KANSAS GEOLOGICAL SURVEY
OPEN-FILE REPORT 90-39

An Overview of Some of the Large Scale
Mechanisms of Salt Dissolution

by

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An overview

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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 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. Investigation suggests that dissolution 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 also conclude that leaching is self-perpetuating; a process whereby the porosity and permeability of sediment is enhanced by the dissolution of underlying salt and the associated collapse, thereby providing a conduit for water which facilitates further leaching.

In this paper, we discuss the four principal mechanisms of dissolution. We include a suite of maps which depict the paleo-distribution of the Wabamun salts, in order to illustrate the ideas presented.

INTRODUCTION

The halite salts of the Wabamun Group (Figures 1 and 2) are thought to have been widely distributed and uniformly deposited throughout the Stettler area, southeastern Alberta, Canada (Figures 3 and 4). As a result of extensive leaching, they are now preserved as isolated to contiguous bodies of irregular shape having maximum net thicknesses on the order of 40 m. Work by Anderson and Brown (1987, 1991a,b), Anderson et al. (1988, 1989, 1991), and Brown and Anderson (1990) suggests that dissolution has occurred, in places, more-or-less continuously from the late Paleozoic to the present, and that leaching has been 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 partial dissolution of the underlying Cairn salt in post-Wabamun time; 3) regional faulting/fracturing during the late Cretaceous; and 4) glacial unloading. In support of their conclusions Anderson and co-workers demonstrate that:

1) Wabamun salts are not encountered along the Wabamun subcrop edge (except in the Buffalo Lake area, where the salts themselves do not subcrop), implying that dissolution initiated during the pre-Cretaceous along the projected salt outcrop edge. This continuous salt-dissolution front is

thought to have 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 porosity/permeability conduit for water which facilitates further dissolution.

2) The orthogonal pattern of dissolution on the suite of Wabamun salt paleo-distribution maps, suggests that regional faulting/fracturing, during the Upper Cretaceous, initiated widespread leaching. These reconstructed salt distribution maps (Figures 5-11) indicate that the dissolution fronts initiated along these fault/fracture planes and moved laterally thereafter at uneven rates.

3) The Cairn salt (pre-Wabamun) has been extensively dissolved, suggesting 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 (Figure 12).

4) Several lakes in the Stettler area (Buffalo, Gough, Sullivan and Dowling: Figure 5) are situated above areas where the salts are thin or absent, suggesting that significant leaching has occurred in post-glacial times, perhaps in response to glacial loading and unloading. The correlation in places, between present day drainage patterns and areas of thin salt,

suggests that dissolution is presently occurring, probably in response to glacial rebound.

5) Spectacular collapse features are imaged on seismic data across the dissolutional edges of the remanent Wabamun salt, implying that leaching and collapse has occurred.

8) Gravity anomalies are observed across some salt remnants. These data are variously consistent with dissolution during the post-Paleozoic and the replacement of salt by higher density clastics.

We have followed up these previous studies, in order to elucidate the four postulated, principal mechanisms of dissolution. The suite of Wabamun salt paleo-distribution maps (Figures 5-11) prepared by Anderson et al. (1991), are used to illustrate the concepts presented.

PALEO-DISTRIBUTION MAPS

Anderson and Brown (1991), identified correlation patterns between the thickness of the Wabamun Group, structural relief at the Wabamun level, relief along post-Wabamun horizons, and the thickness of the Wabamun salt remnants. On the basis of these relationships, the authors mapped the present-day distribution of the Wabamun salts in the Stettler area, and reconstructed the distribution of these salts at the following times (Figures 5-11, respectively):

A) present-day

B) end Lea Park

C) end Colorado

D) end Second Specks

E) end Viking

F) end Mannville

G) end Wabamun (original distribution)

The methodology these authors used to reconstruct the distribution of the Wabamun salts is described in detail by Anderson and Brown (1991).

DISCUSSION

Anderson et al. (1991), drew several significant conclusions on the basis of their suite of reconstructed salt distribution maps. Of particular interest is their suggestion that dissolution was initiated and/or enhanced by four principal processes: 1) the erosion of overlying 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.

With respect to the erosion and near-surface exposure mechanism (Figure 14), the earliest phases of dissolution are thought to have initiated during the pre-Cretaceous along the projected salt outcrop edge (Figures 10 and 11). This front appears to have advanced in a southwesterly direction, supporting the thesis that leaching is a self-perpetuating process (Figures 5 - 11). The present-day main salt edges (salt thicknesses greater than 10 m: Figure 6) are between 15 and 30 km from the projected outcrop edge, suggesting average rates of advancement, due to the self-perpetuating nature of salt dissolution, of between 0.125 and 0.250 km/million years (assuming dissolution along the present-day salt edge initiated during the Barremian stage: 119 - 124 million years ago). These rates are probably high, in that dissolution along the main salt edge was undoubtedly accentuated by the other principal mechanisms.

With respect to the Cairn salt mechanism (Figure 15), work by both the senior author and Brown and Anderson (1990) has shown that the Cairn salt (Figure 12) has been extensively dissolved in places, more-or-less continuously since the late Devonian. Indeed, in the southeastern part of the study area the effects of the leaching of the Wabamun and Cairn salts are difficult to differentiate. We 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. On the suite of reconstructed maps, the leaching of the Wabamun salt in the Cairn basin, is shown as Upper Cretaceous in origin (Figures 7 and 8). However, it is recognized that earlier phases of dissolution in this area might be masked by the effects of erosion during the pre-Cretaceous and later phases of leaching.

With respect to the fault/fracture mechanism (Figure 16), Anderson and Brown (1991a) have identified an orthogonal pattern of dissolution on the suite of paleo-distribution maps (Figure 13). These lineaments strongly suggest that regional faulting/fracturing, during the Coniacian/Turonian stages of the Upper Cretaceous (87.5 - 91 million years ago), initiated widespread leaching along well-defined orthogonal fronts. These fronts appear to have migrated laterally thereafter, and at variable average rates. The average rates at which the salt edges receded from the fracture/fault planes (possibly as high as 0.030 km/million years) cannot be confidently estimated for several reasons: 1) only the more prominent lineaments (Figure 13) can be traced; 2) later stages of faulting/fracturing, perhaps associated with early phases of the Laramide Orogeny could also have initiated leaching; 3) the other principal mechanisms of dissolution contributed to the leaching of salt in the study area. It is interesting to note that: 1) extensive dissolution has occurred above the Stettler reef (T35-38 R20 W4M), implying that it is coincident with one or more major lineaments; and 2) the edges of the main fringing reef, the Bashaw complex, and the Cairn salt remnant (Figure 12) are all consistent with the orientation of the hypothesized fault/fracture planes. Perhaps these lineaments are re-activated planes of weakness which influenced both the deposition of the Leduc (and equivalents) in the study area, and the leaching of the Cairn salt (Figure 17).

With respect to the glacial mechanism (Figure 18), Anderson et al. (1991a) noted that several lakes (Figure 6), in the study area, are situated above areas where the Wabamun salts are thin or absent, suggesting that significant leaching of these salts has occurred in Recent times, probably in response to glacial loading and unloading Figure). If this hypothesis is correct, the width of these lakes (up to 6 km in a direction perpendicular to the main salt edges) indicates that significant volumes of salt have been dissolved during the past 10,000 years, and that the rates at which the dissolution fronts advanced has been extremely variable: up to 6 km during the past 0.01 million years; up to 30 km during the past 120 million years. Very possibly, glacial unloading caused fractures to develop along the preexisting plnes of weakness (lineaments of Figure 13).

On the basis of the suite of reconstructed salt distribution maps, four principal trigger mechanisms have been identified and it has been suggested that leaching is self-perpetuating: a process whereby the collapse of overlying strata enhances porosity and permeability thereby providing a conduit for water and facilitating further dissolution (Figure 19). With respect to this self-perpetuating process, we note that established dissolution fronts advance at uneven and variable rates. For example, particularily extensive dissolution has occurred near the western depositional edge of the salt, in the southwestern part of the study area, and across the Stettler reef. These observations suggest that a number of different factors, in addition to the principal mechanisms, influence the rate of salt dissolution. Consideration should be given to effects of the intenity and magnitude of faulting, regional tectonism, emergence, underlying reefs, the differential compaction of pre-salt sediment, uneven depositional loading and unloading, glaciation, facies changes within both the salt and the encompassing strata, the local hydrological environment, and the effects of oil and gas wells.

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 including: 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 this paper the four principal mechanisms of salt dissolution have been described, a suite of reconstructed salt distribution maps have been included to illustrate the ideas presented, and dissolution has been advanced as a self-perpetuating process of variable rate. Factors that affect the rate of leaching are noted.

The elucidation of the mechanisms of dissolution is important, in that it is prerquisite to understanding the present-day distribution of the Wabamun salt and appreciating the implications of, and potential for further leaching.

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Meijer Drees, N. C.,1986, Evaporitic deposits of western Canada: Geol. Surv. Can. paper 85-20, 118p.

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.

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

Figure 13. Contour map (in meters) showing the distribution (hypothesized) of the Wabamun salts at the end of Colorado time (Anderson et al., 1991). An orthogonal pattern of lineaments, which are thought to represent fault/fracture planes has been superimposed on this paleo-distribution map.

Figure 14. Sketch illustrating how the dissolution of the Wabamun salt would be triggered by near surface exposure during the pre-Cretaceous hiatus.

Figure 15. Sketch illustrating how the dissolution of the Wabamun salt could be triggered by the leaching of the underlying Cairn salt.

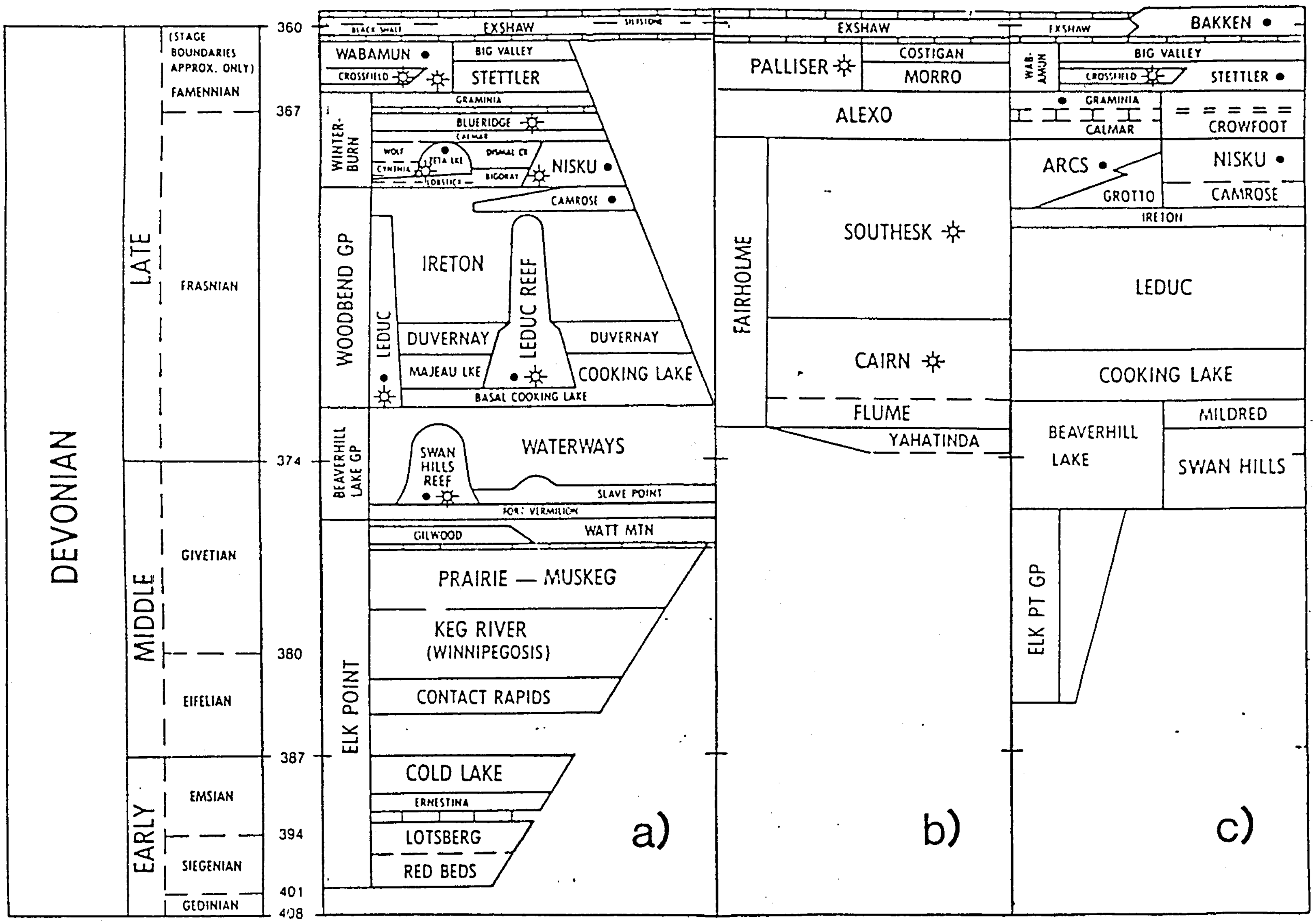
Figure 16. Sketch illustrating how the dissolution of the Wabamun salt could be triggered by regional faulting/fracturing during the late Cretaceous.

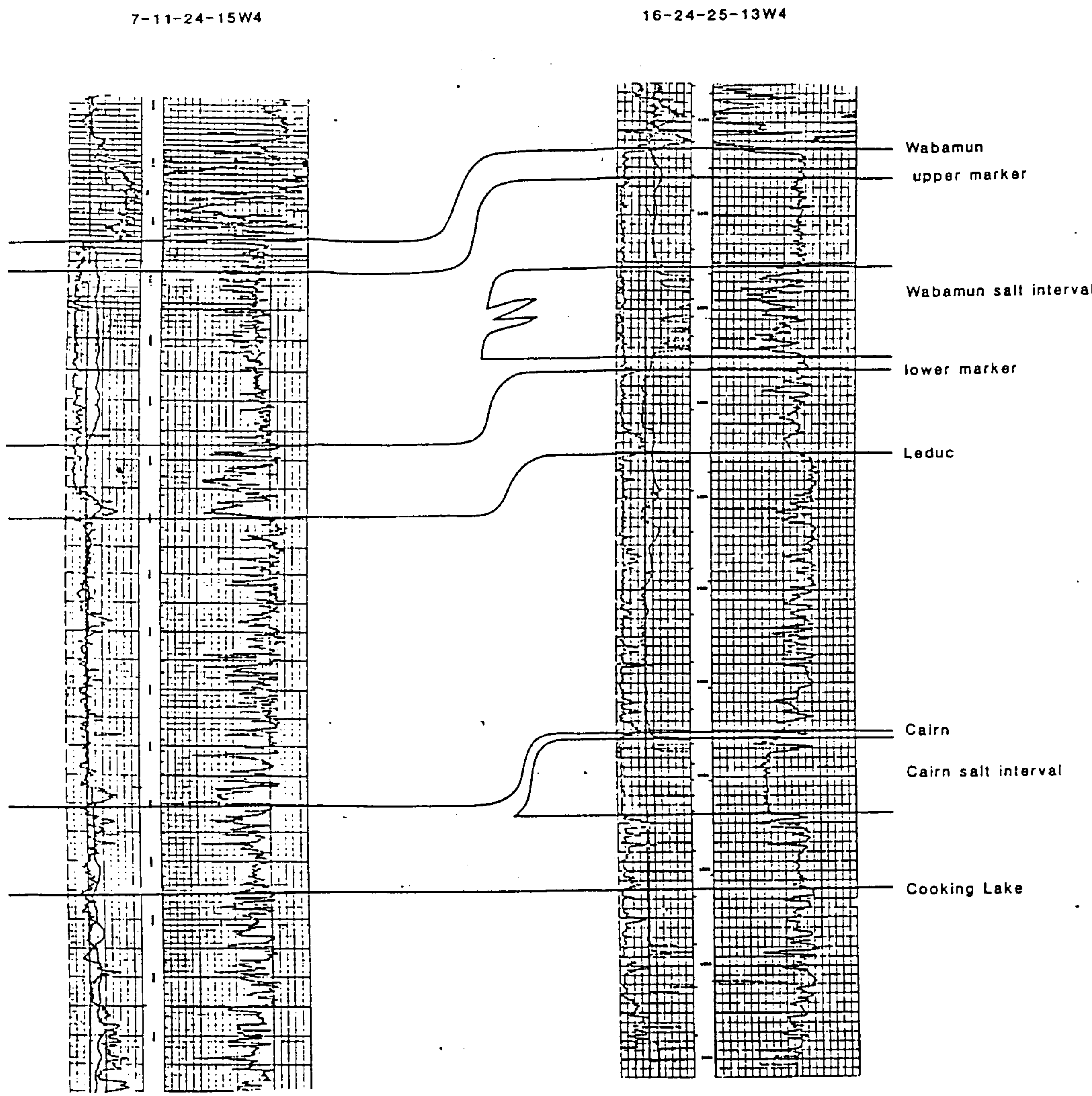
Figure 17. Sketch illustrating how the Leduc reefs in the Stettler study area could have initiated on fault blocks. The re-activation of these postulated planes of weakness could have triggered the widespread dissolution of the

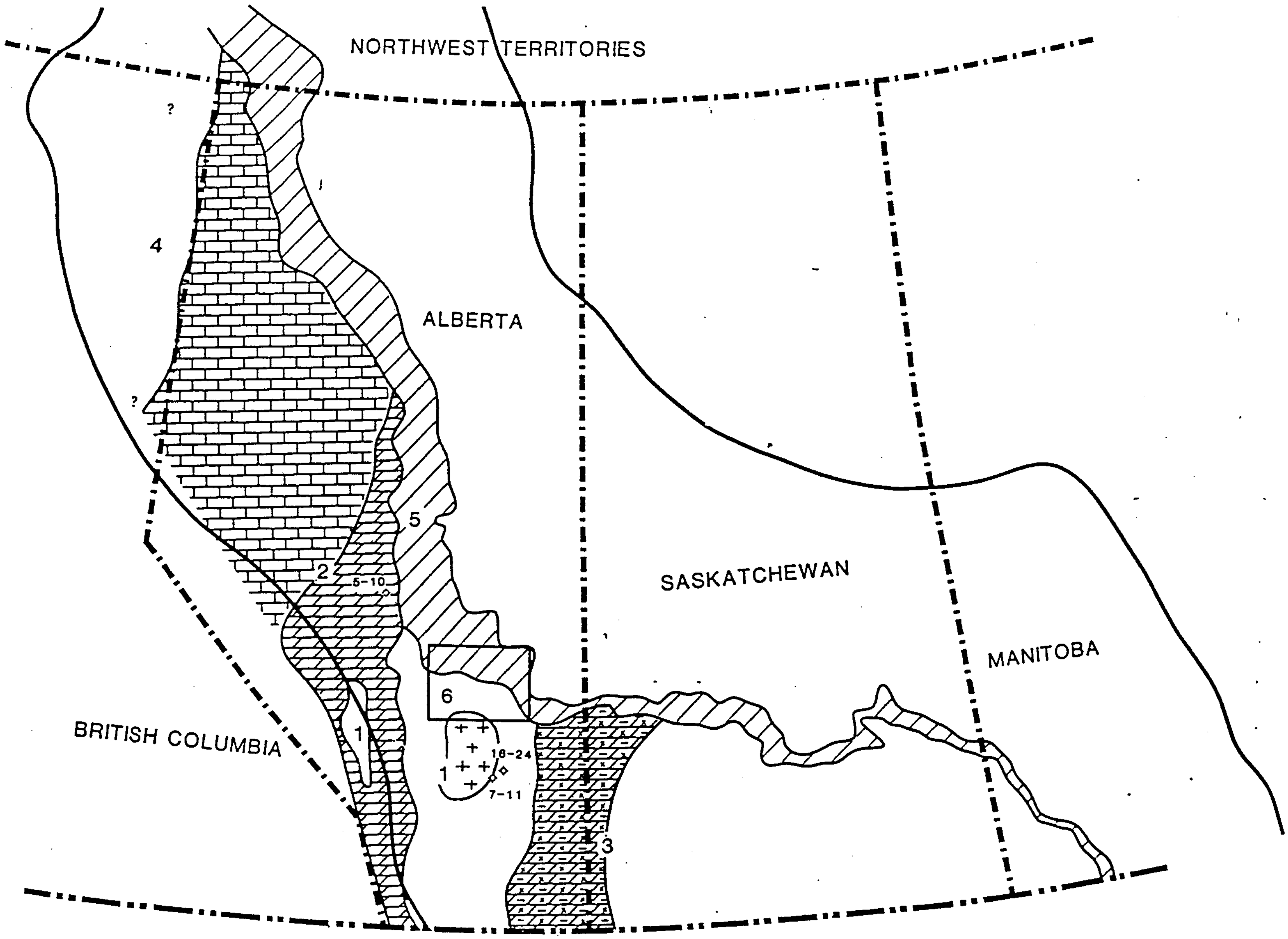
Wabamun salt in the late Cretaceous.

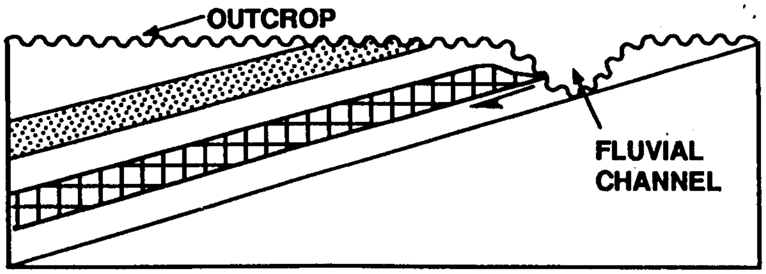
Figure 18. Sketch illustrating how the dissolution of the Wabamun salt could be triggered by glacial unloading.

Figure 19. 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.

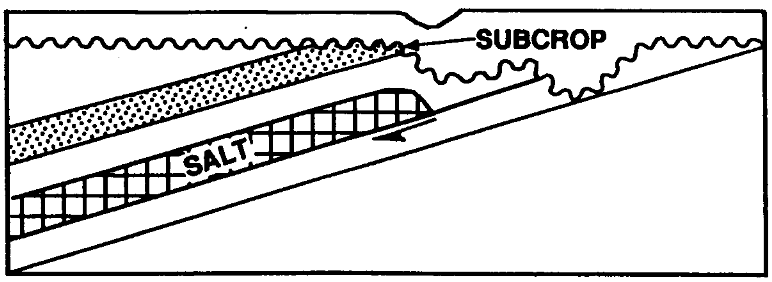

DEVONIAN
EARLY
MIDDLE
LATE
(STAGE BOUNDARIES APPROX. ONLY)
FAMENNIAN
FRASNIAN
GIVETIAN
EIFELIAN
EMSIAN
SIEGENIAN
GEDINIAN
360
367
374
380
387
394
401
408
EXSHAW
WABAMUN
BIG VALLEY
STETTLER
CROSSFIELD
GRAMINIA
BLUERIDGE
CALMAR
WINTER-BURN
NISKU
CAMROSE
WOODBEND GP
IRETON
LEDUC
LEDUC REEF
DUVERNAY
MAJEAU 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)
BAKKEN
WAB-AMUN
ARCS
GROTTO
CROWFOOT
IRETON
LEDUC
COOKING LAKE
BEAVERHILL LAKE
MILDRED
SWAN HILLS
ELK PT GP
c)


7-11-24-15W4
16-24-25-13W4
Wabamun
upper marker
Wabamun salt interval
lower marker
Leduc
Cairn
Cairn salt interval
Cooking Lake


NORTHWEST TERRITORIES
ALBERTA
SASKATCHEWAN
MANITOBA
BRITISH COLUMBIA
U.S.A.
4
5
2
5-10
1
6
1
16-24
7-11
3



STAGE 1



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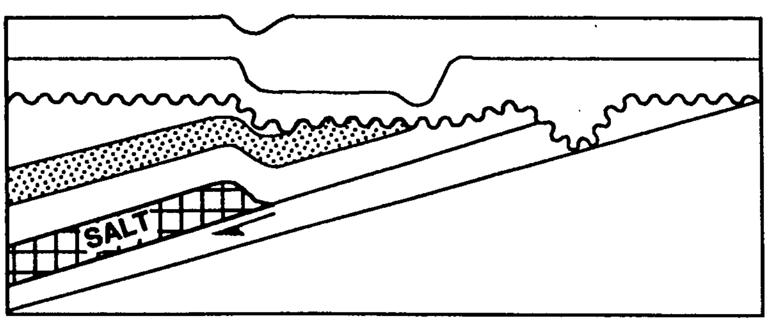

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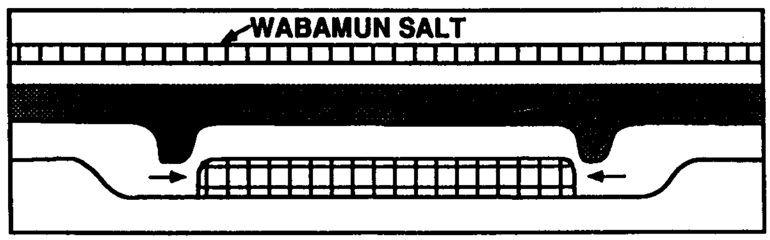

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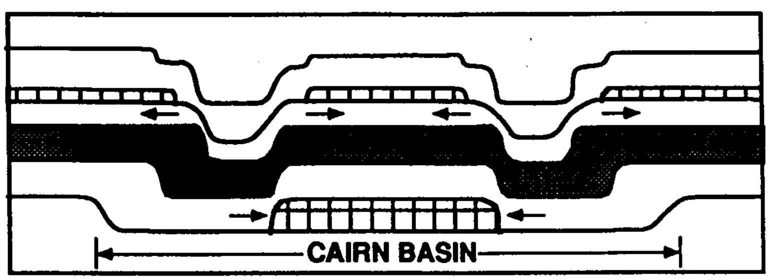

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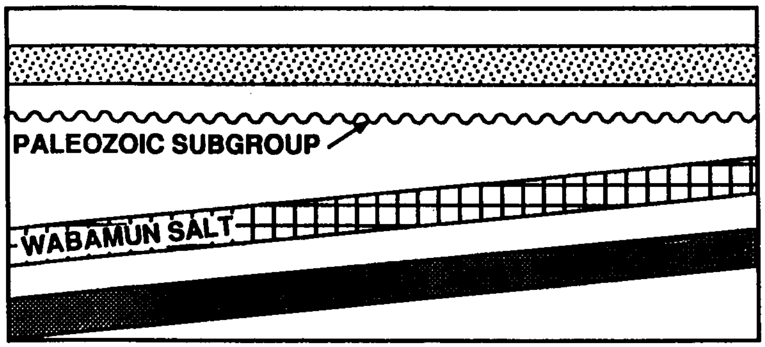

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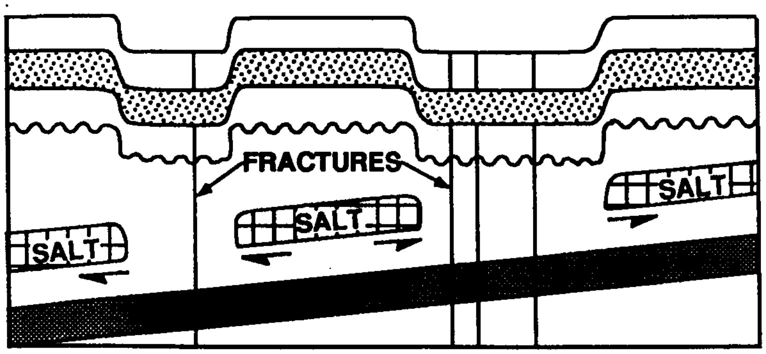
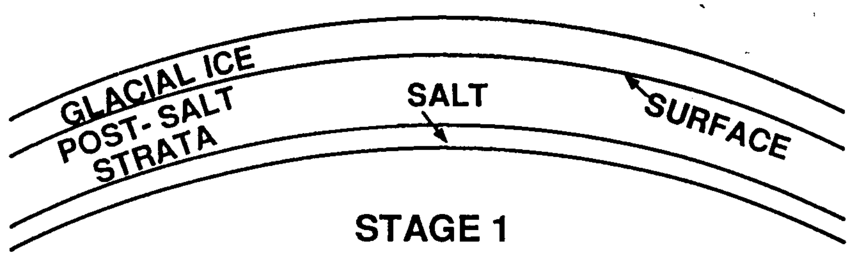
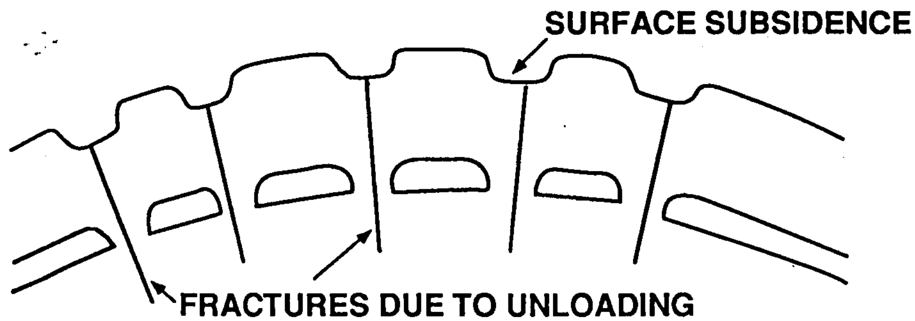


STAGE 2



STAGE 1



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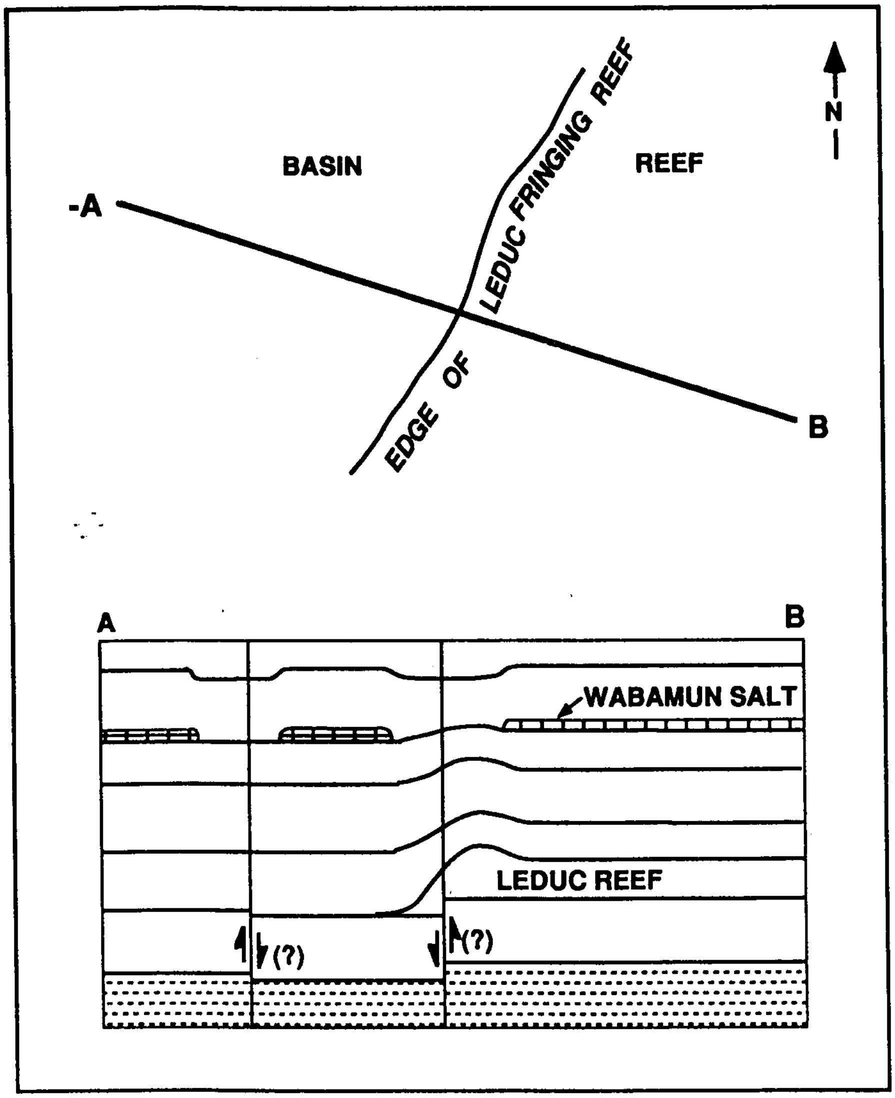
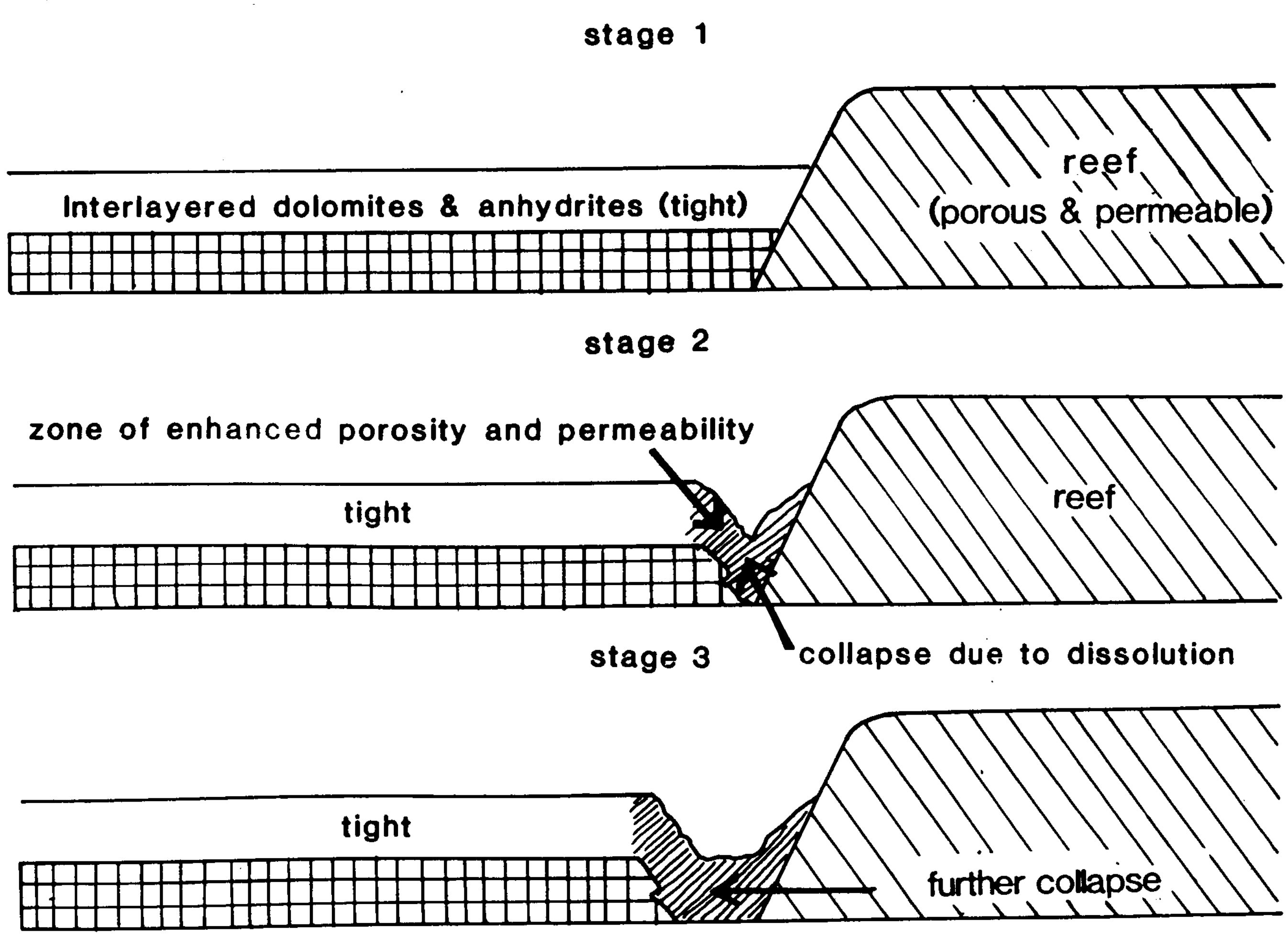
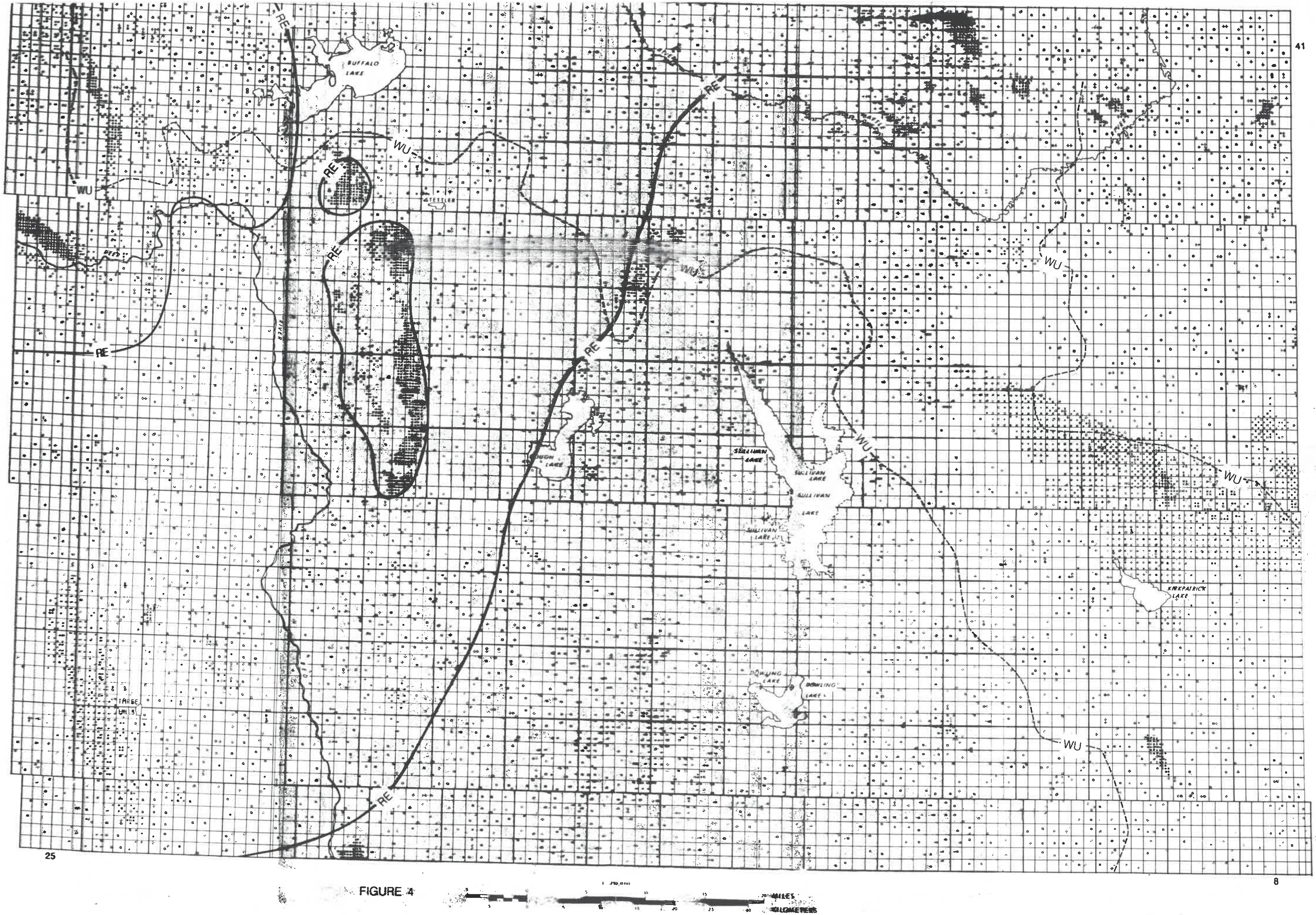
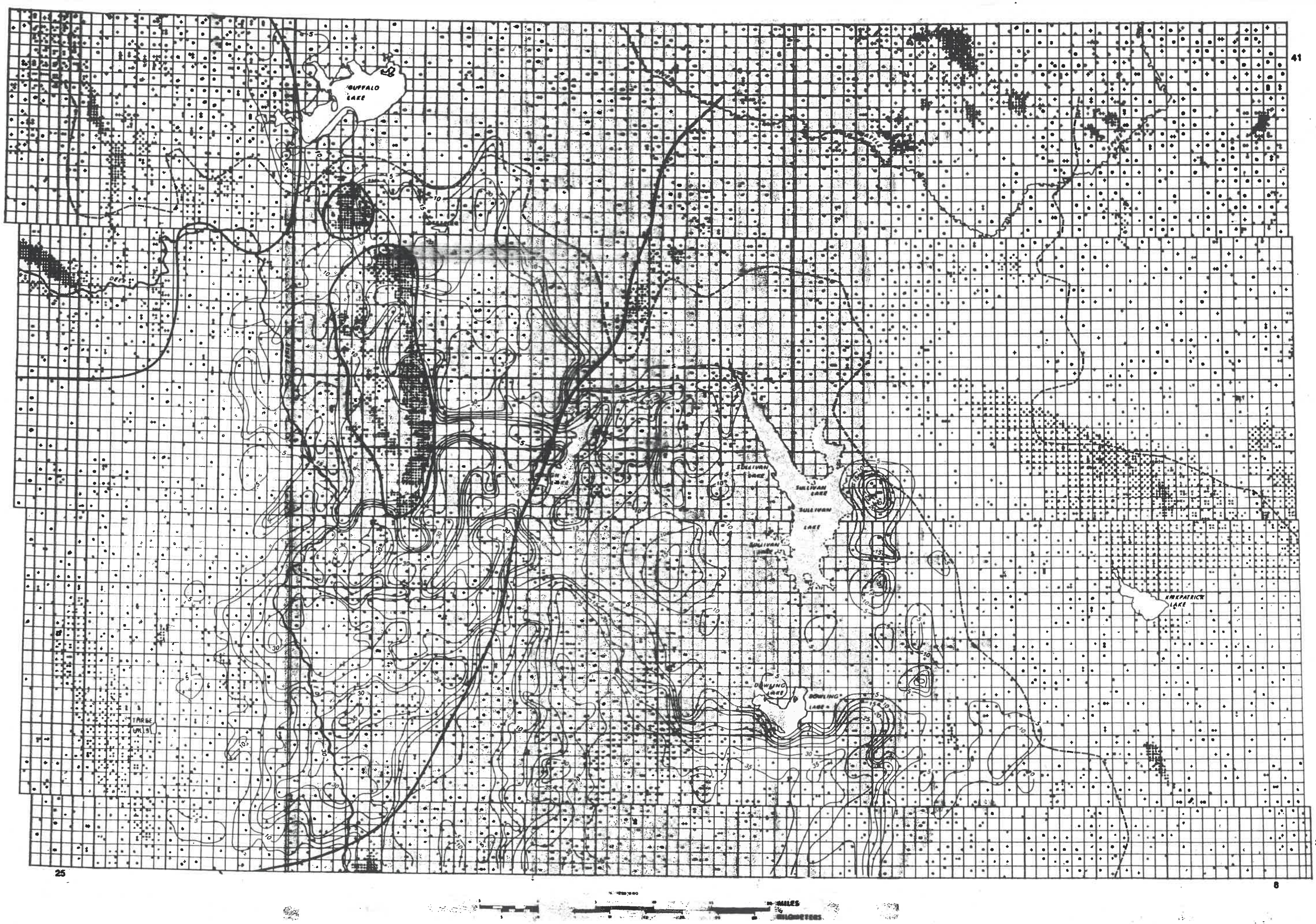

BASIN
REEF
N
A
B
EDGE OF LEDUC FRINGING REEF
A
B
WABAMUN SALT
LEDUC REEF
(?)
(?)


stage 1
Interlayered dolomites & anhydrites (tight)
reef
(porous & permeable)
stage 2
zone of enhanced porosity and permeability
tight
reef
collapse due to dissolution
stage 3
tight
further collapse



BUFFALO LAKE
STETTLER
SULLIVAN LAKE
KIRKPATRICK LAKE
DOWLING LAKE
THREE HILLS
RE
WU
41
30
25
8
MILES
KILOMETERS

FIGURE 4



BUFFALO LAKE
SULLIVAN LAKE
DOWLING LAKE
KIRKPATRICK LAKE
41
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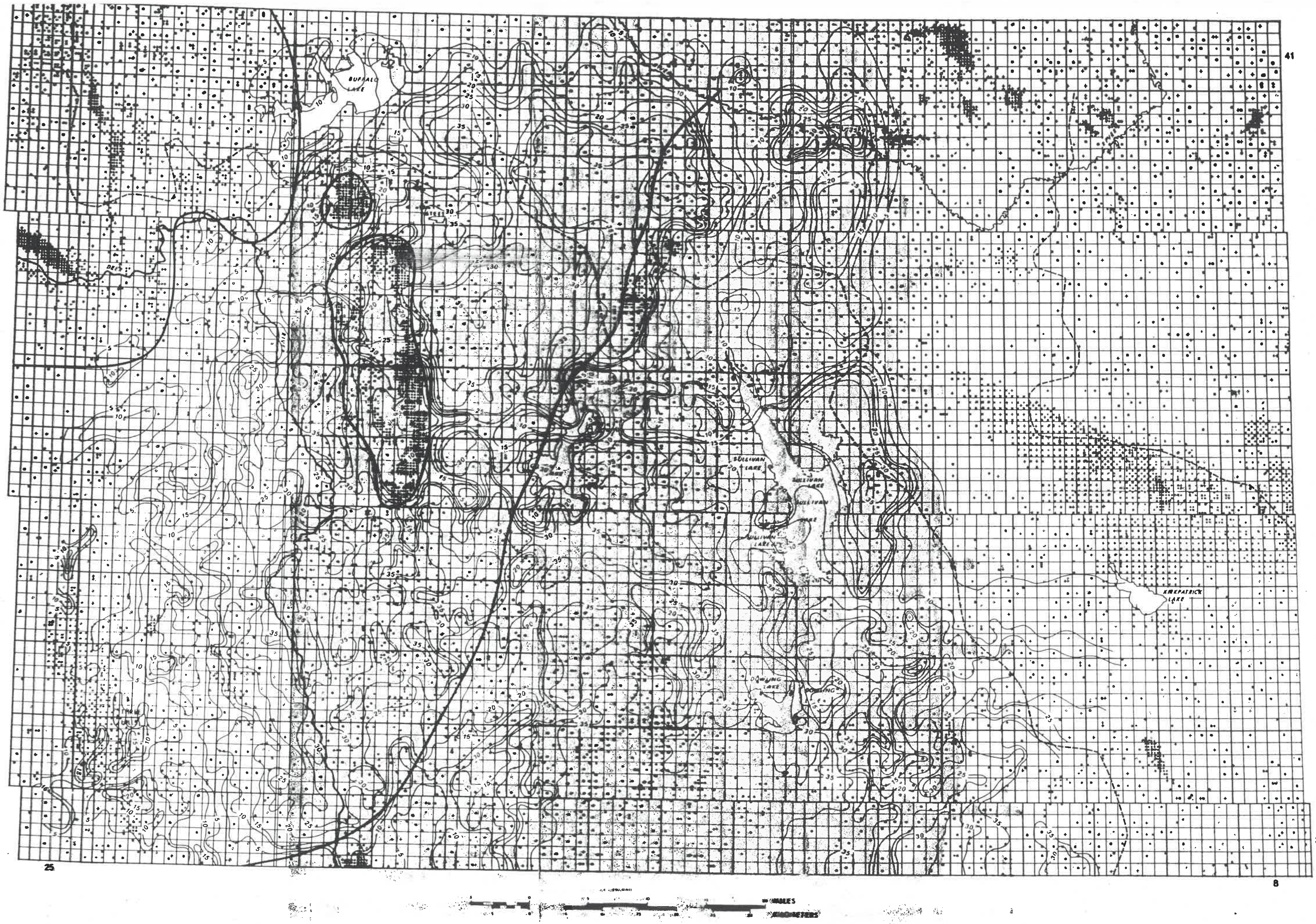
MILES
KILOMETERS


BUFFALO LAKE
SULLIVAN LAKE
KIRKPATRICK LAKE
DOWLING LAKE
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MILES
KILOMETERS

FIGURE [illegible]

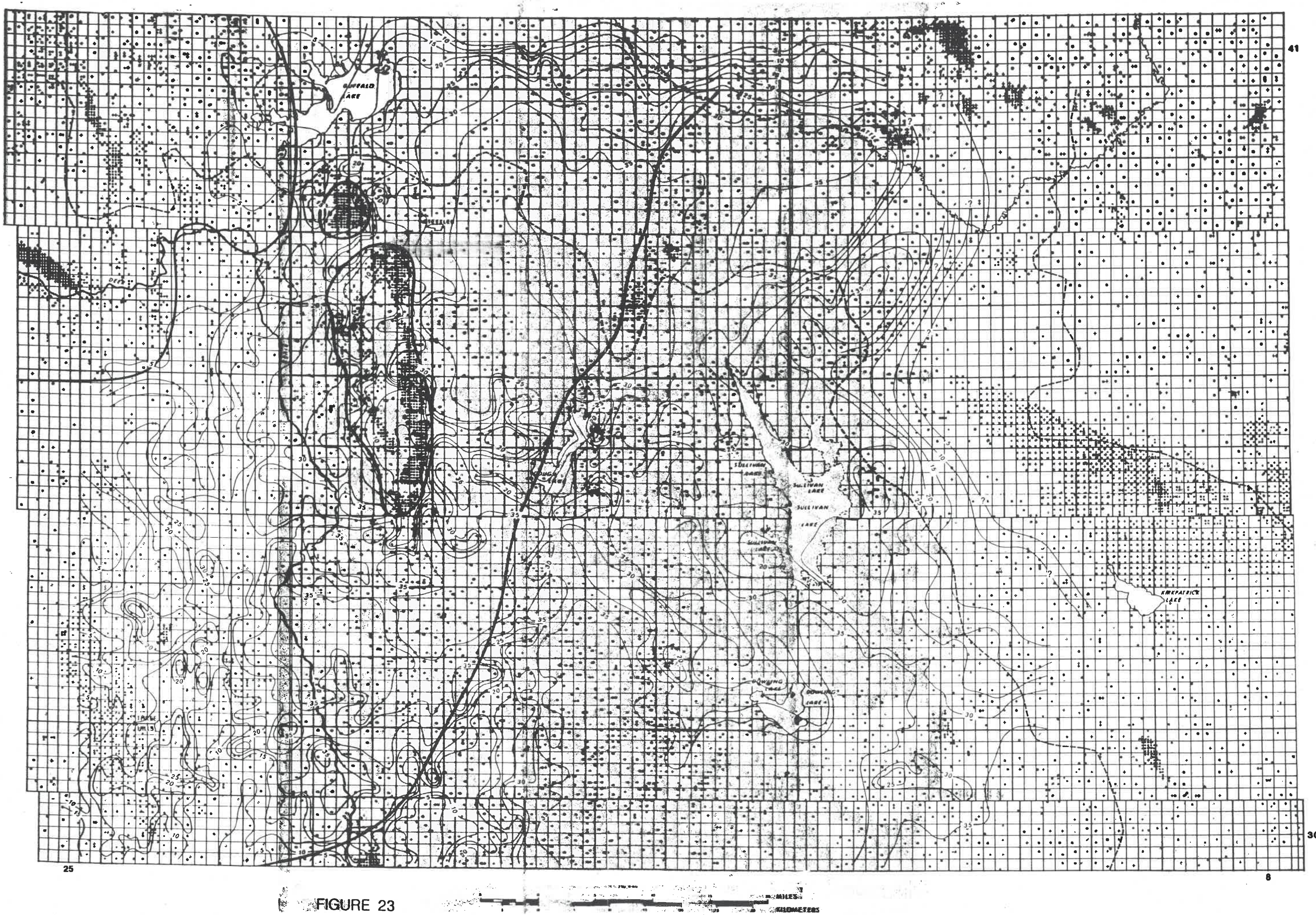
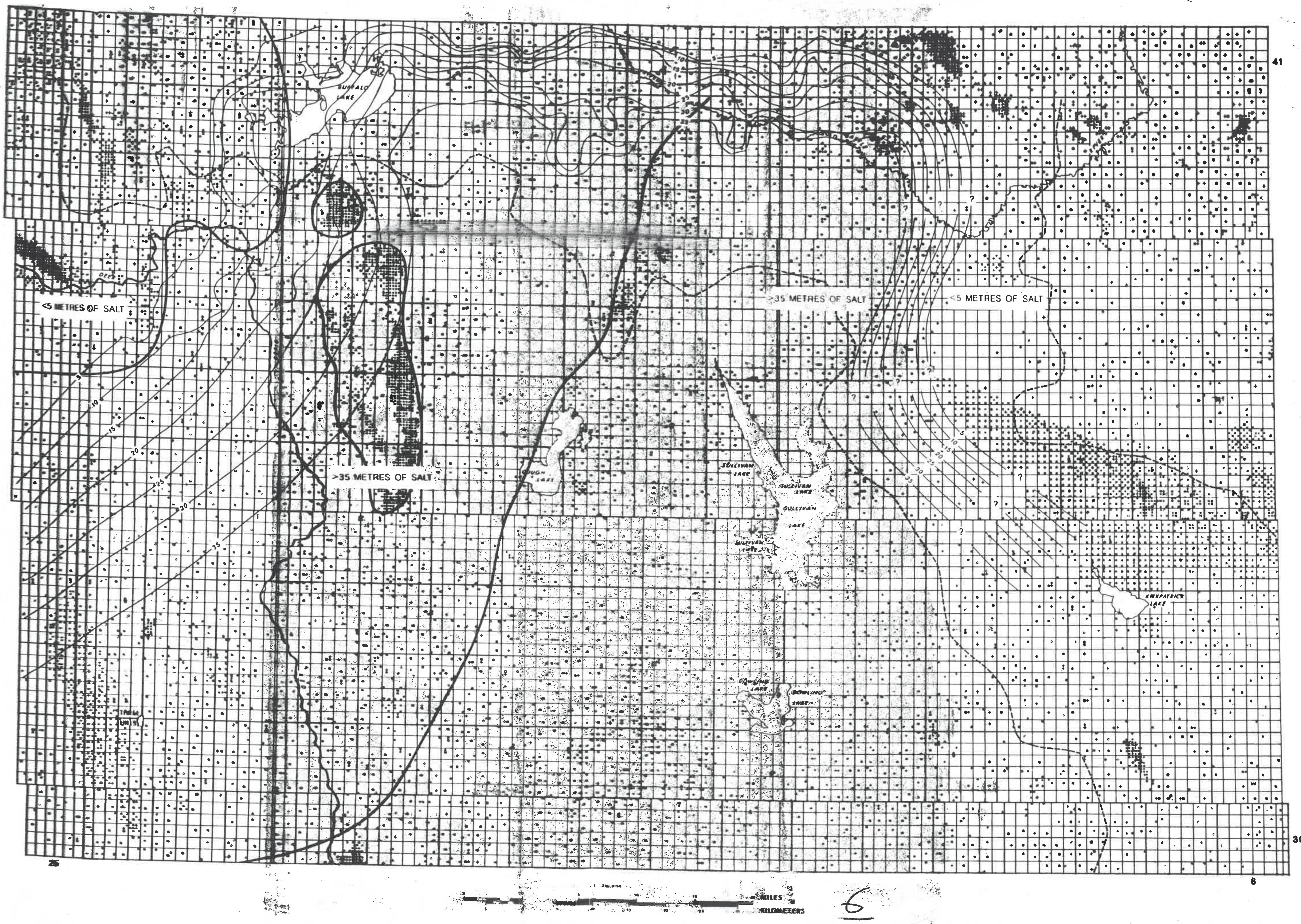
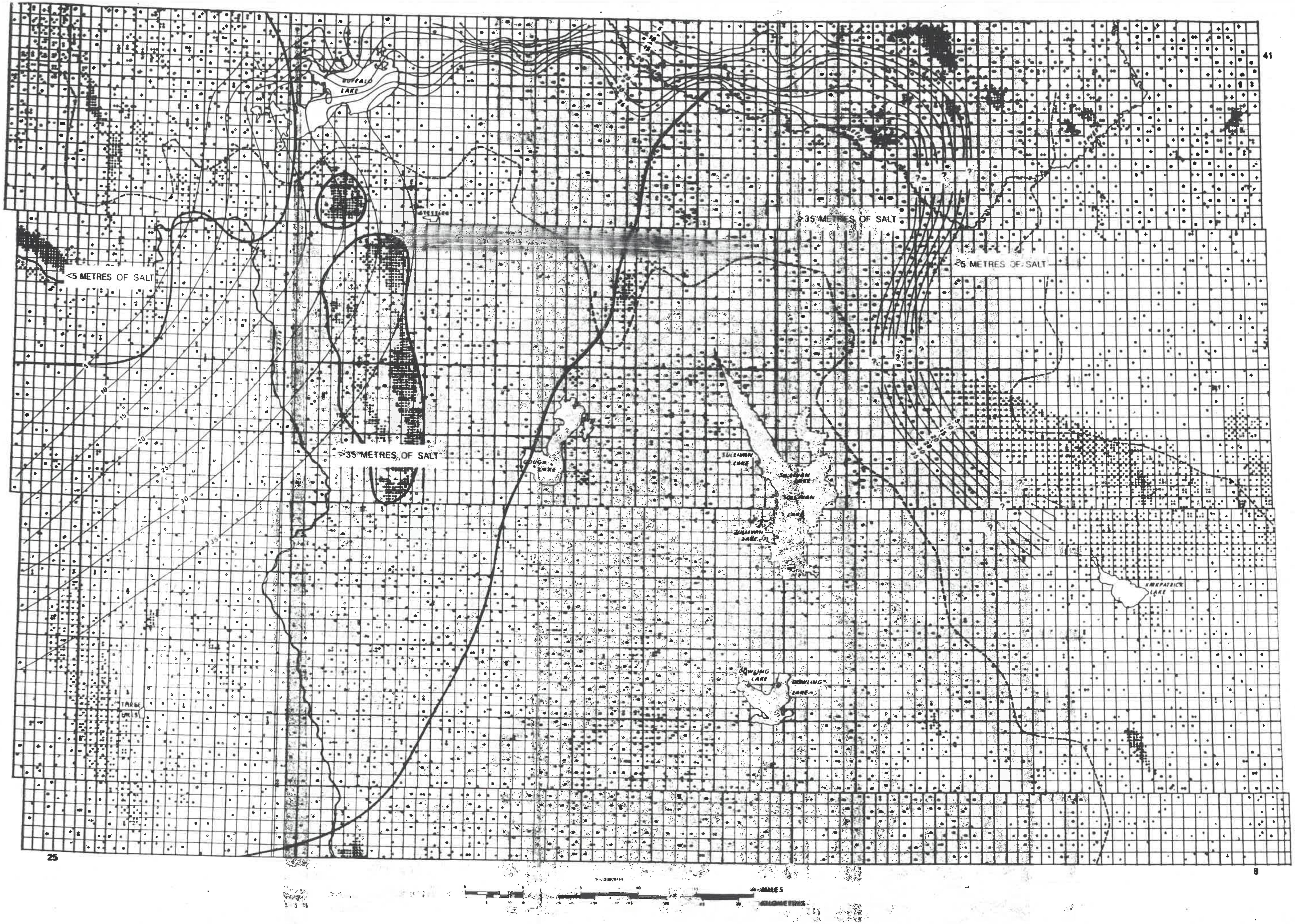


FIGURE 23

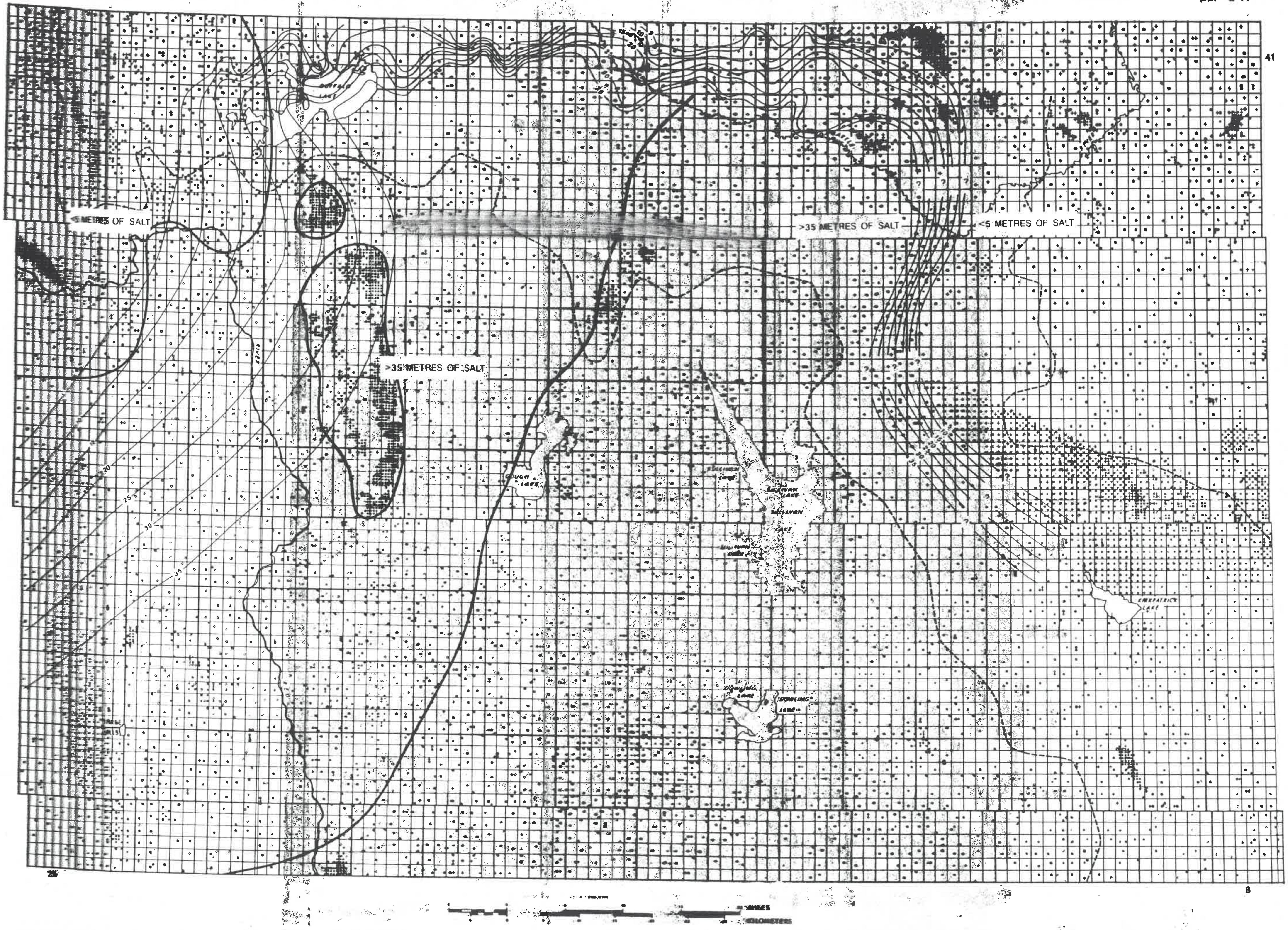

BUFFALO LAKE
<5 METRES OF SALT
>35 METRES OF SALT
>35 METRES OF SALT
<5 METRES OF SALT
GOUGH LAKE
SULLIVAN LAKE
KIRKPATRICK LAKE
DOWLING LAKE
41
30
25
8
MILES
KILOMETERS



BUFFALO LAKE
>35 METRES OF SALT
<5 METRES OF SALT
>35 METRES OF SALT
<5 METRES OF SALT
5
10
15
20
25
30
35
GOUGH LAKE
SULLIVAN LAKE
DOWLING LAKE
KIRKPATRICK LAKE
41
30
25
8
MILES
KILOMETRES

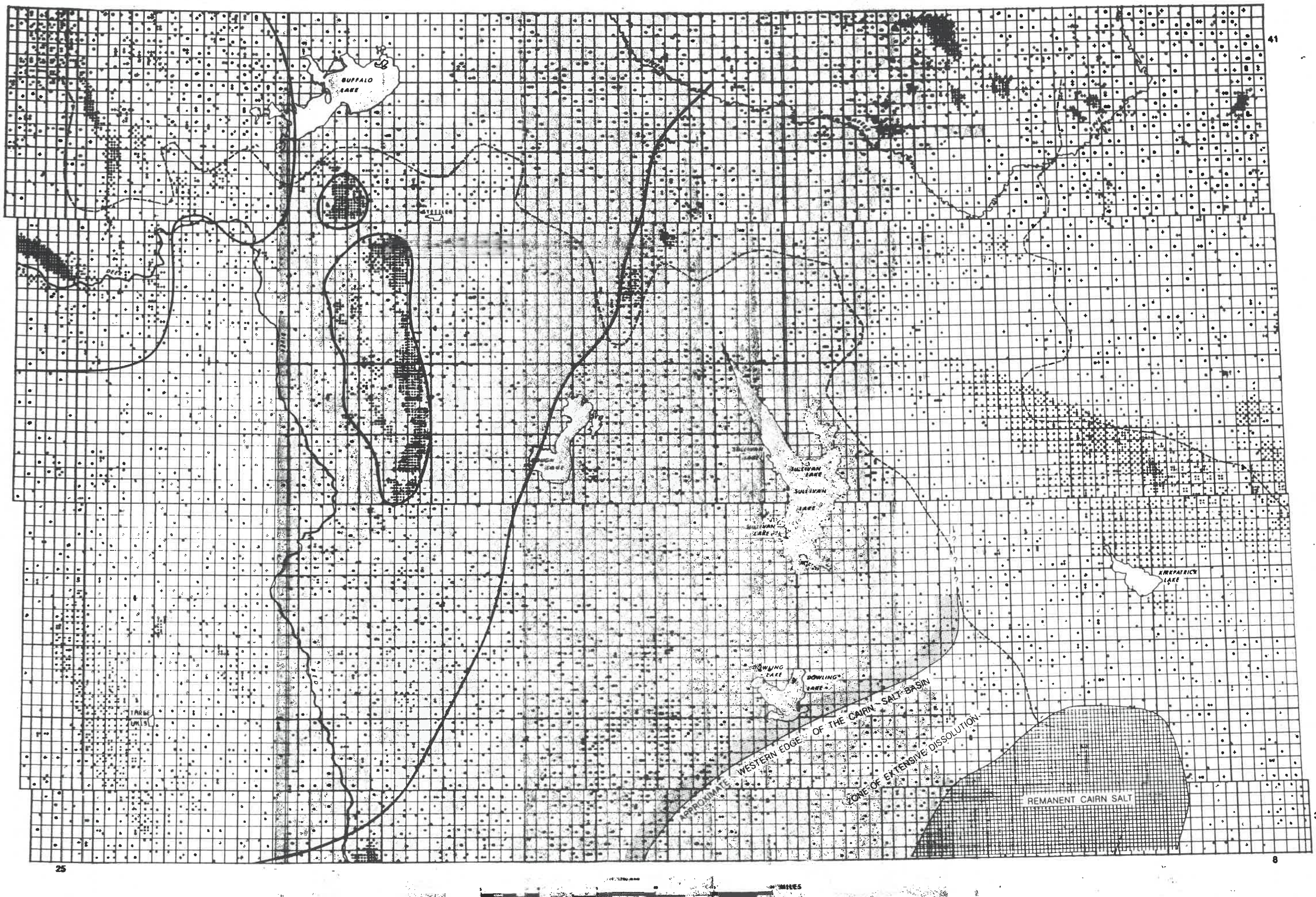
FIGURE 25

ELP & VP


41
<5 METRES OF SALT
>35 METRES OF SALT
<5 METRES OF SALT
>35 METRES OF SALT
20
25
30
35
30
25
8
MILES
KILOMETERS

NEAR ZERO METRES OF SALT
APPROXIMATELY 40 METRES OF SALT
BUFFALO LAKE
SULLIVAN LAKE
DOWLING LAKE
41
30
25
8

FIGURE 5


BUFFALO LAKE
SULLIVAN LAKE
KIRKPATRICK LAKE
DOWLING LAKE
APPROXIMATE WESTERN EDGE OF THE CAIRN SALT BASIN
ZONE OF EXTENSIVE DISSOLUTION
REMANENT CAIRN SALT
41
30
25
8
MILES
KILOMETERS

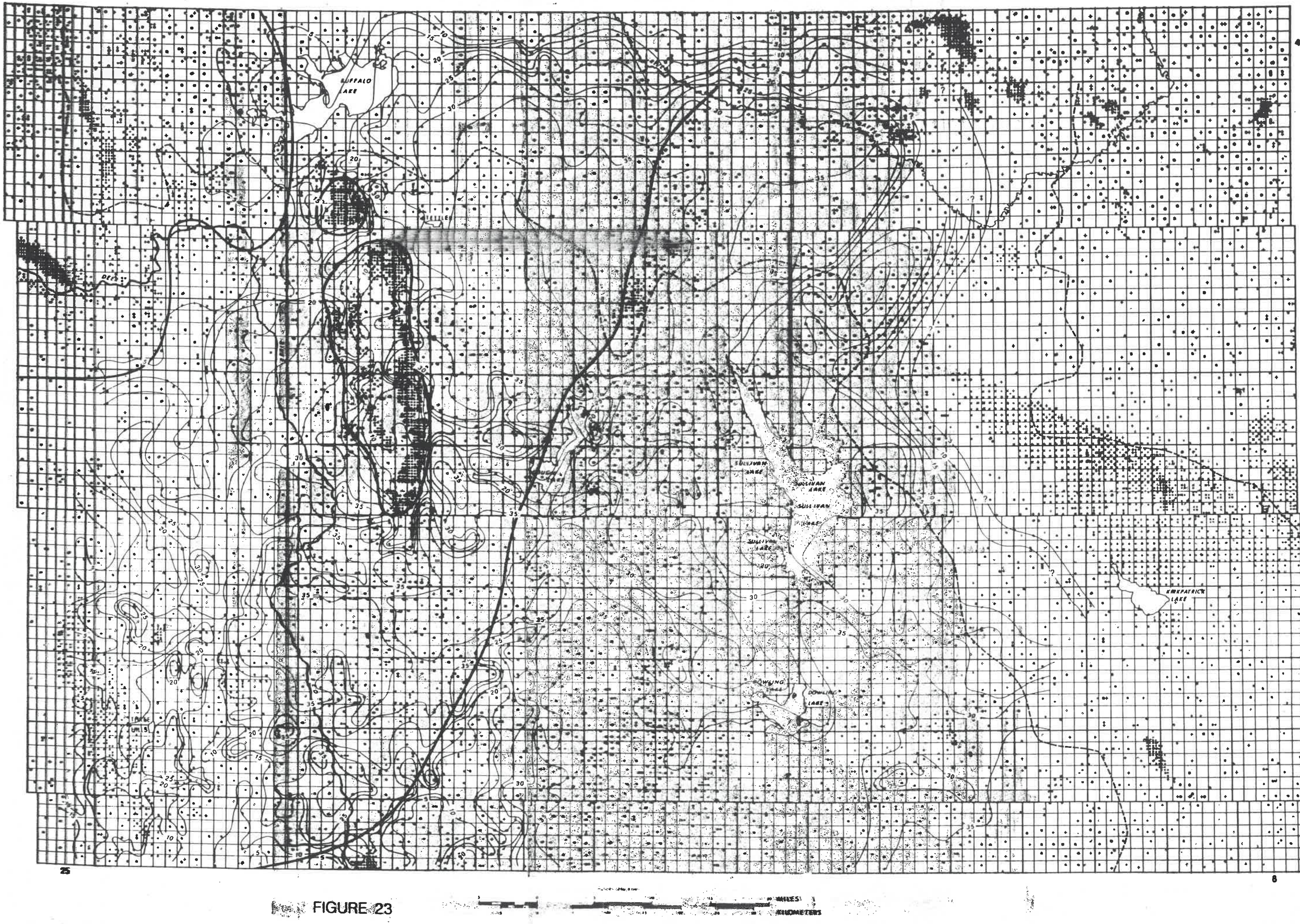

BUFFALO LAKE
SULLIVAN LAKE
DOWLING LAKE
KIRKPATRICK LAKE
41
30
25
8
MILES
KILOMETERS

FIGURE 23