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*Julie A. LeFever and Sidney B. Anderson*

REPORT OF INVESTIGATION No. 84
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*Sidney B. Anderson, Acting State Geologist*
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# ABSTRACT

Wireline logs were examined for oil wells in portions of Bottineau, Burke, Renville, and Ward Counties in north-central North Dakota. The Mississippian Madison Group subcrops in the study area and is divided into two informal intervals, the Frobisher-Alida and Ratcliffe, and two informal subintervals, the Midale and Rival. Three informal marker-defined horizons originally described by Harris and others (1966), the Bluell, Sherwood, and Mohall beds, are also considered in this study. Lithotypes change rapidly across the study area from evaporites to carbonates and are intermittently broken up by siliciclastic marker beds. A series of detailed structure and isopach maps were constructed and analyzed.

Several characteristics are apparent from these maps. Ignoring the erosional effects on the area, the dominant structural trend of the basin is to the southwest toward the basin center. The depositional strike is to the northwest with what appears to be an irregular shoreline, based on the lithotypes present. Along the eastern edge of the study area the southwest trend has shifted to a more southerly direction. Also of interest are several local features: a highly argillaceous section of sediments in Chola, North Grano, and Truro fields; a trough-like feature in the area around Eden Valley Field; and, the distribution of thicker sediments north of Glenburn Field.

Rapid change in lithotypes can be explained by sea-level stillstands followed by a rise or fall in sea level. The irregular shoreline, exhibited by the evaporites and carbonates, results from an alternation of evaporite environments with carbonate environments. No evidence exists for a structural influence over these features. The dominant fold trend is probably related to basin formation, with the exception of the eastern edge of the study area. There, the southerly trend and local features present are related to the dissolution of the Devonian Prairie salt. Other local features are probably due to sedimentary processes.

## INTRODUCTION

Extensive oil well drilling in Bottineau, Renville, and Ward Counties, north-central North Dakota, has made possible a detailed study of a portion of the Mississippian Madison Group. Incorporation of new electric log data with previous studies has helped to develop a detailed structural history of the study area that, hopefully, will encourage and enhance future studies and exploration.

The area of investigation lies along the northeastern margin of the Williston Basin, specifically from T164N to T157N and R85W to R81W (fig. 1). This area is one of the most productive in the basin, with 41 producing oil fields. A list of the fields and their productive horizon is included in Appendix I. All available electric log data, from a total of 1,388 wells, were examined.

## NOMENCLATURE

This report concerns a portion of the Mississippian Madison Group. The following discussion will deal with nomenclature pertinent to this study. The reader is referred to the following papers for a more complete discussion of Madison nomenclature: Thomas (1954); Saskatchewan Geological Society (1956); Fuller (1956); Anderson and Nelson (1956); Harrison and Flood (1957); and Bluemle and others (1980).

The Mississippian Madison Group is subdivided into the Lodgepole, Mission Canyon, and Charles Formations. These formations have been used to describe rocks present in the subsurface Williston Basin for many years. Correlation of the formations to outcrop is difficult, if not impossible. The North Dakota Geological Society suggested changes in Mississippian nomenclature to meet the needs of workers in the basin. Smith (1960) published the suggested revisions, which reduced the Madison Group to formation status and reduced the Lodgepole, Mission Canyon, and Charles Formations to facies within the Madison Formation. In addition, five intervals and two subintervals were defined on easily traceable electric log markers. These informal units include: Bottineau, Tilston, Frobisher-Alida, Ratcliffe, and Poplar intervals and the Rival and Midale subintervals. The Frobisher-Alida interval is further subdivided into marker-defined beds by Harris and others (1966). These marker-defined beds, presently restricted to north-central North Dakota, are named after fields in which they produce and are shown with their corresponding log characteristics on figure 2. Harris and others described two additional marker-defined beds, the Wayne beds and the Landa beds. These two beds were not mapped in this study due to difficulties in correlation.

This study applies the nomenclature used by the North Dakota Geological Survey, as defined by Bluemle and others (1980). Nomenclature used by the Survey divides the Madison Group into three formations, the Lodgepole, Mission Canyon, and Charles. Recognizing the facies relationship of these three formations, five log-defined informal intervals and two subintervals are used. In addition, the marker-defined beds described by Harris and others (1966) are used in this study to further clarify the stratigraphy and the structure of the area. Three cross sections have been constructed to show the correlations of these units across the study area (pls. 1 and 2).

## REGIONAL SETTING

The area of investigation lies along the northeastern margin of the Williston Basin. A major unconformity has affected the subcropping Mississippian rocks of the Frobisher-Alida, Ratcliffe, and Poplar intervals. This unconformity was probably due to

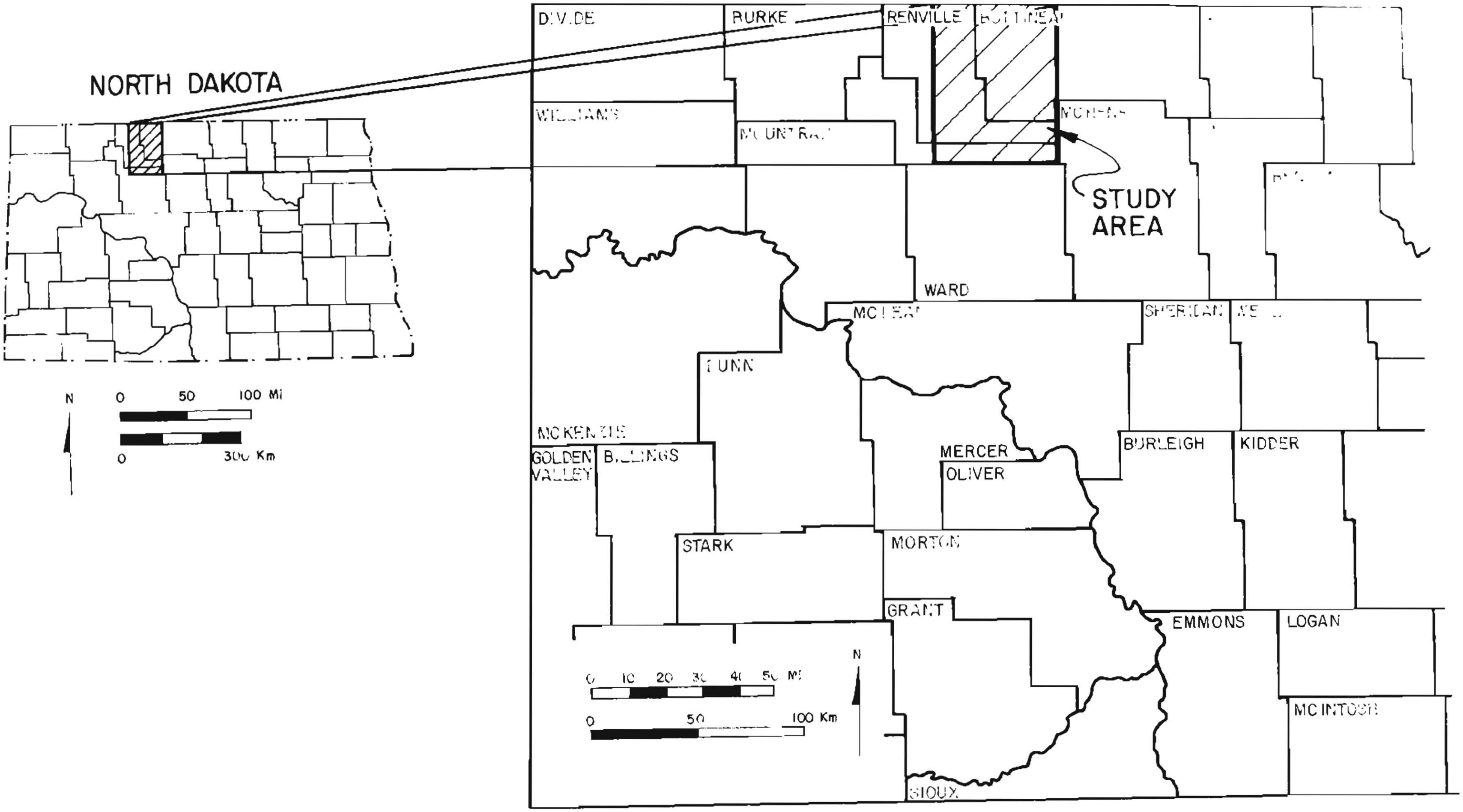

Figure 1. Index map of the area studied.

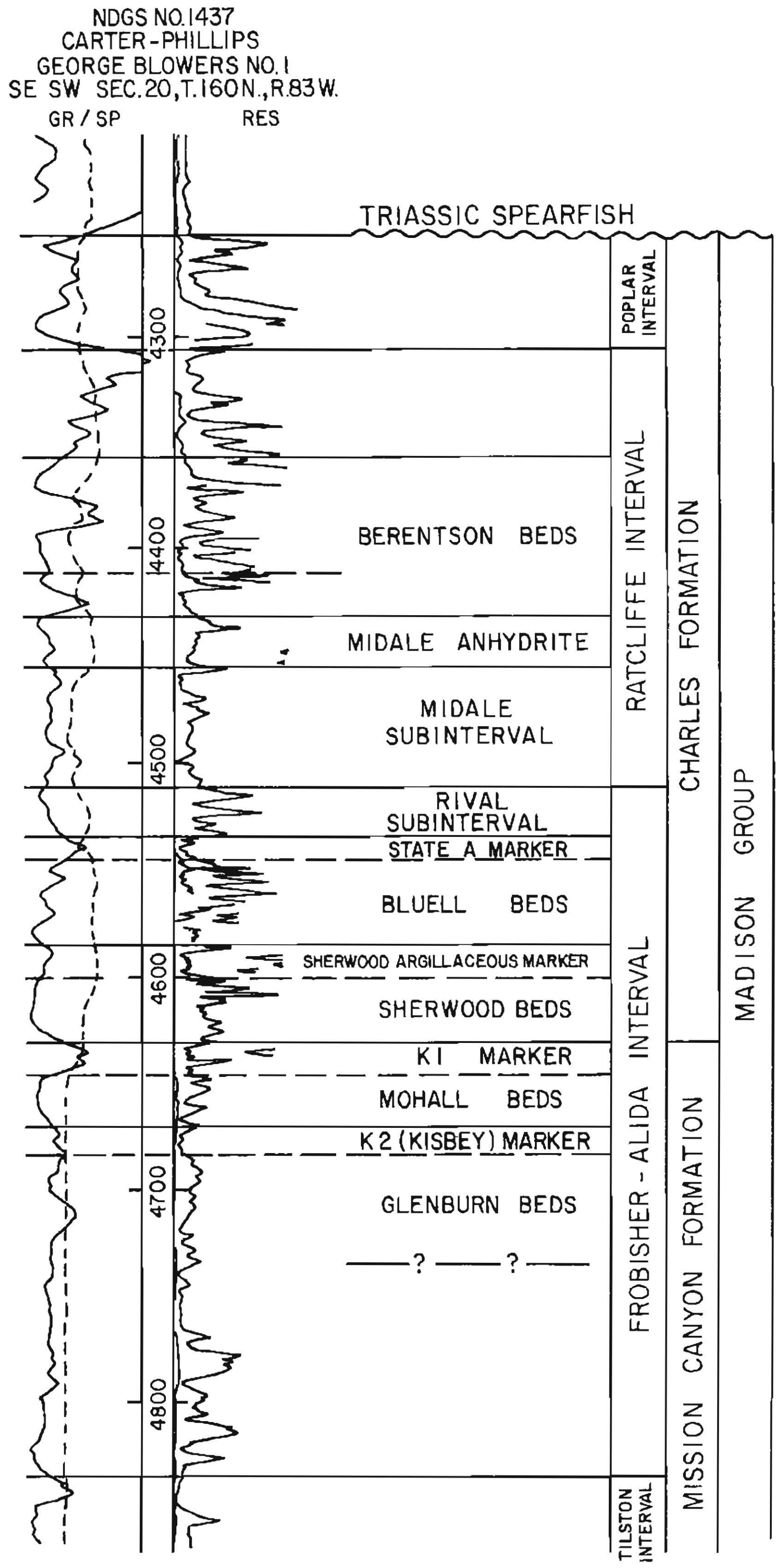

Figure 2. A typical log showing the subdivisions of the Ratcliffe and Frobisher-Alida intervals used in this paper.

basin subsidence with low-stand sea level resulting in large-scale erosion prior to the deposition of the overlying Triassic Spearfish Formation.

This study area lies along the eastern margin of the basin and displays a rapid westward change in lithology from evaporites to carbonates. This sedimentary sequence of evaporites and carbonates is intermittently broken up by thin, siliciclastic beds. Plate 3 shows the distribution of the evaporites and the carbonates for the various beds across the study area. Also illustrated on plate 3 are anomalous areas where porous carbonates zones are surrounded above and below by evaporites or evaporite-plugged carbonates.

## MISSISSIPPIAN STRUCTURE

A series of structure and isopach maps are presented using all the available well control for the study area. In addition, three cross sections were constructed for correlation purposes. The following text will discuss the various structural and/or stratigraphic features found.

### Structure Maps

Structure maps were constructed on four separate horizons. In ascending order, they are: (1) the top of the Tilston interval (pl. 4); (2) the top of the State "A" marker bed (pl. 5); (3) the Ratcliffe marker (pl. 6); and (4) the top of the Mississippian unconformity (pl. 7). The State "A" structure map is used to illustrate present-day structural features for the study area because of the good well control and limited erosion (pl. 8).

### Structure on the Top of the Tilston Interval

Only a limited number of wells penetrate the Tilston interval in the study area; therefore, only large-scale features are apparent on the resulting map (pl. 4). This map perhaps best illustrates the overall northwest strike of the basin margin in the study area. The few subtle folds that are present plunge to the southwest toward the basin center. One exception is found in the area of Glenburn Field (T158N, R81W) where the fold shows a more southerly plunge.

### Structure on the Top of the State "A" Marker Bed

A structure map drawn on the top of the State "A" marker bed gives the most complete map (pl. 5). Erosion on this unit is limited to the northeast portion of the study area. With few exceptions, wells generally penetrate below the marker bed. Where control is the greatest, in areas such as Mohall, Mouse River Park, and Wiley Fields, minor structural features are apparent. Areas between fields have limited well control and thus display lesser amounts of folding. Our interpretation of the structure in this area is superimposed on the State "A" structure map presented on plate 8.

The dominant trend of the folds in the study area is to the southwest, toward the basin center (pls. 5 and 8). This fold orientation, however, changes to a north-south direction along R81W. Major folds of this orientation occur south of Kuroki Field to the area shown along the base of the map, southeast of Glenburn Field. Also associated with those north-south-trending folds are several small, localized depressions.

The northern half of the study area has several small, north-striking faults scattered throughout. The longest one extends from north of Sherman Field to south of Wiley Field. Displacement along these faults is generally only a few feet.

### Structure on the Ratcliffe Marker

Erosion has removed the Ratcliffe marker over nearly half of the study area (pl. 6). In the northern half of the area, the marker is present only in the southwest corner and along a southwest-striking low that occurs adjacent to Wayne Field. The Ratcliffe marker has also been removed in three areas in the southern half of the study area north of Glenburn Field. In part, the erosion of the Ratcliffe marker corresponds with associated features shown on the stratigraphically lower State "A" structure map (pl. 5).

Folds shown on the Ratcliffe structure map trend to the southwest and generally coincide with those shown on the State "A" structure map. The folds are usually better developed and extend over a greater distance on the higher unit. Several of the fold hinge surfaces change slightly in orientation with depth. Where this shift occurs it is generally toward the southeast. Fold orientations in R81W around Glenburn Field are again in a more north-south direction corresponding to the underlying State "A" trend.

A small north-striking fault may exist between the two wells in section 1, T159N, R82W. Again, apparent displacement is only a few feet.

### Structure on the Mississippian Unconformity

A structure map drawn on the Mississippian unconformity displays both topographic highs and lows, as well as structural features (pl. 7). The majority of the folds present on maps of the lower horizons continue upward with only a few minor folds being lost. In addition, numerous highs and lows show up that appear to have no structural basis.

Fold trends present on the unconformity are consistent with those on the maps of the lower stratigraphic units. Several depressions occur around Glenburn Field.

## Isopach Maps

Isopach maps of the seven different stratigraphic horizons are discussed in the following section. Isopach maps of the Frobisher-Alida and Ratcliffe intervals and Midale subinterval (which includes the Midale anhydrite) are presented. Where regional marker beds further subdivide the Frobisher-Alida interval, isopach maps were constructed for the Mohall, Sherwood, and Bluell beds. Three additional units were not individually mapped because of the difficulty in correlating the surrounding markers. These units include the Glenburn, Wayne, and Landa beds. These beds are defined by the K3 and Landa markers, which require close core or sample control for correct correlation. One additional isopach map was drawn of the total thickness of the Frobisher-Alida anhydrite.

Isopach maps of three individual beds, the Mohall, Sherwood, and Bluell, also indicate relative rock types as determined from electric logs. These logs generally show four rock types: (1) anhydrite, Ⓐ ; (2) halite, Ⓢ ; (3) anhydrite-plugged carbonate, (PC) ; and (4) carbonate, Ⓒ . Contacts for the various lithologic types are indicated on the individual isopach maps with a corresponding letter designation.

Isopach maps of the Ratcliffe interval and Midale subinterval are affected by erosion in the northern portion of the study area. Areas shaded on the maps indicate a complete stratigraphic section for the interval involved.

### Isopach Map of the Frobisher-Alida Interval
### (MC-2 Marker Bed--Rival Marker Bed)

The isopach map of the Frobisher-Alida interval has limited well control and therefore limited detail (pl. 4). Erosion has affected the northeasternmost corner of the study area. Thicknesses gradually increase basinward from 240 to 420 feet (73 to 128 m). The only significant feature displayed on the map is a major depression which occurs just north of Glenburn Field in Tps159-161N, and Rs81-82W.

## Isopach Map of the Frobisher-Alida Anhydrite
## (Base of the Anhydrite--State "A" Marker Bed)

The total anhydrite section of the Frobisher-Alida interval was mapped to illustrate the significance of this lithotype to production. Thicknesses range from 0 to 240 feet (0 to 73 m), becoming thicker to the east. Eastwood (1961) constructed a map of the Frobisher-Alida anhydrite. His map showed the presence of strong fold-like noses related to the thickening and thinning of the anhydrite unit relative to the underlying carbonate unit (a "sideboarding" effect) (fig. 3). He also mentioned the stratigraphic relationship between the anhydrite and the carbonate as a potential trap for hydrocarbons.

An updated version of Eastwood's map has been drawn using the additional well control (pl. 9). Contours are substantially more irregular than the original map; however, the same general regional pattern is present. Alternating thicks and thins of anhydrite have led to well-developed stratigraphic traps, as exhibited in Wiley and Haas Fields. This effect is further illustrated by the Frobisher-Alida anhydrite contact on cross-section C-C', drawn parallel to depositional strike (pl. 2).

## Isopach Map of the Mohall Beds
## (K2 Marker Bed-K1 Marker Bed)

The Mohall bed isopach map shows a gradual increase in sediment thickness toward the basin center (pl. 10). Thicknesses range from 40 to 90 feet (12 to 27 m). Distributions of anhydrite, anhydrite-plugged carbonate, and carbonate are indicated on the map.

The eastern side of the isopach shows a much stronger north-south orientation with a substantially thicker section north of Glenburn Field. Similar thick sections occur in Wiley and Wayne Fields and in the area south of Glenburn.

## Isopach Map of the Sherwood Beds
## (K1 Marker Bed-Sherwood Argillaceous Marker Bed)

Areal distribution of sediment thickness is much more varied for the Sherwood beds. Thicknesses range from 15 to 85 feet (5 to 26 m; pl. 11). Again, the lithologies are indicated on the map. In addition to anhydrite, anhydrite-plugged carbonate, and carbonate, halite is present in local areas north and south of Glenburn Field. The most notable difference between the Mohall and the Sherwood isopach maps is that the anhydrite section has prograded substantially westward on the higher unit (the Sherwood beds).

Several features of interest are apparent on the map. Features in the northern half include: a strong southwest-trending nose in the South Haas Field; an abrupt northwest-striking feature at the southwest edge of Haas Field, and a trough-like feature in Eden Valley Field. In the southern half of the study area, thicker sections have developed north and south of Glenburn Field.

## Isopach Map of the Bluell Beds
## (Sherwood Argillaceous Marker Bed-State "A" Marker Bed)

The isopach map of the Bluell beds also has an irregular distribution of sediment, ranging from 0 to 75 feet (0 to 23 m) in thickness (pl. 12). No gradual overall thickening toward the basin center is apparent.

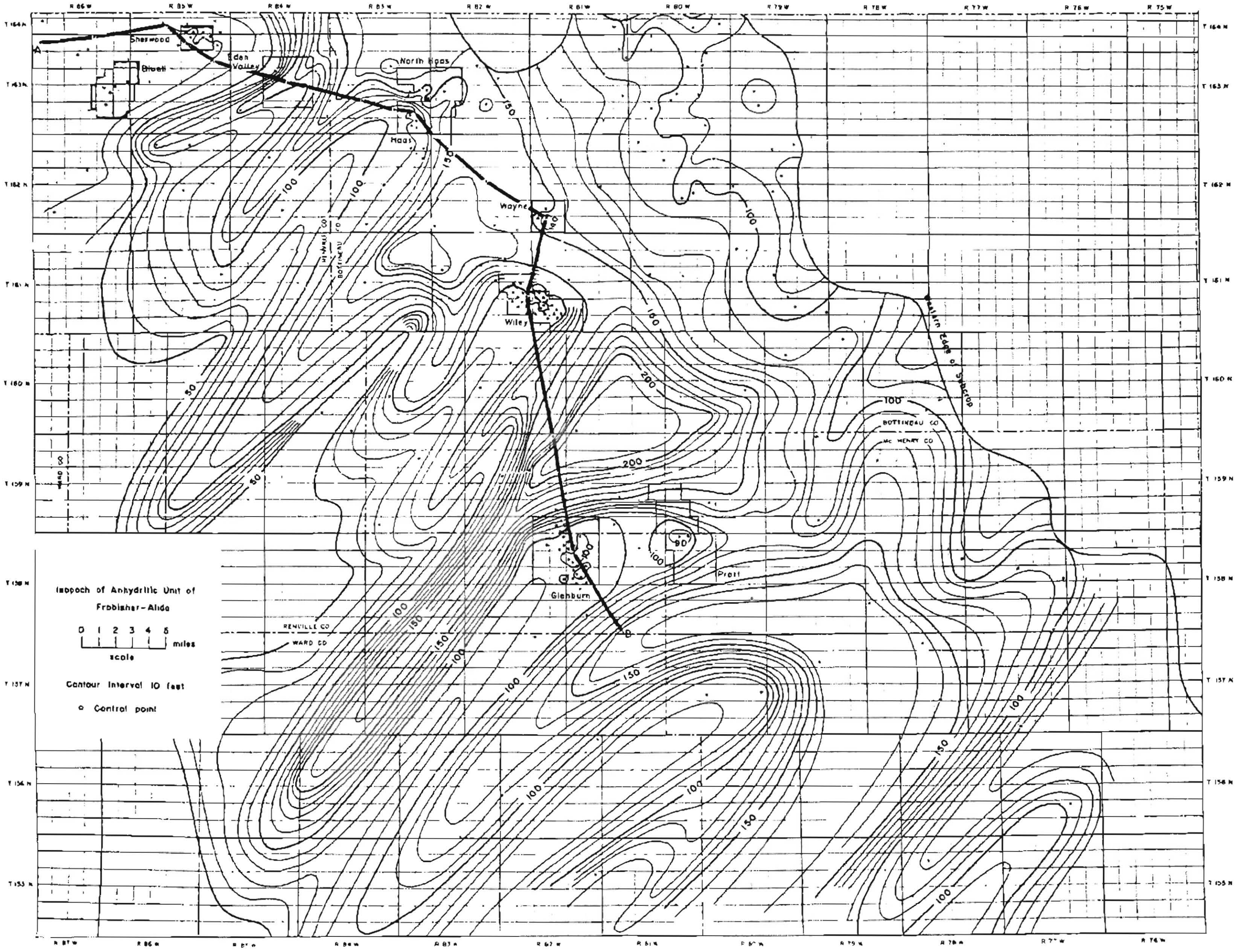

Figure 3. Isopach map of anhydritic unit of Frobisher-Alida interval by Eastwood (1966).

The Bluell beds over the majority of the area are composed of anhydrite, the evaporite/carbonate contact having shifted noticeably to the west. Erosion into and through the Bluell beds is abrupt, occurring over a couple of miles in the northeastern corner of the area. Lithotypes present are the same as those shown on the previous two maps. The Bluell beds, like the Sherwood beds, also have local halite, although they are not as extensive as the Sherwood salts. Another area of lithologic change is around Truro, North Grano, and Chola Fields. There, the beds thicken substantially; the lower portion is a highly argillaceous anhydrite with a prominent log characteristic (fig. 4). Small local carbonate thickenings occur in association with the argillaceous anhydrite.

The trough-like feature found in Eden Valley and the northeast-striking feature at Haas Field are much better developed on the Bluell isopach than on the Sherwood isopach map. Two other additional northeast-trending areas of thick and thin sediments are present near the Des Lacs Field area (T161N, R85W).

In the southern half, the areas of thick sediments north and south of Glenburn are greatly reduced. A thick section of sediment southeast of Blaine Field is also apparent, falling along a trend from North Maxbass Field southwest to Hartland Field.

## Isopach Map of the Ratcliffe Interval (Rival Subinterval-Ratcliffe Marker)

The Ratcliffe isopach map is shown on plate 13. Erosion affects the Ratcliffe interval over approximately half of the study area. Thicknesses change drastically over a short distance from the zero edge to the erosional limit of the Poplar interval. When the entire interval is present, thicknesses remain fairly constant, reaching a maximum of 210 feet (64 m). Along the erosional edge two areas of interest are south and southwest of Wiley Field. There two elongate erosional lobes trend to the west with a thick sequence of sediments between them. Another area of erosion occurs north of Glenburn Field; this area on previous maps has always been indicated as a sedimentary thick. Near Maxbass and Wayne Fields are two areas where the entire Ratcliffe interval is present.

The northern portion of the map area shows the influence erosion had on the interval. There is still a fairly constant southwestward increase in sediment thickness. A north-south-striking fault is present in the area of Colquhoun Field. Here a northeast-trending high appears to terminate against the probable fault with the west side showing a substantial increase in sediment thickness. Notable northeast-trending highs (indicated by a thin section) occur immediately south of Sherwood Field.

In the southern portion of the map area, thicknesses remain fairly constant; however, a few local areas of thicker sediments occur to the east of Glenburn Field.

## Isopach Map of the Midale (Top of the Rival Subinterval-Top of Midale Anhydrite)

The Midale anhydrite is consistently about 20 feet (6 m) thick over the entire study area. It has been included in the isopach map of the Midale subinterval (pl. 14). Thicknesses of the entire Midale section range from 0 to 80 feet (0 to 24 m). Erosion has affected the northern portion of the map area.

Well-developed highs evident on the Ratcliffe map are also evident in the Sherwood and Colquhoun Fields. A thick area is indicated north of Kuroki Field. Isolated thicker sections are also apparent along the eastern side. The southern half of the area shows nearly constant thickness, with only small local

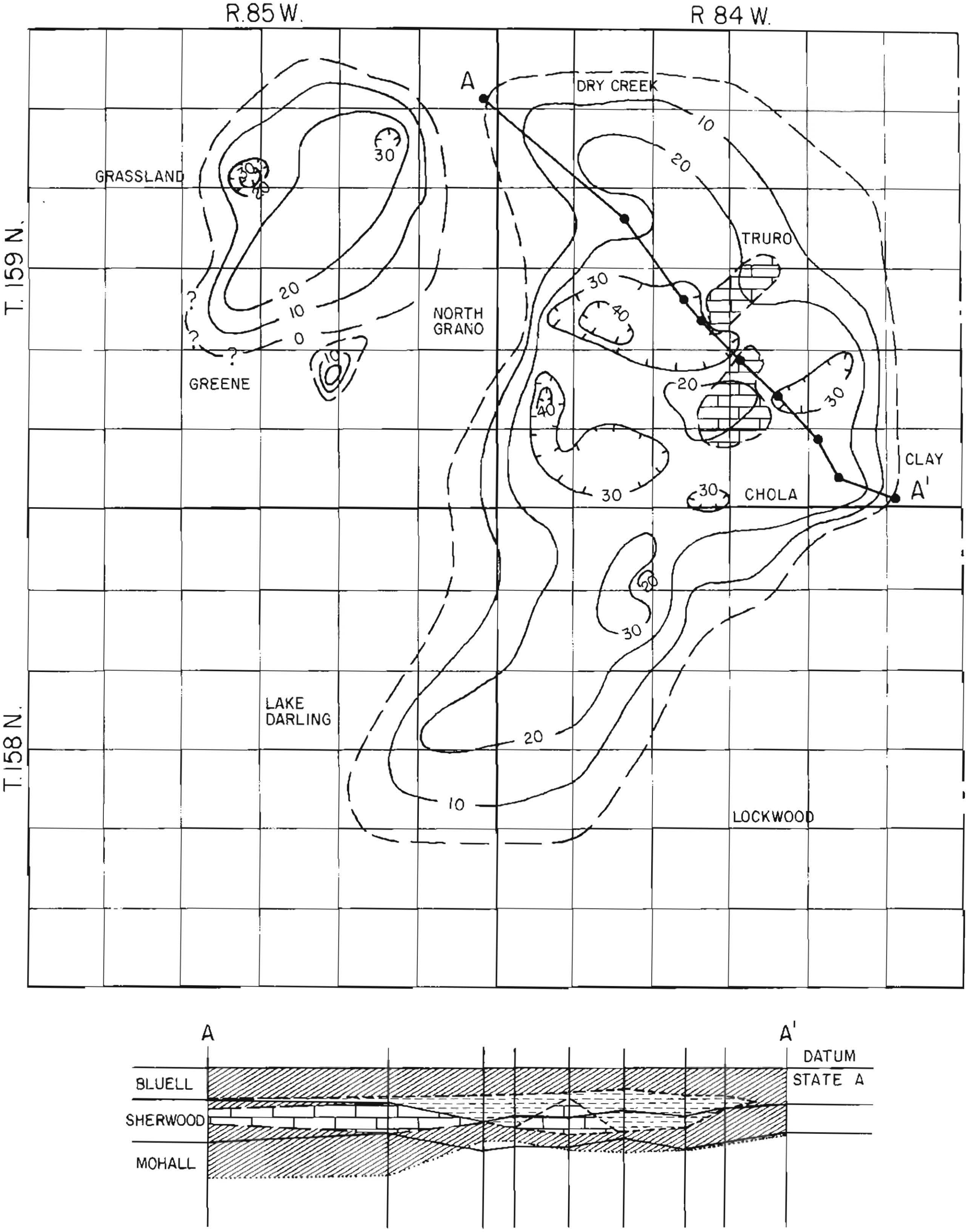

Figure 4. Isopach map of the argillaceous anhydrite within the Bluell beds and associated carbonate thickenings.

changes. Unlike the previous maps, no activity (indicated by thick or thin sections) is shown in the areas north and south of Glenburn.

## Additional Areas of Interest

### Eden Valley Area

All of the isopach maps previously discussed have one feature that stands out in the area of Eden Valley Field. A zone of greater thickness denotes a linear feature, possibly a channel. Plotting the location from the various isopach maps of this channel-like feature on a separate map shows the changes through time (fig. 5).

Another interesting point is that, in this area, during deposition of the Sherwood beds a local change in lithology occurred. A porous carbonate unit, which produces in Elmore Field, occurs between anhydrite and an anhydrite-plugged carbonate. Its distribution is roughly coincident with the location of the channel-like feature.

### Glenburn Area

Several points of interest show up around the Glenburn Field. The distributions of thick sediments for four horizons are indicated on figure 6. These thick sequences show a progressively lesser areal extent moving upsection stratigraphically. This area shows as a structural high on the present-day structure maps. These thick areas are where the salt facies are present in the Sherwood and Bluell beds (pls. 11 and 12).

Glenburn Field produces from a bifurcated, north-trending fold. The location of the hinge lines of this fold for various stratigraphic horizons are shown on figure 6. It is interesting to note that upward through time the hinge surface of the westernmost fold has tilted westward.

## DISCUSSION

Numerous folds are present throughout the study area (pls. 5 and 6). The overall trend of these folds is to the southwest toward the center of the basin; the majority are probably related to basin subsidence. A few folds show up only in specific horizons; for example, the apparent fold in the Sherwood beds for South Haas Field. Where these folds are confined to a specific horizon they probably reflect sedimentary processes rather than tectonic processes. Another possibility is that some of these small structures were active only during the deposition of the affected stratigraphic unit.

It is not the main purpose of this report to discuss the environments of deposition in detail, for this type of information the reader is referred to: Harris and others (1966); Malek-Aslani (1971); Elliott (1982); Shanley (1983); and Obelenus (1985). However, an attempt will be made to discuss several of the features found when dealing with the electric logs.

A rapid change in lithotypes from evaporites to carbonates is immediately apparent when reviewing the electric logs of this area. The westward progradation of evaporites was not continuous. Examination of the logs show that the evaporites prograded westward and then stepped abruptly upsection and basinward to the next stratigraphic horizon. Repetition of this cycle occurred until the deposition of the Bluell beds. Shanley (1983) explained these abrupt vertical changes by relative sea-level rise. He stated that lateral progradation occurred during a sea-level stillstand which enhanced subaerial exposure. Eolian-transported silts and fine-grained sediments were deposited across the area at this time. This was followed by a rise in sea level and vertical

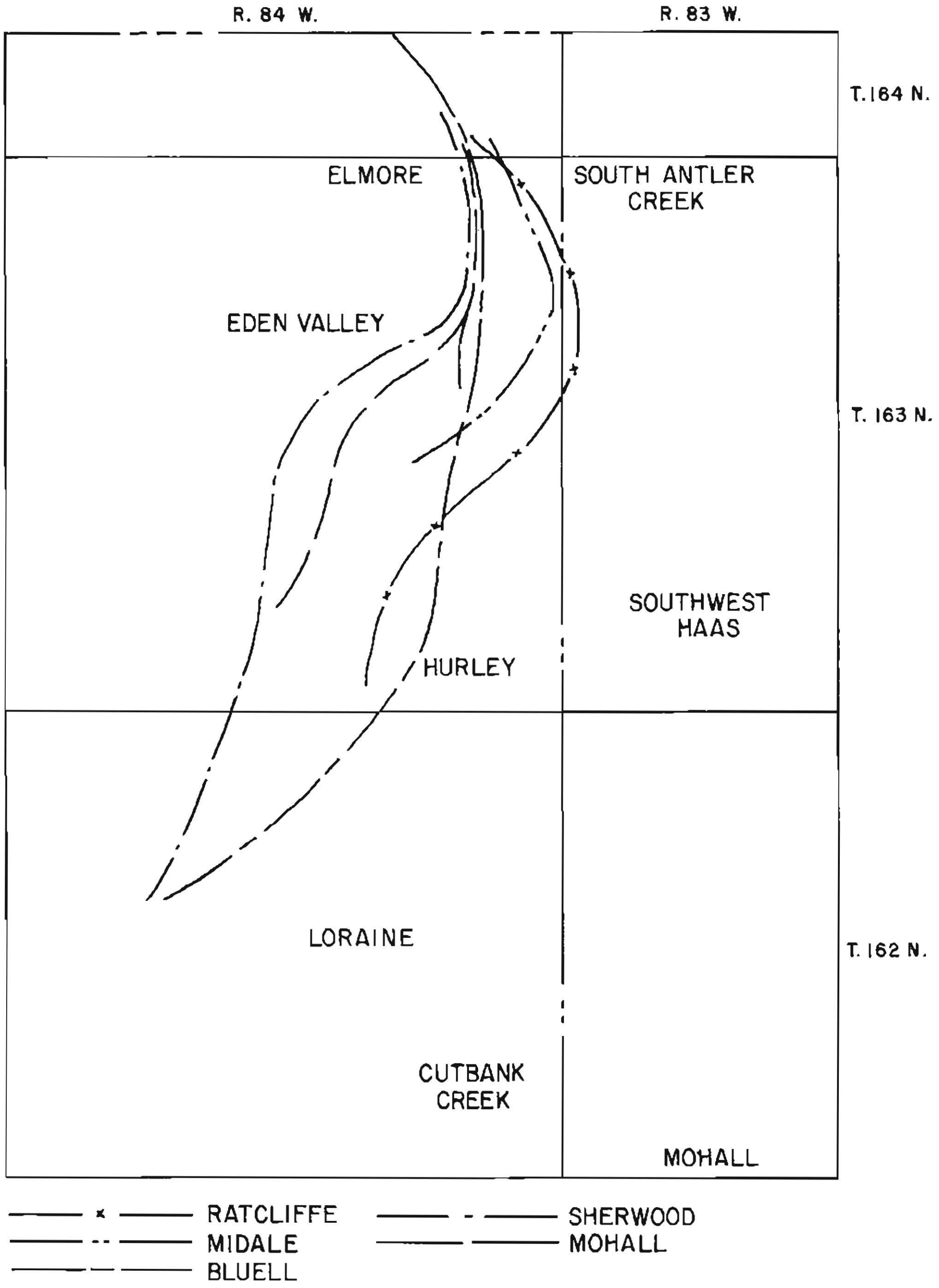

Figure 5. A channel-like feature present near Eden Valley Field.

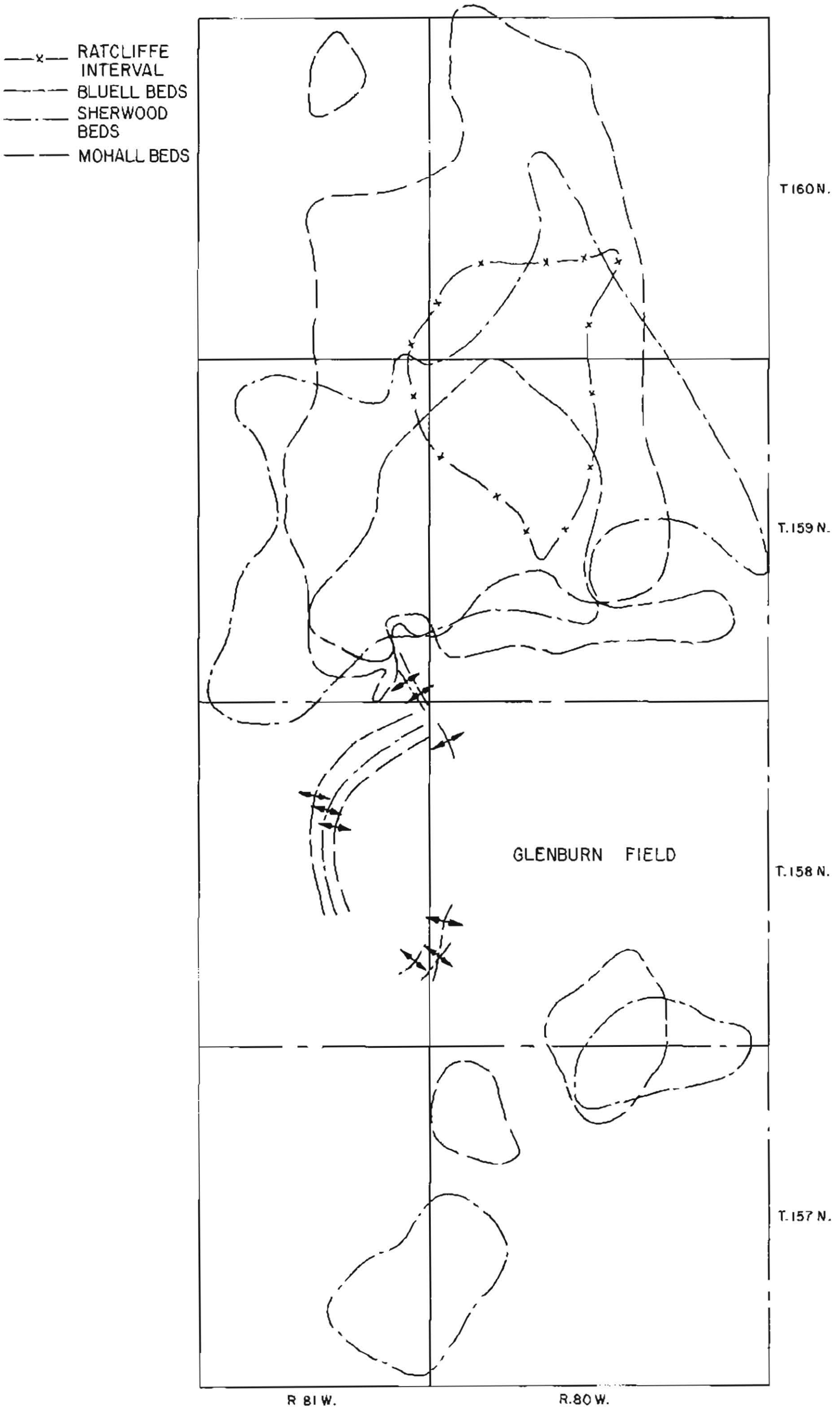

Figure 6. Map indicating the distribution of areas of thicker sediments north and south of Glenburn Field, including the distribution of hinge lines of the informal units for the Glenburn Field.

accretion. The sequence of events was repeated several times. A potential problem with Shanley's explanation is uncertainty about whether carbonate production on a supratidal flat could have kept up with the relative rise in sea level; this is necessary to continually restrict the expanded area of evaporite deposition (R. Burke; personal commun., 1986). An alternate explanation would be to use the same model only with a lowering of sea level instead of a rise. Lowering the sea level lessens the problem of carbonate production rates. The shoals which Shanley uses to restrict circulation would continue to develop offshore with the drop in sea level, leading to expansion of the area of evaporite deposition. Periodic stillstands or minor transgressions could still explain the presence of the marker beds.

Exceptions to this mode of progradation do exist. The Bluell beds in the westernmost portion of the study area show a continuous westward progradation. Also, porous carbonates are found, locally, surrounded by evaporites or evaporite-plugged carbonates (pl. 3).

Another feature that needs to be discussed is the "nosing" appearance of the evaporite/carbonate contact (pl. 3). Shanley (1983) explained the alternating salients/embayments displayed by the alignment of shorelines for the various informal intervals by movement along a series of east-west-striking faults. Those east-west-striking faults are said to have their origin in basement rocks. Assuming the carbonates and evaporites are laterally equivalent, Obelenus (1985) explained the "nosing" or "digitate" appearance by alternating environments of evaporite production with environments of carbonate production. Thickness of these lithofacies is then based on the duration of progradation and sedimentation. He stated the linearity of the environments suggest that it may have had a structural control or have been influenced by the dissolution of the Devonian Prairie salt.

No evidence exists to suggest a structural control. From subsurface mapping it seems unlikely that the east-west faults proposed by Shanley (1983) are rooted in the basement rocks, but proprietary seismic data may provide evidence for this. These faults go against the overall structural grain of the area and the basin. Folds are generally oriented in a southwest direction toward the basin center. A major fault adjacent to the study area is responsible for local dissolution of the Devonian Prairie salt. The structural features of the area around the fault and local salt dissolution exhibit a pronounced north-south orientation. The east-west-striking faults are not consistent with models presented by Gerhard and others (1982) or Green and others (1985). If the faults do exist, the authors suggest that they are not of a tectonic origin (rooted in basement rocks). A fault system may develop on the sides of the embayments/salients as a result of slip along differing rock types due to differential compaction. This could explain the shoreline appearance.

A small area of lithologic change occurs in Truro, North Grano, and Chola Fields (pl. 12). The Bluell beds thicken substantially in this area; the lower portion is highly argillaceous. Logs indicate a potential carbonate thickening in the center of the area and to the west. The possibility of a lagoon or similar restricted area is suggested.

A model described originally by Swenson (1967) and modified by Longman (1981) for an area in northeastern Montana can be used to explain the situation shown on the structure maps north of Glenburn Field. This area, which consists of a thick sequence of sediments on the isopach maps (considered to be a low at the time of deposition of the various Mississippian units) shows on the structure maps as a structural high. A possible explanation for this feature comes from the logs that penetrate into the Devonian Winnipegosis. Along the eastern margin of the study area a tectonic boundary exists in the Precambrian rocks. Suspected movement along this zone has allowed fluid to migrate into the Devonian Prairie salt. Subsequent dissolution of the salt and resultant collapse of the overlying sediments caused a depression to form during most of the duration of the time the Madison Group was being deposited. Differential compaction followed, with the areas of additional sediment thickness becoming a high on present-day structure maps.

The north-south orientation of the bifurcated fold that forms the Glenburn Field is also probably due to the dissolution of the Devonian Prairie salt. As the salt dissolved to the east of the fold, it is not unreasonable to suppose that the hinge line migrated west, resulting in a westward tilt to the hinge surface. The relative positions of the hinge lines for the same stratigraphic horizons for the eastern fold remained essentially stationary. Dissolution started in the east during the deposition of post-Prairie Formation Devonian sediments and moved westward. North of Glenburn Field, as exhibited on the log of the California Company-Blanche Thompson #1, primary dissolution was occurring during deposition of the Tilston sediments. By the time the Mohall and younger beds were deposited, dissolution was farther west and the eastern structure was well established. The eastern hinge surface would have been almost vertical with the hinge line essentially stationary when the western fold was experiencing the most movement. Lack of deeper well control eliminates the possibility of examining the evolution of the eastern fold to see if a similar, earlier, situation occurred for it.

Several small north-striking faults are scattered throughout the study area, mainly in the eastern half. Slip along these faults is minor, generally only a few feet. Because these faults have the same orientation as the Precambrian tectonic boundary and the area of salt dissolution, they are probably a local readjustment of rocks to the dissolution phenomena.

Salt dissolution is still occurring within the study area. Evidence of this is the presence of small depressions on the present-day structure maps (pls. 6, 7, and 8).

The Eden Valley area shows a linear feature on isopach maps that is interpreted to be a channel. Additional support for this idea may be the localized lense of carbonate rock within the Sherwood beds. Surrounded by evaporitic-type rock, the channel may have been a source of fresher water which enabled the Sherwood carbonates to develop.

## ACKNOWLEDGMENTS

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# APPENDIX A

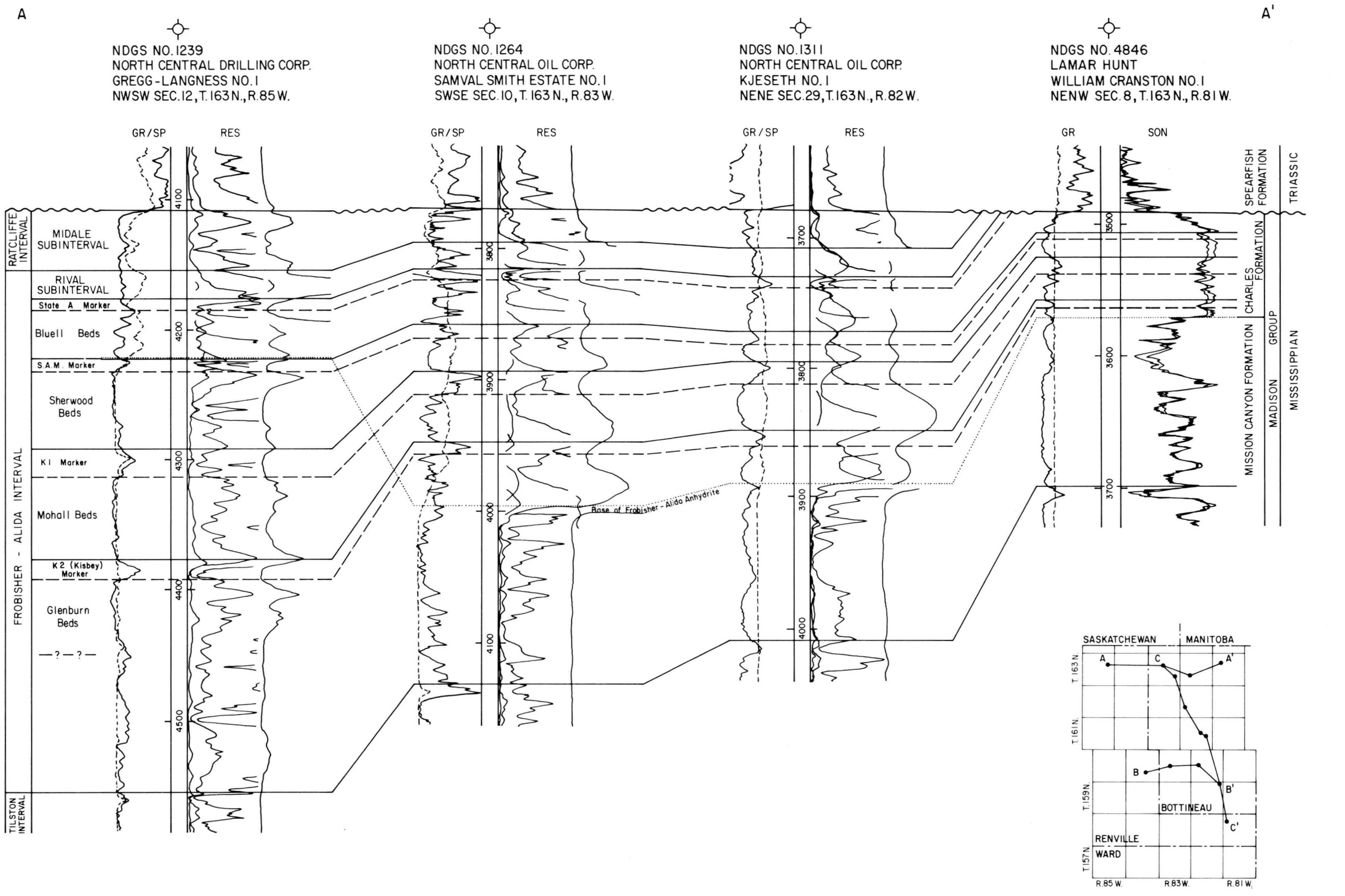
## Oil Fields Within the Study Area and Their Producing Horizons

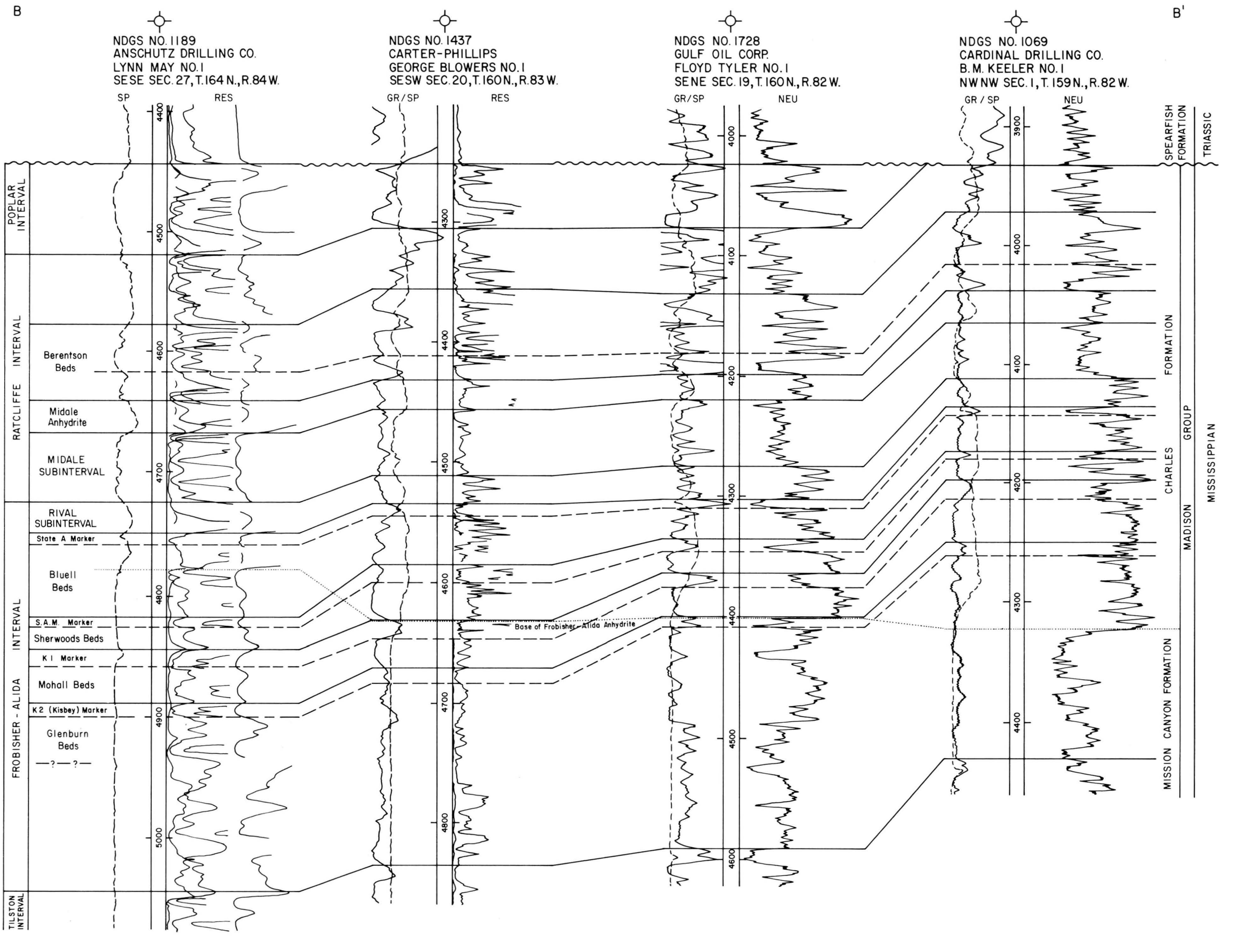
| Field | County | Location | Producing Horizon |
|---|---|---|---|
| Antler | Bottineau | T163N, Rs81-82W | Midale Subinterval |
| Baumann Drain | Bottineau | T163N, R82W | Midale Subinterval |
| Blaine | Bottineau | T160N, R83W | Mohall Beds |
| Bluell | Renville | T163N, Rs85-86W | Bluell Beds |
| Chola | Renville | Tps159-160N, R84W | Bluell Beds |
| Clay | Renville | T160N, R84W | Sherwood Beds |
| Cutbank Creek | Renville | T162N, R84W | Mohall Beds |
| Colquhoun | Renville | Tps162-163N, R85W | Mohall Beds |
| Des Lacs | Renville | T161N, R85W | Sherwood Beds |
| Dry Creek | Renville | T160N, R84W | Bluell Beds |
| Eden Valley | Renville | T163N, R84W | Mohall Beds |
| Elmore | Renville | T164N, R84W | Sherwood Beds |
| Glenburn | Bottineau,<br>Renville | Tps158-159N, Rs81-82W | Glenburn Beds |
| Grassland | Renville | T160N, R85W | Bluell Beds |
| Greene | Renville | T160N, R85W | Bluell Beds |
| Haas | Bottineau | T163N, R83W | Glenburn Beds |
| Hartland | Ward | T157N, R84W | Mohall Beds |
| Hurley | Renville | T163N, R84W | Mohall Beds |
| Kuroki | Bottineau | T163N, R81W | Midale Subinterval |
| Lake Darling | Renville | Tps158-159N, R85W | Sherwood Beds |
| Lansford | Bottineau | T160N, R83W | Mohall & Glenburn Beds |
| Little Deep Creek | Renville | T161N, R85W | Sherwood Beds |
| Lockwood | Renville | T159N, R84W | Mohall Beds |
| Loraine | Renville | T162N, R84W | Mohall Beds |
| Mackobee Coulee | Renville | T158N, R85W | Bluell & Sherwood Beds |
| Mad Max | Bottineau | T161N, R81W | Wayne Beds |
| Mohall | Bottineau | Tps161-162N, Rs83-84N | Mohall Beds |
| Mountrose | Bottineau | Tps160-161N, Rs82-83W | Sherwood Beds |
| Mouse River Park | Renville | Tps161-162N, Rs85-86W | Sherwood Beds |
| North Grano | Renville | T160N, Rs84-85W | Bluell Beds |
| North Haas | Bottineau | T163N, Rs82-83W | Kisbey Sandstone |
| North Maxbass | Bottineau | T161N, R81W | Wayne Beds |
| Sherman | Bottineau | T162N, R82W | Wayne Beds |
| Sherwood | Renville | Tps163-164N, Rs84-85W | Sherwood Beds |
| South Antler Creek | Bottineau,<br>Renville | T164N, Rs83-84W | Midale Subinterval |
| South Haas | Bottineau | T162N, R83W | Glenburn Beds |
| Southwest Haas | Bottineau | T163N, R83W | Glenburn Beds |
| Truro | Renville | T160N, R84W | Bluell Beds |
| Wayne | Bottineau | T162N, Rs81-82W | Wayne Beds |
| West Sherwood | Renville | Tps163-164N, R85W | Midale Subinterval & Sherwood Beds |
| Wheaton | Bottineau | T164N, R83W | Midale Subinterval |
| Wiley | Bottineau | T161N, Rs81-82W | Glenburn Beds |

# PLATE 1. CROSS-SECTIONS A-A' AND B-B'

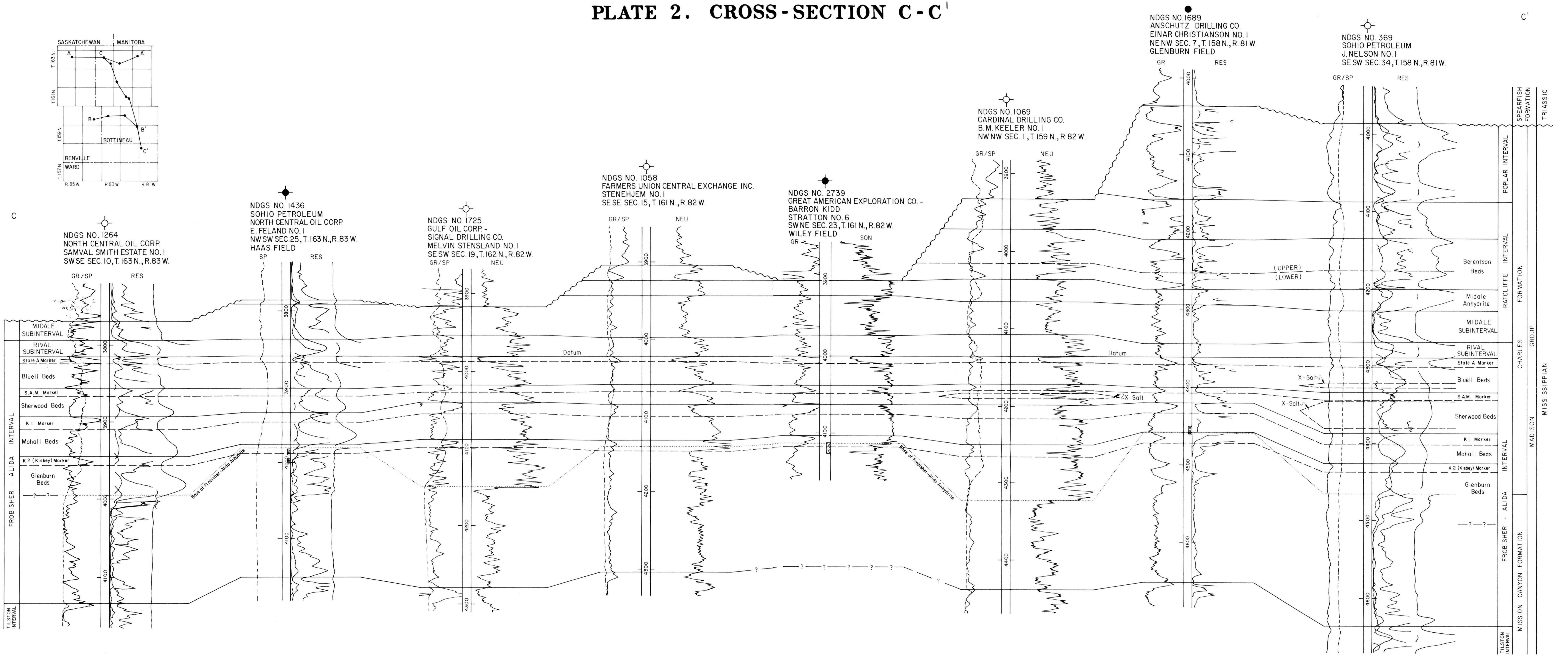
REPORT OF INVESTIGATION 84

NORTH DAKOTA GEOLOGICAL SURVEY
SIDNEY B. ANDERSON, ACTING STATE GEOLOGIST



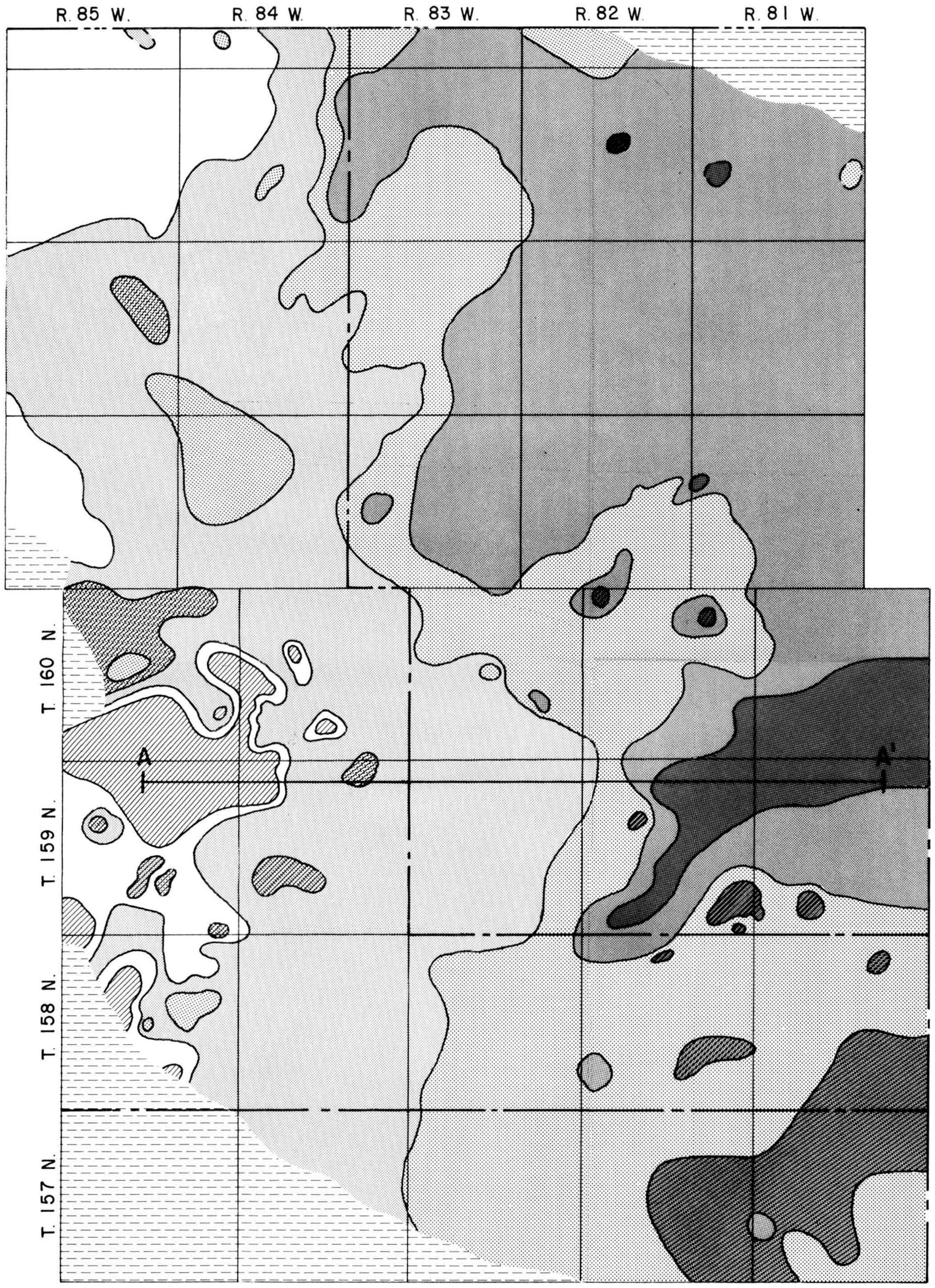


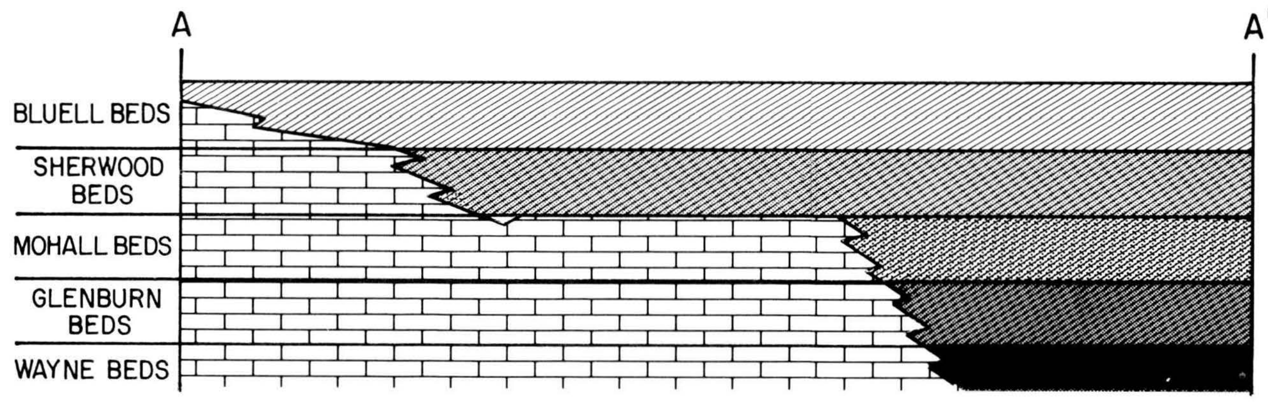
# PLATE 2. CROSS-SECTION C-C'



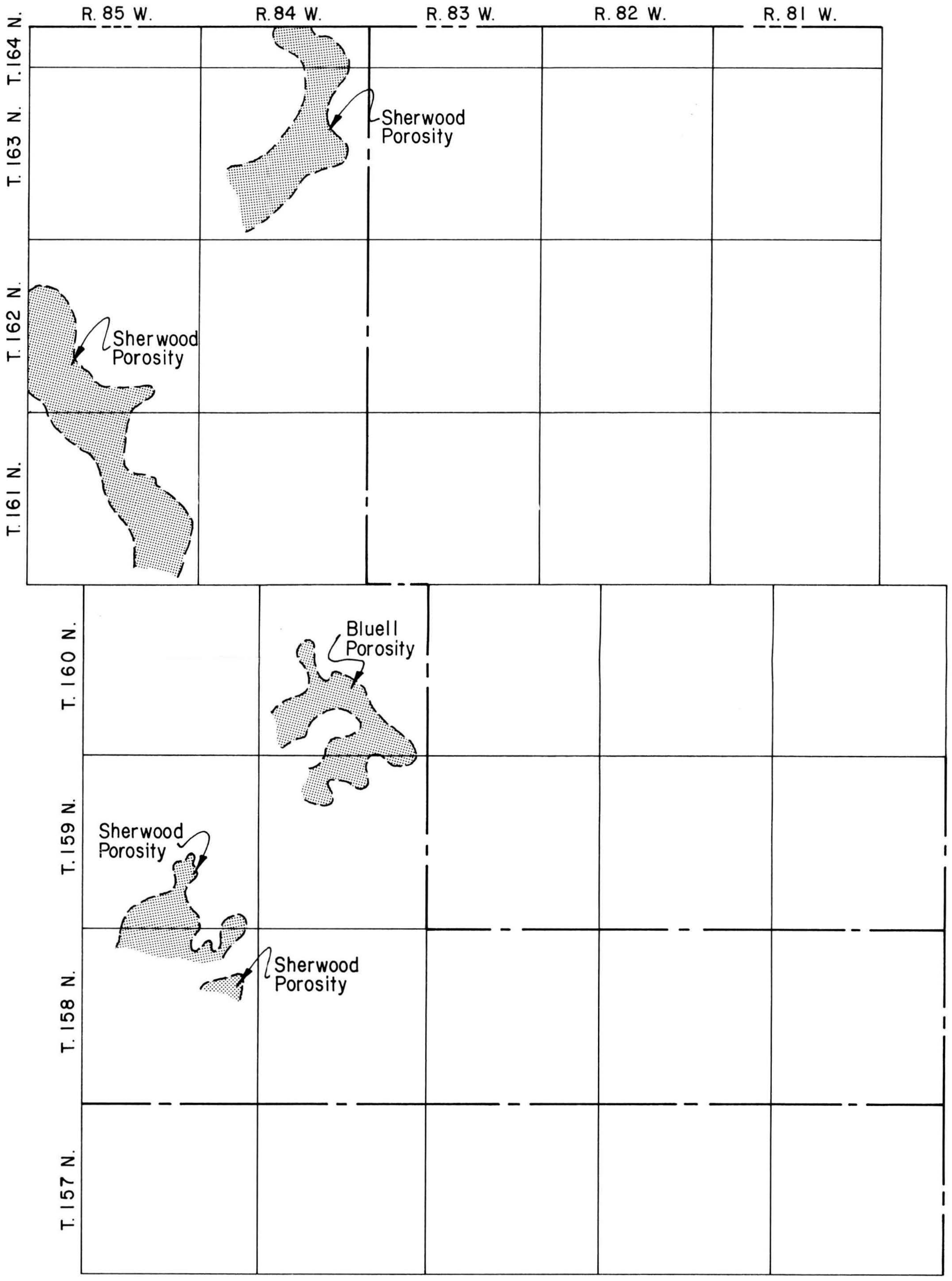
# PLATE 3

## RELATIONSHIP BETWEEN EVAPORITES AND CARBONATES FOR VARIOUS MAPPABLE HORIZONS



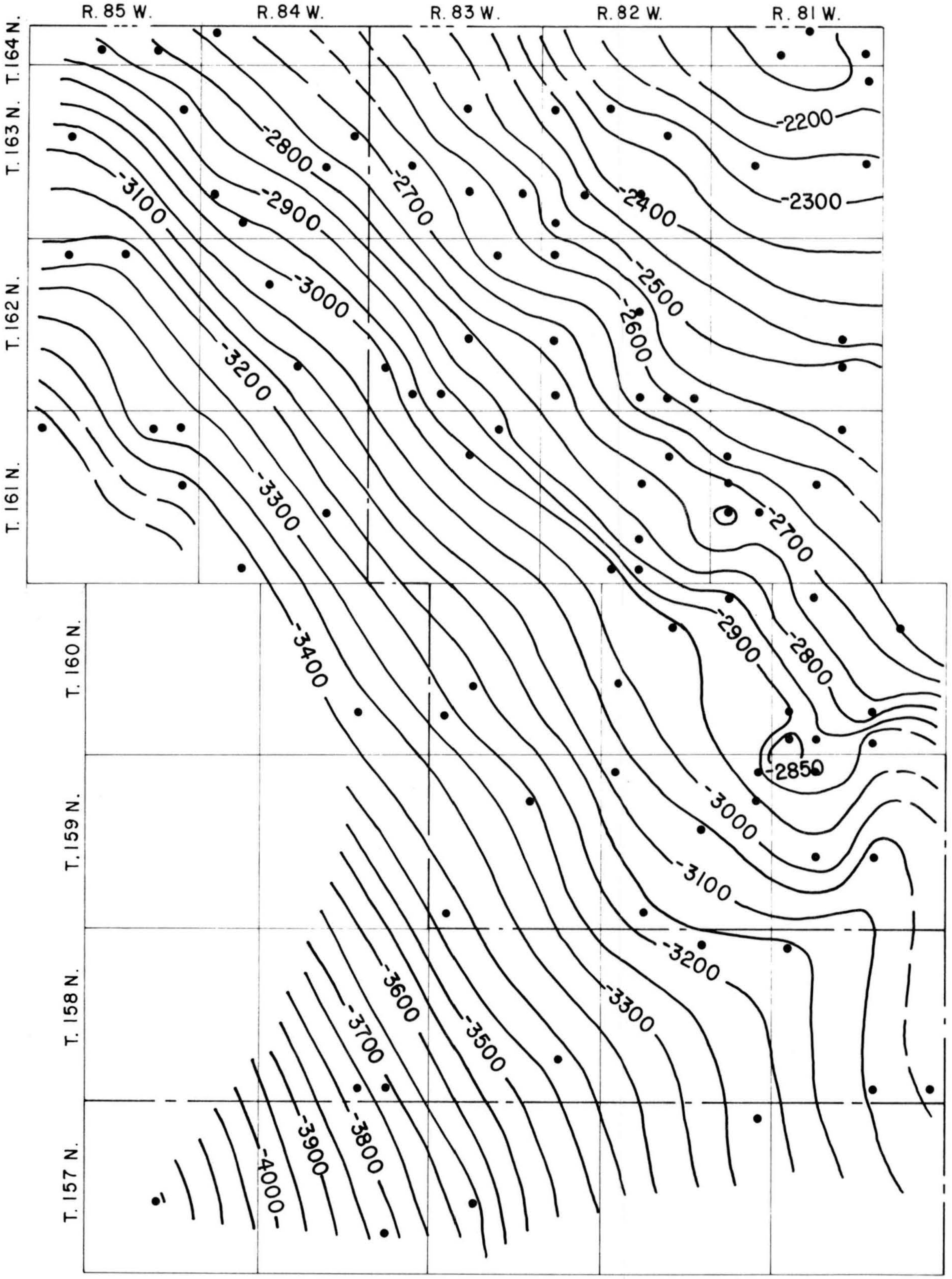


## ANOMALOUS POROSITY ZONES

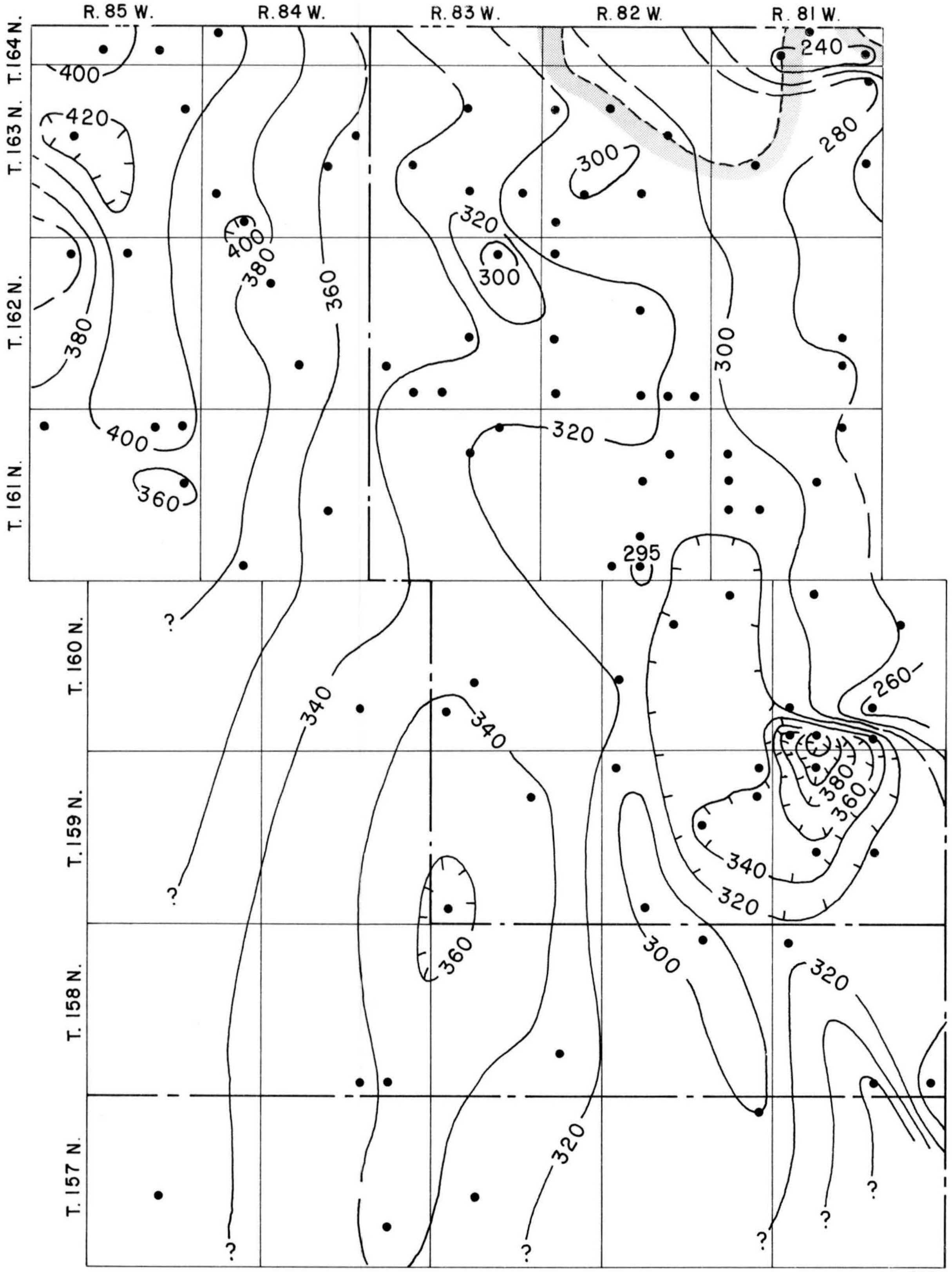


# PLATE 4

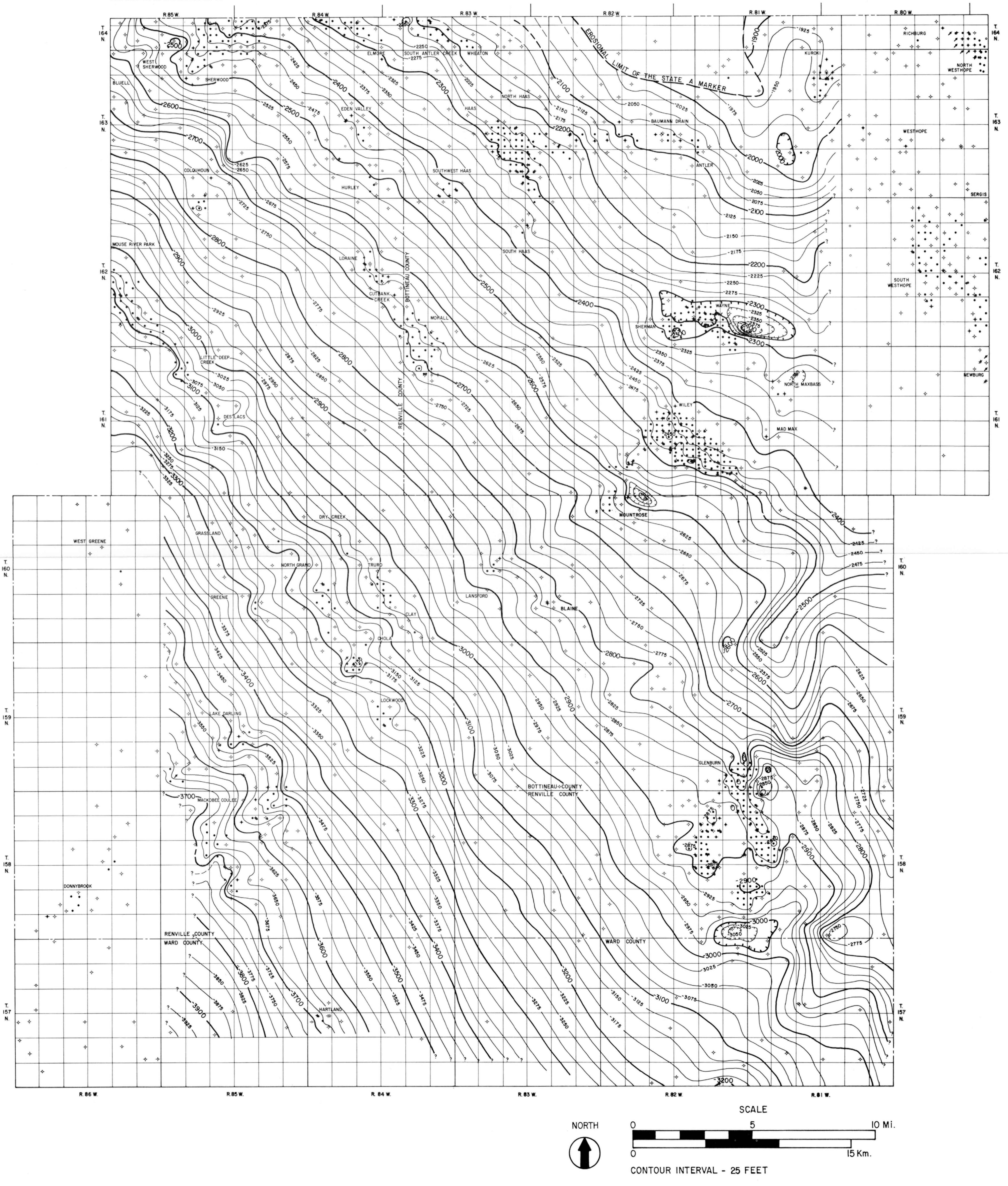
## STRUCTURE MAP ON THE TOP OF TILSTON INTERVAL



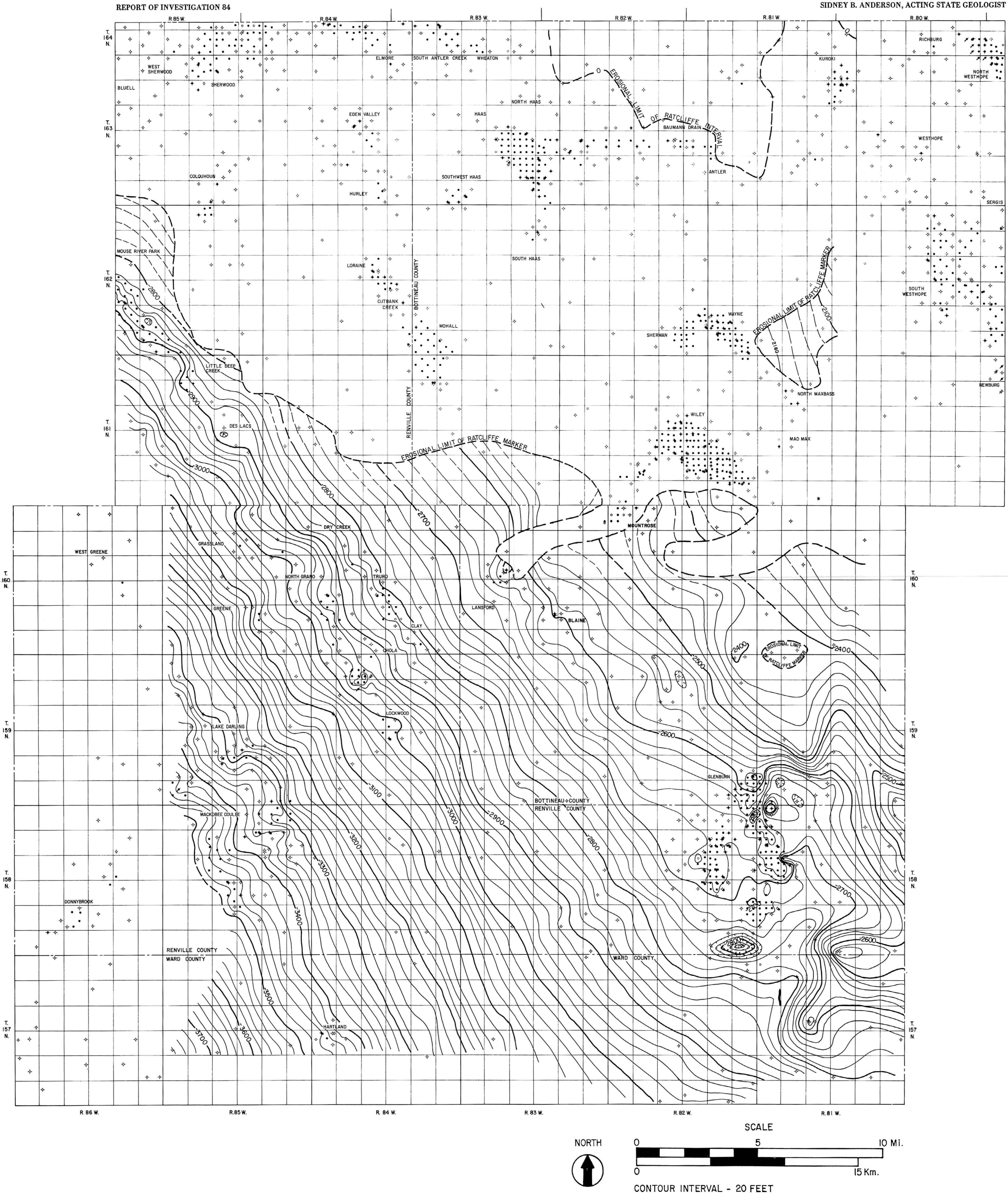
## ISOPACH MAP OF THE FROBISHER-ALIDA INTERVAL



# PLATE 5. STRUCTURE MAP ON THE STATE "A" MARKER BED

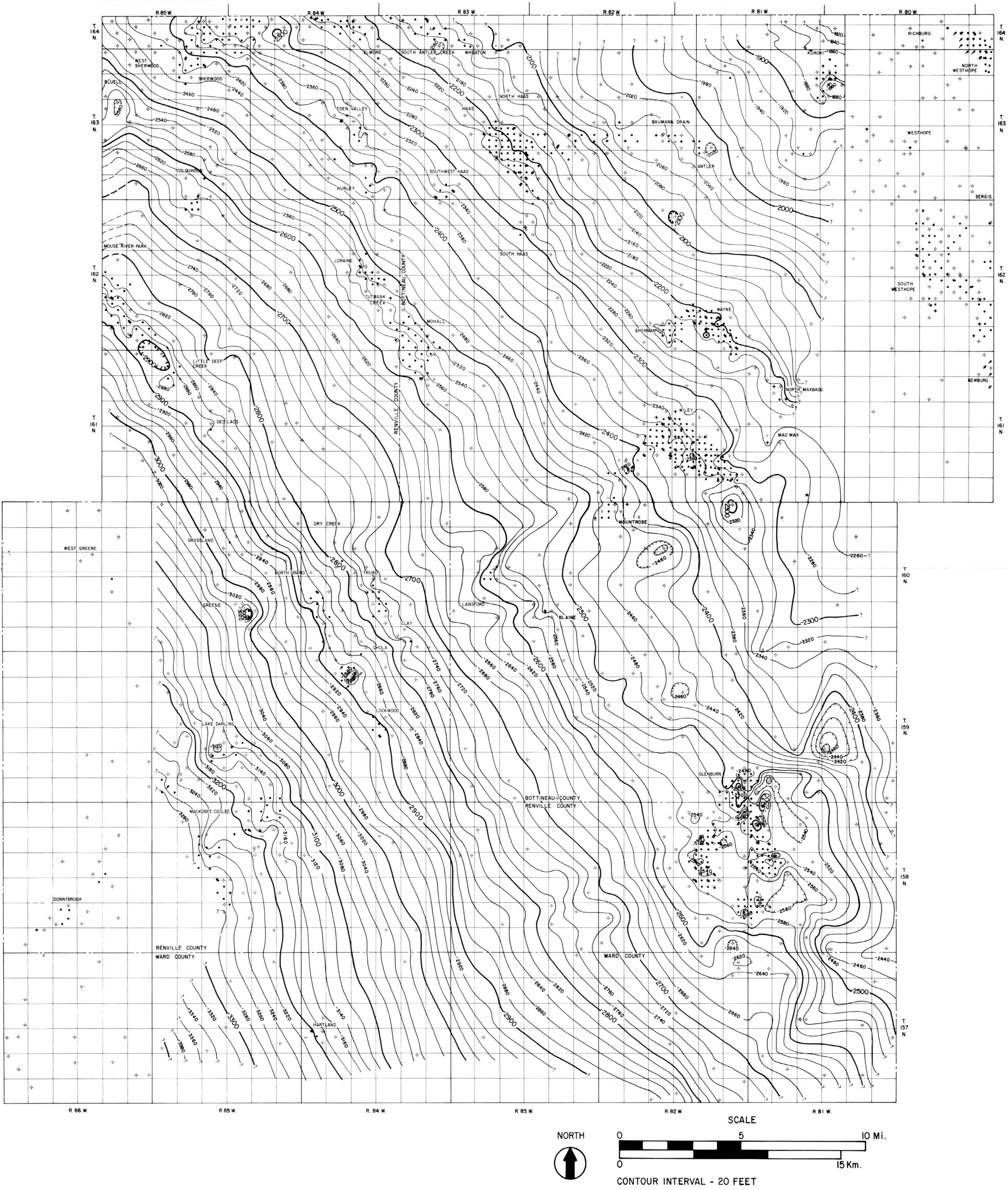


# PLATE 6. STRUCTURE MAP ON THE RATCLIFFE MARKER



CONTOUR INTERVAL - 20 FEET

# PLATE 7. STRUCTURE MAP ON THE MISSISSIPPIAN UNCONFORMITY



# PLATE 8. STRUCTURE MAP ON THE STATE "A" MARKER BED WITH INTEPRETATION

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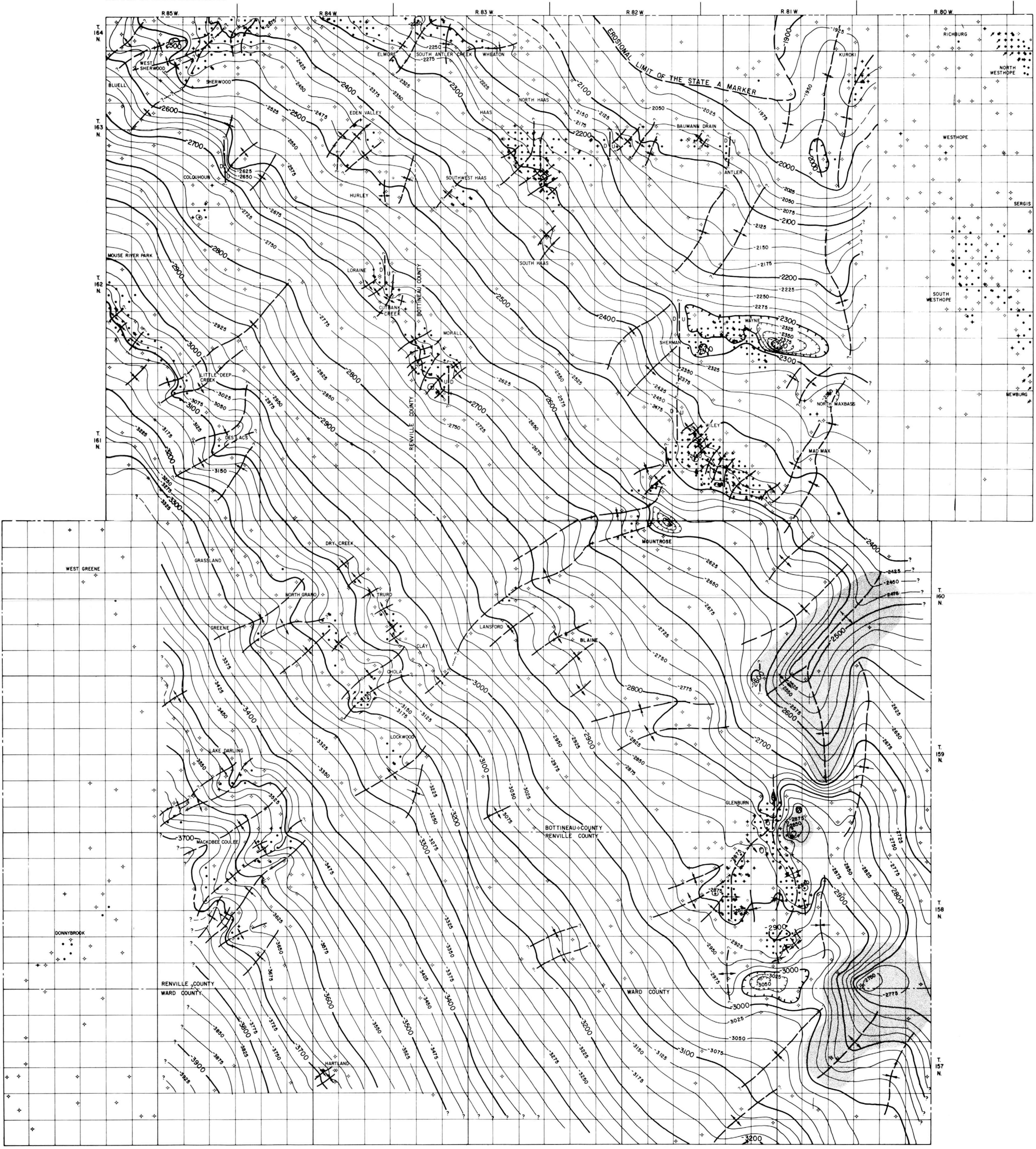
SIDNEY B. ANDERSON, ACTING STATE GEOLOGIST



## EXPLANATION

**FOLDS**

Showing hinge surface trace; dashed where approximate; queried where uncertain

Anticline ?

Syncline ?

**FAULTS**

Dashed where approximately located; queried where uncertain; U - probable upthrown side; D - probable downthrown side

U
D ?

▨ **STRUCTURAL HIGHS** – due to differential compaction

NORTH

SCALE

0 5 10 Mi.

0 15 Km.

CONTOUR INTERVAL - 25 FEET

# PLATE 9. ISOPACH MAP OF THE FROBISHER-ALIDA ANHYDRITE

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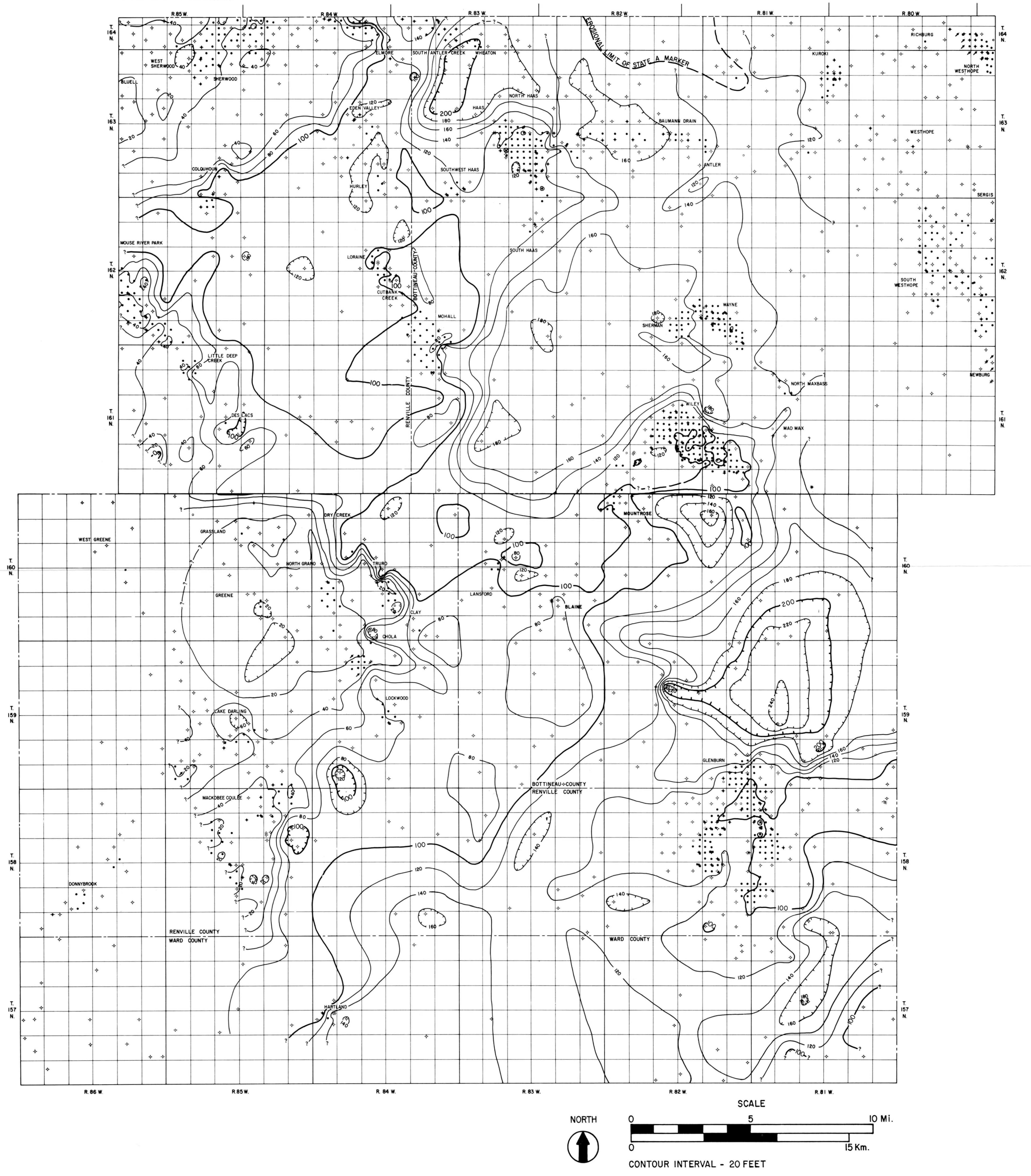
NORTH DAKOTA GEOLOGICAL SURVEY
SIDNEY B. ANDERSON, ACTING STATE GEOLOGIST



# PLATE 10. ISOPACH MAP OF THE MOHALL BEDS

REPORT OF INVESTIGATION 84

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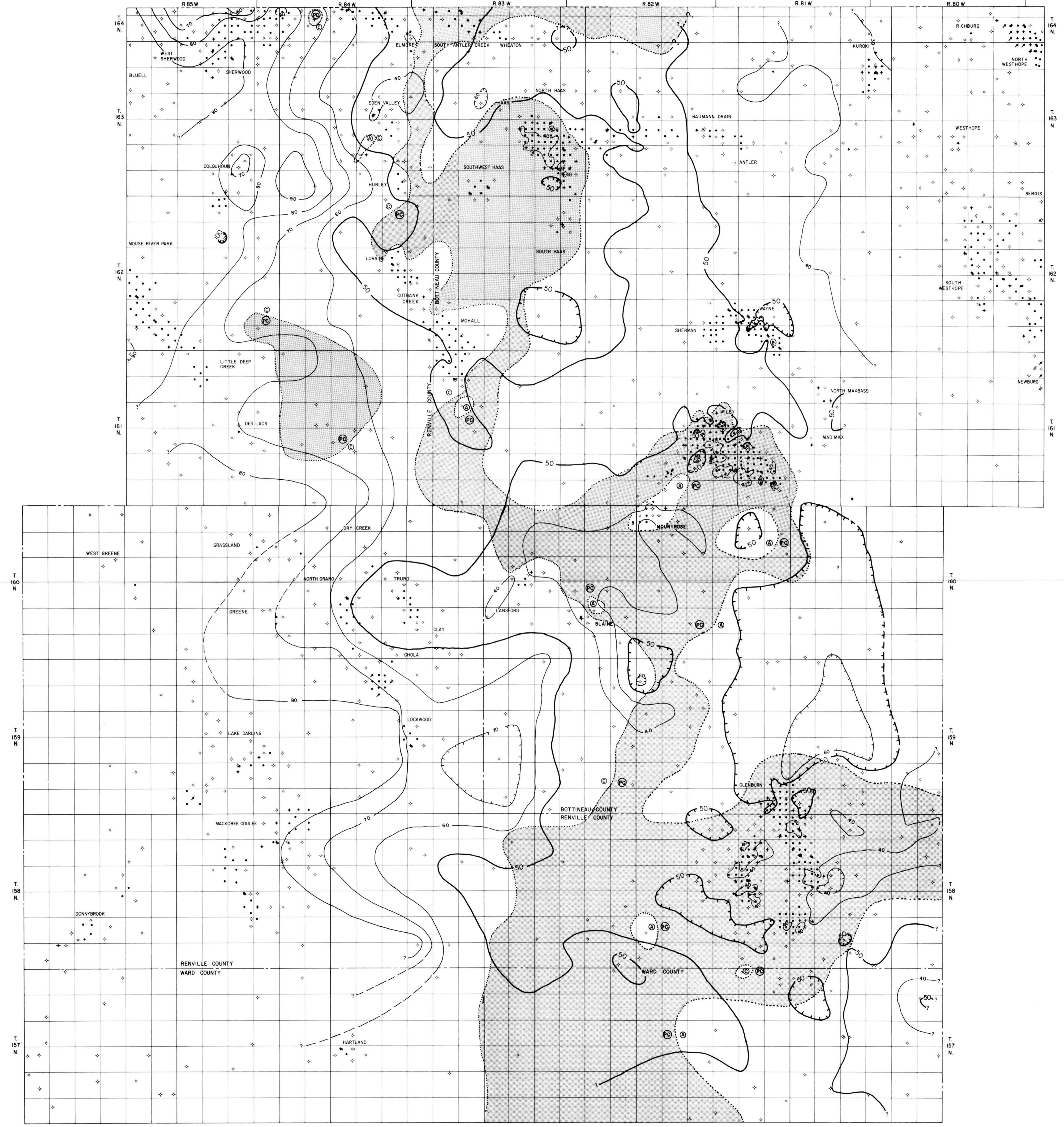
SIDNEY B. ANDERSON, ACTING STATE GEOLOGIST



EXPLANATION

Ⓐ/Ⓒ FACIES CONTACT – Letter indicates lithotype

Ⓐ – Anhydrite

Ⓟⓒ – Anhydrite - plugged carbonate

Ⓒ – Carbonate

NORTH

SCALE

0 5 10 Mi.

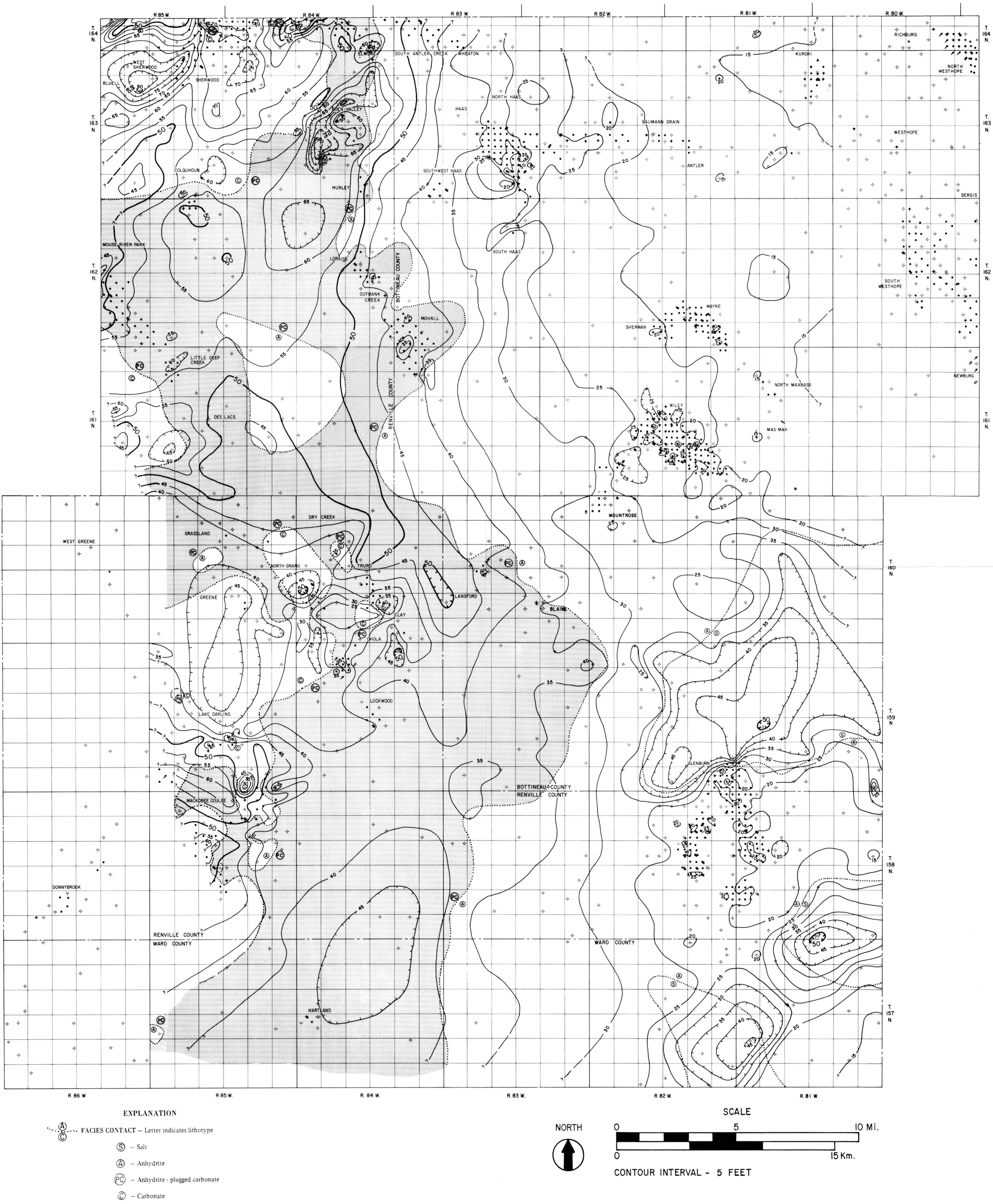
0 15 Km.

CONTOUR INTERVAL - 10 FEET

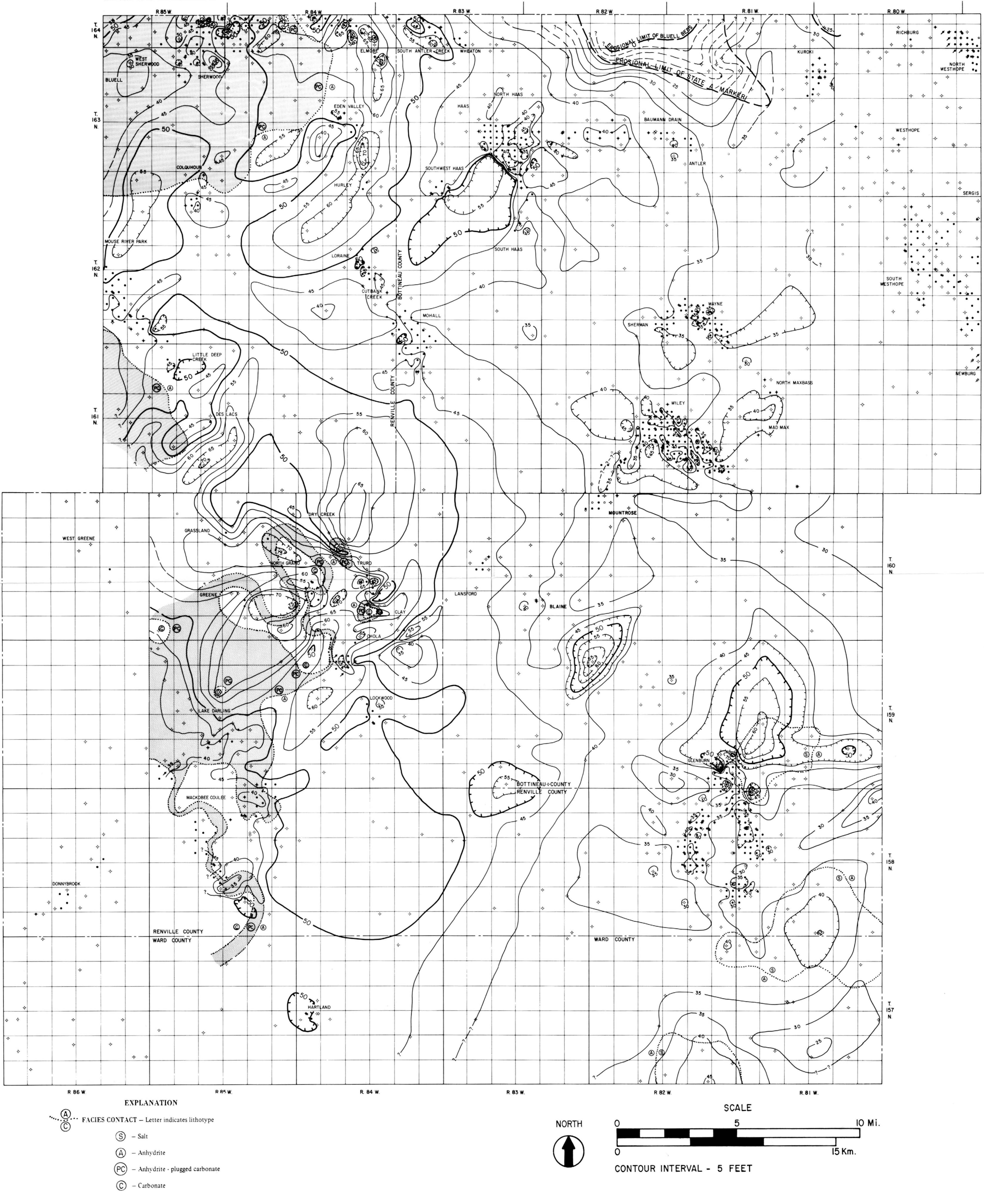
# PLATE 11. ISOPACH MAP OF THE SHERWOOD BEDS

REPORT OF INVESTIGATION 84

NORTH DAKOTA GEOLOGICAL SURVEY
SIDNEY B. ANDERSON, ACTING STATE GEOLOGIST



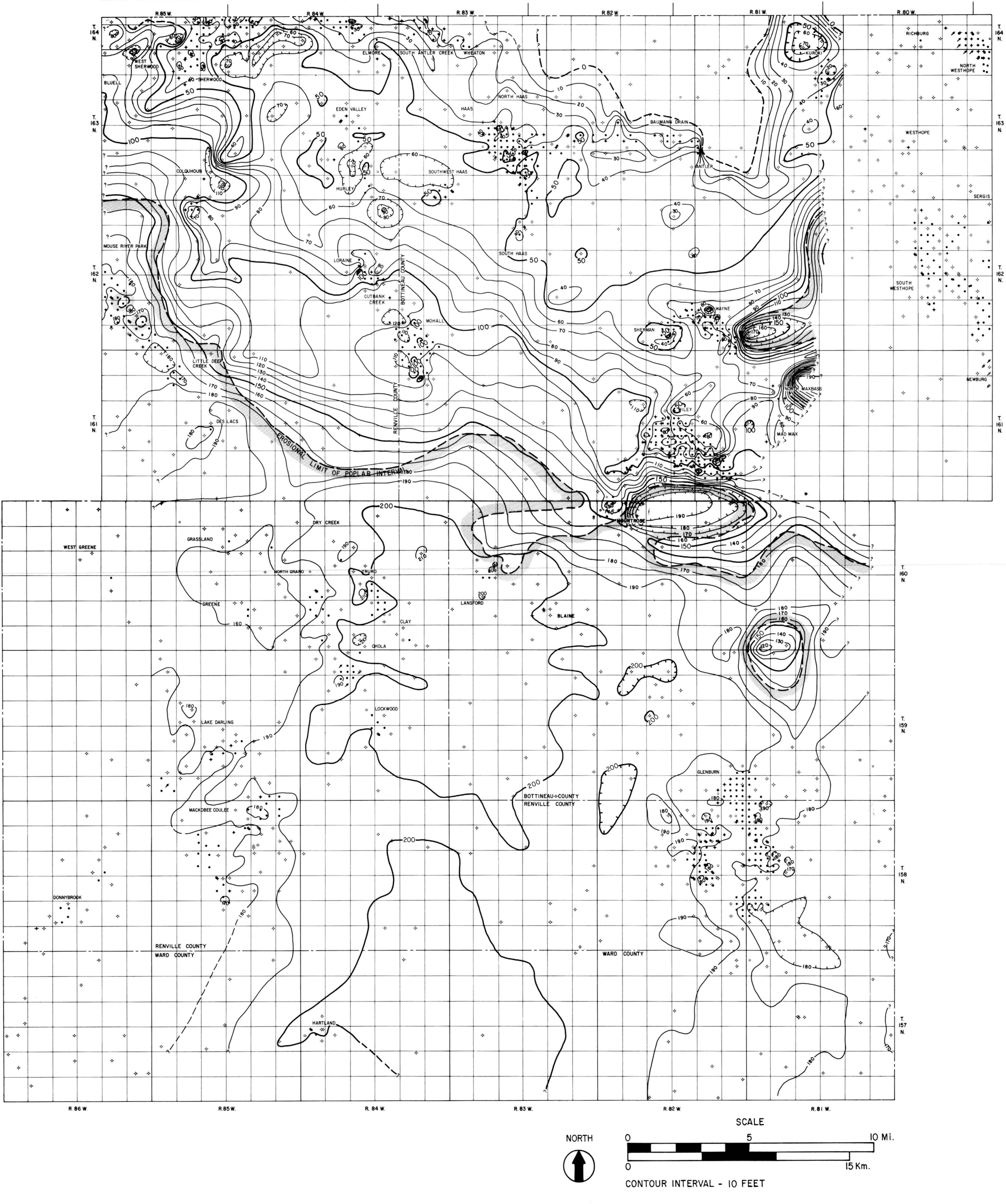
# PLATE 12. ISOPACH MAP OF THE BLUELL BEDS



# PLATE 13. ISOPACH MAP OF THE RATCLIFFE INTERVAL

REPORT OF INVESTIGATION 84

NORTH DAKOTA GEOLOGICAL SURVEY
SIDNEY B. ANDERSON, ACTING STATE GEOLOGIST

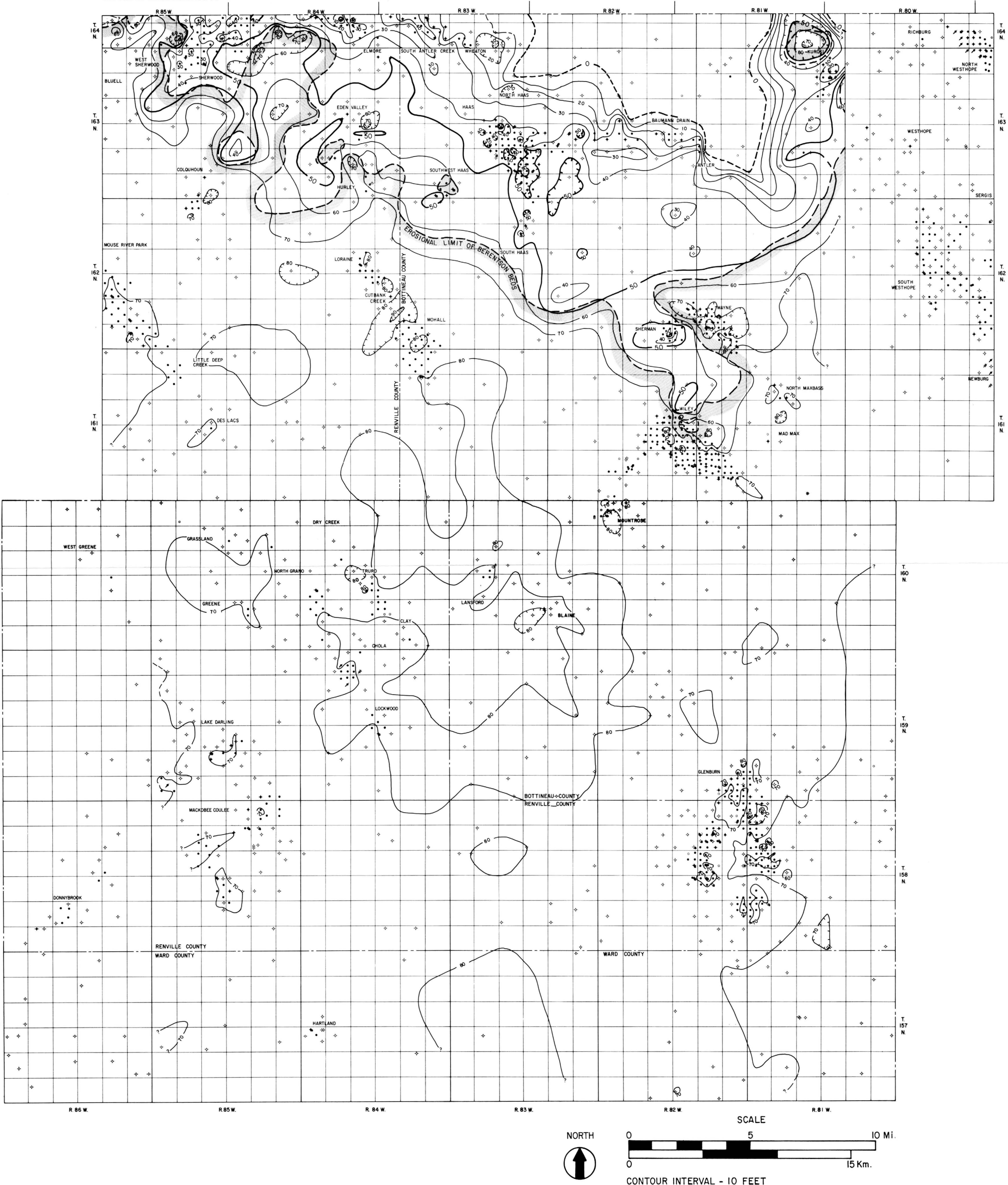


CONTOUR INTERVAL - 10 FEET

# PLATE 14. ISOPACH OF THE MIDALE SUBINTERVAL INCLUDING THE MIDALE ANHYDRITE

REPORT OF INVESTIGATION 84

NORTH DAKOTA GEOLOGICAL SURVEY
SIDNEY B. ANDERSON, ACTING STATE GEOLOGIST



CONTOUR INTERVAL - 10 FEET