Exploration implications of salt dissolution

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ABSTRACT

The halite salts of the Wabamun Group (Upper Devonian) were widely distributed and uniformly deposited throughout the Stettler area, southeastern Alberta. Subsequent to deposition, these salts were extensively leached. They are now preserved as isolated to contiguous bodies of irregular shape having maximum net thicknesses on the order of 40 m.

The dissolution of the Wabamun salts 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; 2) reservoir facies can develop in high energy environments like topographic highs that are controlled by salt edges or remnants; and 3) structural traps can form where reservoir facies are draped across salt remnants or collapse features.

In this paper, the significance of salt dissolution is discussed from the perspective of the explorationist. A suite of maps, which depict the paleo-distribution of the Wabamun salts, is included, in order to illustrate the ideas presented.

INTRODUCTION

Work by Anderson and Brown (1991a,b), Anderson et al. (1988, 1991), 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 as isolated to contiguous bodies of irregular shape having maximum net thicknesses on the order of 40 m.

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 maps (Figures 5-11) which depict the distribution of the Wabamun salts at selected times throughout the geologic past. 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) The Cairn salt (Figure 12) has been extensively dissolved. Within the confines of the Cairn salt basin, 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 at variable rates.

4) Several lakes within the Stettler area are situated above thin salt, suggesting that significant leaching has occurred in post-glacial times, probably 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 to the explorationist. Herein we discuss: 1) potential stratigraphic play fairways in the study area; and 2) potential structural play fairways.

STRATIGRAPHIC TRAPS

Stratigraphic traps can form where reservoir facies were either preferentially deposited (Figure 13) or preserved (Figure 14) in salt-dissolution lows. (Reservoir facies preferentially deposited on topographic highs, which are related to salt-dissolution, are considered in the discussion of structural traps: Figure 15). Salt-related stratigraphic traps would generally develop within fluvial, lacustrine, and marine environments. The typical reservoir facies would be sandstones of channel, deltaic, beach, or off-shore bar origin.

The matching of potential reservoir facies and areas of contemporaneous salt dissolution is the key to exploring for salt-related stratigraphic traps. In Figures 15-20, areas which have been extensively leached during the following time intervals are highlighted: 1) Wabamun/end Mannville; 2) end Mannville/end Viking; 3) end Viking/end Second Specks; 3) end Second Specks/end Colorado; 4) end

Colorado/end Lea Park; 5) end Lea Park/present-day. These highlighted areas are favourable for the formation of stratigraphic traps, within those sediments deposited more-or-less contemporaneously with leaching.

STRUCTURAL TRAPS

Reservoir facies can develop in high energy environments like topographic highs that are controlled by salt edges or remnants; structural traps can form where reservoir facies are draped across salt remnants (Figure 21) or collapse features (Figure 22). In Figures 23-30, areas of potential closure (due to salt dissolution) at the following horizons, are highlighted: 1) Wabamun; 2) Mississippian; 3) Mannville; 4) Viking; 5) Second Specks; 6) Colorado; 7) Lea Park; and 8) post-Lea Park. These highlighted areas are favourable sites for both structural traps, and high-energy reservoir facies.

Anderson et al. (   ) concluded that dissolution, in places, was triggered by regional fault/fracture patterns of Late Cretaceous origin. Although these authors found no evidence of significant throw across the mapped lineaments, displacement could be present. Hydrocarbons could be structurally entrapped on uplifted fault bocks.

POTENTIAL PITFALLS

The Wabamun salt paleo-distribution maps (Figures 5-11) were constructed on the basis of several key observations/assumptions: 1) that the Wabamun salts were uniformly deposited within the Stettler study area (Figure 11); and 2) that correlations exist between the thickness of the Wabamun, structural relief at the Wabamun level, relief along post-Wabamun horizons, and the present-day and initial thicknesses of the Wabamun salt; and 3) that the timing and extent of salt dissolution can be determined through an analysis of subsurface patterns of relief. This later premise assumes that the leaching of salt causes the contemporaneous collapse of the overlying sediments.

While the method appears robust from a regional perspective (a high degree of correlation is observed between the present-day salt distribution map and deep well control where available), structural data, on a local scale, could easily be misinterpreted. Reefs, extreme relief along the pre-Cretaceous subcrop, and faults where undetected, could introduce anomalous structure into the subsurface (Figure 32). Such structures could be incorrectly interpreted as indicative of residual salt. In a somewhat analogous manner, collapse patterns caused by the dissolution of pre-Wabamun salts (Cairn, Beaverhill Lake or Prairie Evaporite) in post-

Wabamun time could be erroneously attributed to the leaching of the Wabamun salts themselves (Figure 12). (Indeed, within the Cairn salt basin the dissolution of some 80 m of salt, which represents the combined depositional thicknesses of the Cairn and Wabamun salts, is required to explain anomalous relief).

SUMMARY

The Wabamun salts were widely distributed and uniformly deposited within the Stettler area. They appear to have been extensively dissolved, more-or-less continuously in places, and by a variety of processes. The timing and extent of such leaching is of significance to the explorationist in that both stratigraphic and structural traps can form as a result. F o r example, stratigraphic traps can form where reservoir facies were either preferentially deposited (Figure) or preserved in salt-dissolution lows. In contrast, reservoir facies can develop in high energy environments like topographic highs that are controlled by salt edges or remnants and structural traps can form where reservoir facies are draped across salt remnants or collapse features.

Herein we have presented a suite of maps on which areas favourable for for the formation of stratigraphic and structural traps have been highlighted. These maps illustrate some of the relationships between the timing and the extent of Wabamun salt dissolution, and hydrocarbon play fairways. They demonstrate the utility of reconstructed salt distribution maps.

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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. Example gamma-ray and sonic logs 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 2 (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.

Figure 5. Contour map (in meters) depicting the present day distribution of the Wabamun salts.

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

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

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

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

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

Figure 11. Contour map (in meters) depicting the original distribution (hypothesized) of the Wabamun Group salts.

Figure 12. Map depicting the Cairn salt basin and the present-day distribution of the Cairn salt.

Figure 13. Schematic diagram showing how a reservoir facies can be preferentially deposited within a salt-dissolution low (Anderson et al., 1988).

Figure 14. Schematic diagram showing how a reservoir facies can be preferentially preserved in a salt-dissolution low (Anderson et al., 1988).

Figure 15. Schematic diagram showing how a reservoir facies can be preferentially deposited across a topographic high, formed as a result of contemporaneous salt dissolution.

Figure 16. Contour map (in meters) showing the distribution (hypothesized) of the Wabamun salts at the end of Mannville time. Areas which were extensively leached during the Wabamun/Mannville interval are highlighted.

Figure 17. Contour map (in meters) showing the distribution (hypothesized) of the Wabamun salts at the end of Viking time. Areas which were extensively leached during the Mannville /Viking interval are highlighted.

Figure 18. Contour map (in meters) showing the distribution (hypothesized) of the Wabamun salts at the end of Second Specks time. Areas which were extensively leached during the Viking/Second Specks interval are highlighted.

Figure 19. Contour map (in meters) showing the distribution (hypothesized) of the Wabamun salts at the end of Colorado time. Areas which were extensively leached during the Second Specks/Colorado interval are highlighted.

Figure 20. Contour map (in meters) showing the distribution (hypothesized) of the Wabamun salts at the end of Lea Park time. Areas which were extensively leached during the Colorado /Lea Park interval are highlighted.

Figure 21. Contour map (in meters) depicting the present day distribution of the Wabamun salts. Areas which were extensively leached in post-Lea Park time are highlighted.

Figure 22. Schematic diagram showing how a reservoir facies can be structurally closed across the updip edge of a salt remnant (Anderson et al., 1988).

Figure 23. Schematic diagram showing in four stages how a reservoir facies can be structurally closed over a salt remnant as a result of progressive leaching (Anderson et al., 1988).

Figure 24. Contour map (in meters) depicting the present day distribution of the Wabamun salts. Areas of potential closure at the Wabamun level (due to the dissolution of the Wabamun salt) have been highlighted.

Figure 25. Contour map (in meters) depicting the present day distribution of the Wabamun salts. Areas of potential closure at the Mississippian level (due to the dissolution of the Wabamun salt) have been highlighted.

Figure 26. Contour map (in meters) depicting the present day distribution of the Wabamun salts. Areas of potential closure at the Mannville level (due to the dissolution of the Wabamun salt) have been highlighted.

Figure 27. Contour map (in meters) depicting the present day distribution of the Wabamun salts. Areas of potential closure at the Viking level (due to the dissolution of the Wabamun salt) have been highlighted.

Figure 28. Contour map (in meters) depicting the present day distribution of the Wabamun salts. Areas of potential closure at the Second Specks

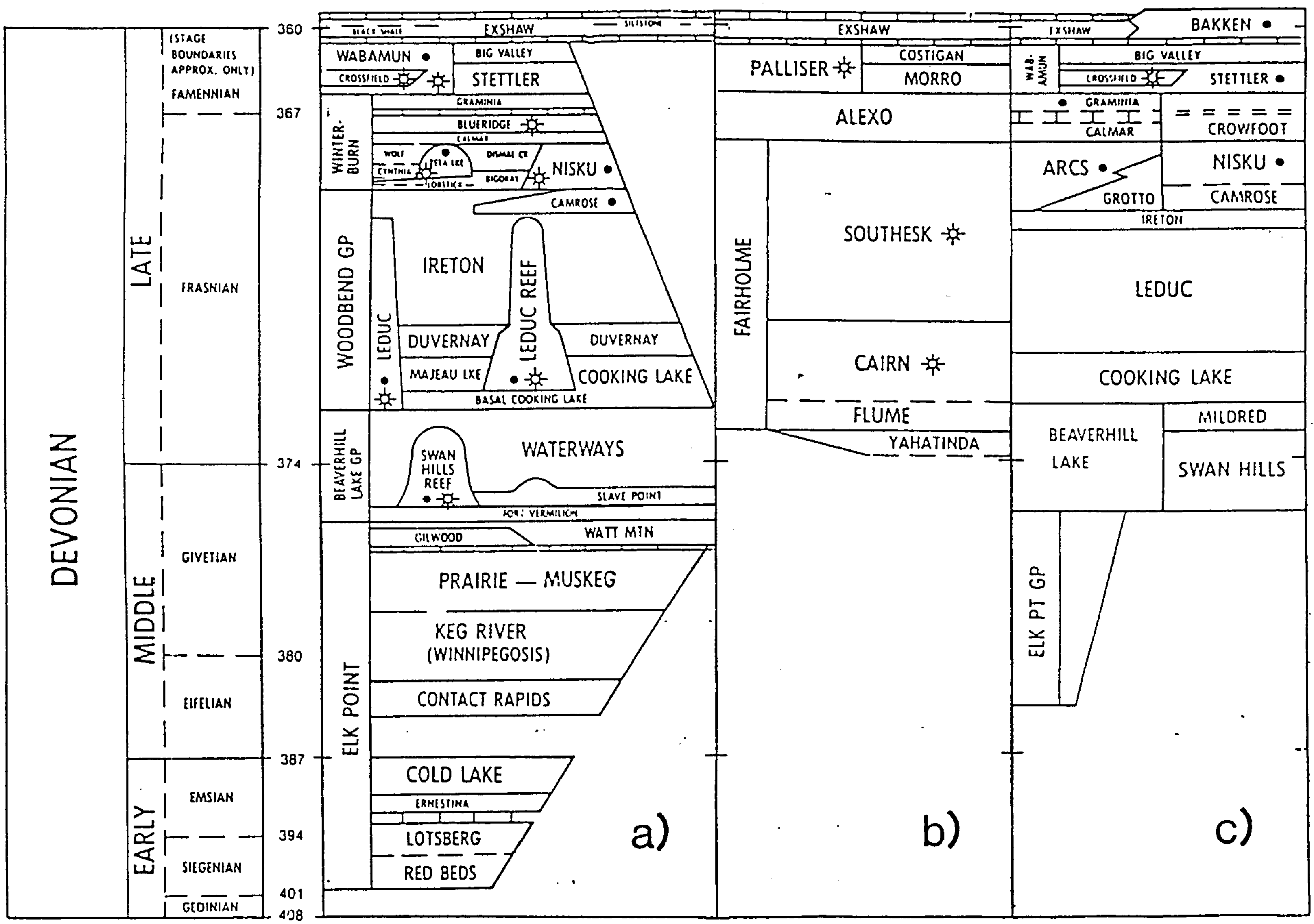
level (due to the dissolution of the Wabamun salt) have been highlighted.

Figure 29. Contour map (in meters) depicting the present day distribution of the Wabamun salts. Areas of potential closure at the Colorado level (due to the dissolution of the Wabamun salt) have been highlighted.

Figure 30. Contour map (in meters) depicting the present day distribution of the Wabamun salts. Areas of potential closure at the Lea Park level (due to the dissolution of the Wabamun salt) have been highlighted.

Figure 31. Contour map (in meters) depicting the present day distribution of the Wabamun salts. Areas of potential closure at post-Lea Park levels (due to the dissolution of the Wabamun salt) have been highlighted.

Figure 32. Sketch illustrating why remanent salts could be misinterpreted as reefs, fault blocks, and subcrop topography.



DEVONIAN
LATE
MIDDLE
EARLY
(STAGE BOUNDARIES APPROX. ONLY)
FAMENNIAN
FRASNIAN
GIVETIAN
EIFELIAN
EMSIAN
SIEGENIAN
GEDINIAN
360
367
374
380
387
394
401
408
EXSHAW
WABAMUN
CROSSFIELD
BIG VALLEY
STETTLER
WINTER-BURN
GRAMINIA
BLUERIDGE
CALMAR
NISKU
CAMROSE
WOODBEND GP
LEDUC
IRETON
LEDUC REEF
DUVERNAY
MAJEAU LKE
COOKING LAKE
BASAL COOKING LAKE
BEAVERHILL LAKE GP
SWAN HILLS REEF
WATERWAYS
SLAVE POINT
FORT VERMILION
GILWOOD
WATT MTN
ELK POINT
PRAIRIE — MUSKEG
KEG RIVER (WINNIPEGOSIS)
CONTACT RAPIDS
COLD LAKE
ERNESTINA
LOTSBERG
RED BEDS
a)
PALLISER
COSTIGAN
MORRO
ALEXO
FAIRHOLME
SOUTHESK
CAIRN
FLUME
YAHATINDA
b)
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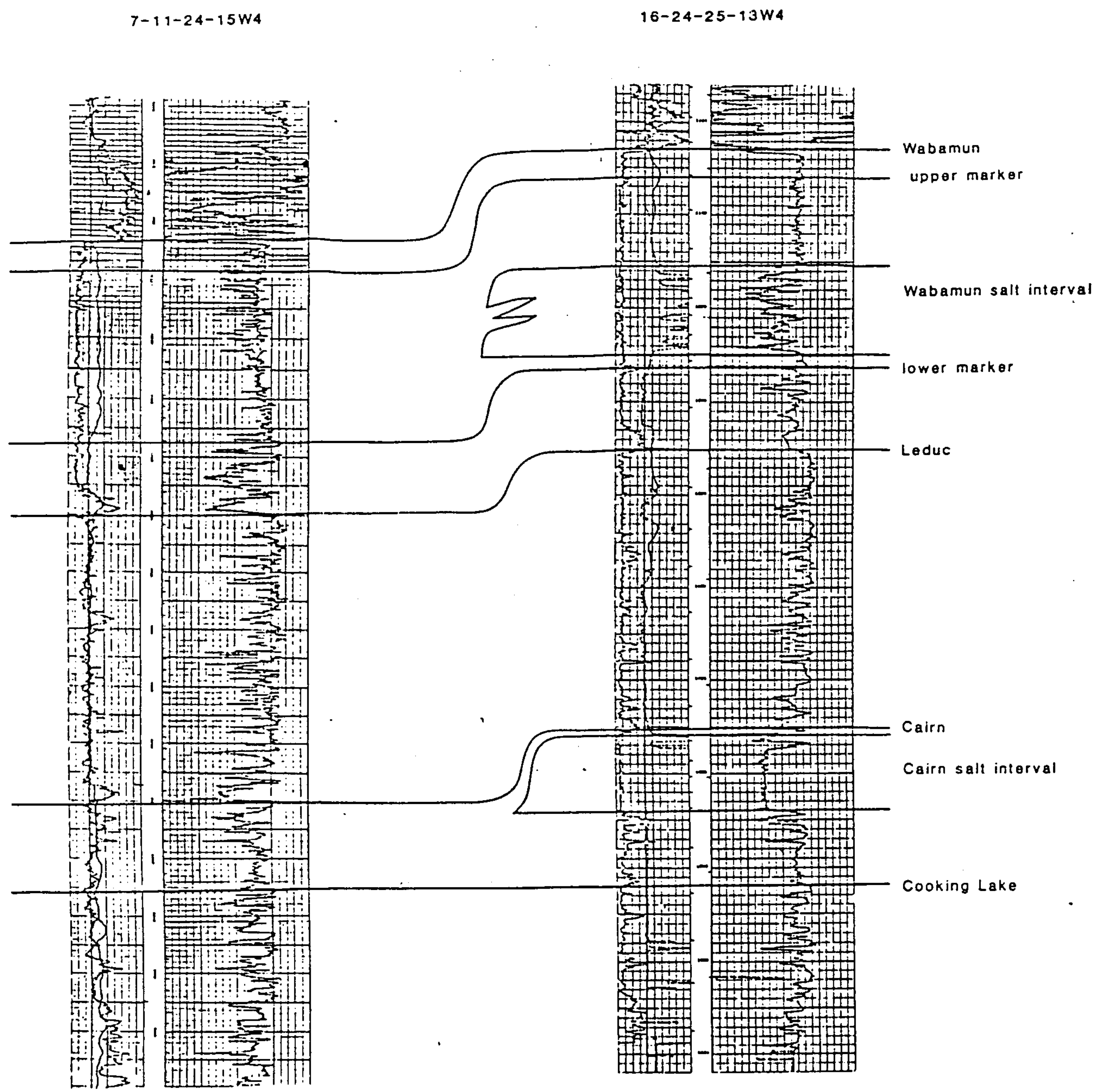
ELK PT GP
c)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16-24-25-13W4
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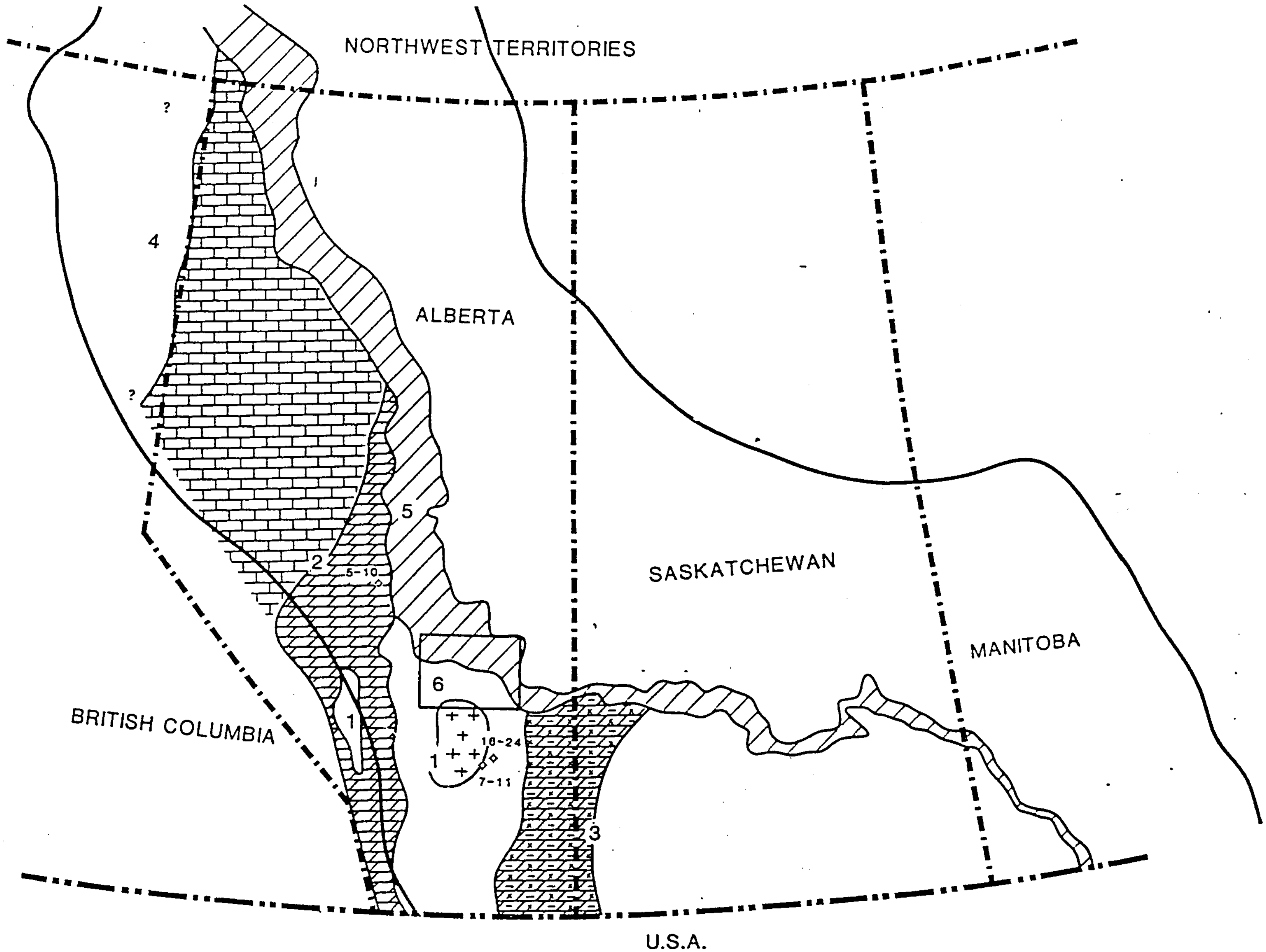
upper marker
Wabamun salt interval
lower marker
Leduc
Cairn
Cairn salt interval
Cooking Lake


NORTHWEST TERRITORIES
ALBERTA
SASKATCHEWAN
MANITOBA
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4
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1
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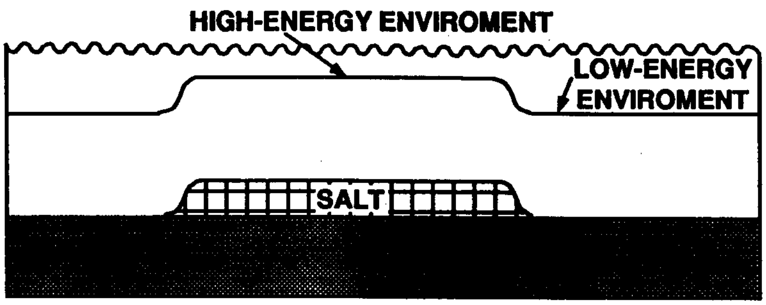
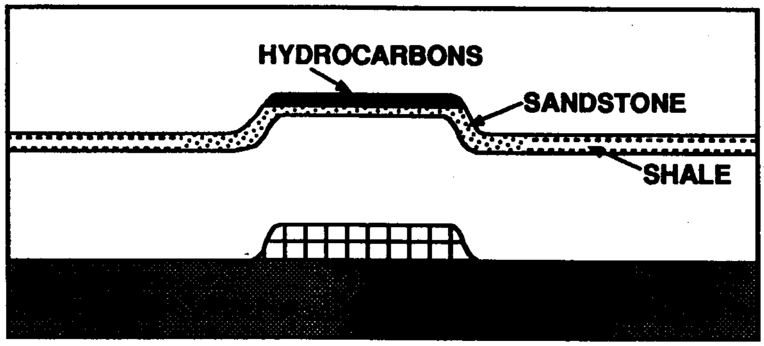
7-11
3



STAGE 1



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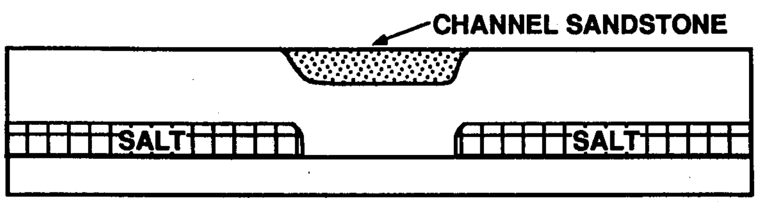

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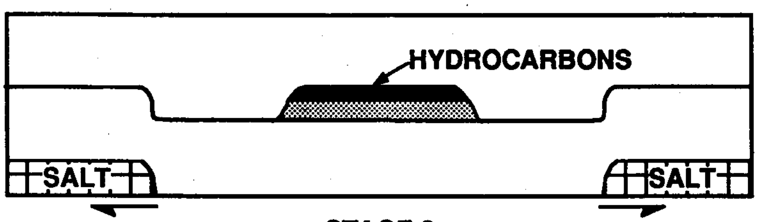

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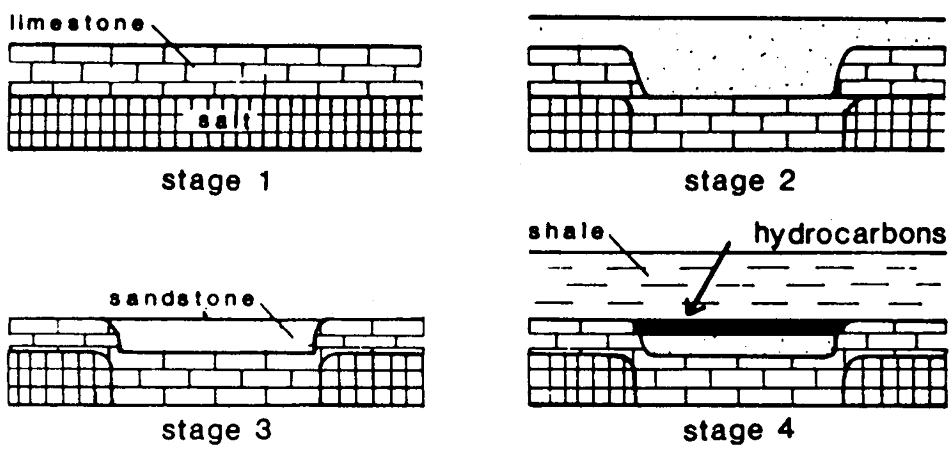

limestone
salt
stage 1
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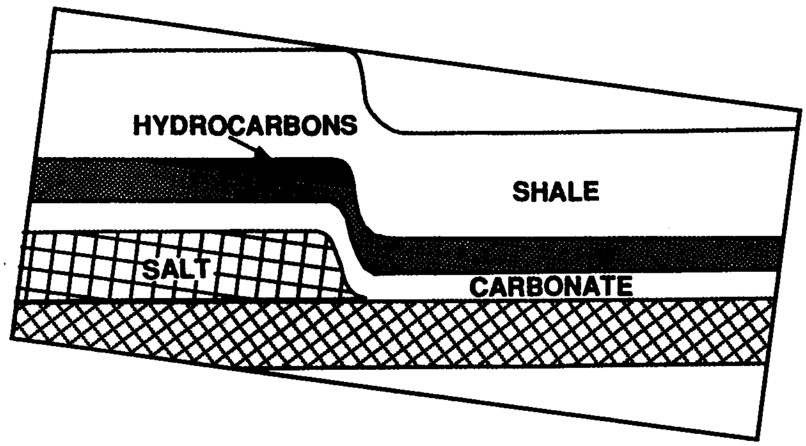
shale
hydrocarbons
stage 4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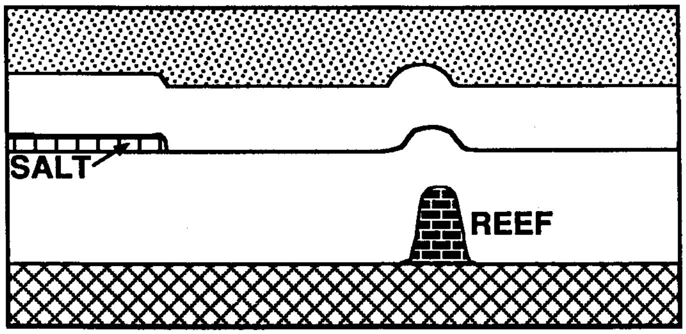
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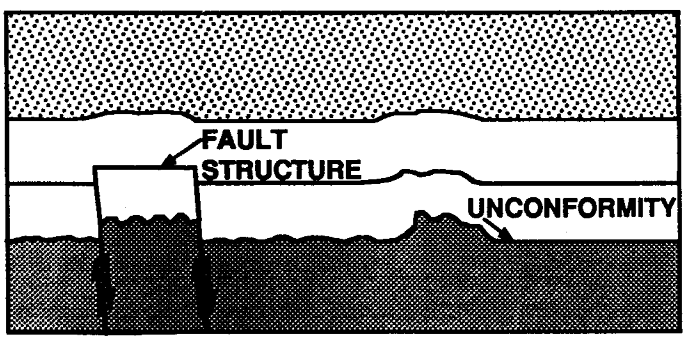
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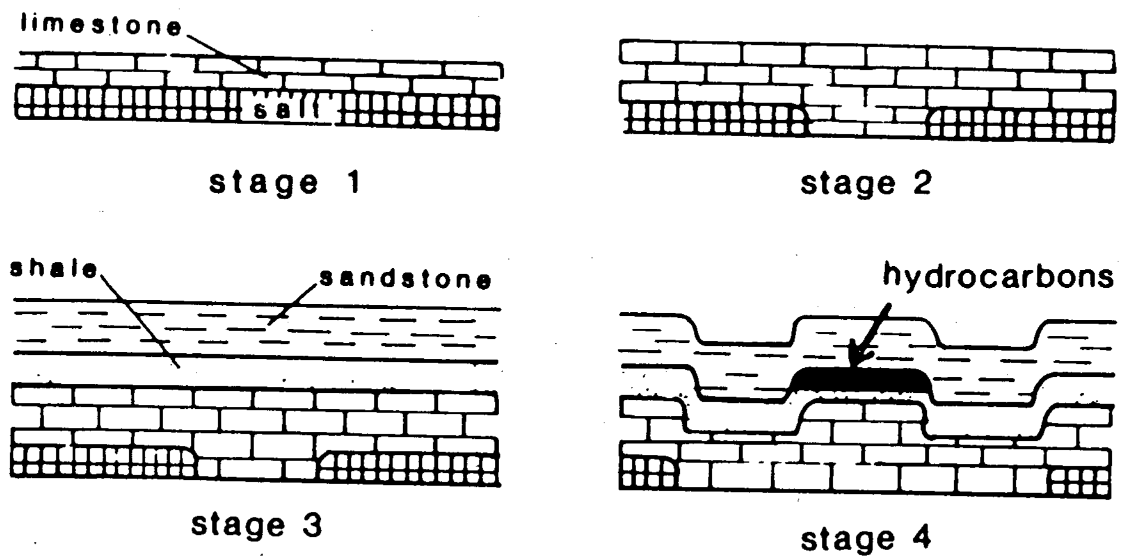
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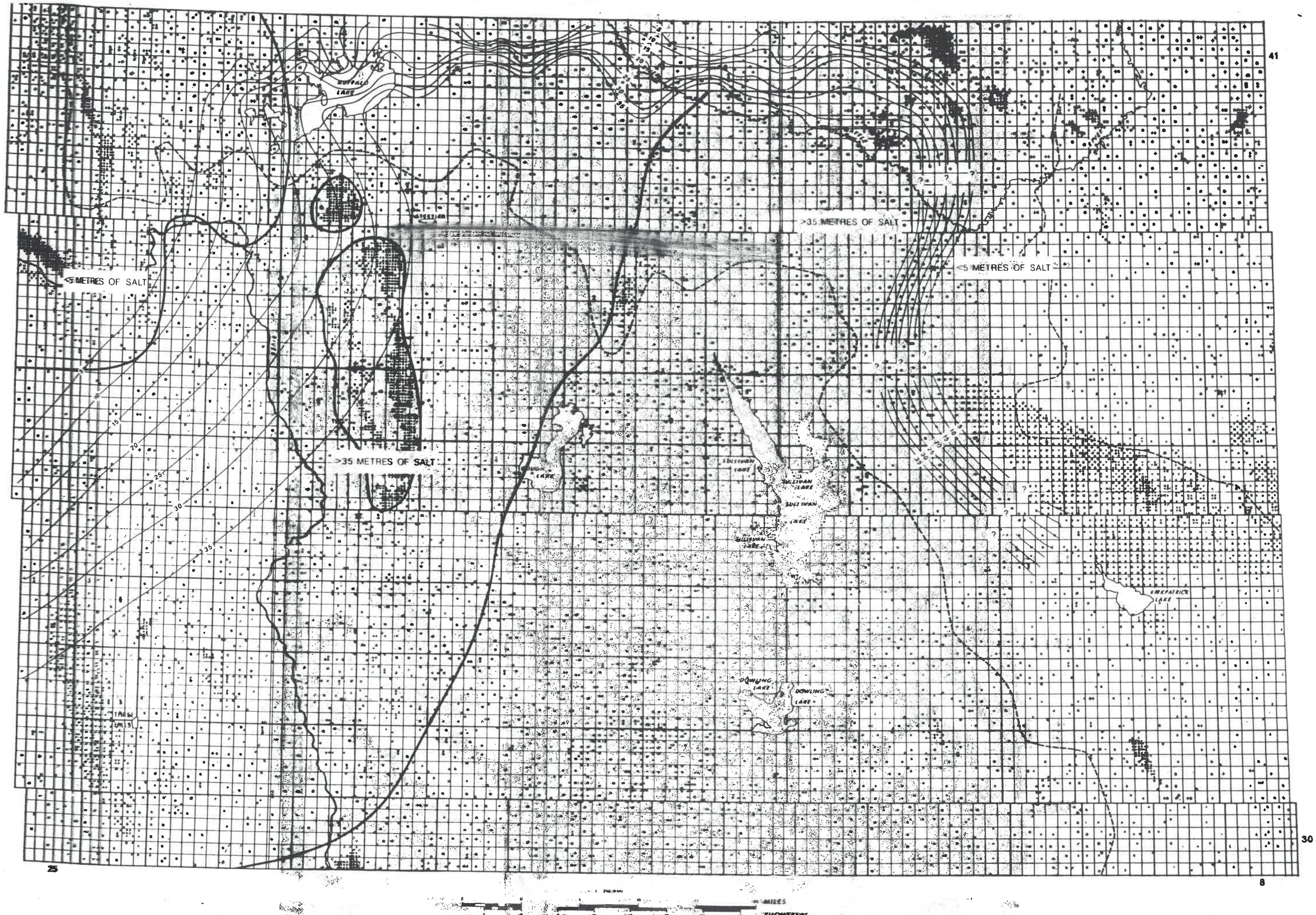
41
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DOWLING LAKE
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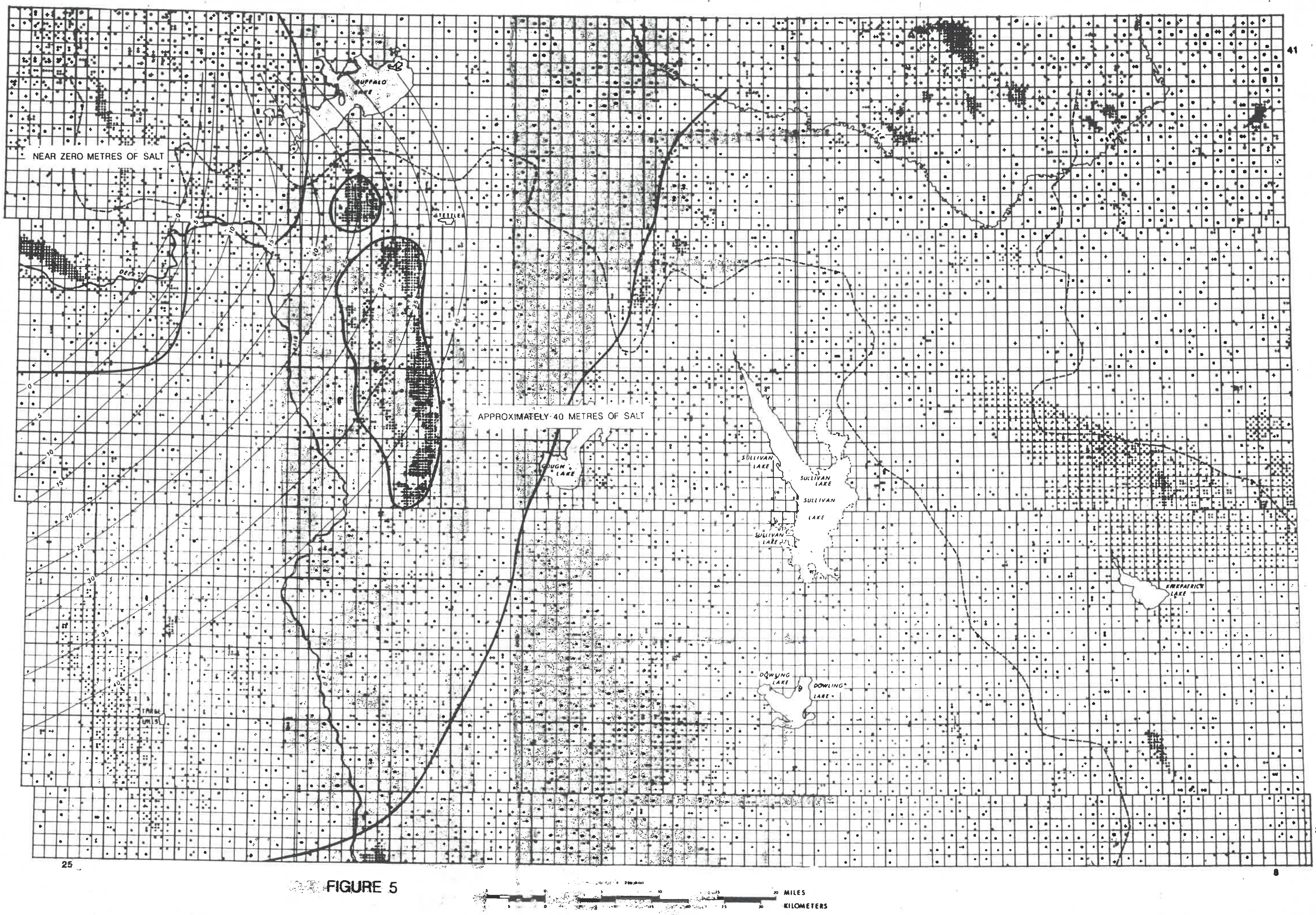
MILES
KILOMETERS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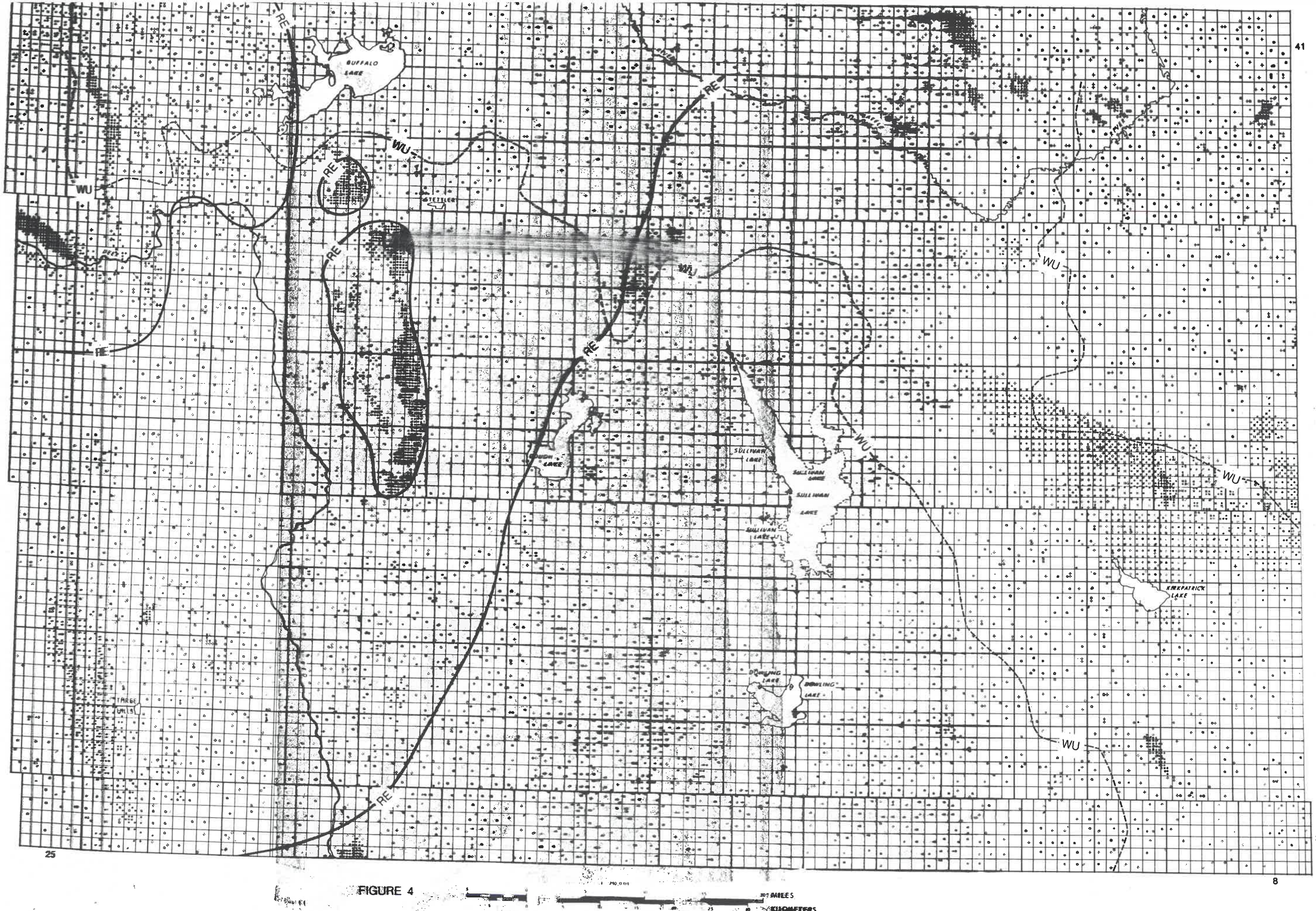
MILES
KILOMETERS

FIGURE 5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KILOMETERS

FIGURE 4