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Paleo-restoration of Leached Salts:
An Overview of the Methodology Used in the
Reconstruction of the Wabamun Group Salt,
Southern Alberta, Canada

by

Neil L. Anderson

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KANSAS GEOLOGICAL SURVEY
1930 Constant Avenue
University of Kansas
Lawrence, KS 66047

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**Paleo-restoration of leached salts:
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Neil L. Anderson*

* Kansas Geological Survey, University of Kansas, 1930
Constant Avenue, Campus West, Lawrence, Kansas 66046

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. (630 cubic km of salt is estimated to have been removed from the Stettler study area alone). 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 partial dissolution of the underlying Cairn salt in post-Wabamun time; 3) regional faulting/fracturing during the late Cretaceous; and 4) glacial unloading. Such leaching appears to be self-perpetuating; a process whereby fractures, created by the collapse of overlying strata, provide a conduit for water, thereby facilitating further dissolution.

We have identified correlation patterns between the thickness of the Wabamun, structural relief at the Wabamun level, relief along post-

Wabamun horizons, and the thickness of the salt remnants. On the basis of these relationships, we have mapped the distribution of the Wabamun Group salt in the Stettler area, southeastern Alberta (T35-41, R14-25 W4M) and reconstructed the distribution of these salts at selected intervals from late Paleozoic to the present. These maps are significant in that they elucidate the timing, the extent, and the mechanisms of dissolution.

INTRODUCTION

The halite salts of the Wabamun Group (Figures 1 and 2) are preserved throughout southeastern Alberta (Figure 3) 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 thicknesses of regionally uniform strata are associated with these salts, suggesting that they were widely distributed, uniformly deposited, and extensively leached. Preliminary work by Anderson and Brown (1991), 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. In support of their conclusions Anderson and co-workers demonstrate that:

A) 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 along the Wabamun outcrop during pre-Cretaceous hiatus (Anderson et al., 1988,1991).

B) In places, Cretaceous strata drape across salt remnants implying that some dissolution occurred during the Cretaceous (Anderson and Brown, 1991; Anderson et al., 1988, 1989, 1991; Brown and Anderson, 1990).

C) Present day drainage patterns appear to correlate in places, to areas of thin salt, suggesting that dissolution is presently occurring (Anderson et al., 1988,1991).

D) Spectacular collapse features are imaged on seismic data across dissolutional edges, implying that leaching and collapse have occurred (Anderson and Brown, 1991; Anderson et al., 1988).

E) Gravity anomalies are observed across some salt remnants. These data are variously consistent with either dissolution during the Paleozoic and the replacement of salt by carbonate, or leaching

during the post-Paleozoic and replacement by clastics (Anderson et al., 1988).

We have followed up these previous studies and discuss herein: 1) the original distribution of the Wabamun salts in the Stettler study area (Figure 4); 2) the present-day distribution of these salts; and 3) the paleo-distribution of these salts. (In the discussion of the paleo-distribution of the Wabamun salts, the principal mechanisms of dissolution are summarized).

ORIGINAL DISTRIBUTION OF THE WABAMUN SALTS

In order to estimate the original distribution of the Wabamun salt in the Stettler study area (OST map; Figure 5), we constructed three maps: 1) net salt (NS), based on sonic/density/ caliper log control only (a modified version of this map (PST) is shown as Figure 6); 2) present-day Wabamun (PDW) structure (Figure 7); and 3) restored Wabamun (RW) structure (Figure 8). (Ideally, the restored Wabamun map was created by replacing all of the dissolved salts). We also studied a proprietary Wabamun isopach map (not shown).

On the net salt map (NS), the halite remnants attain maximum thicknesses on the order of 40 m, suggesting that the initial thickness of

the Wabamun salt was about 40 m. This estimate is supported by the Wabamun isopach map that we examined. More specifically, throughout the study area (T20-25, R34-41 W4M excluded) a direct, linear correlation can be made between the thickness of the salt and the thickness of the Wabamun interval, suggesting that about 40 m of salt were uniformly deposited. To the northwest (T34-41 R20-25 W4M) progressively less correlation is observed, suggesting that the salts depositionally thin in this direction (OST map: Figure 5).

The present-day (PDW) and restored (RW) Wabamun maps also support the theses: 1) that about 40 m of salt were uniformly deposited throughout most of the study area; and 2) that the salts depositionally thin to the northwest. More specifically, the difference in relief between these two maps, at each control point, is consistent with both the thickness of any preserved salt (NS) as well as the initial salt distribution map (OST; Figure 5). Exceptions to these relationships occur the Cairn salt basin (Figure 9). In this area, the underlying Cairn salt was similarly partially dissolved in post-Wabamun time, a process which also resulted in the relative subsidence of post-Wabamun strata. (The superimposed effects of the dissolution of the Cairn and Wabamun salts are very difficult to differentiate in places.)

PRESENT-DAY DISTRIBUTION OF THE WABAMUN SALTS

In order to estimate the present-day distribution of the Wabamun salt (PST; Figure 6), we analyzed three maps: 1) original salt thickness (OST); 2) present-day Wabamun (PDW) structure; and 3) restored Wabamun (RW) structure (Figures 5, 7 and 8, respectively). At each control point, the original salt thickness less the difference between the restored and present-day Wabamun structure values is our present-day salt thickness (PST) estimate. We use the formula: $(PST = (OST - (RW - PDW)))$. (In those areas where Wabamun control does not exist, contouring was constrained by apparent local trends, and structural patterns along shallower horizons).

Note that these salt thickness estimates are based on the assumption that the dissolution of these salts occurred in post-Wabamun time. This thesis is supported by the present-day salt map (PST) which is consistent with: 1) the salt thicknesses (NS values) as determined directly from sonic/ density/caliper log control; 2) the suite of reconstructed salt distribution maps; and 3) the initial salt distribution map (OST).

PALEO-DISTRIBUTION OF THE WABAMUN GROUP SALTS

Reconstruction methodology

The paleo-distribution of the Wabamun salt was estimated using the three steps outlined below:

Step 1) The subsea depths to the seven horizons listed below were determined at about 5000 well locations within the study area; (increasing depth and age, top to bottom:

- A) Lea Park
- B) Colorado
- C) Second Specks
- D) Viking
- E) Mannville
- F) base Cretaceous
- G) Wabamun

Step 2) Both present-day (PDS) and restored structure (RS) maps (Figures 10-21, 7 and 8, respectively; increasing age) were drafted for each of the seven data sets. Ideally, the restored maps represent the patterns of structural relief which would exist if all of the dissolved Wabamun salt were replaced. Differences in structural

relief, between corresponding present-day and restored maps, are therefor estimates of the thickness of salt removed after the deposition of the relevent strata.

The contouring of the restored structure maps was constrained by: 1) well-log control; and 2) several key guidelines. The following key guidelines were used: 1) the contour patterns were to be both consistent with regional trends, and relatively smooth (implying uniform deposition); 2) the estimated thicknesses of dissolved salt were to be consistent with both the present-day (PST) and original (OST) salt thickness maps; and 3) the suite of present-day (PD?) and restored structure (R?) maps were to be compatible, such that the structural difference (PD?-R?) at a specific location on any horizon, was less than or equal to, the difference at that location on any deeper level.

Step 3) The paleo-distribution of the Wabamun salt was determined at the following times (Figures 6, 22-26 and 5, 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 thickness of the salt remnants at these times was estimated on the basis of: 1) the original salt distribution map (OST); 2) the present-day structure maps; and 3) the restored structure maps. For example, the present-day thickness of the salt (PST) was determined first, and estimated to be the original salt thickness (OST) less the difference between the restored (RW) and present-day (PDW) Wabamun structure maps: $(PST = OST - (RW - PDW))$. Similarly, the thickness of the salt at the end of Lea Park time (RLP) was calculated as the present-day (PDT) thickness plus the difference between the restored (RLP) and present-day (PDLP) Lea Park structure maps: $(PDT + RLP - PDLP)$. Salt thicknesses at the other selected times within the Cretaceous were determined in an analogous manner.

Paleo-reconstruction of the salt

The present-day and paleo-distribution of the Wabamun salts is depicted in Figures 6, 22-26, and 5 (increasing age). From these maps several significant conclusions can be drawn:

1) The Wabamun salts were uniformly deposited. The net depositional thicknesses of these salts varies gradually from 0 m in the northwestern part of the study area to about 40 m to the east (Figure 5).

2) 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 partial dissolution of the underlying Cairn salt in post-Wabamun time; 3) regional faulting/fracturing during the late Cretaceous; and 4) glacial unloading.

3) With respect to erosion, the earliest phases of dissolution occurred during the pre-Cretaceous along the projected salt outcrop edge. Later phases occurred successively further to the southwest, suggesting that leaching is a self-perpetuating process (Figures 5, 6, and 22-26).

4) Work by both the senior author and Brown and Anderson (1990) has shown that the Cairn salt (Figure 8) 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 both the Wabamun salt could have been triggered by the leaching of the underlying Cairn. Such leaching could have occurred at any time after the deposition of the Wabamun salt. (Note, that on the suite of reconstructed maps, the leaching of the Wabamun salt in this area is shown as initiating during the Upper Cretaceous; additional detailed work is necessary to convincingly establish whether or not earlier phases of dissolution occurred).

5) The orthogonal patterns of dissolution shown on the suite of paleo-distribution maps strongly suggests that regional faulting/fracturing during the Upper Cretaceous initiated widespread leaching. These patterns also imply that the dissolution fronts, initiated along these fault/ fracture planes, moved laterally thereafter. It is interesting to note that the Stettler reef (T35-38 R20 W4M) is situated across a major lineament, and that the edges of both the main reefs, as well as the Cairn salt, are consistent with the hypothesized fault/ fracture

planes. (Perhaps the lineaments are re-activated planes of weakness.)

6) Several lakes (Buffalo, Gough, Sullivan and Dowling: Figure 6) are situated in areas where the salts are thin or absent, suggesting that significant leaching has occurred in post-glacial times, probably in response to glacial loading and unloading.

7) Dissolution of the Wabamun salt has occurred at various times during the geologic past, supporting the thesis that dissolution, in places, has been more-or-less continuous since deposition. The correlation between the present-day drainage pattern and remanent salt suggests that significant leaching is still occurring.

8) Leaching is self-perpetuating: a process whereby the collapse of overlying strata enhances both their porosity and permeability, thereby providing a conduit for water, and facilitating further dissolution.

9) Several trigger mechanisms have been identified and it has been suggested that leaching is self-perpetuating. With respect to this self-perpetuating process, we note that the established dissolution fronts

do not advance at either a uniform or constant rate. For example, particularly 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 secondary factors influence salt dissolution. Consideration should be given to effects of the intensity and magnitude of faulting, regional tectonism, periods of emergence, underlying reefs, the differential compaction of pre-salt sediment, uneven loading and unloading, glaciation, rebound, facies changes within both the salt and encompassing strata, the local hydrological environment and changes therein, and the effects of wells.

Complicating factors

The methodology employed is based on the premise that the dissolution of subsurface salt causes the contemporaneous collapse of the overlying strata. The thickness of leached salt and the magnitude of collapse are assumed to be equal. Although the methodology appears to be relatively robust, as evidenced by the suite of compatible, consistent, restored structure maps, it might not, in places, adequately account for processes such as: 1) non-uniform deposition or erosion; 2) lateral strain associated with collapse; 3) differential compaction of infill (compensation)

sediments; 4) salt flowage; 5) dissolution of underlying salts; and 6) faulting.

Primary deposition and secondary processes such as erosion and differential compaction (particularly across reefs) can create anomalous lateral variations in sub-surface structure. Although we have attempted to incorporate drape across both known Leduc reefs and the sub-Cretaceous unconformity into our restored structure maps, we have undoubtedly attributed some components of such relief to salt dissolution. As evidenced by the suite of restored maps, the timing of salt dissolution is difficult to estimate to the west of the Wabamun subcrop edge. Due to extreme relief at the Wabamun and post-Wabamun levels in this area, we had difficulties creating consistent restored maps. We were also unable to determine whether the paleo-topography is simply erosional in origin, or if it is partially attributable to the leaching of the Cairn salt (Figure 9).

Our methodology assumes that only vertical strain occurs in response to leaching and does not account for the lateral movement of overlying strata. Although we recognize this source of error, previous work (Anderson and Brown, 1987) suggests that it should not affect our interpretations significantly. Similarly, the differential compaction between the sediments which infill the salt dissolution lows and the adjacent strata

should not compromise our results.

With respect to the mobilization of salt, we have found neither evidence of flowage nor attempted to compensate for such processes. We do however, recognize that the Cairn salt has been extensively leached in post-Wabamun time, in places (Figure 8). Due to a paucity of deep well control, the effects of the dissolution of these two salts are difficult to differentiate. As a result, our reconstructed salt distribution maps have a greater degree of uncertainty in this area. We have not seen any evidence that the Prairie salt (Figure 1) has been leached, however well control at this level is sparse.

The patterns of dissolution on the suite of reconstructed salt distribution maps (Figures 6, 21-26, and 5) suggest that leaching, in places, was initiated by widespread regional faulting and/or fracturing in the late Cretaceous (as opposed to localized slumping due to the dissolution of pre-Wabamun salts). Although there is no conclusive evidence of vertical displacement, significant movement (on the order of 10 m or more) could have occurred and may be incorrectly attributed to either salt dissolution and/or drape across either reefs or the pre-Cretaceous subcrop. The relative absence of salt in the southwestern part of the study area suggests that the intensity of faulting might have been

greater here.

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. We have, as well, discussed our reconstruction methodology and concluded that it is relatively robust. This technique can be applied to areas where the effects of leaching are not effectively masked by other processes including erosion, compaction and salt flowage.

REFERENCES

AGAT Laboratories, 1988, Table of formations of Alberta: AGAT Laboratories, Calgary.

Anderson, N.L., and Brown, R.J., 1987, The seismic signatures of some western Canadian Devonian reefs: Journ. Can. Soc. Expl. Geophy. 1, 7-26.

Anderson, N.L., Chapman, J., and Brown, R.J., 1991, Present-day and initial distribution of the Wabamun Group salt, Alberta, Canada; Bull. Can. Petr. Geol., submitted.

Anderson, N.L., Brown, R.J., and Hinds, R.C., 1988, Geophysical aspects of Wabamun salt dissolution in southern Alberta: Can. Jour. Expl. Geophy. 24, 166-178.

Anderson, N.L., White D.G., and Hinds, R. C., 1989, Woodbend Group Reservoirs, in Anderson, N.L., Hills, L.V., and Cederwall, D.A., Eds., Geophysical atlas of western Canadian hydrocarbon pools: Can. Soc. Expl. Geophy. and Can. Soc. Petr. Geol., 101-132.

Anderson, N.L., and Brown, R.J., 1991, Black Creek and Wabamun salt collapse features, Western Canadian Sedimentary Basin: Geophy., accepted pending revisions.

Belyea, H.R., 1964, Woodbend, Winterburn and Wabamun groups, in McCrossan, R.G. and Glaister, R.P., Eds., Geological history of western Canada: Alta. Soc. Pet. Geol., 66-88.

Brown, R.J., and Anderson, N.L., 1990, An overview of salt dissolution and related hydrocarbon trapping potential in western Canada: Bull., Am. Ass. Petr. Geol., submitted.

Hopkins, J.C., 1987, Contemporaneous subsidence and fluvial channel sedimentation: Upper Mannville C pool, Berry field, Lower Cretaceous of Alberta: Bull., Am. Ass. Petr. Geol. 71, 334-345.

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) depicting the original distribution (hypothesized) of the Wabamun Group salts.

Figure 6. Contour map (in meters) depicting the present day distribution of the Wabamun salts.

Figure 7. Contour map (in meters) of the subsea depth to the top of the Wabamun.

Figure 8. Restored contour map (in meters) depicting what the elevation of the Wabamun (hypothesized) would be if dissolution had not occurred.

Figure 9. Map depicting the Cairn salt basin and the present-day distribution of the Cairn salt.

Figure 10. Contour map (in meters) of the subsea depth to the top of the Lea Park.

Figure 11. Restored contour map (in meters) depicting what the elevation of the Lea Park (hypothesized) would be if dissolution had not occurred.

Figure 12. Contour map (in meters) of the subsea depth to the top of the Colorado.

Figure 13. Restored contour map (in meters) depicting what the elevation of the Colorado (hypothesized) would be if dissolution had not occurred.

Figure 14. Contour map (in meters) of the subsea depth to the top of the Second Specks.

Figure 15. Restored contour map (in meters) depicting what the elevation of the Second Specks (hypothesized) would be if dissolution had not occurred.

Figure 16. Contour map (in meters) of the subsea depth to the top of the Viking.

Figure 17. Restored contour map (in meters) depicting what the elevation of the Viking (hypothesized) would be if dissolution had not occurred.

Figure 18. Contour map (in meters) of the subsea depth to the top of the Mannville.

Figure 19. Restored contour map (in meters) depicting what the elevation of the Mannville (hypothesized) would be if dissolution had not occurred.

Figure 20. Contour map (in meters) of the subsea depth to the top of the base Cretaceous.

Figure 21. Restored contour map (in meters) depicting what the elevation of the base Cretaceous (hypothesized) would be if dissolution had not occurred.

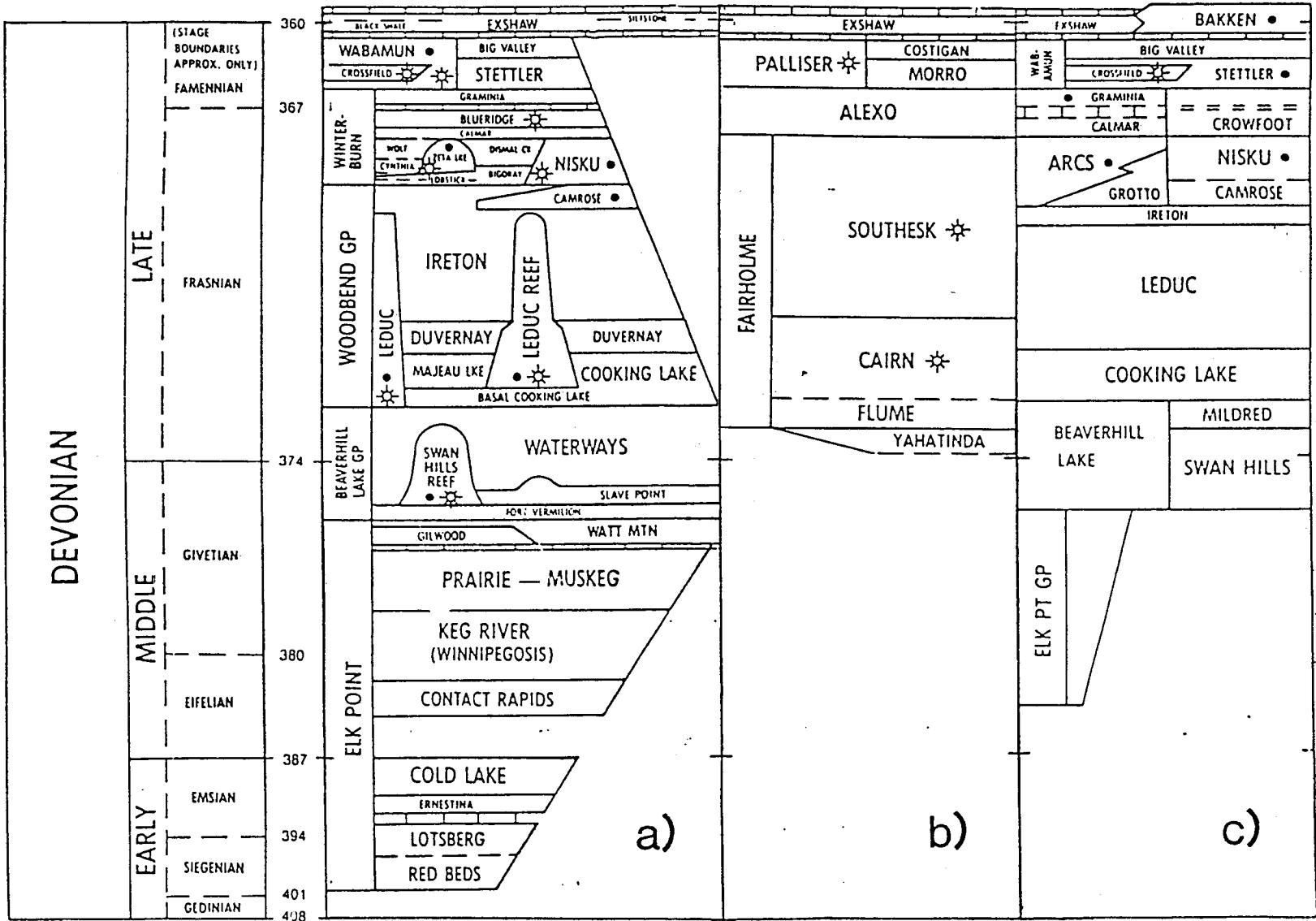
Figure 22. Contour map (in meters) showing the distribution (hypothesized) of the Wabamun salts at the end of Lea Park time.

Figure 23. Contour map (in meters) showing the distribution (hypothesized) of the Wabamun salts at the end of Colorado time.

Figure 24. Contour map (in meters) showing the distribution (hypothesized) of the Wabamun salts at the end of Second Specks time.

Figure 25. Contour map (in meters) showing the distribution (hypothesized) of the Wabamun salts at the end of Viking time.

Figure 26. Contour map (in meters) showing the distribution (hypothesized) of the Wabamun salts at the end of Mannville time.



7-11-24-15W4

16-24-25-13W4

