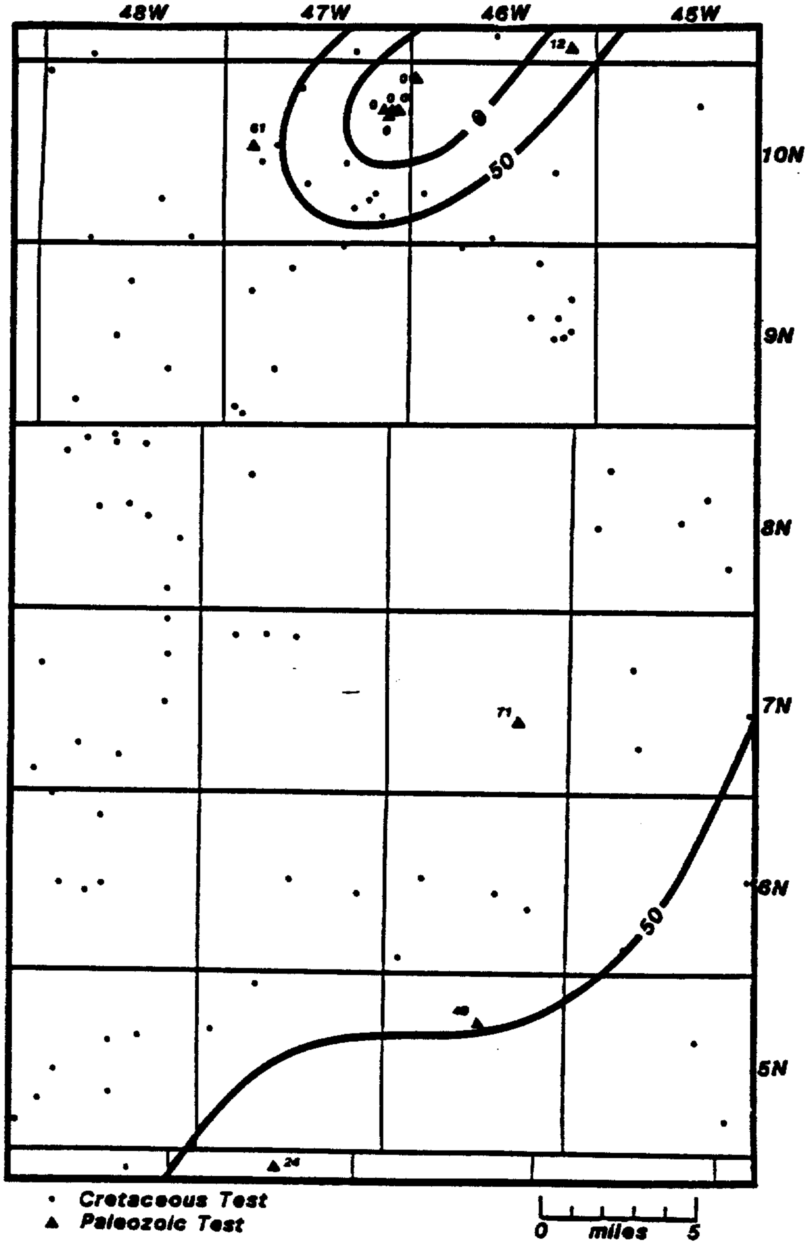

Fig. 8 Isopach of total Sumner salts over study area. C.I.: 50 ft.

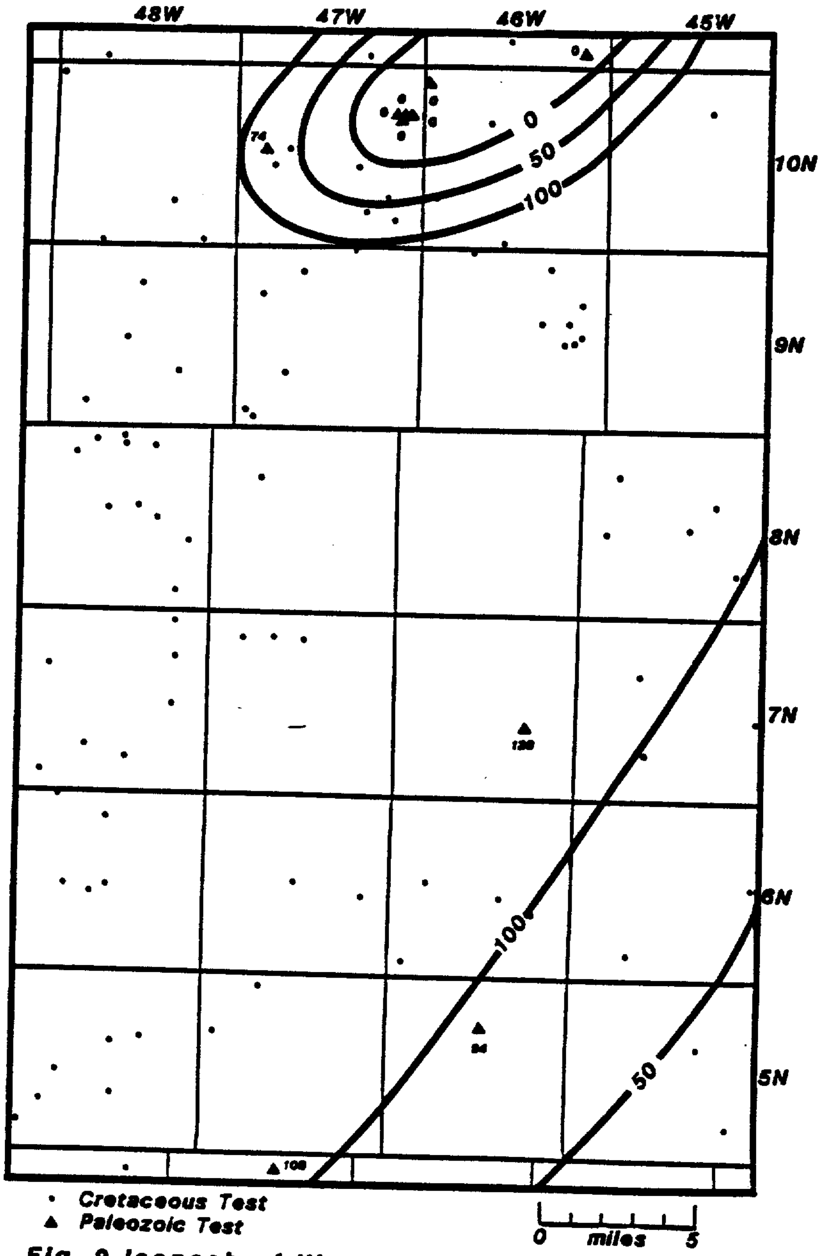

Fig. 9 Isopach of Nippewalla First Salt over study area. C.I.: 50 ft.

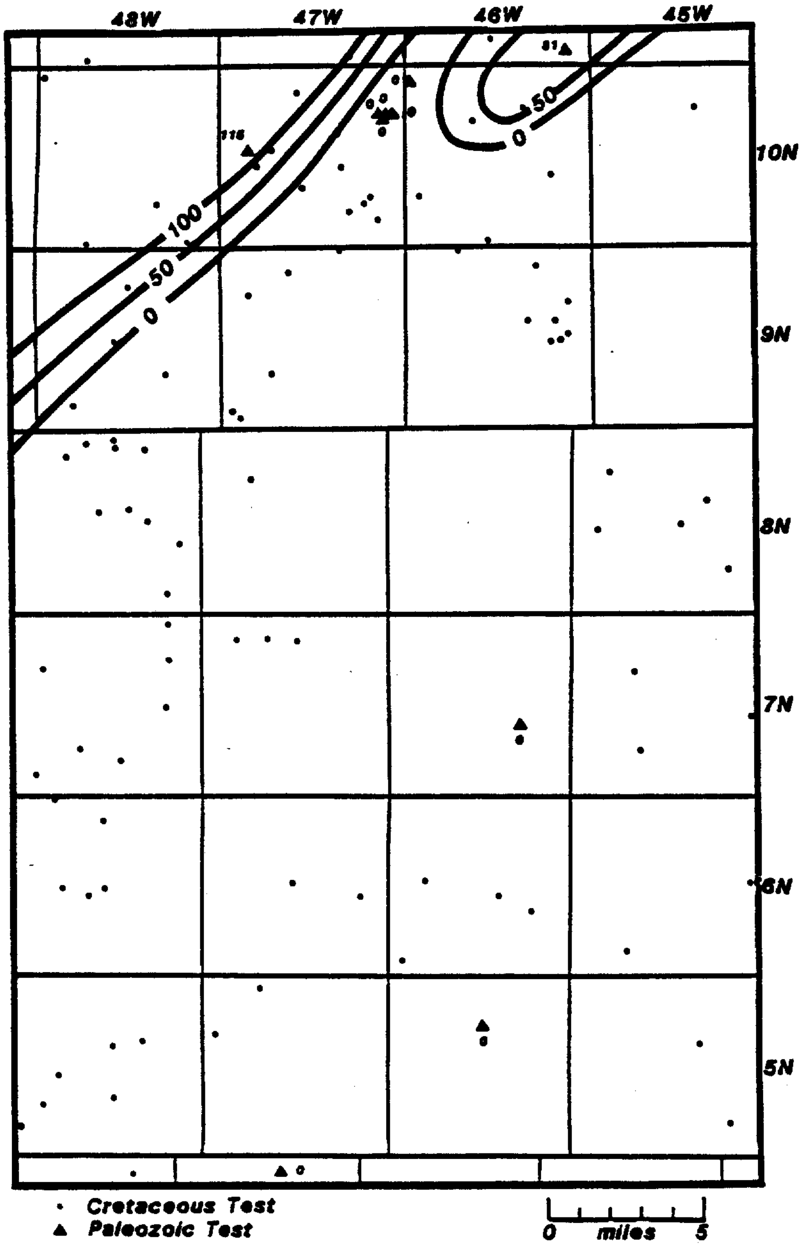

Fig. 10 Isopach of Nippewalla Second Salt over study area. C.I.: 50 ft.

majority of the thinning and thickening is directly related to the presence or absence of salt.

Regional Structure

Basement tectonics in the vicinity of the study area influenced Permian sedimentation and subsequent salt dissolution features in the Permian section of Leonard Age. Tweto (1980) and Warner (1978) have discussed the origination of major fault systems and shear zones in Colorado during the Precambrian. While recurrent movement of Precambrian fault systems controlling sedimentation throughout Phanerozoic time has been suggested by a number of authors (Baars, 1966, Gerhard, 1967 Baars and See, 1968), Weimer (1978, 1980) and Sonnenberg and Weimer (1981) have completed studies relating this theme to the Northern Denver Basin. Recent work by Perry (1985) has drawn together those lineament features determined by the above referenced authors for the Northern Denver Basin, and has provided additional evidence of lineaments through remote sensing data analysis. That portion of her work related to the study area is indicated at Fig. 11. Recurrent movement of Precambrian faults within the study area represented by these lineaments may have caused localized brittle deformation in the Paleozoic sediments, creating pathways for migration of undersaturated waters. This provides a

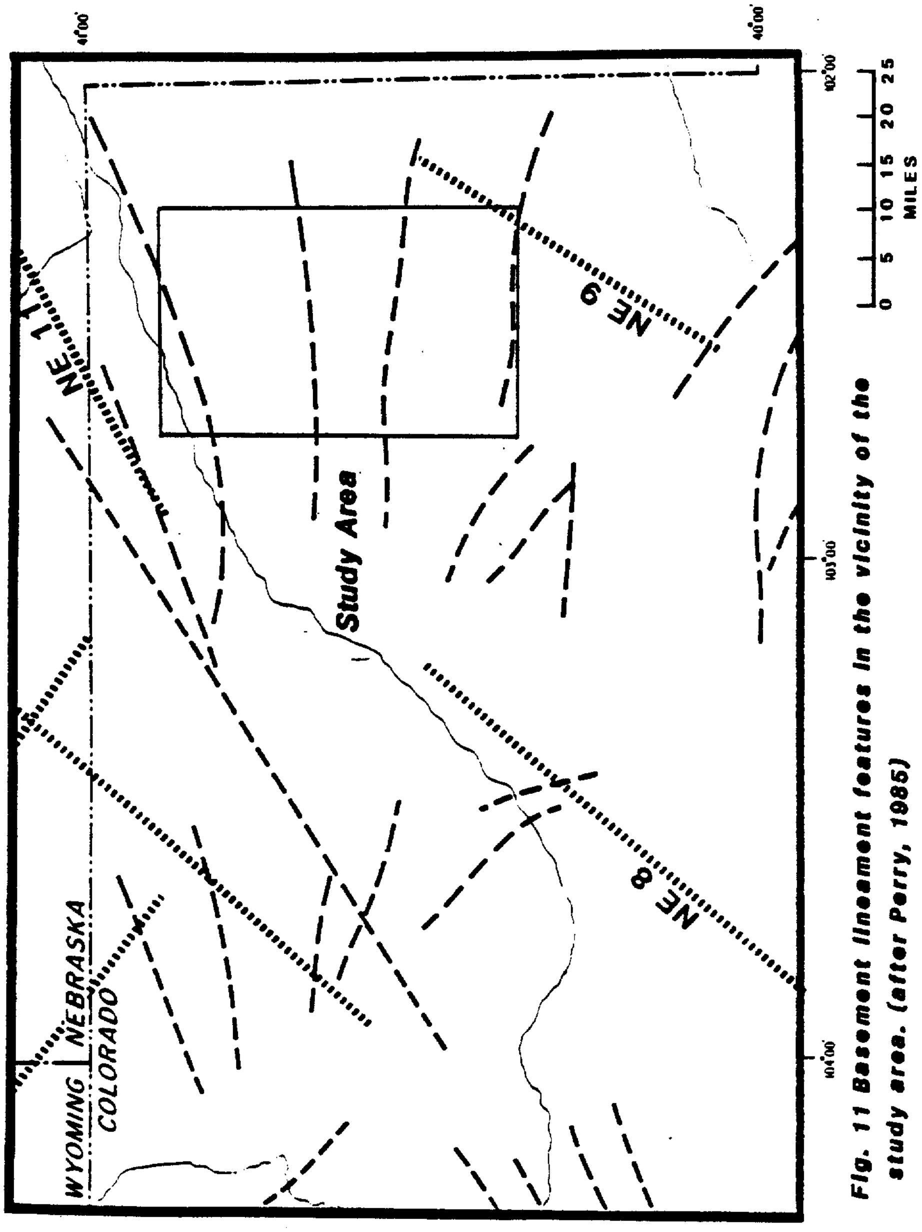

Fig. 11 Basement lineament features in the vicinity of the study area. (after Perry, 1985)

possible mechanism for salt dissolution as discussed by Simpson (1978).

A structure map drawn on the first anhydrite at the top of Permian Wolfcamp exhibits regional dip into the Denver Basin to the west (Fig. 12). A structure map on the top of the D Sand (Fig. 13) shows several localized features that are interpreted to be collapse structures. A structure map drawn on the top of Blaine Anhydrite (Fig. 14) shows that although the well control is less than for the D Sand structure map, the northernmost area of collapse is still evident. These interpreted collapse structures indicated on the structure maps of post-Leonard Salts strata and not on the structure map of pre-Leonard Salts strata provide evidence of a salt dissolution event.

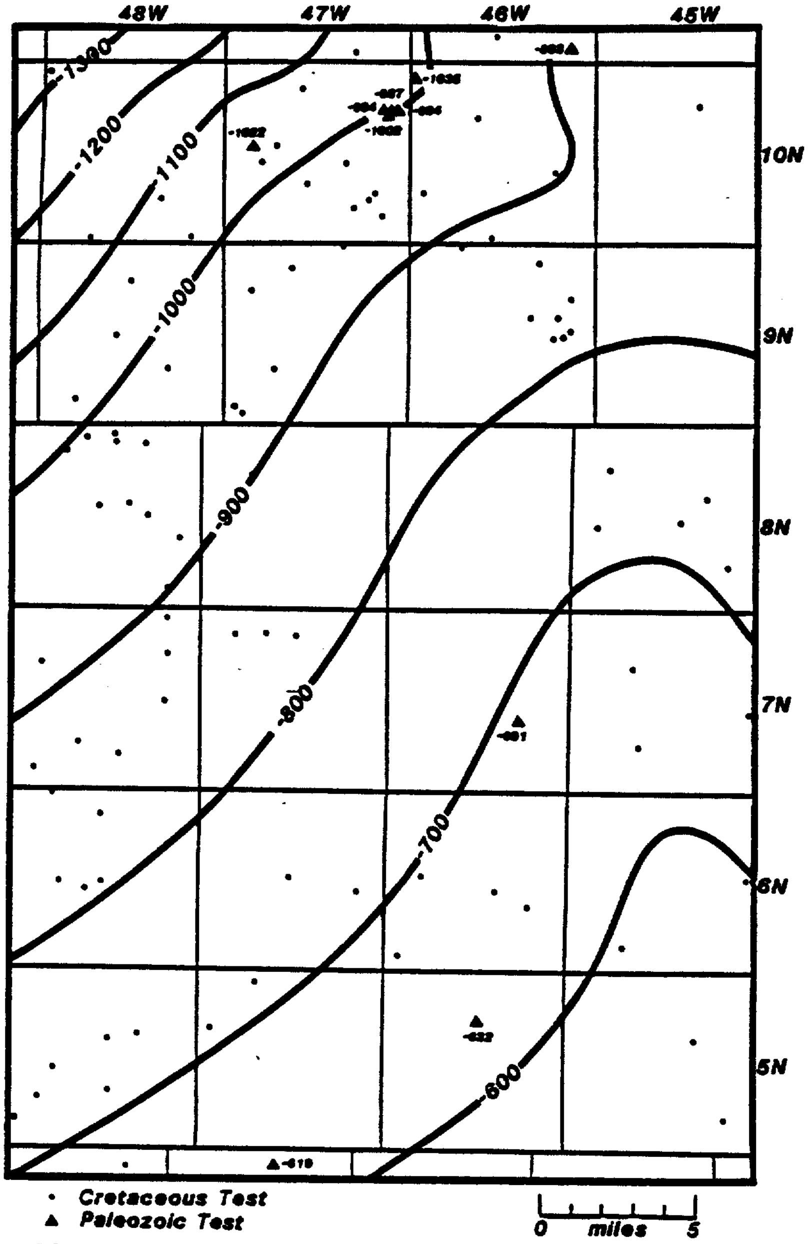

Fig. 12 Structure on top of Wolfcamp showing west dip into the Denver Basin. C.I.: 100 ft.

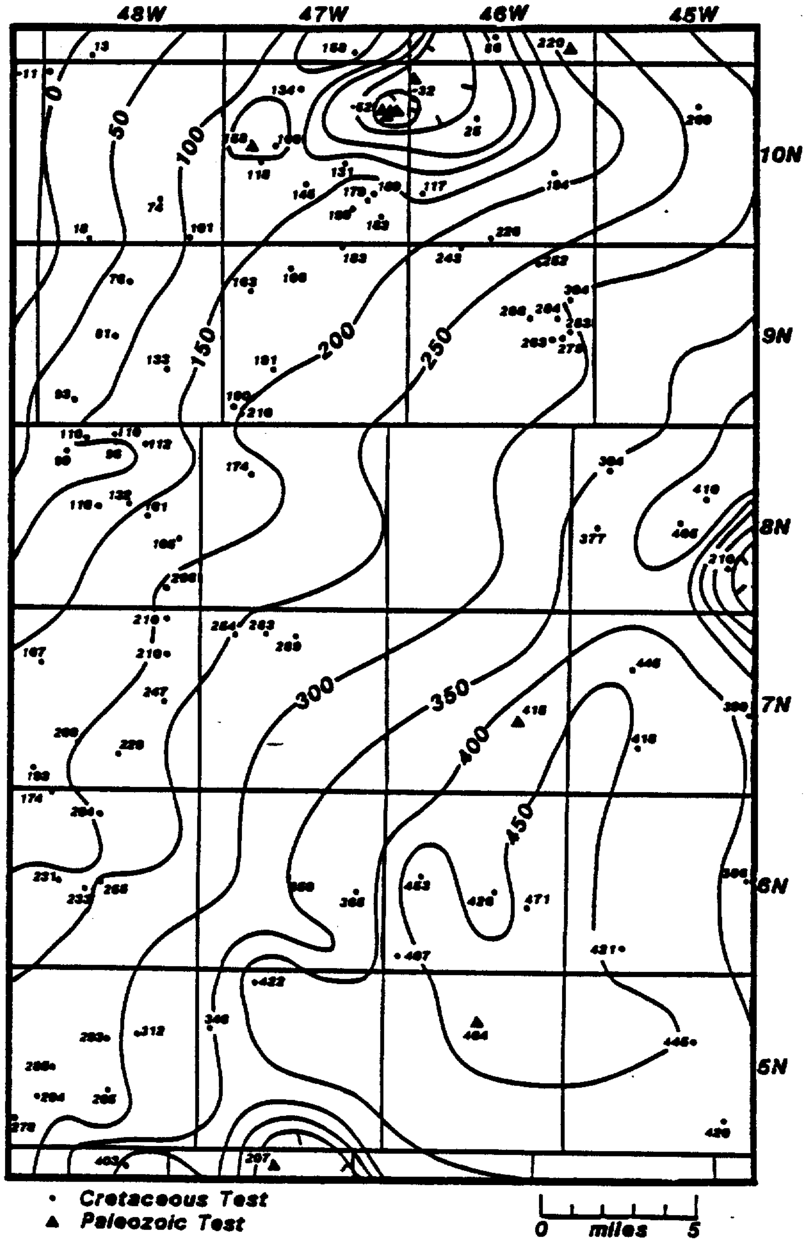

Fig. 13 Structure map on the top of D Sand over study area showing collapse features to the north, east and south. C.I.: 50 ft.

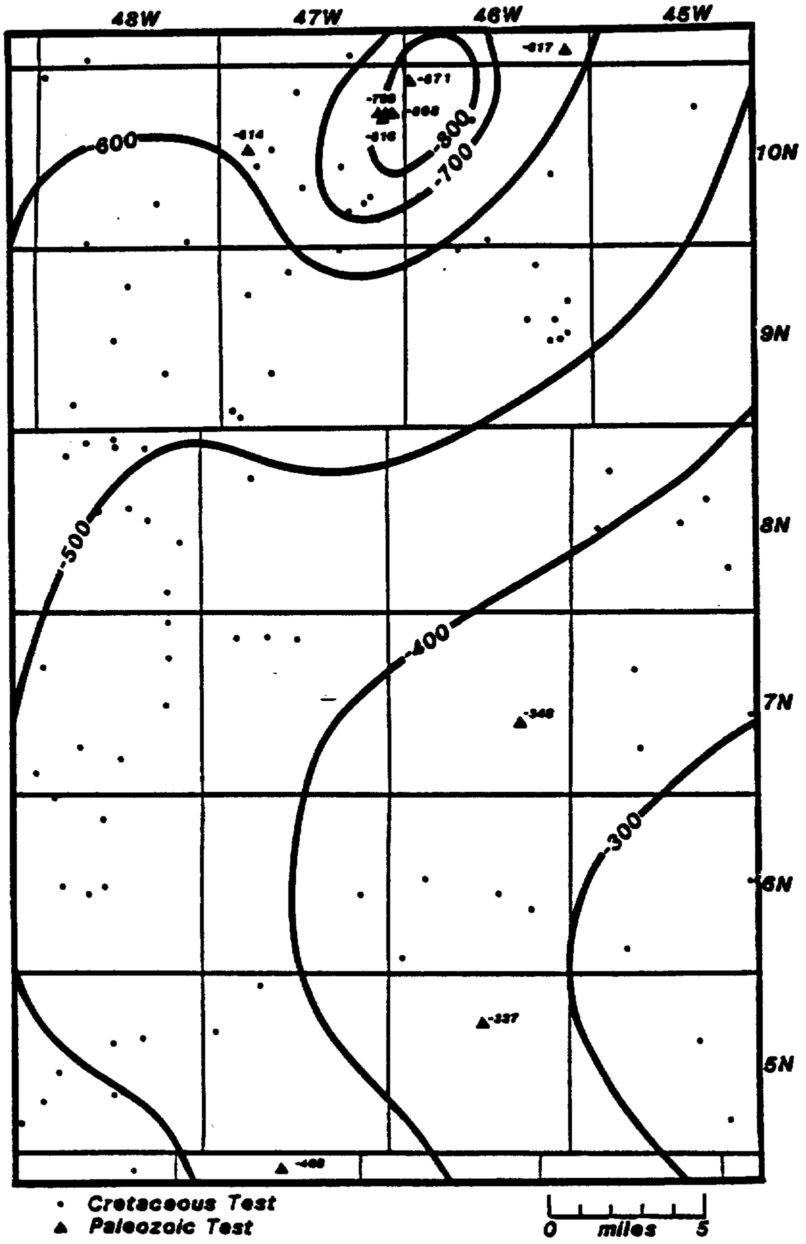

Fig. 14 Structure map on top of Blaine Anhydrite over study area showing collapse feature to the north. C.I.: 100 ft.

SALT DISSOLUTION STUDY AREA

Seismic and Well Data

Plate 1 shows the well control in the study area penetrating to the Permian Wolfcamp. Cross section A - A' is also indicated and will be discussed later. The three wells used in the seismic models are indicated by arrows. Proprietary seismic data utilized in this study area are indicated by hatchered lines and comprise approximately 142 miles of modern common depth point, two and twelve fold seismic data. Acquisition and processing parameters are indicated at Table 1. Because all seismic data used in this study are confidential only 2 lines are included for inspection (Plates 6 and 7). However, a number of figures have been included to show the intervals of interest, synthetic ties, and overall data quality in a number of places within the study area. Seismic data quality is good for the twelve fold data and fair for the two fold data. The data is assumed to be close to zero phase because of the excellent tie to synthetics in the area. A portion of line 8 and a synthetic generated from the Franson well in Section 3-4N-47W are shown in Fig. 15. The data is adequate for isochron mapping within the Leonardian interval.

TABLE 1

DATA PARAMETERS

Acquisition Parameters -	Two Fold	Twelve Fold
Date:	1981	1982
Group Interval:	110 feet	220 feet
Shot Point Interval:	1,320 feet	880 feet (2 shots/hole)
Number of Channels:	48	48
Sample Interval:	2 msec	2 msec
Near Offset:	110 feet	220 feet
Far Offset:	2640 feet	5280 feet
Recording Filters High:	125 hertz	125 hertz
Low :	8 hertz	10 hertz
Geophones/Group:	24	24
Geophone Array:	Inline	Inline
Source:	Dynamite	Dynamite
Charge Size:	25#/200 feet	25#/200 feet, 5#/Varies
Miles:	113	29

Processing Parameters

Two Fold

True Amplitude Recovery
Designature Deconvolution
Time Variant Scaling
Datum Statics
Velocity Evaluation
Residual Statics
Velocity Evaluation
Normal Moveout Corrections
CDP Stack
Time Variant Scaling
Time Variant Filter 12-40 Hertz
Display

Twelve Fold

Pre-decon Ramp
Time Varying Spiking Deconvolution
Velocity Analysis
Normal Moveout Corrections
Automatic Residual Statics
Trim Statics
CDP Stack
Digital Filter (Zone of Interest: 12-60 Hertz)
Trace Equalization

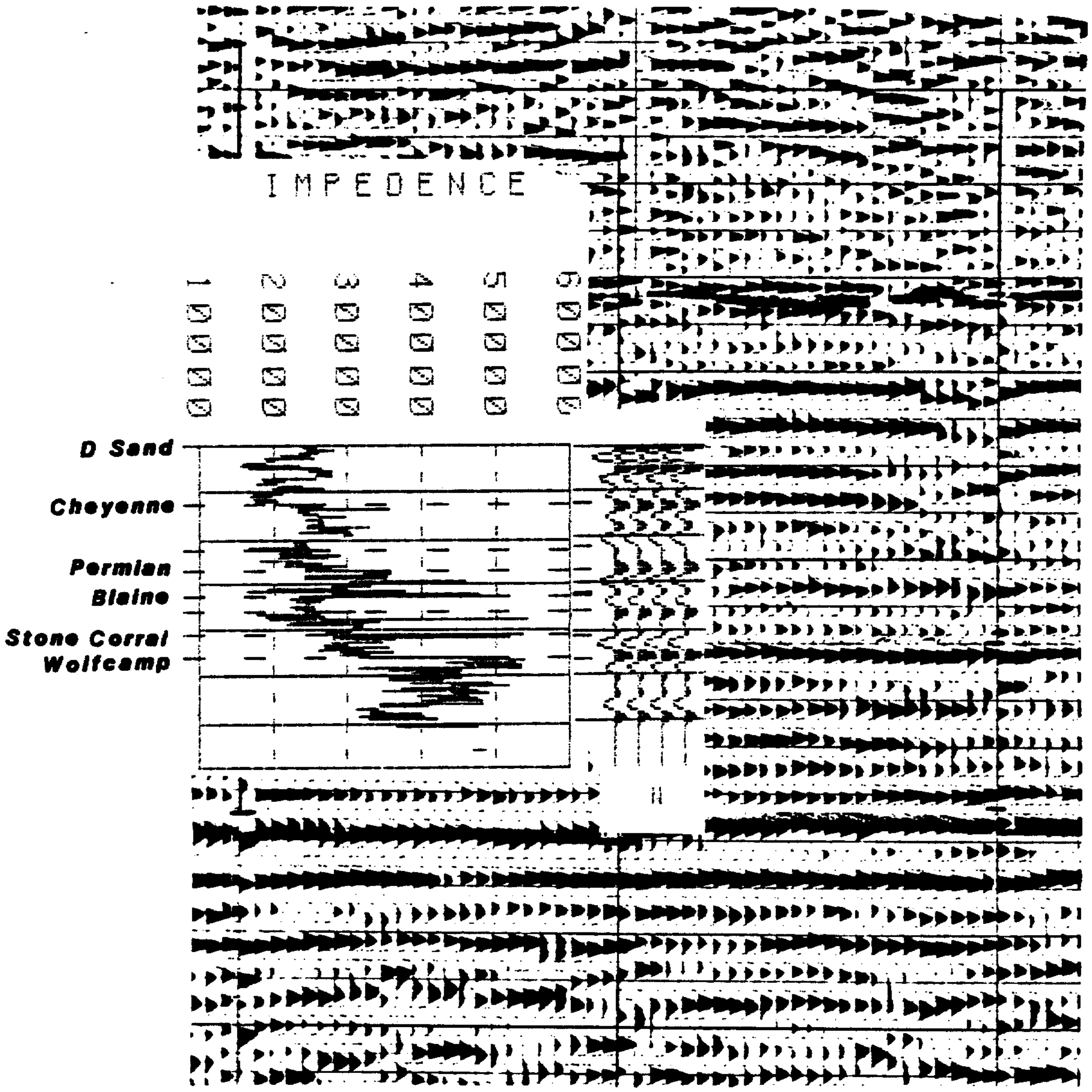

Fig. 15 Synthetic from Franson well tied to southern portion of line 8 (16 miles).

Modeling

Well log seismic models were created utilizing three wells in the study area (Figs. 16, 17, and 18). These were the Stuarco et al, Sprague Brothers #1 in Section 18, Township 10 North, Range 47 West, Sedgewick County; the American Petrofina Company of Texas Franson #1-3 in Section 3, Township 4 North, Range 47 West, Yuma County; and the Intercontinental State #1-12 in Section 12, Township 10 North, Range 46 West, Sedgewick County (Plate 2). These wells were selected because they had sonic logs. The two salts in the Nippewalla Group and the thinner Sumner Group salts are present in the Sprague well. The sonic log of this well was used as the base case for one of the seismic models. Salts were removed from it during the modeling process (Fig. 16) and can be compared to model results from the sonic logs to other wells in the area (Fig. 17). The lower salt in the Nippewalla Group, here termed the Second Salt, is not present in the Franson and the State wells. Finally, in the State well both the upper salt in the Nippewalla Group, here termed the First Salt, and the Sumner Group salts are absent. A model containing the sonic logs of these three wells shows the effects of the Second Salt removal and then the loss of the First and Sumner Group salts, and therefore provides a comparison to

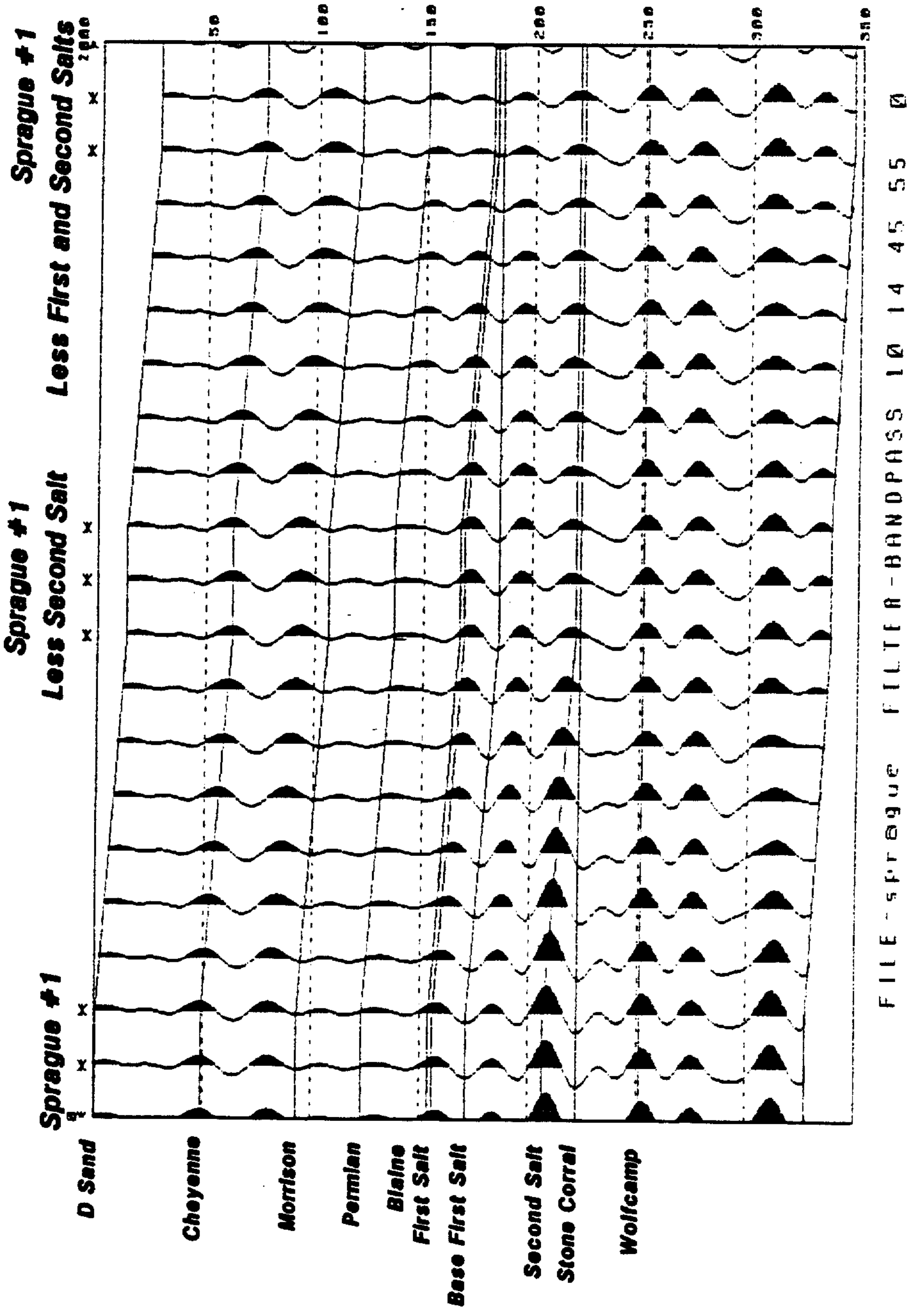

Fig. 16 Seismic model #1 showing removal of salts from Sprague well.

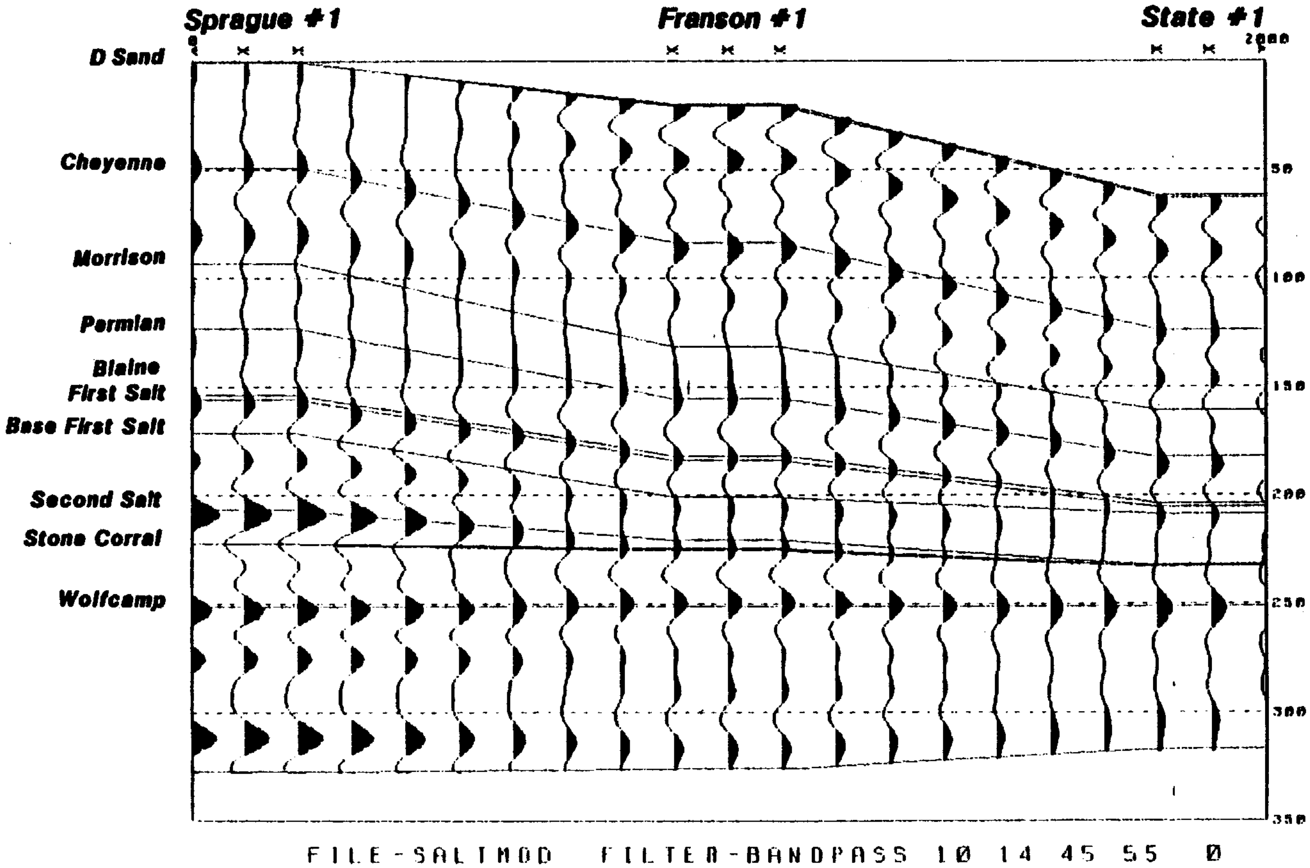

Fig. 17 Seismic model #2 showing changes in seismic response over three wells with fewer salts present from left to right.

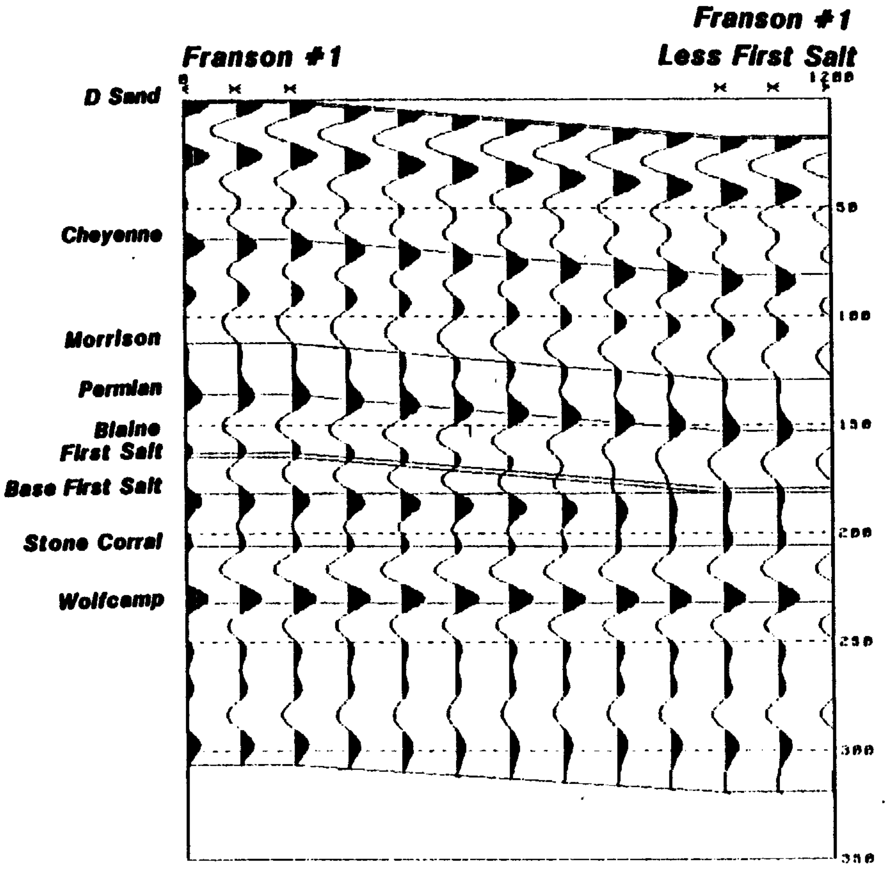

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Fig. 18 Seismic model #3 showing that the addition of density information does affect amplitude response.

the model containing only the Sprague well.

The models were constructed utilizing the Geo-Micro System software package developed by Kimtech, Inc. This software allows interpolation between the selected well logs, thickening or thinning of specific intervals, and generates a zero phase seismic modeled response. Since the Sprague well did not have a density log available, only sonic logs were used in the first two models. To assess the effect of including density information in the modeling process a third model was run using only the Franson well, which did have a density log (Fig. 18). A number of markers were selected to control the interpolation intervals for each model, including the top and the bottom of the respective salts in the Nippewalla interval. To better tie the sections the final model was filtered with wavelets that match the final filters on the data. The best fit was obtained with a bandpass wavelet of 12 - 50 hertz.

Theoretical Considerations

Given a center frequency content in the data of approximately 35 hertz and a velocity for the salt interval of approximately 13,800 feet per second, Sheriff (1980) points out that theoretically we are within tuning range as the stratigraphic interval approaches 100 feet thick.

This thickness approaches the maximum thickness of the individual salts that we have present in the study area. As such we must use amplitude as a criteria for thickness of salt present and will not be able to isochron map the singular event. Therefore we seek a broader interval to measure. Inspection of the models show two intervals that vary within the well control (Figs. 16 and 17). Correlating these intervals with the markers of the models reveals that the first interval is bounded by a peak at the Blaine Anhydrite and another strong peak at the top of the Second Salt. This latter peak bounds the second interval at the top with the anhydrite at the top of the Wolfcamp giving us a peak at the base of the interval. Upon a review of the logs over these intervals (Plate 2) it can be seen that the other sedimentary rocks are relatively consistent in thickness. As these other rocks average approximately 130 feet of thickness for the first interval and 150 feet of thickness for the second interval, the loss of the salt gives a reduction from about 250 feet to 130 feet for the first interval and 270 feet to 150 feet for the second interval. The changes in both of these intervals can be resolved by isochron mapping of these intervals. A linear relationship exists between the amount of salt present and the time measured between the top and the bottom of the intervals. For a salt velocity of 13,800 feet per second the two way travel time is approximately 14.5 milliseconds per 100 feet of salt. Since each interval contains a salt of approximately 120 feet of thickness, total dissolution of each would cause a reduction of about 18 milliseconds within that interval.

In actuality the thickness of the other portion of the upper interval varies by up to 40 feet regionally across the study area according to well control. The Sumner interval, which comprises the other portion of the lower interval, not only varies in thickness as a result of the regional variation in sedimentation, but also has salts present, that even though thin, are affected by the dissolution process; yielding up to 85 feet of variation within this interval. With an average velocity for both non-salt intervals of approximately 12,500 feet per second these variations add 7 milliseconds to the upper interval for a total variation of 25 milliseconds and add 14 milliseconds to the lower interval for a total variation possible for 32 milliseconds over the study area. Although this reduces the ability to imply a linear relationship in time between two markers and the thickness of salt present, the ability to detect dissolution of the salt, especially within the upper interval, is possible qualitatively.

As the salts are removed from the models, and we reach the tuning level, note the loss of amplitude in the model sections at the top of each interval. The peak at the top of the Second Salt at the Sprague well loses amplitude as the Second Salt is removed. The same loss of amplitude occurs as the First Salt is removed as well. In the model with density data included, amplitude variations exist as the salt is removed; however, here the highest amplitude peak is at the base of the First Salt.

DATA INTERPRETATION

Seismic Data

A review of the Second Salt isopach (Fig. 14) shows that this salt is not present over most of the study area according to well control. A comparison of the seismic data to the models also shows this to be the case. As such, no interpretation of the lower interval was made, nor was any attempt made to assess whether this salt was dissolved out of the section or just never deposited. Waveforms from about the middle 50 percent of the first two models are the norm for the seismic data throughout the mapped area. Plate 3 and Fig. 19 show an isochron map of the interval from the Blaine Anhydrite to Stone Corral. As the Second Salt is not present, this is a Nippewalla Group isochron.

Although the density of control influences the mapping, three areas stand out. The first is an area of intense dissolution to the northwest of the study area. Values here drop to less than 30 milliseconds in places. Figs. 19, 20, 21, 22, and 23 show portions of lines crossing this feature. A comparison of the data with the models confirms that although complete dissolution is not present the Nippewalla interval is missing a substantial amount of salt. Southeast of this northeast trending feature are a number of lessor dissolution features that

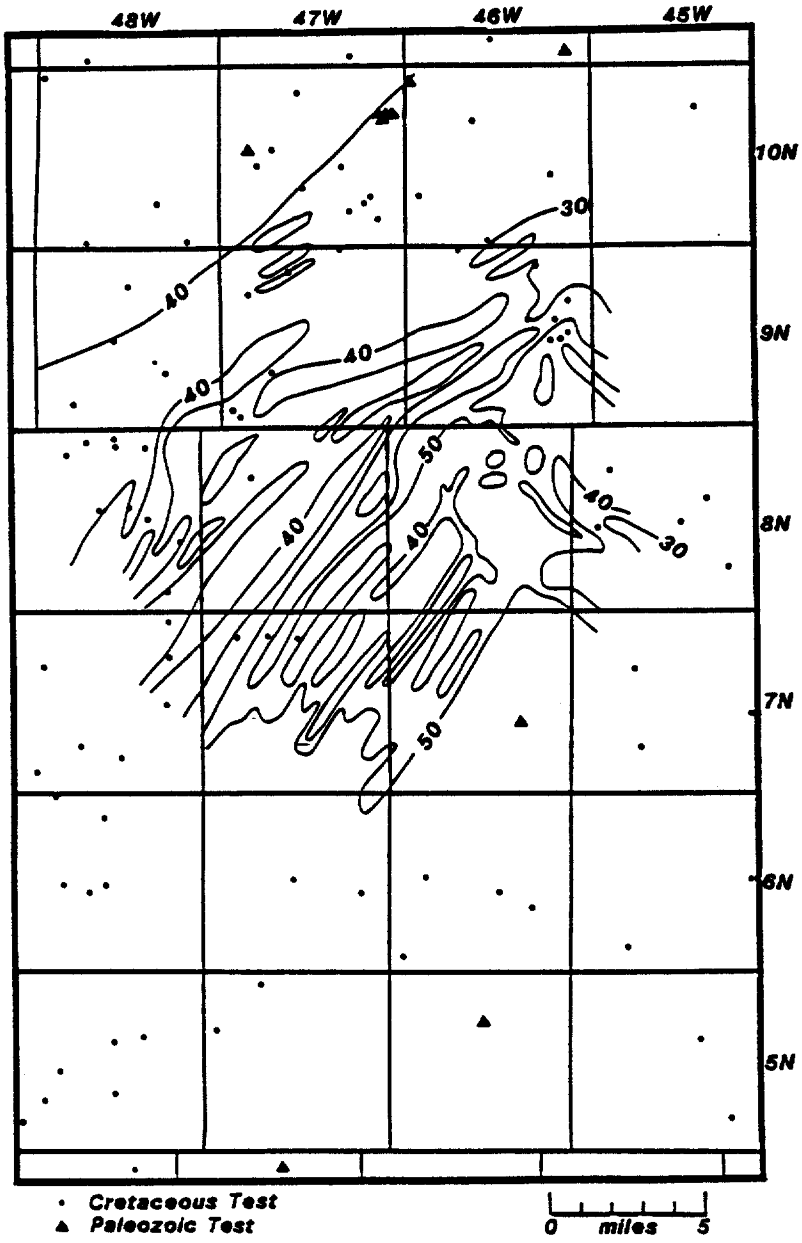

Fig. 19 Isochron of the Nippewalla Group over the study area. C.I.:10 msec.

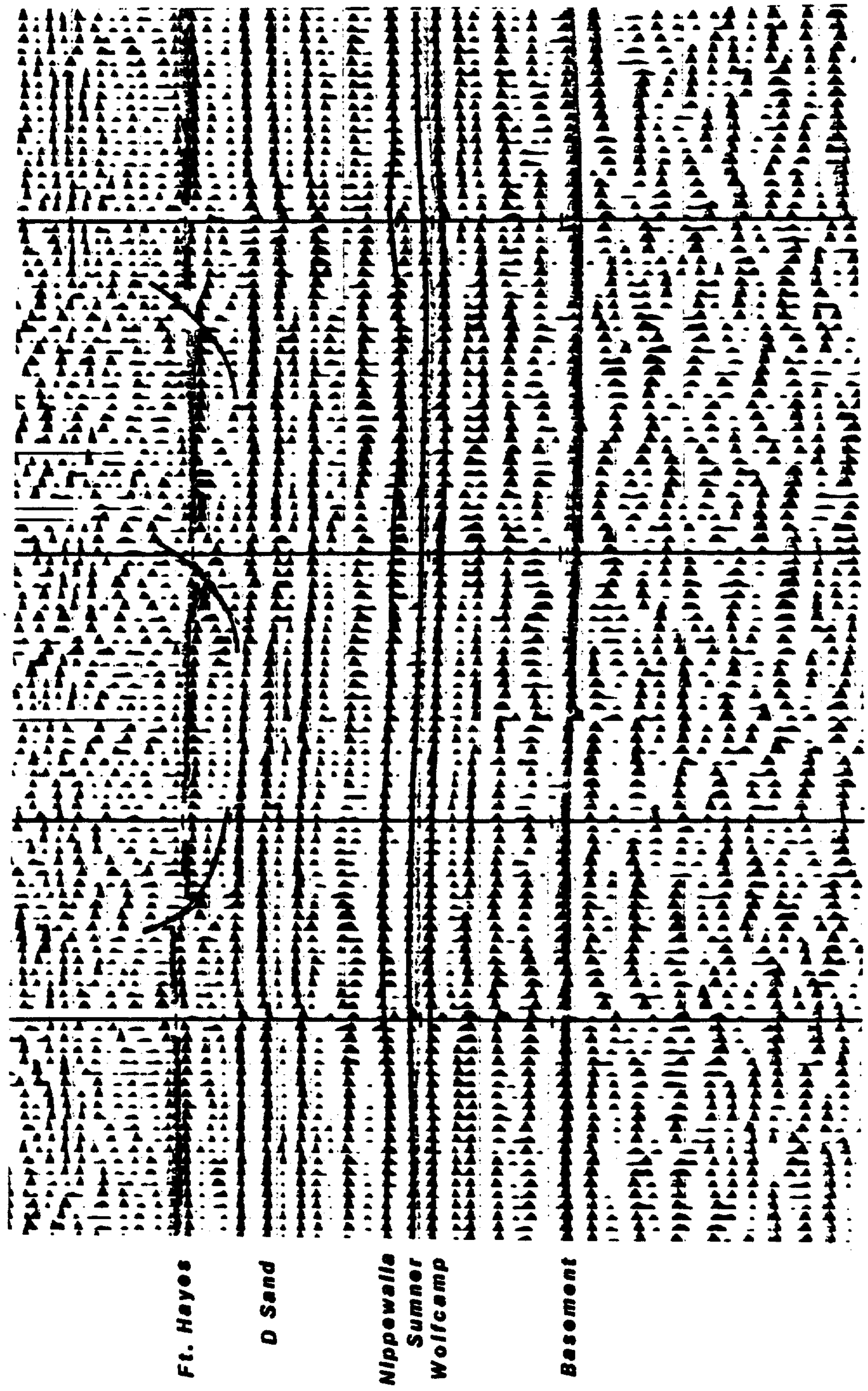

Fig. 20 Portion of line 1 showing Nippewalla First Salt dissolution and Niobrara listric faulting.

Fig. 21 Portion of line 2 showing Nippewalla First Salt dissolution and Niobrara listric faulting.

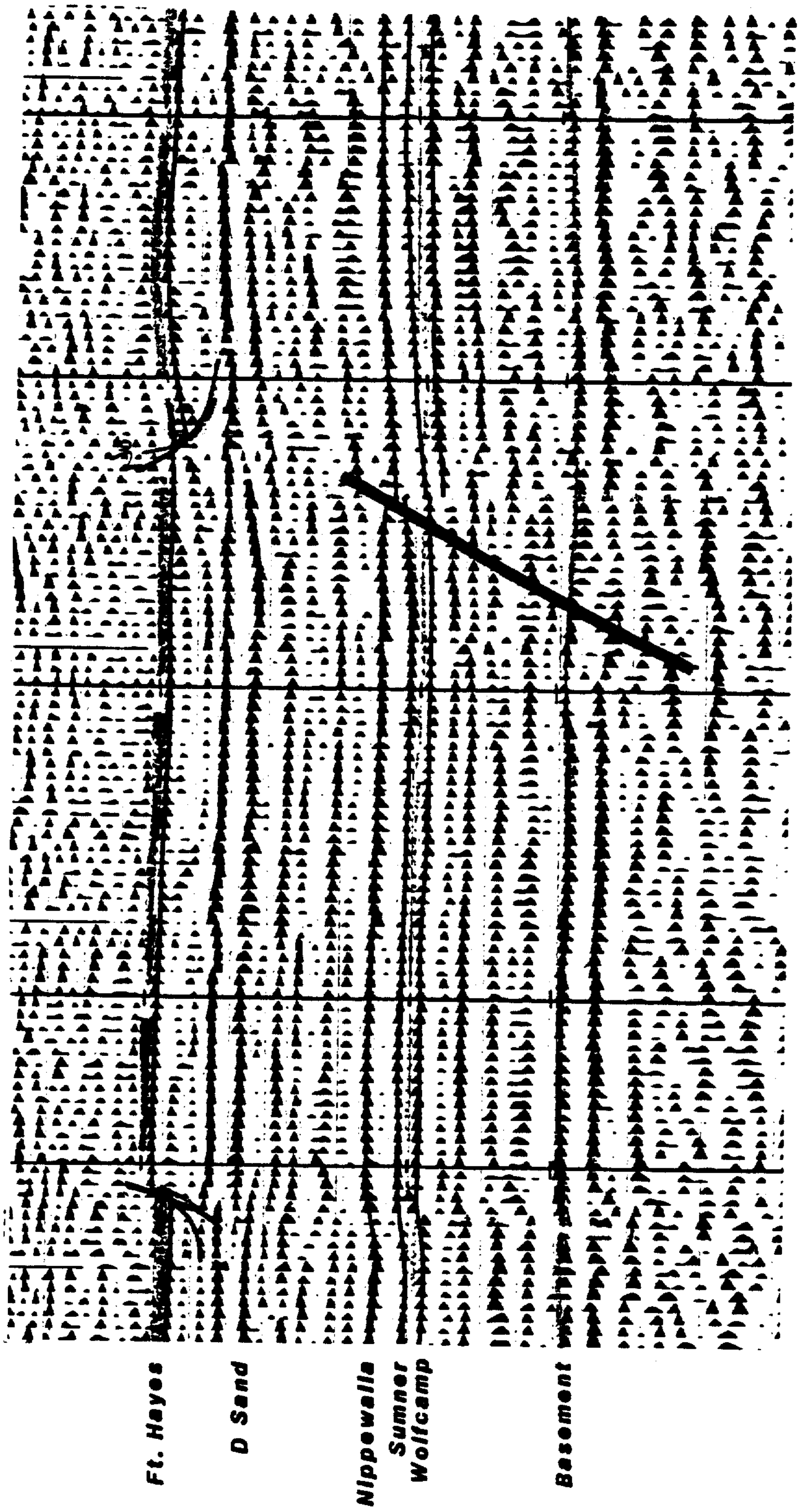

Fig. 22 Portion of line 3 showing Nippewalla First Salt dissolution, basement faulting and Niobrara listric faulting.

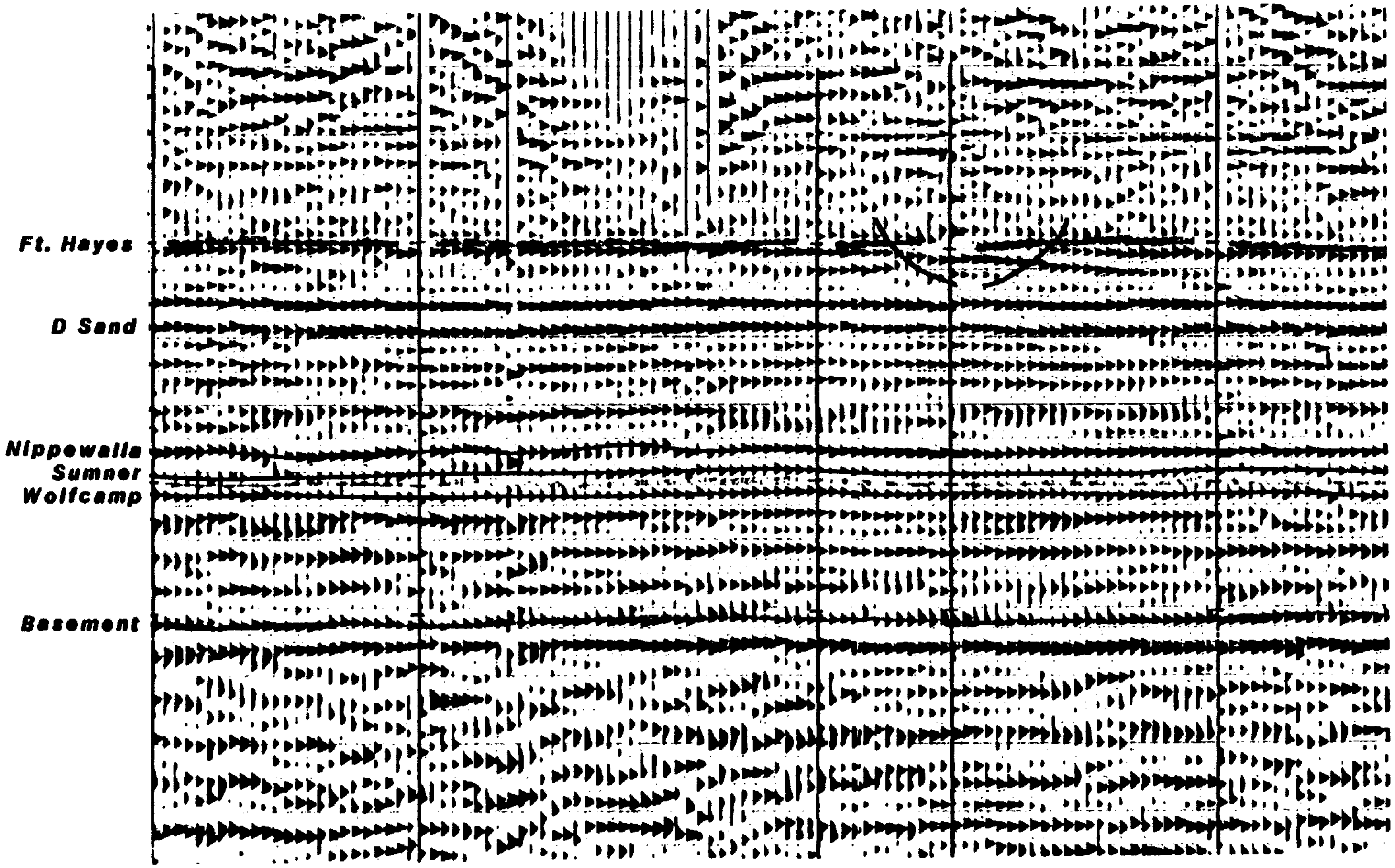

Fig. 23 Portion of line 4 showing Nippewalla First Salt dissolution and Niobrara listric faulting.

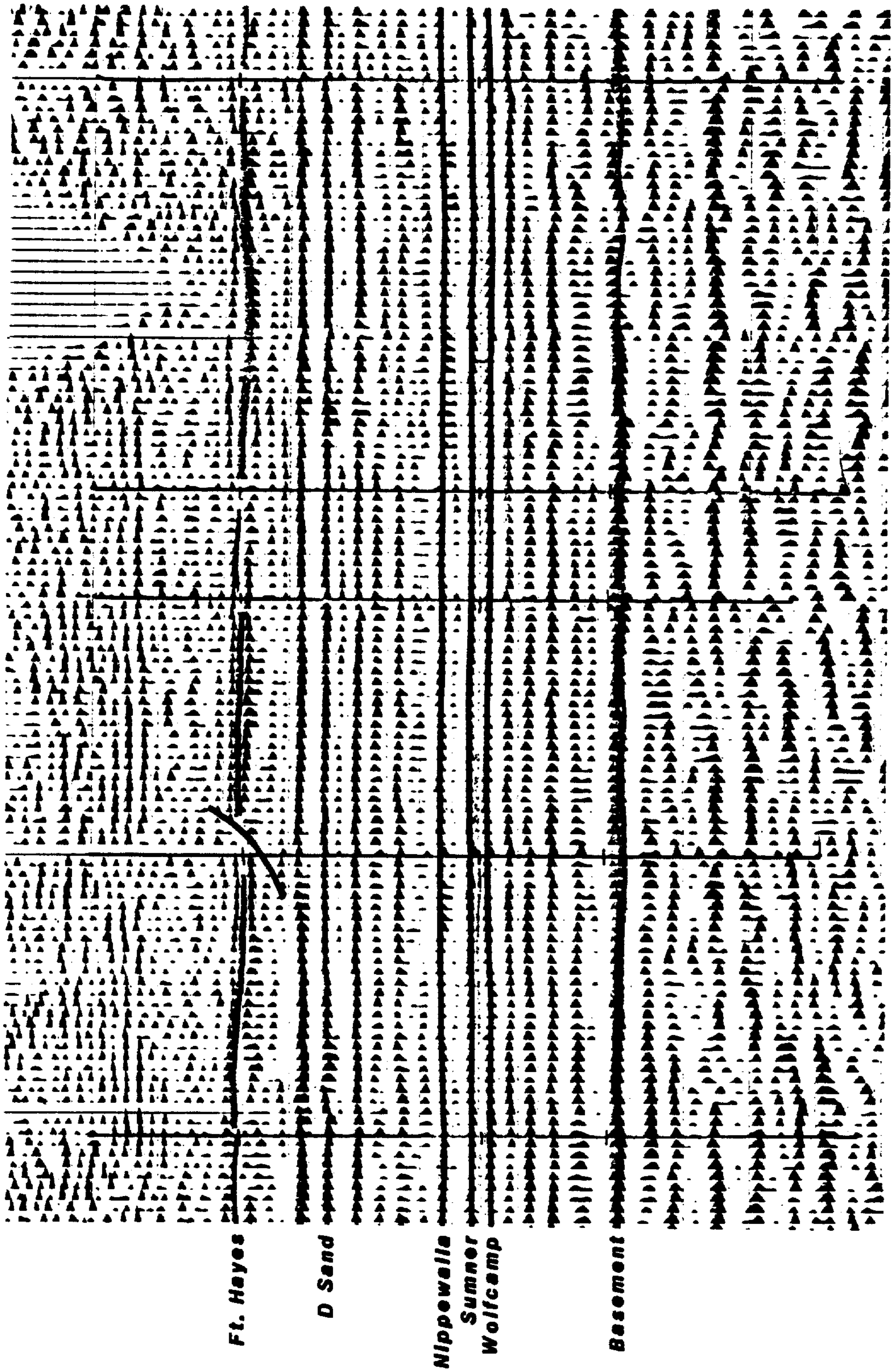

Fig. 24 Portion of line 5 showing minor Nippewalla First Salt dissolution and Niobrara listric faulting.

just appear to resolve a strong northeast trend. A comparison of Figs. 24 and 25 with the models shows a thicker interval for the Nippewalla group. The center peak is present on the majority of the sections as predicted by the model. In this area, dissolution has occurred but not to the same degree as to the northwest. Finally to the east of the study area, the trend of the features appears more northwestward.

The above features are interpreted as follows:

1) An area of major salt dissolution is interpreted to overlie a major shear complex in the basement. Movement of this system may have caused fractures through Leonardian rocks allowing migrating waters to dissolve the salt. Timing of the dissolution is discussed later.

2) The second area is interpreted to represent salt dissolution caused by fracturing of Leonardian rocks related to a smaller order basement faulting. This led to a less effective fracture system within the Leonardian rocks and less dissolution.

3) The third area is interpreted to be salt dissolution related to fracturing of Leonardian rocks that is the result of conjugate faulting in the basement.

Basement Fault Complex

By utilizing isochron thins on the Nippewalla isochron

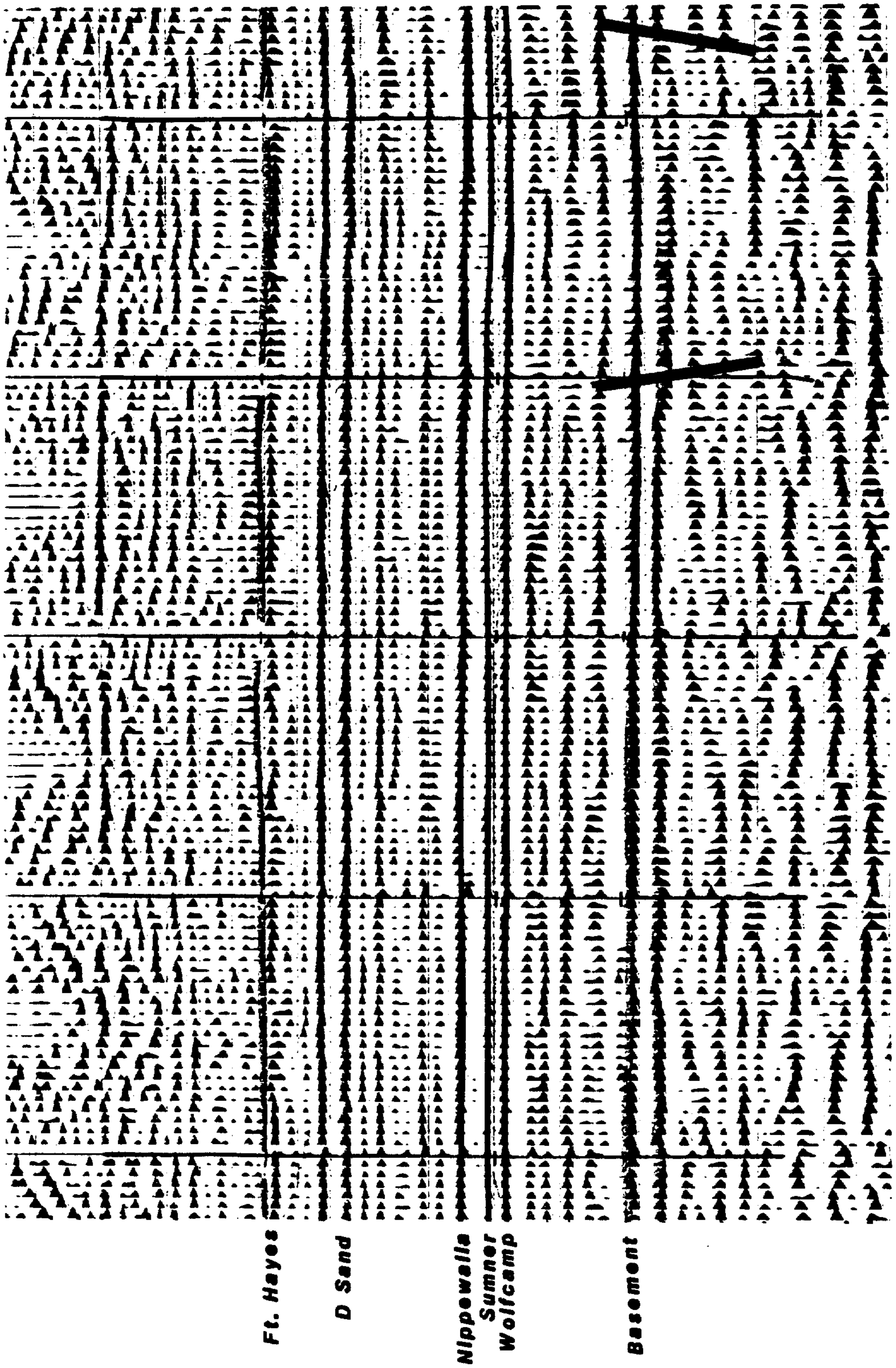

Fig. 25 Portion of line 7 showing partial Nippewalla First Salt dissolution and basement faulting.

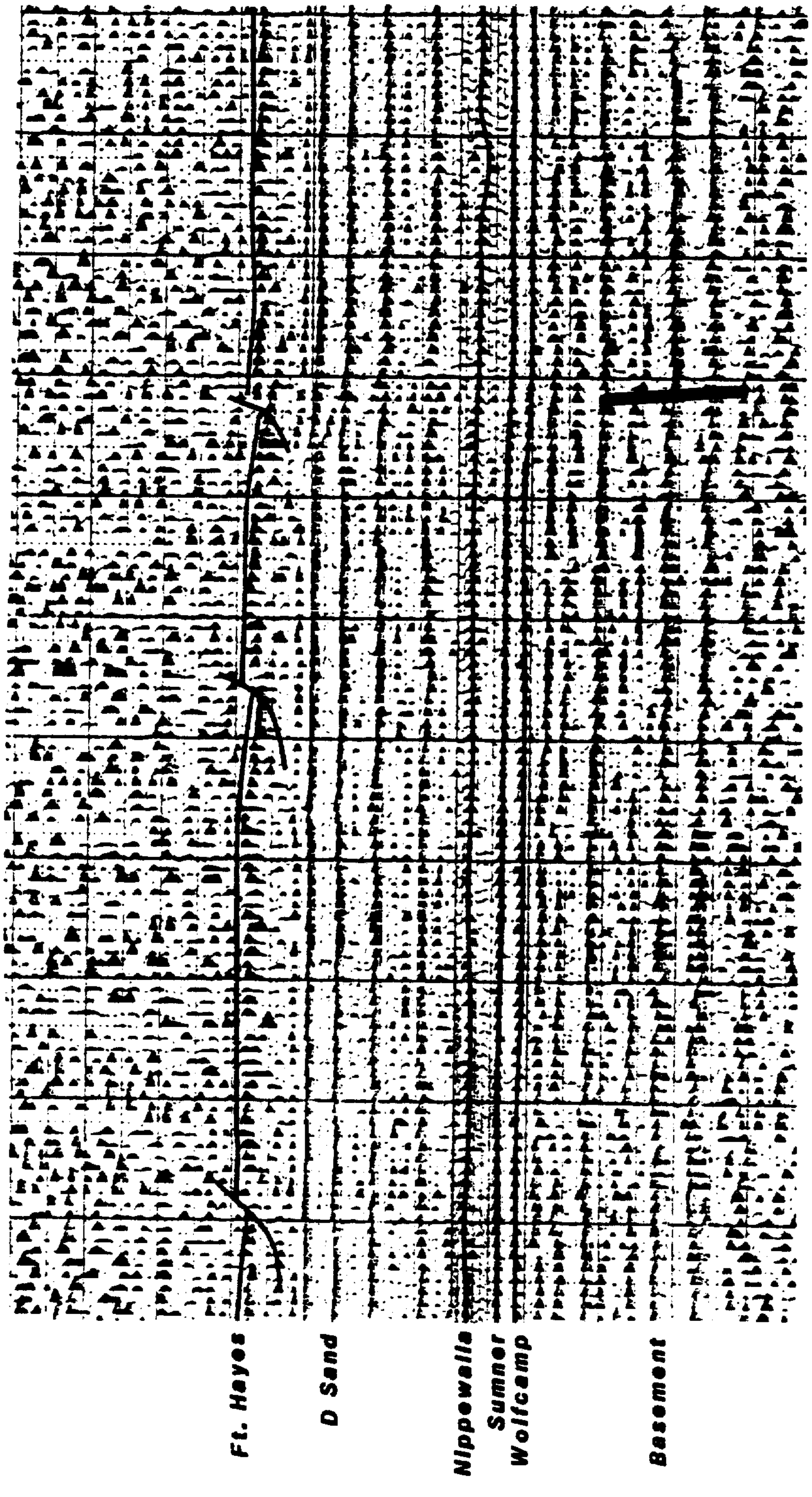

Fig. 26 Portion of line 10 showing little Nippewalla First Salt dissolution and Niobrara listric faulting.

map to control placement of lineaments, Plate 4 is derived. This map shows the area of intense fracturing of basement rocks to the north of the study area. Lineaments to the south may be associated with individual faults in the basement. A review of the basement horizon on the seismic data shows only a few vertical displacement faults (Fig. 27). These are indicated by solid lines on Plate 4. A review of other seismic data including an isopach from top of Wolfcamp to basement also fails to support significant vertical movement in the area. The remainder of the lineaments, therefore, are dashed and may be associated with a lateral shear system in the basement or are the result of other dissolution processes. To attempt to confirm that the interpreted fault system represents what is actually happening in the basement, the aeromagnetic and gravity maps over the State of Colorado were compared with the interpreted data. The faults were plotted on these maps and are shown at Figs. 25 and 26. A correlation is suggested on both the gravity and the aeromagnetic maps for both northeast and northwest trending systems.

Timing of Salt Dissolution

Cross section A - A' (Plate 5) was developed in an effort to determine the timing of dissolution. This cross section has the anhydrite at the top of the Wolfcamp as a

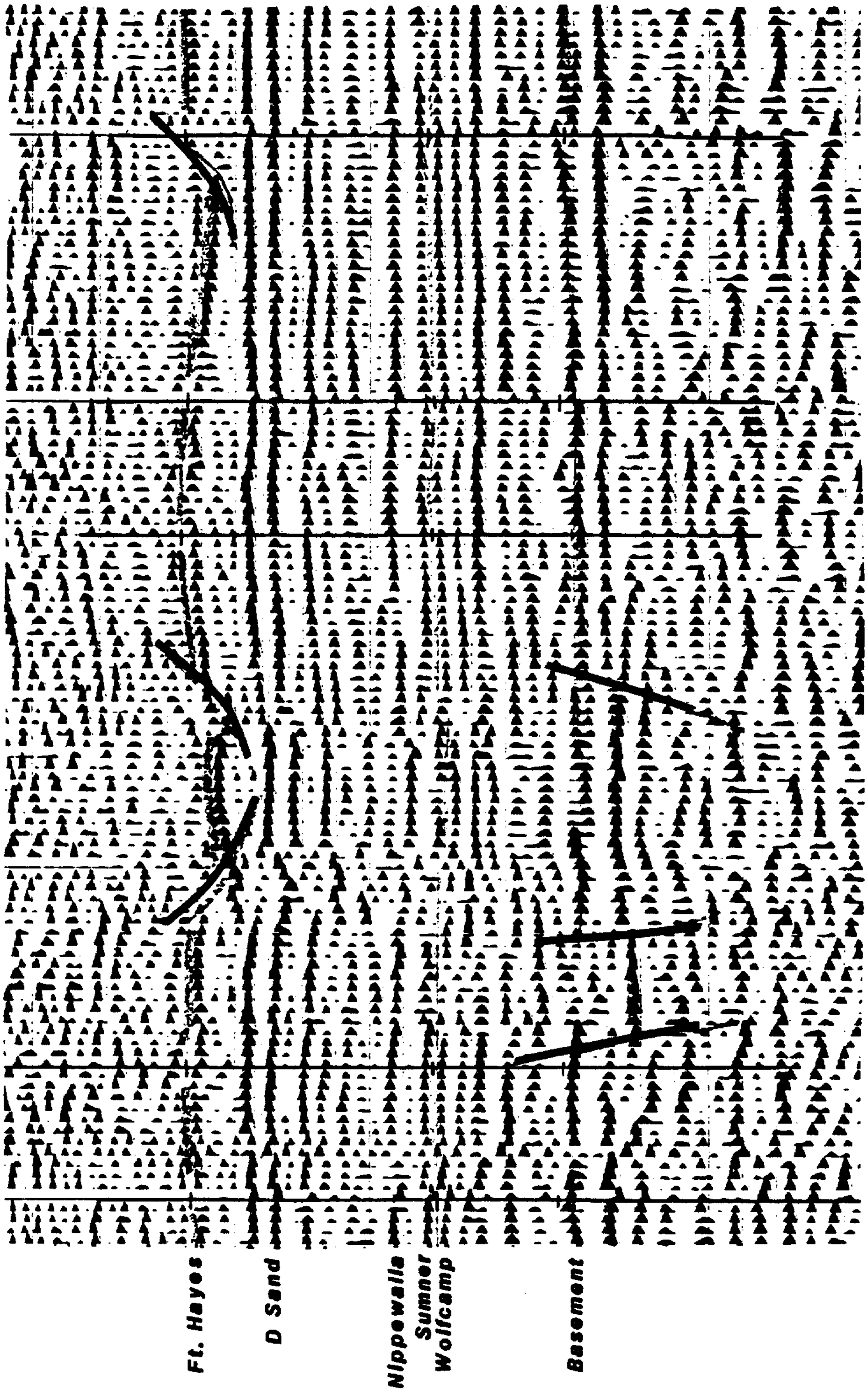

Fig. 27 Portion of Line 1 showing basement faults in the vicinity of dissolution features.

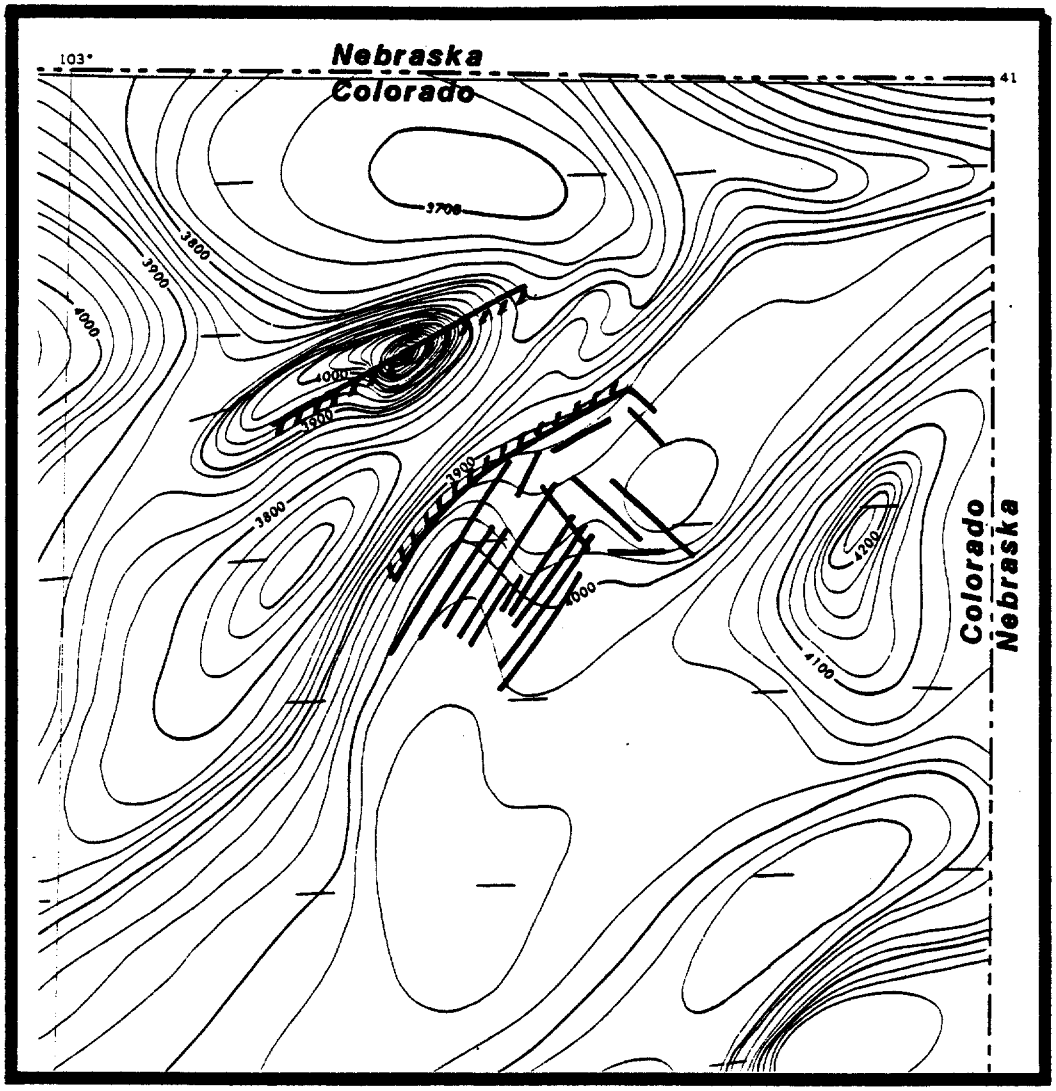

Fig. 28 Basement interpretation map overlain on state total field aeromagnetic map showing correlation to basement features. (after Zietz and Kirby, 1972) C.I.:20 gammas

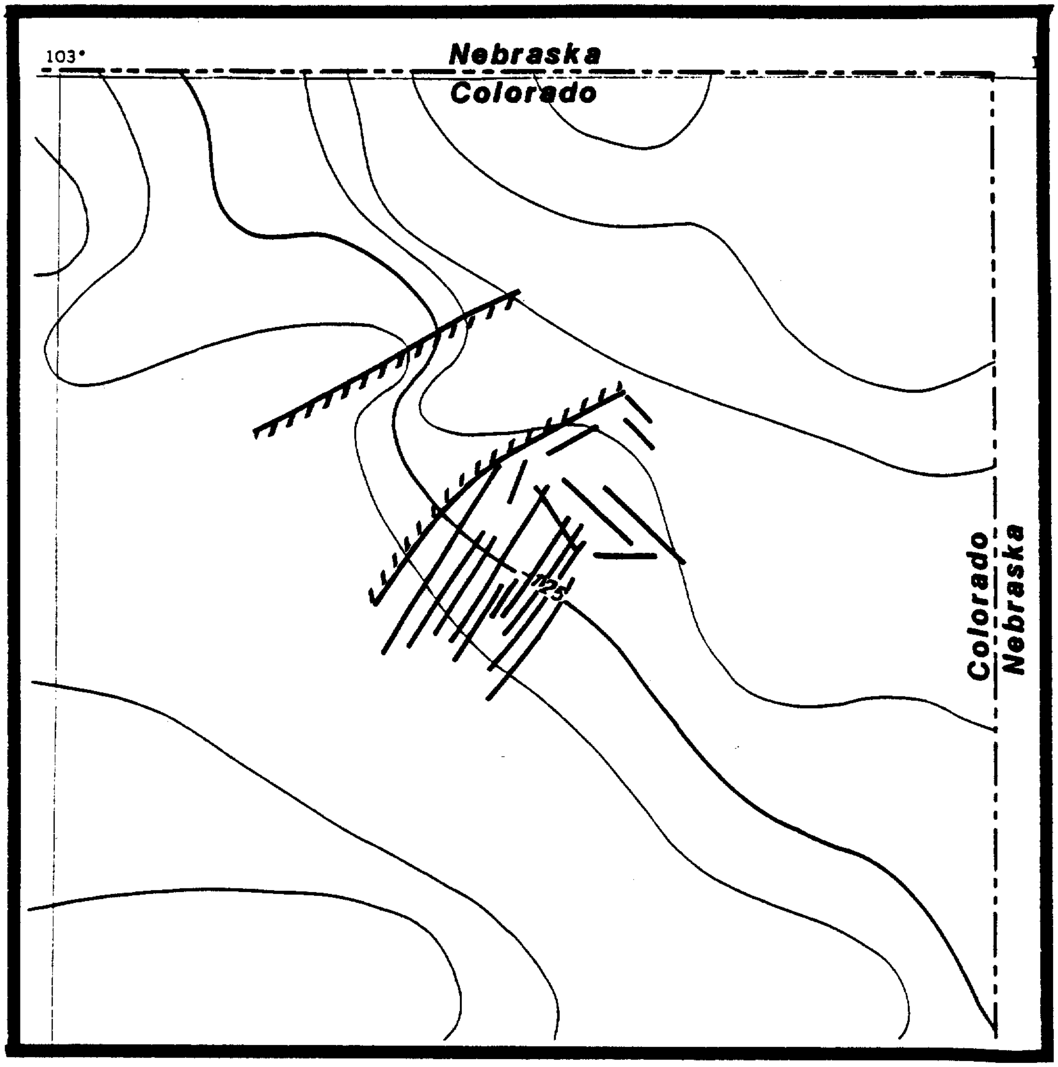

Fig. 29 Basement interpretation overlain on state bouguer gravity map showing correlation to basement features. (after Behrendt and Bajwam, 1974)
CJ.:5 milligals

datum. The Stone Corral and Blaine Anhydrites are indicated as well as the top of Permian, Morrison, D Sand of the Dakota Group, Fort Hayes Limestone, the Niobrara, and a number of markers in the Pierre. Correlations are taken from Bortz, Matuszczak, McClure, and Moredock (1976). This section shows major salt dissolution and collapse occurred at two points in time. The first was during the close of Absaroka deposition during the Jurassic, as evidenced by a thicker section in the Morrison interval, in the Morgan State and Southland Royalty State wells. The second period of major dissolution occurred after the uppermost Pierre marker was deposited. The section becomes difficult to correlate above this marker due to limited log suites. As the end of Pierre deposition was approximately 68 million years ago (Berman, Poleschook, and Dimelow, 1980) it is suggested that reactivation of the basement fault complex initiated a second stage of significant dissolution of the First Salt during the Laramide Orogeny.

A closer review of cross section A - A' shows thickening of smaller order in the Cheyenne, Dakota, and Niobrara intervals. A detailed study of these isopachs may yield additional localized dissolution. Lastly the brittle Niobrara Formation is an excellent indicator of post consolidation movement that may be related to salt dissolution (Figs. 19 - 25). Plate 8 shows zones of localized Niobrara faulting based on seismic data, and indicates two trends. The northeast trend, indicated by dissolution features, is supported by two groups of northeast trending Niobrara faults, indicated by dashed lines. A strong east-west trend is also evident that reflect Creteceous influence more than Paleozoic.

FUTURE WORK

Further research suggested as a result of this thesis study are as follows:

1) Continued study into the relationship between salt dissolution and faulting in the basement.

2) In other areas of the Denver Basin thickness variations within the Permian are the result of not only salts, but also eolian dunes. A study of the interrelationships between these features would be enlightening.

3) This thesis addressed only timing of significant salt dissolution. Additional isopoach studies of the Niobrara, Dakota, and Cheyenne intervals could possibly document relationships between stratigraphic changes in these intervals and earlier episodes of salt dissolution.

4) Modeling addressed the lack of density log control within the study area. Additional work on the variations to amplitude near the critical tuning interval with the inclusion of density information would also be important.

CONCLUSIONS

From this study the following conclusions are drawn:

1) A qualitive measure of the amount of salt present may be mapped by isochron and amplitude analysis techniques.

2) Salt dissolution appears to be predominately the result of rejuvination of basement faults causing fractures in the overlying sediments allowing migrating fresh waters to dissolve the salts.

3) Salt dissolution is suggested to have begun sometime after reactivation of a northeast trending shear system within the basement during the Laramide orogeny.

4) Isopach mapping of Permian salt intervals coupled with seismic studies may provide a better understanding of stratigraphic and structural develpment of the overlying stratigraphic section and may lead to better exploration models.

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