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**Hydrological, geological, biological,**

**environmental and exploration**

**implications of**

**salt dissolution**

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## **ABSTRACT**

The halite salts of the Wabamun Group (Upper Devonian) are preserved throughout southeastern Alberta, at subsurface depths of between 1000 and 2000 m, as isolated to contiguous bodies of irregular shape having maximum net thicknesses on the order of 40 m. Collapse features and anomalous variations in the structure of overlying strata are associated with these salts suggesting that they were widely distributed, uniformly deposited, and extensively leached. Investigation suggests that dissolution, a self-perpetuating process, was initiated and/or enhanced by four principal processes: 1) the near surface exposure of the salt as a result of the erosion of the overlying Paleozoic sediment during the pre-Cretaceous hiatus; 2) the dissolution of the underlying Cairn salt in post-Wabamun time; 3) regional faulting/fracturing during the late Cretaceous; and 4) glacial unloading.

We have mapped the Wabamun Group salts in the Stettler area, southeastern Alberta (T.35-41, R.14-25 W4M) and reconstructed the distribution of these salts at selected intervals from late Paleozoic to the present thereby elucidating both the timing and the extent of dissolution. Such leaching is of significance from several perspectives including: 1) hydrology; 2) geology; 3) biology; 4) environmental; and 5) exploration.

## **INTRODUCTION**

Work by Anderson and Brown (1991a,b), Anderson et al. (1988, 1991a,b), and Brown and Anderson (1990), supports the theses that the Wabamun Group salts (Figures 1 and 2) were: 1) widely distributed and uniformly deposited throughout the Stettler area, southeastern Alberta (Figures 3 and 4); and 2) subsequently leached to the extent that they are now preserved only as isolated to contiguous bodies of irregular shape having maximum net thicknesses on the order of 40 m (Figure 5).

These authors suggest that dissolution is a self-perpetuating process which has occurred, in places, more-or-less continuously from the late Paleozoic to the present. They conclude that leaching was initiated and/or enhanced by four principal mechanisms: 1) the near surface exposure of the salt as a result of the erosion of the overlying Paleozoic sediment during the pre-Cretaceous hiatus; 2) the dissolution of the underlying Cairn salt; 3) regional faulting/fracturing during the late Cretaceous; and 4) glaciation. In support of their conclusions Anderson and co-workers prepared a suite of reconstructed salt distribution maps (Figures 5-11). These maps support the following observations and conclusions:

1) Dissolution initiated during the pre-Cretaceous along the projected salt outcrop edge. This continuous salt-dissolution front advanced, at an uneven rate, in a generally southwestly direction, indicating that leaching is self-perpetuating process. The authors envision a process whereby the collapse of overlying strata provides a conduit for water which results in further dissolution.

2) These authors report that the Cairn salt (Figure 12) has been extensively dissolved and conclude, that within the confines of the Cairn salt basin, that the dissolution of the Wabamun salt could have been triggered by the leaching of the underlying Cairn.

3) The orthogonal pattern of dissolution, on the suite of paleo-distribution maps, suggests that regional faulting/ fracturing, during the Upper Cretaceous, initiated widespread leaching. The suite of reconstructed salt distribution maps indicate that the dissolution fronts initiated along these fault/fracture planes moved laterally thereafter.

4) Several lakes in the study area are situated above thin salts, suggesting that significant leaching has occurred in post-glacial times, perhaps in response to glacial loading and unloading.

We have followed up these previous studies, with a view to elucidating the significance of Wabamun salt dissolution from the perspectives of: 1) hydrology; 2) geology; 3) biology; 4) environmental; and 5) exploration.

## **HYDROLOGICAL CONSIDERATIONS**

Anderson et al. (1991a) conclude that the dissolution of the Wabamun salt has a self-perpetuating process (Figure 12), initiated and/or enhanced, in the Stettler area, by four principal mechanisms: 1) the near surface exposure of the salt as a result of the erosion of the overlying Paleozoic sediment during the pre-Cretaceous hiatus (Figure 13); 2) the dissolution of the underlying Cairn salt (Figure 14); 3) regional faulting/fracturing during the late Cretaceous (Figure 15); and 4) glacial unloading (Figure 16).

In support of their thesis of dissolution due to near-surface exposure, these authors show that a continuous dissolution front developed during the pre-Cretaceous (Figures 10 and 13), along the projected Wabamun salt outcrop edge. This dissolution front is coincident with anomalous structural lows (interpreted to be major fluvial channels) along the top of the sub-

Cretaceous unconformity (Wabamun) during Lower Mannville time. These channels were controlled by the near-surface leaching of the Wabamun salt and accentuated by erosion during the pre-Cretaceous. On the suite of reconstructed salt distribution maps (Figures 5-11), the dissolution front is shown to advance, at an uneven rate and in a generally southwestly direction, indicating that leaching is a self-perpetuating process. (The authors envision a process whereby the collapse of overlying strata provides a conduit for water which results in further dissolution). On the basis of the present-day and reconstructed salt distribution maps, the average rate at which the dissolution front advanced is calculated to be on the order of 0.125 - 0.250 km/million years. As evidenced by the suite of reconstructed maps, the rate of advancement varied significantly over time.

Anderson and Chappell (1987) mapped three present-day salt distribution maps for the Stettler area: one each for the Prairie, Cairn and Wabamun. These authors found no substantiative evidence of Prairie salt dissolution, but established that the Cairn salt (within the confines of the Cairn salt basin: Figure 17) had been extensively leached, more-or-less continuously since deposition. These authors concluded that the dissolution of the Wabamun salt in the Cairn salt basin could have been triggered by the leaching of the underlying Cairn, and the associated collapse of post-Cairn strata (Figure 14). The resultant fault/fracture planes could have

been conduits for both relatively fresh water and saline brines. On the suite of reconstructed salt distribution maps, the dissolution of the Wabamun salt in the Cairn salt basin, is shown as starting during the Upper Cretaceous. The authors do recognize that earlier phases of leaching, related to the ongoing dissolution of the Cairn salt, probably occurred. More detailed work however, is required in this area, in order to differentiate the superposed effects of erosion, and the leaching of two salts.

To the southwest of the Wabamun subcrop, the reconstructed salt distribution maps (Figures 5-11) strongly suggest that dissolution initiated in places, during the Upper Cretaceous, along well-defined, orthogonally-oriented lineaments. These lineaments (dissolution fronts) are thought to be regional fault/fracture planes, re-activated during the Late Cretaceous regional tectonism (Figure 15). On the reconstructed maps, these dissolution fronts, are shown to have migrated laterally at uneven rates.

Several lakes in the Stettler study area (Figure 5) are located near the edges of relatively thick remnants of Wabamun salt. These sites are interpreted to be areas of active dissolution: the lakes are thought to infill the associated surface sinkholes. If this hypotheses is correct, the inference, given the areal extent of these lakes, is that significant leaching

has occurred in post-glacial times. Perhaps vertical and/or horizontal fractures developed in response to glacial loading and unloading (Figure 16). Such fractures would be natural subsurface conduits for glacial meltwaters. Additional investigation into the apparent correlation between drainage patterns in the Stettler area and the more recent hypothesized phases of dissolution is warranted. The possibility and the consequences of major changes in the drainage pattern in response to further leaching, should be ascertained.

The dissolution of the Wabamun salts appears to have been triggered by several independent mechanisms, with one or more mechanisms dominating in a certain area. Leaching, once initiated, is thought to be a self-perpetuating process, which proceeded at different rates in different areas. With respect to such differential rates, consideration should be given to effects of the intensity and magnitude of faulting/fracturing, emergence, the presence or absence of underlying reefs, the differential compaction of pre-salt sediment, uneven loading and unloading, glacial loading and unloading, facies changes within both the salt and encompassing strata, the local hydrological environment and changes therein, the effects of oil and gas wells, and the contemporaneous dissolution of underlying salts.

With respect to the hydrology of salt dissolution, further investigation into the migration of salt in the subsurface is warranted. Questions regarding migration paths, relative solubilities, vertical and lateral permeabilities, migration rates, and areas of discharge, should be addressed (Figure 18).

## **GEOLOGICAL CONSIDERATIONS**

Analysis of the present-day and initial Wabamun salt distribution maps suggests that as much as 360 cubic km of salt were leached from the Stettler study area alone. There are several interesting geological considerations with respect to the leaching and flushing of this large volume of salt: 1) what are the diagenetic consequences of the flushing of large volumes of brine through sediment?; 2) how has the dissolution of the Wabamun salt affected the contemporaneous surface sedimentary environment?; and 3) have the mechanisms, which initiated leaching, had any other significant affects (Figure 19).

The diagenetic affects of flushing Wabamun salt brine through the subsurface sediment, have not been evaluated in detail by the authors. We have, however, in a preliminary sense, considered several relevant questions: 1) was the composition of the dissolved salt significantly

different from that of the remnants?; 2) is there a relationship between the flushing of these brines and dolomitization?; and 3) how are associated evaporites affected by the leaching of salt?

While the effects of leaching on subsurface sediment are unclear, the effects on the near surface environment is more apparent: dissolution can create topographic relief, and affect the salinities of near surface waters. Topographic relief, in turn influences sedimentation, and determines factors such as whether the environment is depositional or erosional, terrestrial or aqueous. The salinities of the near surface waters, could similarly profoundly influence sedimentation. Amongst other factors, they would affect relative solubilities, cementation, and types of organisms.

With respect to the mechanisms of dissolution, it is interesting to note that the Stettler reef (T35-38, R20) is situated across a major postulated lineament, and that the edges of both the main Leduc fringing reef, the Bashaw complex, and the remanent Cairn salt are consistent with the hypothesized fault/fracture planes. Perhaps the lineaments are re-activated planes of weakness (Figure 20).

## **BIOLOGICAL CONSIDERATIONS**

Investigation suggests that large volumes of salt were leached from the Stettler area. Such salt has been discharged as (into) surface water, reprecipitated in the subsurface, or retained as solute in subsurface water. From a biological perspective, of greatest concern is the potential contamination of near-surface waters. As suggested above, further investigation is necessary in order to determine: 1) current rates of dissolution; 2) migration pathes; 3) migration rates; and 4) areas of discharge.

## **ENVIRONMENTAL CONSIDERATIONS**

Large volumes of salt are currently being dissolved in the Stettler area. There are some significant associated environmental concerns. Consideration must be given to: 1) the potential for catastrophic collapse at the surface (Figure 21); 2) the potential for surface water and groundwater contamination (Figure 22); 3) the security of petroleum products stored in salts; and 4) the use of salts as waste disposal vessels. These important issues should be addressed, in order to minimize the environmental hazards of natural leaching, and in order to avoid accentuating the problem.

## **EXPLORATION CONSIDERATIONS**

Anderson et al. (1988, 1989, 1990), Brown and Anderson (1990), and Hopkins (1987) have convincingly shown that dissolution is of significance to the explorationist for several reasons: 1) stratigraphic traps can form where reservoir facies were either preferentially deposited or preserved in salt-dissolution lows (Figures 23 and 24); 2) reservoir facies can develop in high energy environments like topographic highs that are controlled by salt edges or remnants (Figure 25); 3) structural traps can form where reservoir facies are draped across salt remnants or collapse features (Figures 26 and 27); and 4) closure across salt remnants can be misinterpreted as drape across a non-existent reef, or can distort the drape across an actual reef, or it may be falsely attributed to deep-seated structure (Figure 28).

## **SUMMARY**

The Wabamun salts are thought to have been widely distributed and uniformly deposited within the Stettler area. They appear to have been extensively dissolved more-or-less continuously throughout geological time by a variety of processes. Herein we have presented a suite of reconstructed salt distribution maps in order to substantiate the theses of continuous leaching and diverse mechanisms.

The timing and extent of leaching has important hydrological, geological, biological, environmental and exploration implications. These have been discussed briefly in order to illustrate some of the potential implications of dissolution, many of which are beyond the scope of our current study.

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Figure 1. Stratigraphic chart for the Devonian of southern and central Alberta (modified after AGAT Laboratories, 1988): a) central plains; b) south-central mountains and foothills; c) southern plains.

Figure 2. Gamma-ray and sonic logs for the wells indicated for the Wabamun to Cooking Lake interval (Anderson et al., 1988).

Figure 3. Distribution of the Stettler Formation (Wabamun Group) and its equivalents within the western Canadian interior plains (modified after Belyea, 1964; Meijer Drees, 1986). The approximate time equivalents are: 1 = Stettler Formation (white: anhydrite; crosses: halite and anhydrite; 2 = Wabamun Group (diagonal hatching: dolomite; vertical hatching: limestone); 3 = Torquay Formation (white: redbeds; hatching: dolomite, anhydrite and shale) and 4 = Kotcho Formation (fossiliferous shale). In addition 5 = the Wabamun (and equivalents) subcrop area and 6 = the study area. Also shown are the locations of the two wells of Figure 4 (7-11 and 16-24).

Figure 4. Stettler study area. The edges of the Leduc reef complexes are shown by the solid lines labelled RE; the edge of the Wabamun subcrop is denoted by the dashed line labelled WU (Anderson et al., 1991).

Figure 5. Contour map (in meters) showing the present-day distribution (hypothesized) of the Wabamun salts (Anderson et al., 1991).

Figure 6. Contour map (in meters) showing the distribution (hypothesized) of the Wabamun salts at the end of Lea Park time (Anderson et al., 1991).

Figure 7. Contour map (in meters) showing the distribution (hypothesized) of the Wabamun salts at the end of Colorado time (Anderson et al., 1991).

Figure 8. Contour map (in meters) showing the distribution (hypothesized) of the Wabamun salts at the end of Second Specks time (Anderson et al., 1991).

Figure 9. Contour map (in meters) showing the distribution (hypothesized) of the Wabamun salts at the end of Viking time (Anderson et al., 1991).

Figure 10. Contour map (in meters) showing the distribution (hypothesized) of the Wabamun salts at the end of Mannville time (Anderson et al., 1991).

Figure 11. Contour map (in meters) depicting the original distribution (hypothesized) of the Wabamun Group salts (Anderson et al., 1991).

Figure 12. Sketch illustrating our concept of why salt dissolution appears to be a self-perpetuating process. In this model, the zone of enhanced porosity and permeability act as a conduit for relatively fresh water, thereby facilitating further leaching.

Figure 13. Sketch illustrating how the dissolution of the Wabamun salt would be triggered by near surface exposure during the pre-Cretaceous hiatus.

Figure 14. Sketch illustrating how the dissolution of the Wabamun salt could be triggered by the leaching of the underlying Cairn salt.

Figure 15. Sketch illustrating how the dissolution of the Wabamun salt could be triggered by regional faulting/fracturing during the late Cretaceous.

Figure 16. Sketch illustrating how the dissolution of the Wabamun salt could be triggered by glacial unloading.

Figure 17. Map depicting the Cairn salt basin and the present-day distribution of the Cairn salt (Anderson et al., 1991).

Figure 18. Sketch depicting, in a regional sense the hydrological environment of the Wabamun salts.

Figure 19. Sketch depicting brines being flushed through the sediment.

Figure 20. Sketch illustrating how the Leduc reefs in the Stettler study area could have initiated on fault blocks. The re-activation of these postulated planes of weakness could have triggered the widespread dissolution of the Wabamun salt in the late Cretaceous.

Figure 21. Sketch depicting the hypothetical failure of a bridge as a result of progressive salt dissolution.

Figure 22. Sketch depicting the contamination of near surface and surface waters as a result of the vertical and lateral migration of brines.

Figure 23. Schematic diagram showing how a reservoir facies can be preferentially deposited within a salt-dissolution low (Anderson et al., 1988).

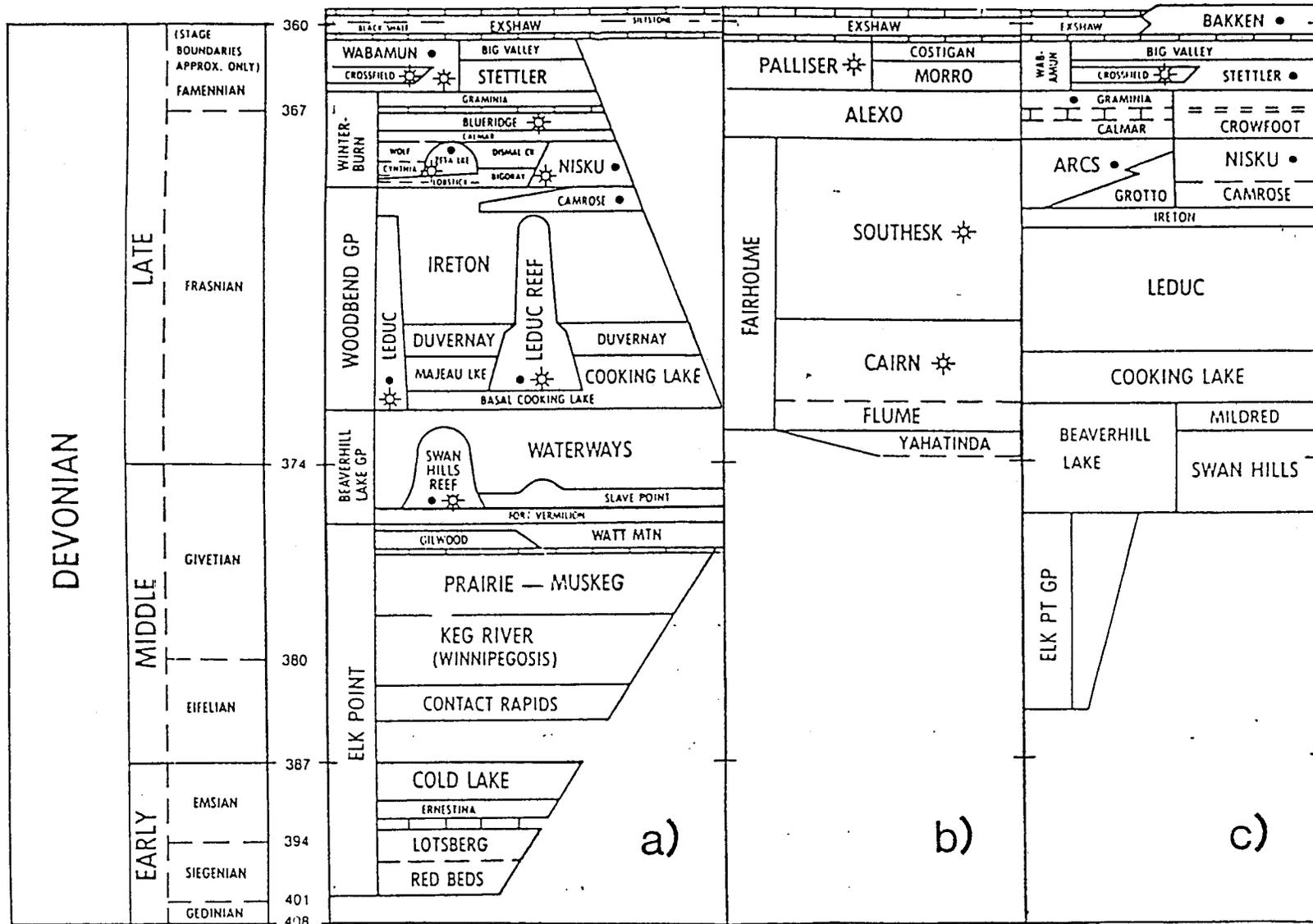
Figure 24. Schematic diagram showing how a reservoir facies can be preferentially preserved in a salt-dissolution low (Anderson et al., 1988).

Figure 25. Sketch showing how a reservoir facies can be preferentially deposited on a topographic high caused by the contemporaneous leaching of salt.

Figure 26. Schematic diagram showing how a reservoir facies can be structurally closed across the updip edge of a salt remnant (Anderson et al., 1988).

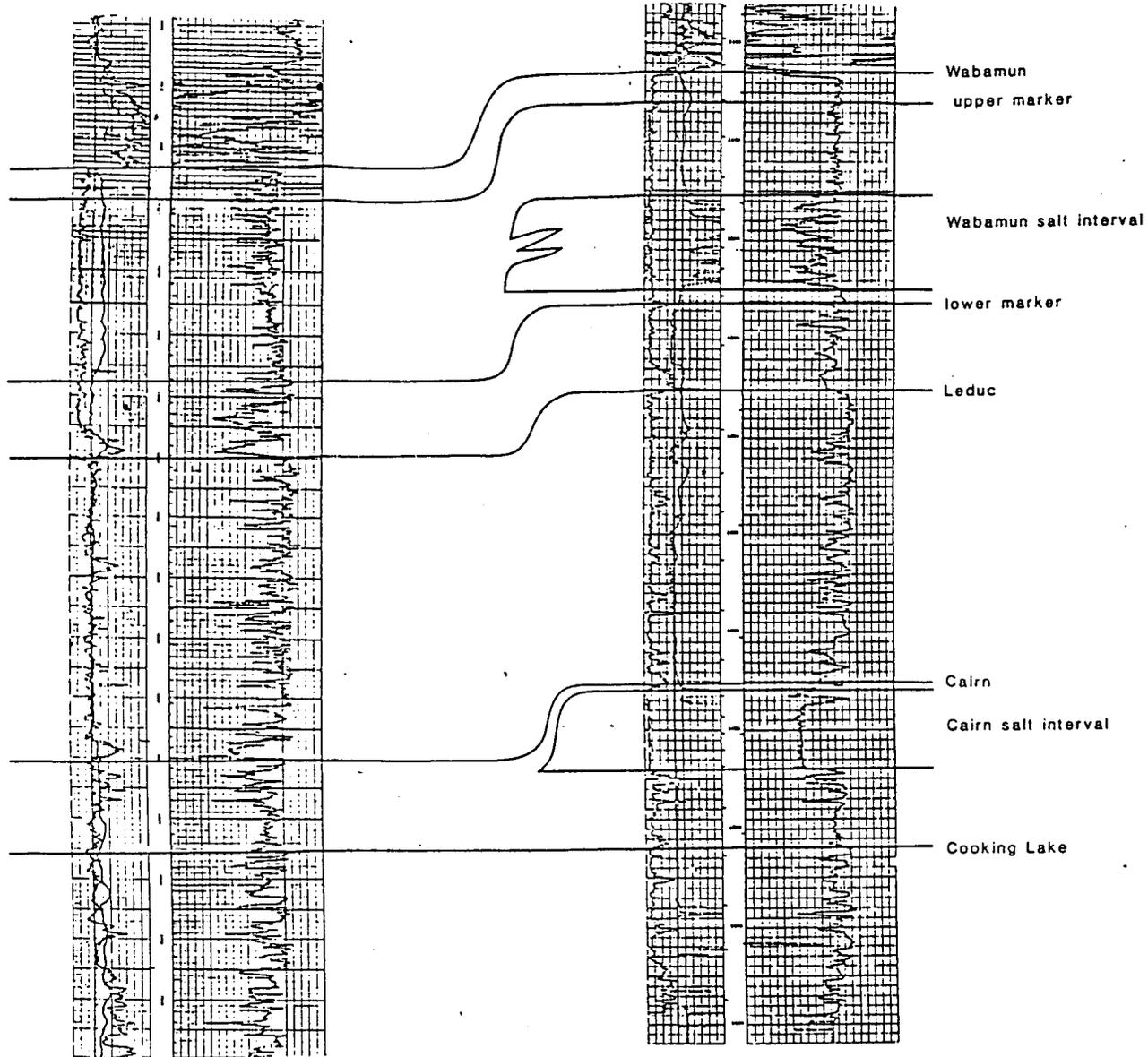
Figure 27. Sketch showing how a reservoir facies can be structurally closed as a result of the progressive dissolution of salt.

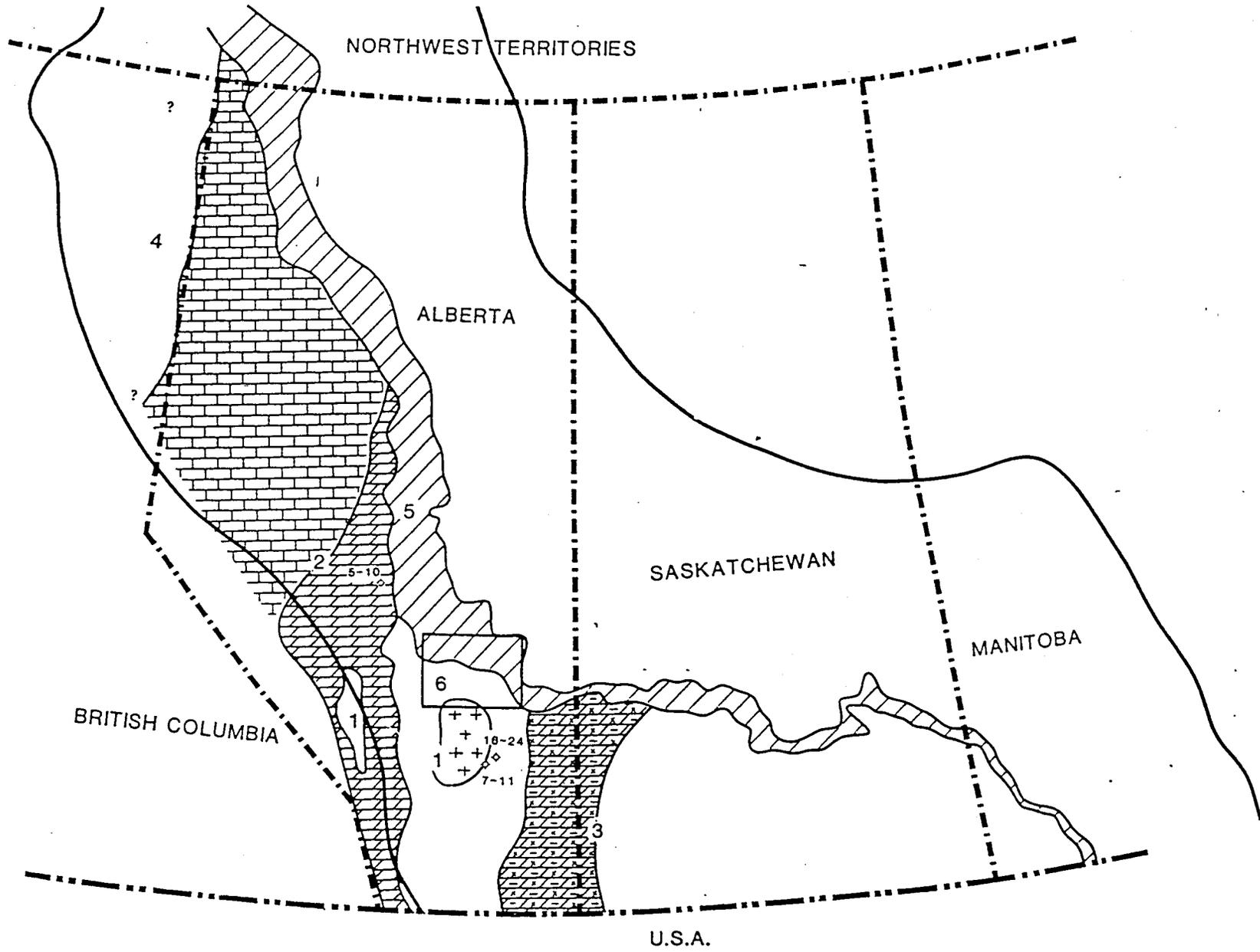
Figure 28. Sketch illustrating possible relationships between the Leduc reefs and the hypothesized fault/fracture planes in the Stettler area.



7-11-24-15W4

16-24-25-13W4





NORTHWEST TERRITORIES

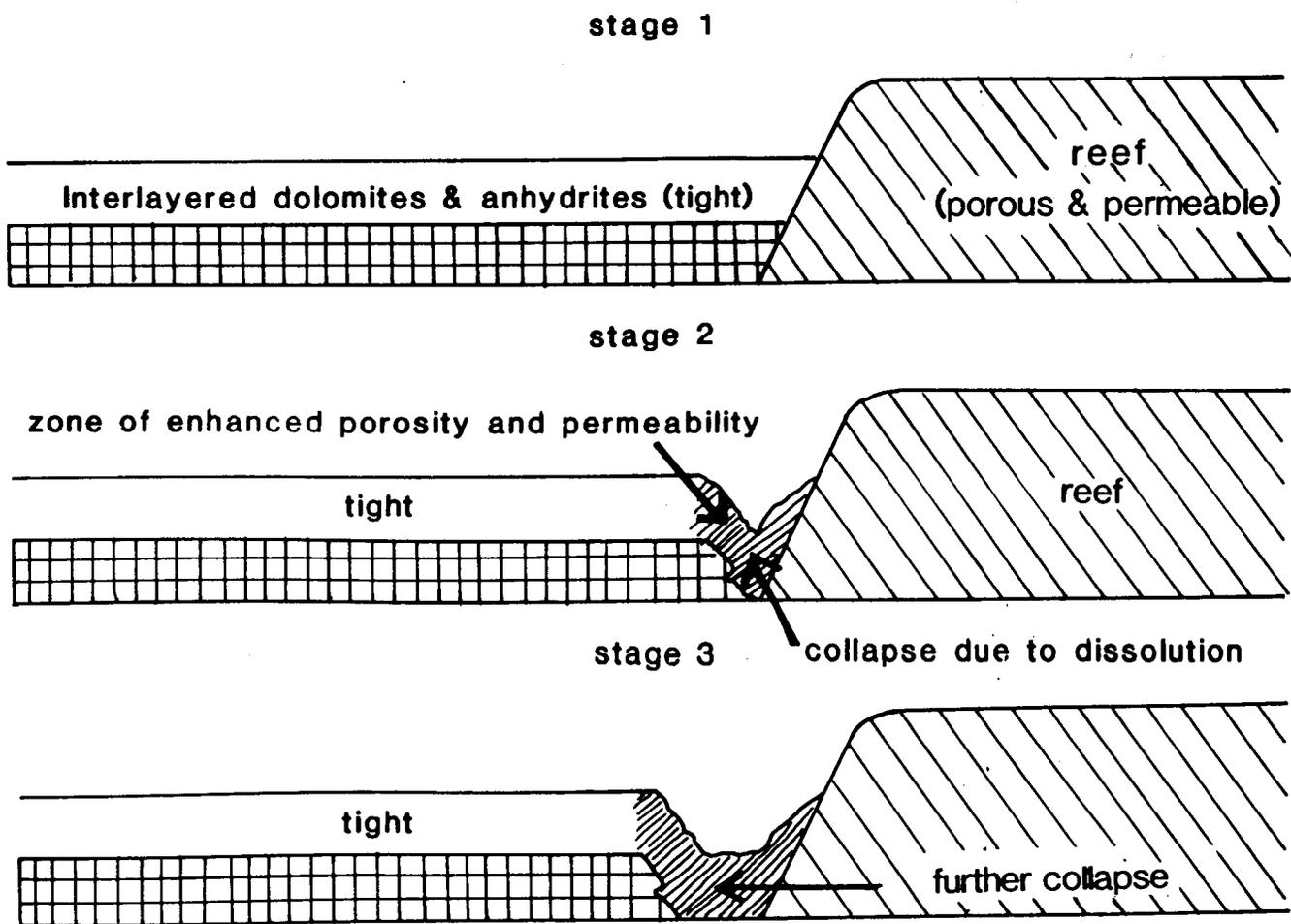
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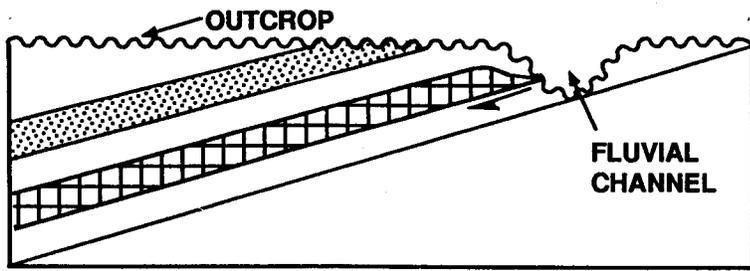
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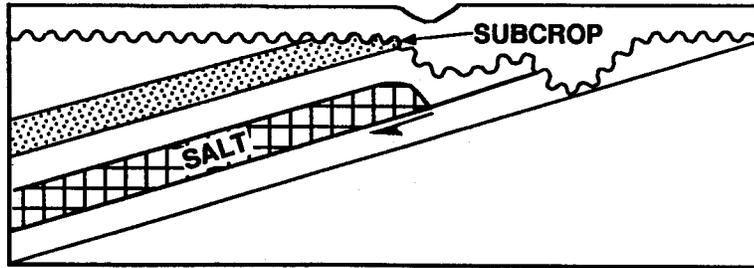
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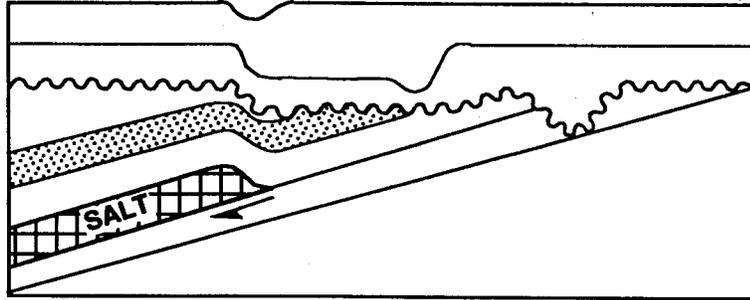




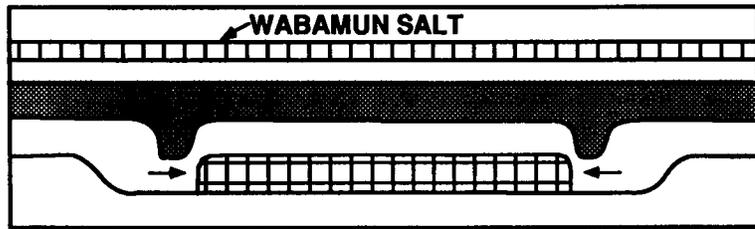
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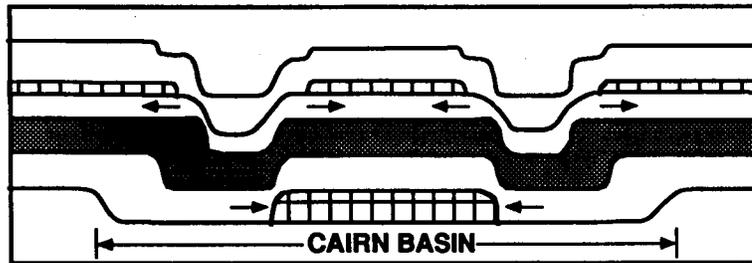
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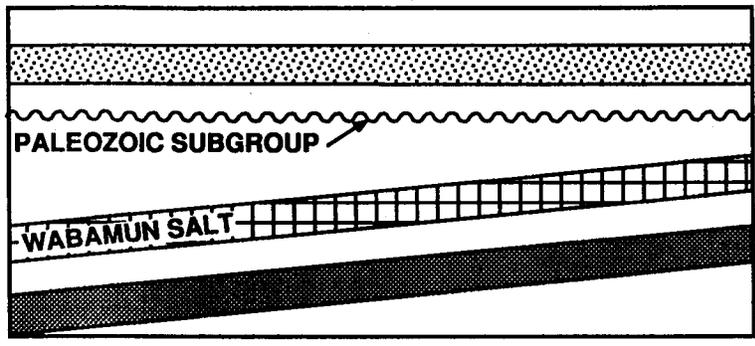
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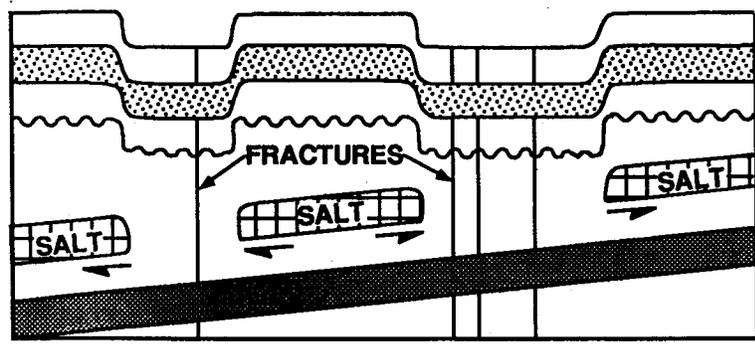
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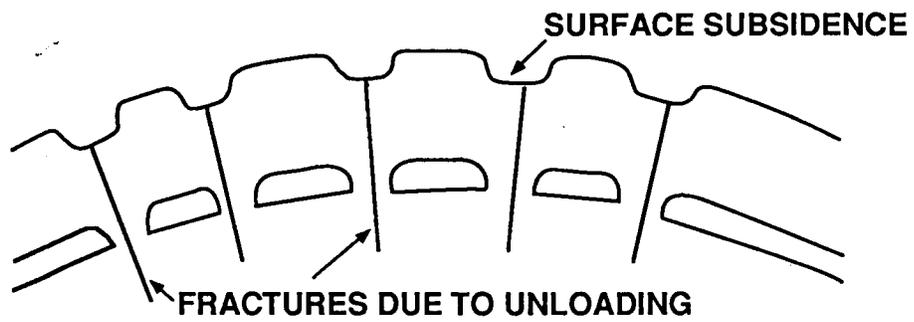
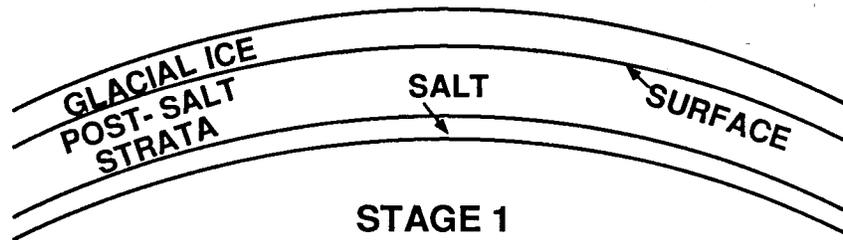
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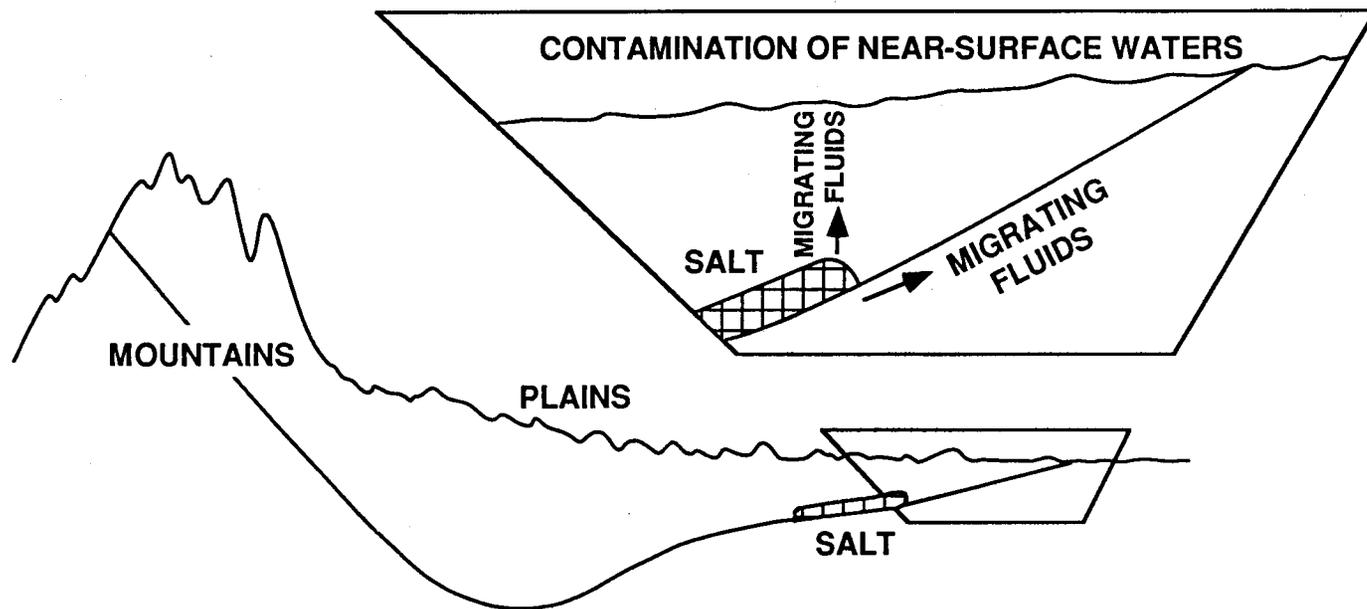


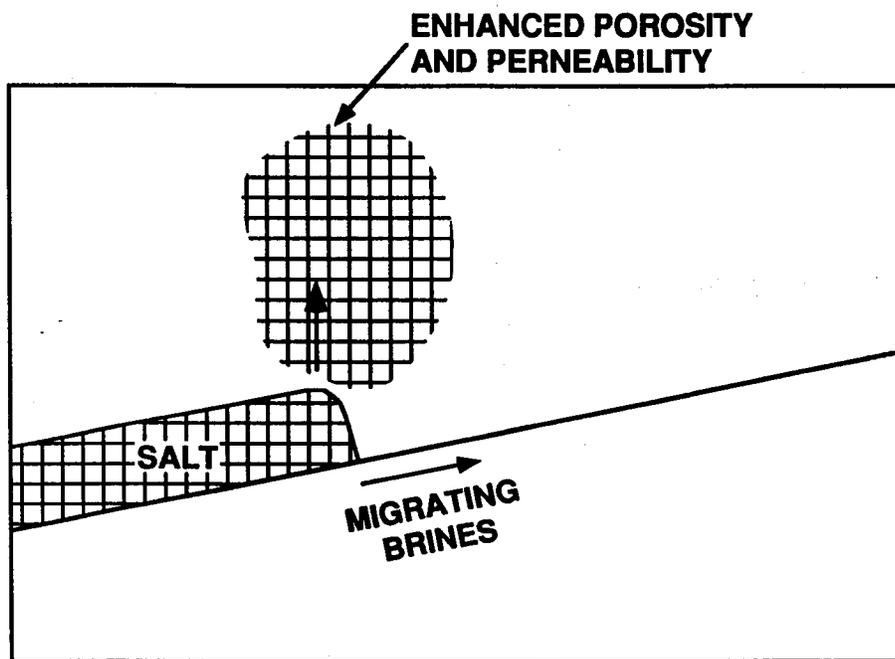
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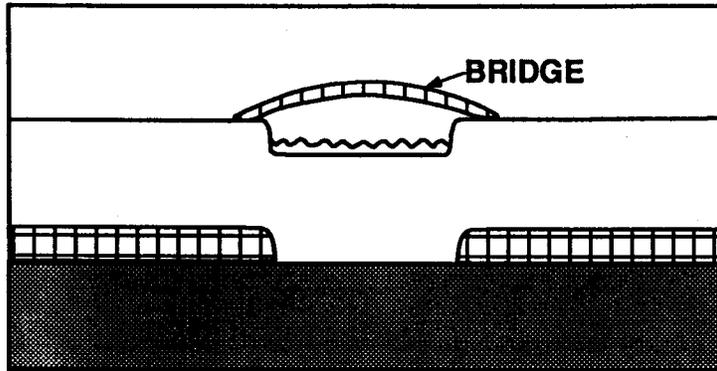
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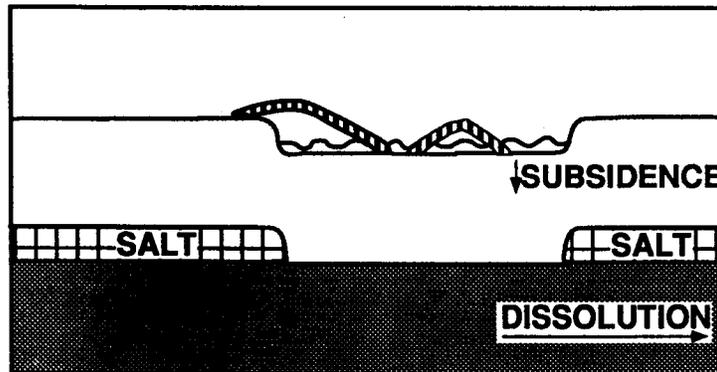




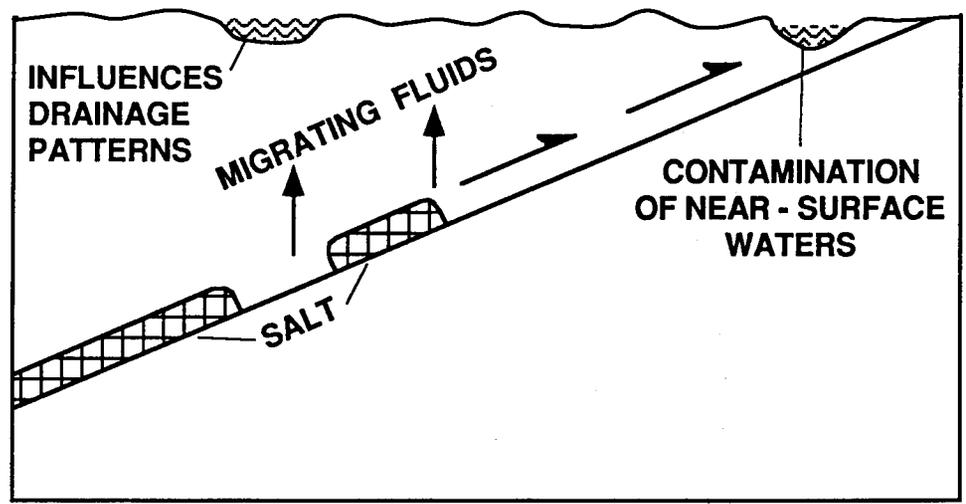


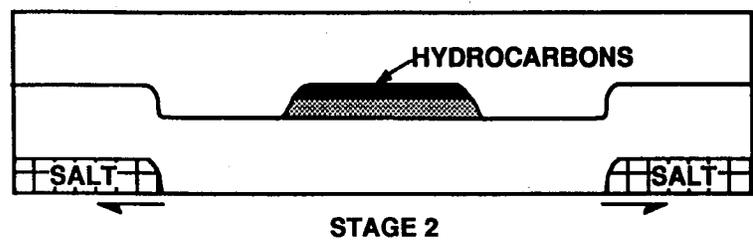
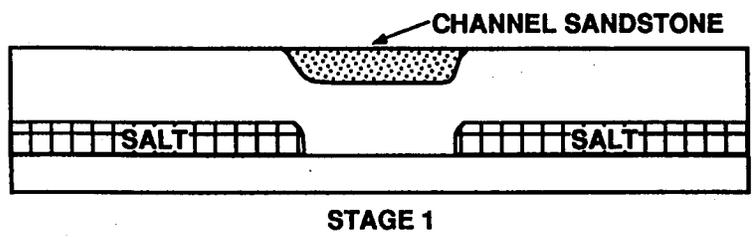


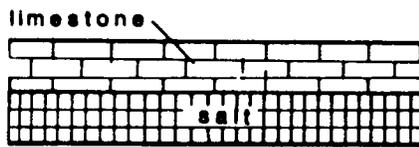
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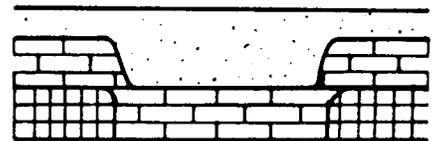
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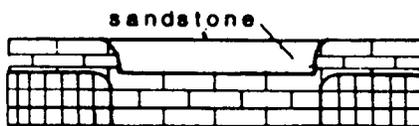




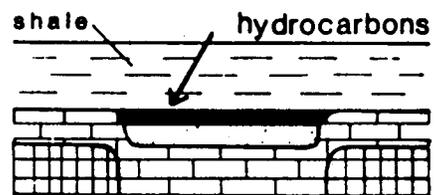
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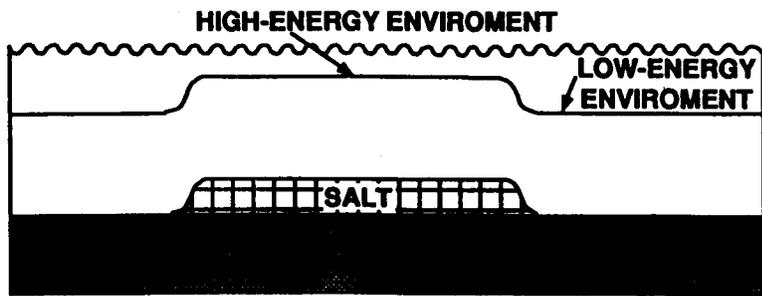
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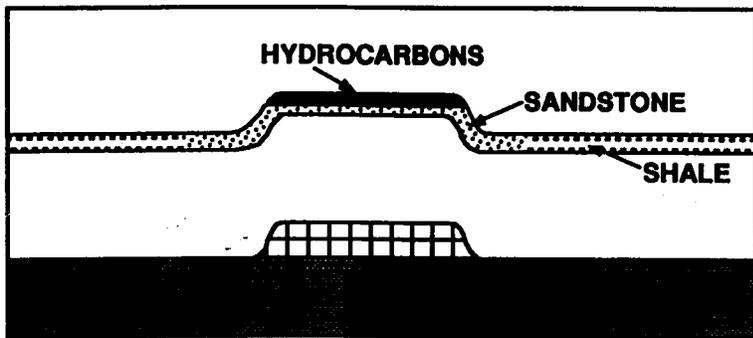
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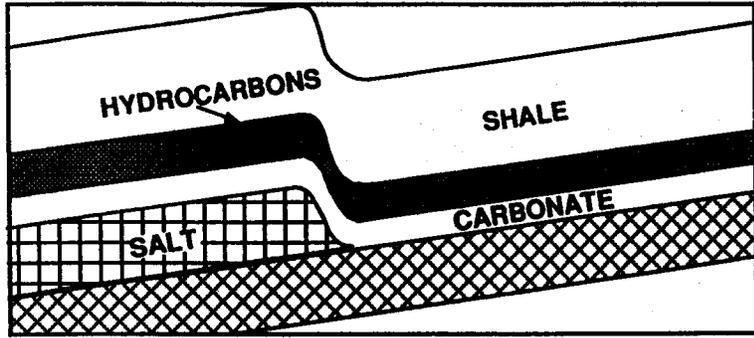
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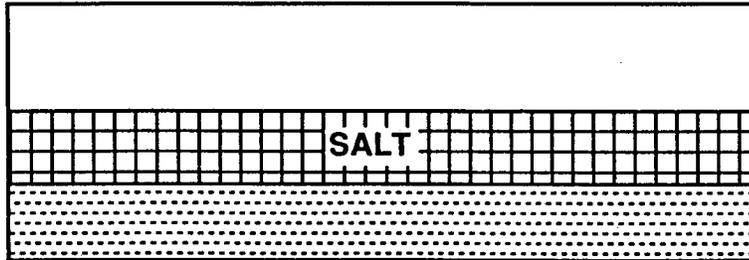


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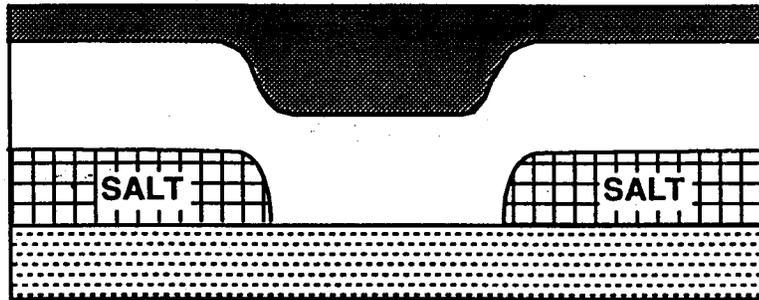


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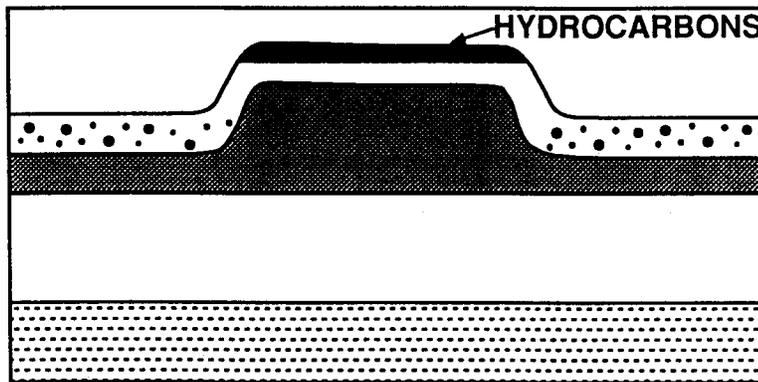




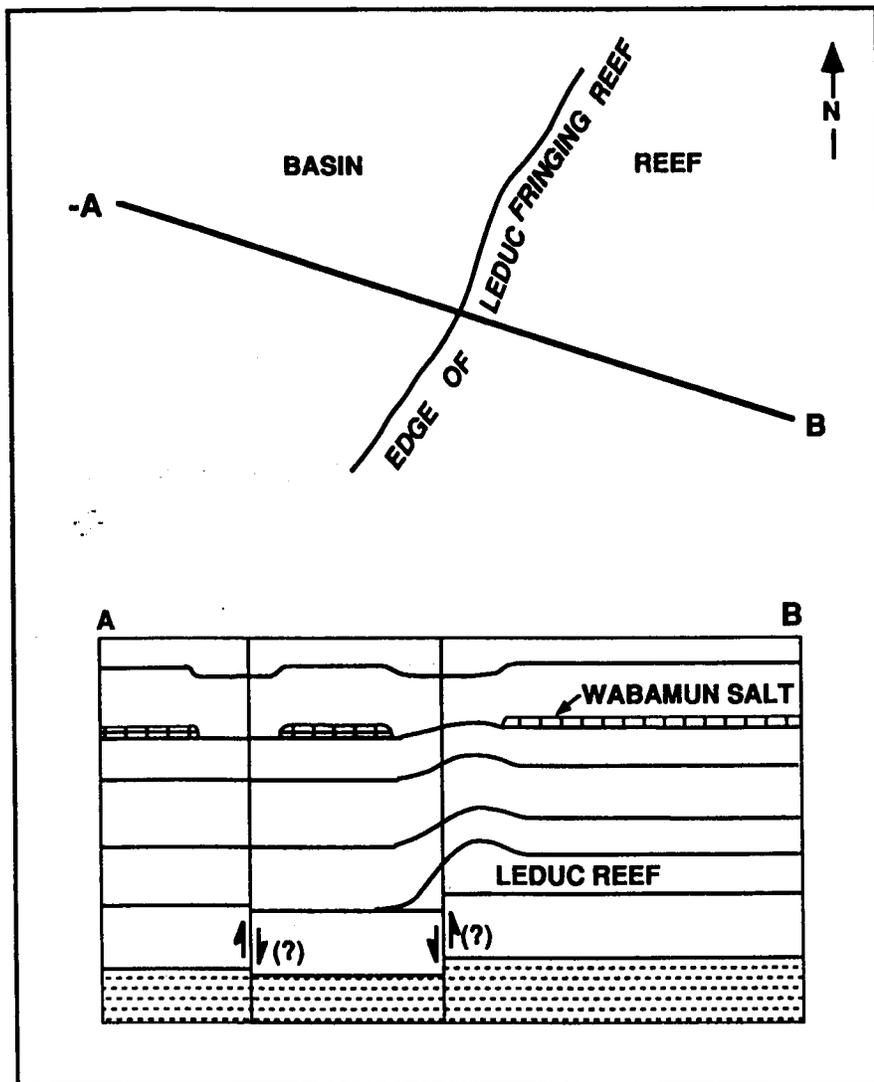
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STAGE 2



STAGE 3



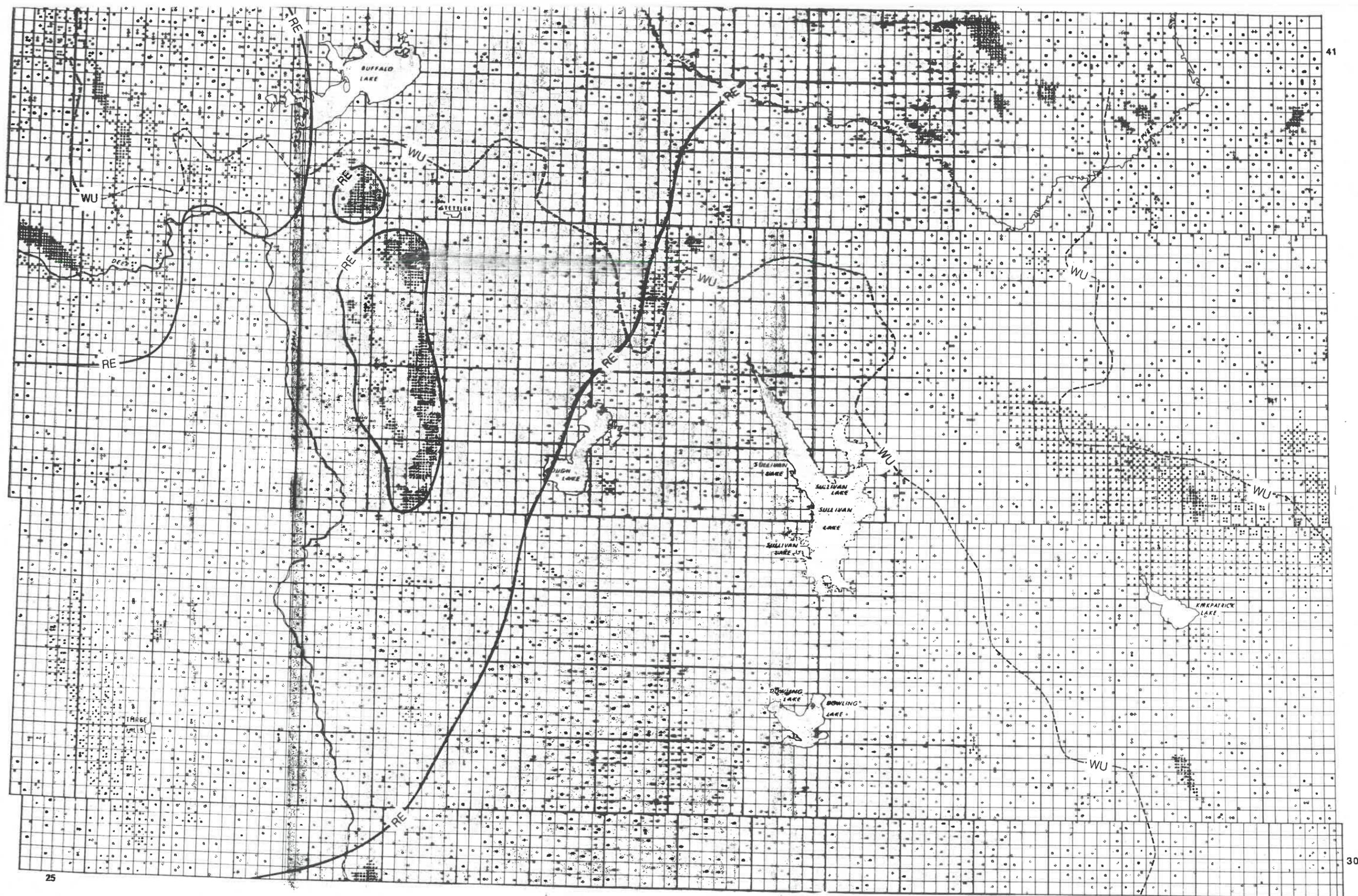


FIGURE 4

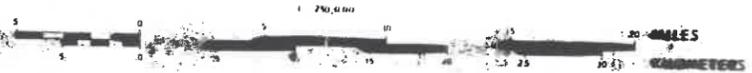
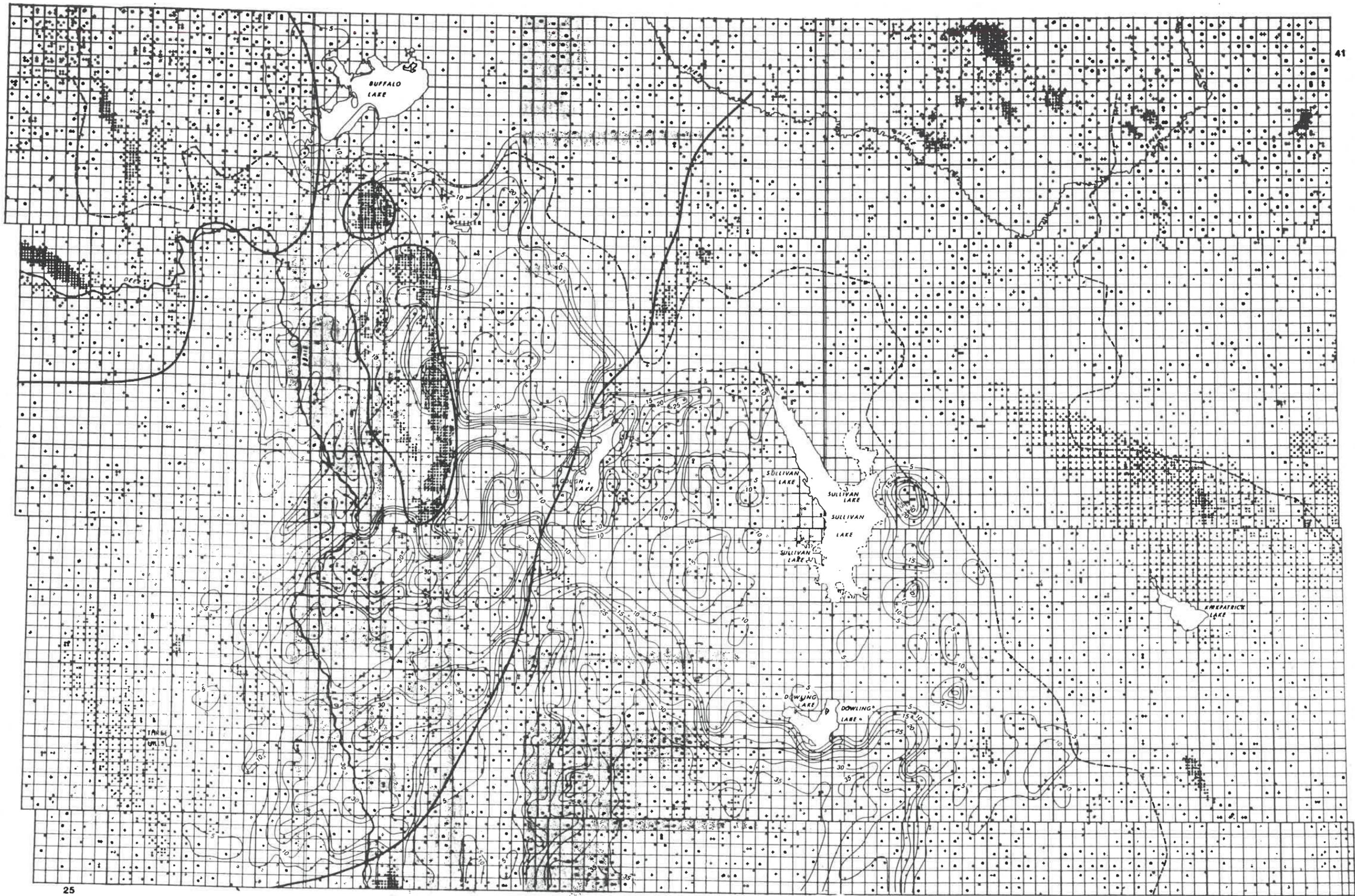




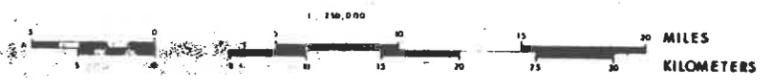
FIGURE 5



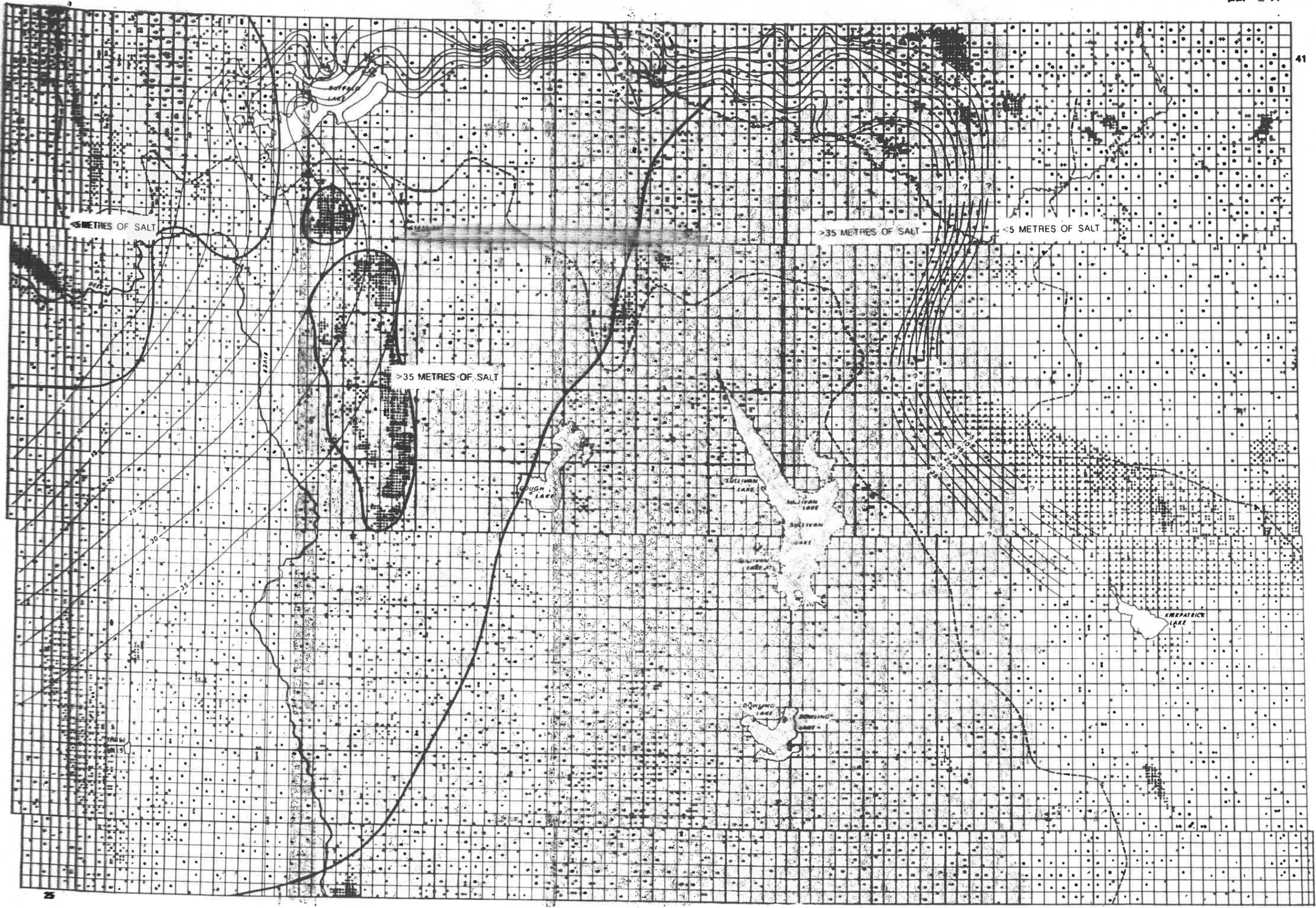


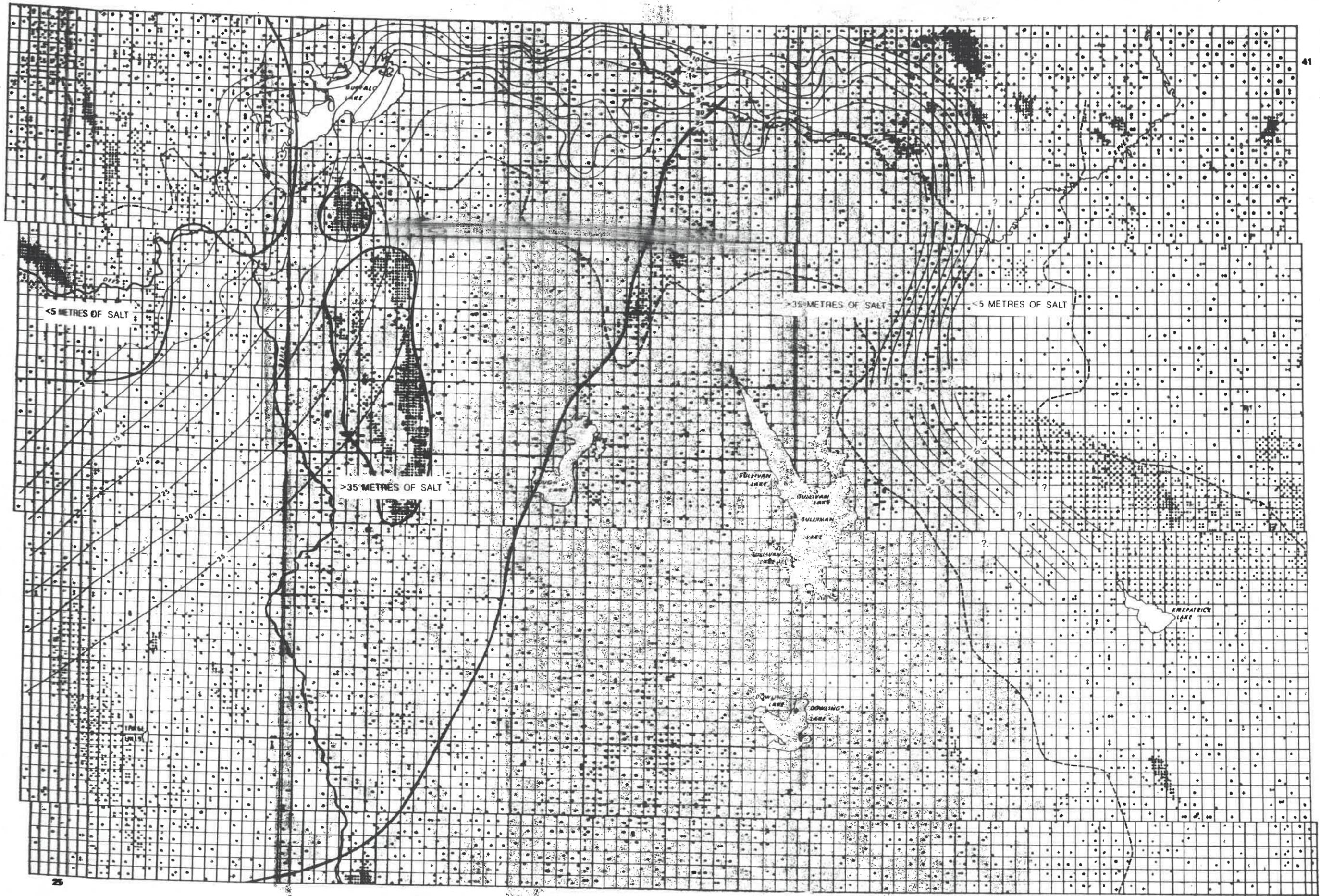
25

30



8





41

<5 METRES OF SALT

>35 METRES OF SALT

<5 METRES OF SALT

>35 METRES OF SALT

25

30



8





25

41

30

8



FIGURE 20

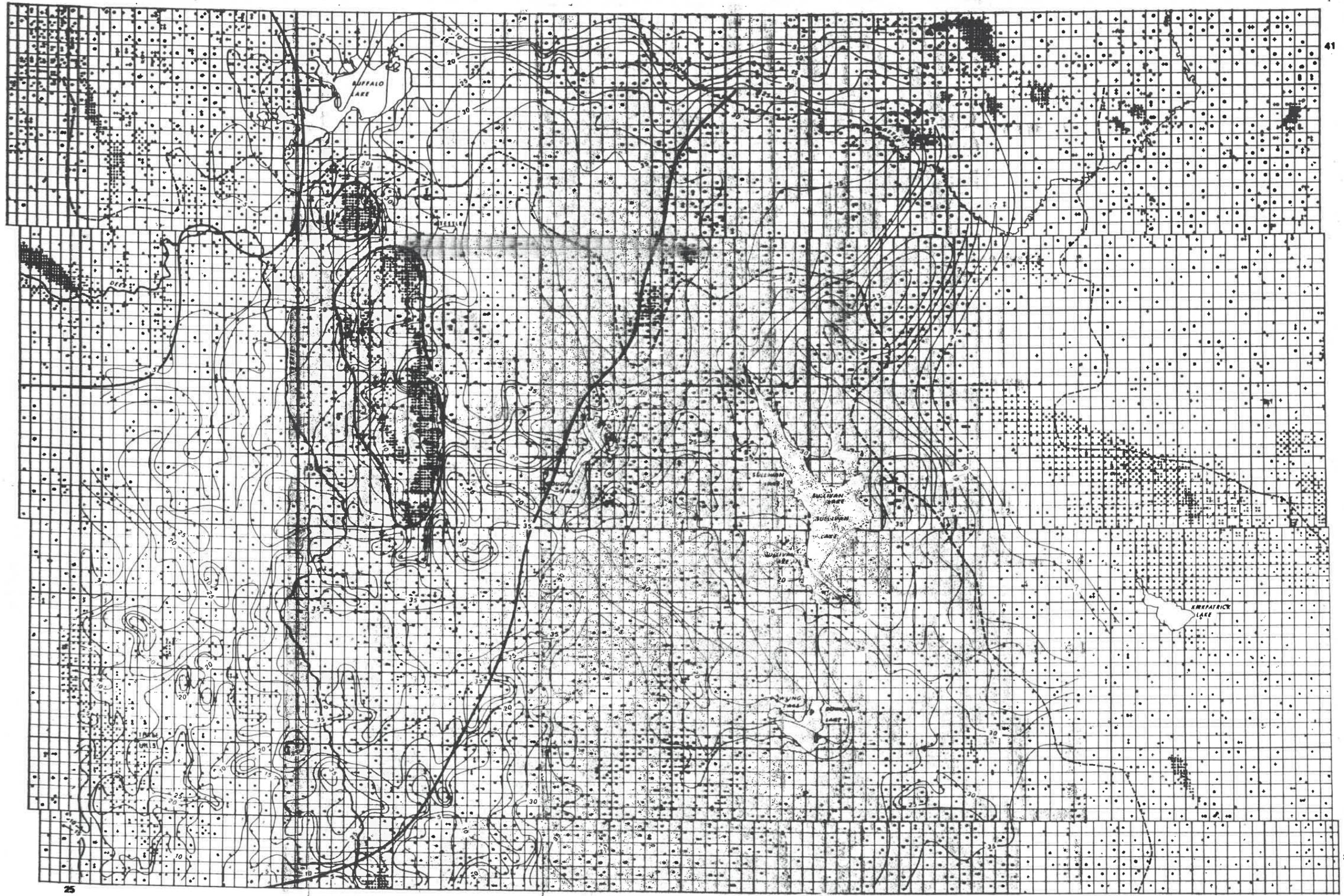


FIGURE 23



25

8

30

41