

**Large scale mechanisms
of salt dissolution:
illustrated case histories**

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KANSAS GEOLOGICAL SURVEY
OPEN-FILE REPORT 91-57

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ABSTRACT

There are six main Devonian salts in Alberta, those of the Lotsberg Formation, Cold Lake Formation, Prairie Formation (and equivalents), Beaverhill Lake Group, Leduc Formation and Wabamun Group. Each of these salts has been extensively leached in places and as a result of one or more large-scale mechanisms.

In an effort to elucidate some of the large-scale mechanisms of salt dissolution, we have conducted a number of regional and local studies of the Devonian salts. On the basis of both our work and a review of the published literature, we have concluded that salt-dissolution, in western Canada, is generally attributable to one or more of the following seven principal processes: 1) the centrifugal flow of unsaturated groundwater from the basin interior and towards the basin margin; 2) the near-surface exposure of salt as a result of erosion; 3) the centripetal (basinward) flow of unsaturated waters from the basin margin and towards the basin interior; 3) regional faulting/fracturing; 4) pressure dissolution/localized fracturing; 5) glacial loading and/or unloading; 6) dissolution of the underlying salt; and 7) salt flow. In addition we have concluded that leaching self-perpetuating; a process whereby fractures, created by the collapse of overlying strata, provide conduits for water thereby facilitating

further dissolution.

In support of our premise that these seven principal large-scale mechanisms initiate and/or accentuate the leaching of subsurface salts in western Canada, we present three dissolution case histories. In each case, the observed leaching can attributed to one or more of our proffered causes.

INTRODUCTION

There are six main Devonian salts in Alberta, those of the Lotsberg Formation, Cold Lake Formation, Prairie Formation, Beaverhill Lake Group, Leduc Formation and Wabamun Group. The Lotsberg and Cold Lake salts are Early Devonian age; the Prairie salts (Muskeg and Black Creek equivalent) are Middle Devonian age; the Beaverhill Lake, Leduc and Wabamun are Upper Devonian in age (Figure 1).

There are significant differences between these six main Devonian salts: some are thick (>160 m) - others are thin (<45 m); some are massive - others are bedded; some are areally extensive - others are areally restricted. In spite of all of their differences, these salts have one common characteristic; each has been extensively dissolved in places.

The leaching of these salts is of significant interest 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 such as topographic highs that are controlled by salt edges or remnants; 3) structural traps can form where reservoir facies are draped across salt remnants or collapse features; and 4) salt remnants can be misinterpreted

as reefs, faults or other structural features.

In view of the relationships between salt dissolution and hydrocarbon traps, it is imperative that the explorationist determine the causes (large scale mechanisms) and timing of such leaching. These parameters are very closely linked. Often by elucidating the timing, we can pinpoint the cause; in other situations, by elucidating the most probable cause, we can pinpoint the timing. The cause and timing must be compatible.

In Anderson and Brown (1991a), a technique for elucidating the timing of salt dissolution is presented. These authors describe a well-log based study of the Stettler area, Alberta in which they identified correlation patterns involving the thicknesses of the Wabamun interval, structural relief at the Wabamun level, relief along post-Devonian horizons, and the thicknesses of the remnants of Wabamun salt. On the basis of these relationships, they reconstructed the distribution of these salts (Wabamun Group) at selected times from late Paleozoic to the present and effectively determined the timing of salt dissolution. On the basis of their interpretations, these authors proposed several large-scale mechanisms as the most probable causes of the inferred periods of intensive leaching.

We have employed the technique described by Anderson and Brown (1991a) in follow-up studies of the Wabamun and Leduc salts, and the Prairie salts in the Youngstown area and Lloydminster area, respectively. On the basis of these most recent studies, and previously published work by these authors as well as others, we have compiled an overview of some of the envisioned large scale mechanisms of salt dissolution.

LARGE-SCALE MECHANISMS OF DISSOLUTION

In the published literature, various authors have demonstrated that in places each of the six main Devonian salts has been post-depositionally leached in places. In some instances the phenomena of dissolution is simply documented; in other instances, the causes (large-scale mechanisms) and timing of the observed leaching is discussed. In the more detailed analyses of dissolution, the authors generally conclude that the inferred major episodes of dissolution were initiated and/or enhanced by one or more of the following seven principal processes: 1) the centrifugal flow of unsaturated groundwater from the basin interior and towards the basin margin; 2) the near-surface exposure of the salts as a result of erosion; 3) the centripetal (basinward) flow of unsaturated waters from the basin margin and towards the basin interior; 3) regional

faulting/fracturing; 4) pressure dissolution/localized fracturing; 5) glacial loading and/or unloading; 6) dissolution of the underlying salt; and 7) salt flow. In addition the researchers often conclude that leaching self-perpetuating; a process whereby fractures, created by the collapse of overlying strata, provide conduits for water thereby facilitating further dissolution.

Centrifugal-flow (Figure 2)

Sediments in the shallow subsurface of a subsiding, juvenile basin are subjected to diagenesis; the sum total of all physical, chemical and biochemical changes in a sedimentary deposit after burial (excluding metamorphism). Many facets of diagenesis involve the expulsion of interstitial waters of various origin (eg. physical compaction of sediment, dehydration of clay minerals, the conversion of gypsum to anhydrite).

According to Perrodon (1983), in normally-pressured sediment, this interstitial water is progressively expelled from the deepest zones subjected to the highest pressures, and migrates towards zones with a weaker potential, laterally towards the edges and vertically through the beds into the surface layers. As a result of the thermal expansion of the deep aquifers, interstitial water at depth also flows from the warmer basin center towards the colder basin margins. Generally, as a result of

electrofiltration, the expelled waters are less saline than the interstitial waters that remain.

The outward flow of unsaturated interstitial waters in response to burial, could result in the dissolution of subsurface salt. For example, leaching, as a result of the lateral flow of fluids, could occur along the upper and lower surfaces of salt beds in those places where the salt beds and aquifers were juxtaposed. Perhaps the most extensive dissolution would occur near the outer margins of the salt bed, as a result of the increased relative vertical permeability and the focusing of vertically migrating waters.

Near-surface exposure (Figure 3)

Salt is chemically unstable at the earth's surface and under typical atmospheric conditions is readily dissolved. As a result, it is rarely preserved in either outcrop or subcrop. The inference is that dissolution will generally occur in response to the erosion of the overlying sediment and the resultant near-surface exposure of the salt. Physical, chemical and biochemical changes in the adjacent sediments, as a consequence of erosion and near-surface exposure, could also facilitate leaching.

Centripetal-flow (Figure 4)

According to Perrodon (1983), in a mature basin of great structural stability and relatively low geothermal gradient, hydrological flow will be from the highland areas towards the basin center. This influx of water could cause extensive dissolution of subsurface salts, particularly in places where the salts are in direct contact with unsaturated aquifers. The earliest phases of centripetal-flow induced dissolution could be expected to occur along the edges of the salt nearest the basin margins where the salinity of the water would be at a minimum, and the relative vertical permeability of the sediment would be the maximum.

Regional faulting/fracturing (Figure 5)

Regional tectonism can cause widespread fracturing and/or faulting of varying intensity. These fault/fracture planes can act as conduits in the subsurface and enhance both the lateral and vertical flow of fluids, thereby facilitating the dissolution of salt.

It is also recognized that regional tectonism can result in uplift and erosion, rapid subsidence and/or major changes in the geothermal gradient. Such processes could significantly affect the hydrological environment of some or all salt. Any resultant leaching could be classified as due to near-surface exposure, centripetal flow, centrifugal flow, etc.

Pressure dissolution/localized fracturing (Figures 6 and 7)

The differential compaction of juxtaposed sediments such as reef and off-reef shales, and crystalline basement and sedimentary fill generally introduces post-depositional structure into the sub-surface. Localized tensional fracturing and/or pressure dissolution could occur in the overlying strata in response to this gradual deformation. (Pressure dissolution is a process in which a solid dissolves along its contact with another solid, and in the presence of water, because increased pressure has increased its solubility.)

There are many situations in western Canada where, as a result of the differential compaction of underlying sediments, salts are draped across underlying structures. It is conceivable that such salts could be subjected to pressure dissolution and/or leached as a result of the the introduction of fracture permeability into the adjacent strata.

Glacial loading and/or unloading (Figure 8)

The process of glacial loading could significantly affect the hydrological environment of the subsurface. The rapidly applied load would cause further compaction and necessitate the expulsion of additional interstitial water. An increase in the geothermal gradient and the thermal expansion of the deep aquifers could result as well. Conceivably the rate of

centrifugal flow within the basin could be significantly increased and the associated dissolution of salts could be accentuated.

The process of glacial unloading could also significantly affect sub-surface salts. The relatively rapid decrease in applied load would be manifested as glacial rebound. This process could result in a net increase in the gross porosity and fracture permeability of the sub-surface, and a net decrease in the geothermal gradient. As a consequence, the rate of centripetal flow could be significantly enhanced. (It is conceivable that the flow regime could change from centrifugal to centripetal.) This postulated increase in flow rates and the potential influx of unsaturated glacial meltwaters could significantly enhance the rate of salt dissolution.

Dissolution of the underlying salt (Figure 9)

The subsurface is heterogeneous, both with respect to lithology and hydrology. As a result, certain bodies of salt could be more susceptible to dissolution than others. In those situations where underlying salts are preferentially leached, the resultant collapse of the overlying strata could create fracture permeability and initiate or accentuate the dissolution of the upper salts.

Salt movement (Figure 10)

The movement of salt is generally thought to occur in response to the density differential between salt and the adjacent strata, differential loading, and lateral stresses, and to be enhanced by the presence of water. Salt flow has been documented at the earth's surface (Kent, 1979), but more typically occurs at depth and in a higher temperature/higher pressure environment. Such movement stresses the overlying strata and is likely to cause the development of fracture permeability and to result in the leaching of the salts.

Dissolution: a self-perpetuating process (Figure 11)

The dissolution of sub-surface salts is thought to be triggered by numerous dependent and independent mechanisms, some of which are discussed above. Once leaching has been initiated at a specific site, however, the associated salt-dissolution front appears to migrate over time indicating that leaching is self-perpetuating; a process whereby fractures, created by the collapse of overlying strata, provide conduits for water thereby facilitating further dissolution.

CASE HISTORY EXAMPLES

The dissolution of the Devonian salts in western Canada has been extensively discussed in the literature. Below, we review three previously published case histories with a view to illustrating and supporting our thesis that the dissolution of salt in the western Canadian Sedimentary Basin can generally be attributed to one or more of seven principal large-scale mechanisms. In each of the case histories, Prairie Evaporite (or equivalent) salt has been dissolved (Figure 12).

Lloydminster Area: west-central Saskatchewan

The Prairie Evaporite is subdivided into three units: the basal Whitkow Member salt, the Shell Lake Member anhydrite, and the upper Leofnard Member salt. Only the Leofnard salt was deposited in the vicinity of the geologic section (Figures 13). In the study area it attains maximum thicknesses on the order of 150 m and consists of interbedded massive salts and thin anhydrite, with minor dolostone and shale.

Anderson and Brown in an unpublished study of the Lloydminster area (T35-65, R15W3M-R10W4M), Brown and Anderson (1992), and Cederwall and Anderson (1991) conclude that the leaching of the Prairie Evaporite salts was triggered and/or accentuated by some or all of six principal processes: A) the near-surface exposure of these salts, as a result of the

erosion of the overlying Paleozoic sediment during the pre-Cretaceous hiatus; B) the influx of meteoric water, which could have been introduced into the system along the Elk Point out-crop/subcrop to the east; C) the partial dissolution of the underlying Cold Lake and upper Lotsberg salt; D) faulting/fracturing during or after the mid-Late Cretaceous; E) salt movement; and F) glacial loading and unloading. As support for some of their conclusions, the geologic section of Figure 13 is presented. These sections cross the main eastern dissolutional edge of the Prairie Evaporite salt.

As a result of erosion during the pre-Cretaceous, the Elk Point Group subcrops to the east of the Lloydminster study area. The consensus in the literature is that Prairie salts were initially deposited within the subcropping section, but were leached when exposed to a near-surface environment. Anderson and Brown (1991) postulate that the dissolution front, that was established along the Elk Point outcrop during the pre-Cretaceous, migrated basinward thereafter. These authors conclude that in general terms, the rate of advance was relatively high in pre-Cretaceous and earliest Cretaceous time, relatively low during the Early Cretaceous to mid-Late Cretaceous interval, and moderate thereafter. With respect to the geologic sections (Figures 13 and 14), we submit that the main dissolution front was situated to the east of these lines prior to the deposition of the

upper Colorado (mid-Late Cretaceous time), and that most of the leaching in these vicinities occurred thereafter. As a consequence, the regional southwesterly dip of the Colorado has been locally reversed.

The postulated process of dissolution in and to the east of the Lloydminster study area as outlined below, is consistent with the previously cited large-scale mechanisms of dissolution.

- 1) Dissolution is thought to have initiated, during pre-Cretaceous time as a result of the near-surface exposure of these salts along the Elk Point subcrop edge.

- 2) The established dissolution front is believed to have migrated basinward and relatively rapidly during the pre-Cretaceous hiatus. The rate of advance appears to have slowed significantly during the Early to mid-Late Cretaceous interval. These conclusions are consistent with accelerated centripetal flow as a result of uplift and unloading during the pre-Cretaceous, and decelerated flow as a result of renewed subsidence thereafter. Another point to consider is that with the onset of Cretaceous sedimentation, the Elk Point outcrop would be covered with clastic deposits and in hydrologic contact with marine water. The influx of water would be additionally

slowed, and the dissolution potential of such water would be diminished.

3) As evidenced by the geologic section, the rate of salt dissolution increased markedly in mid-Late Cretaceous time. Similar observations have been reported by Anderson and Brown (1991a) for the Wabamun and Leduc salts in the Stettler area of Alberta. These authors have identified lineaments on reconstructed salt distribution maps, and suggest that they were caused by regional faulting and/or fracturing during the mid-Late Cretaceous (Anderson et al., 1988a). The proximity of the Stettler and Lloydminster area and the linearity of the main Prairie Evaporite salt edge suggests that the same mechanism could have affected leaching here.

4) The nature of the main Prairie Evaporite salt edge is consistent with the thesis that some movement of these salts has occurred during or after the mid-Late Cretaceous. Such movement (envisioned by the authors as somewhat analogous to growth-fault type slumping/salt flow; Figure 15) could have been triggered by the postulated regional faulting/fracturing or glacial loading. This process could have been and enhanced by pre-existing fault/fracture planes and/or an influx of meteoric water.

5) Several lakes and rivers (Jackfish Lake, Murray Lake, Birch Lake, Helene Lake, Midnight Lake, Stony Lake, Turtle Lake, Brightsand Lake, Bronson Lake, Cold Lake, Marie Lake, and Saskatchewan River) in the study area of Anderson and Brown (T35-65, R15W3M-R10W4M) are situated in areas where the Leofnard salts are thin or absent, suggesting that a significant amount of leaching has occurred in post-glacial times, possibly in response to glacial loading and unloading.

Trout Area: north-central Alberta

The anhydritic equivalent of the Prairie Evaporite in northern Alberta is known as the Muskeg Formation. It is described by Meijer Drees (1986) as a light coloured succession of interbedded white and grey salt, brown anhydrite, brownish gray dolostone and limestone. In the Trout area, salt comprises about one-half of the section, with the exception of those isolated places where extensive dissolution has occurred (Figure 16).

Anderson et al. (1988, 1989) interpret seismic and geologic data from the Trout field study area (Figure 16) with a view to documenting the seismic signature of the dual Keg River/Granite Wash reservoir and elucidating the

localized dissolution of Muskeg salts. These authors conclude that the Keg River reservoir facies depositionally pinched-out against the flanks of the pre-existing Precambrian structure penetrated by the 2-10 well, and are now structurally closed as a result of differential compaction on and off-structure. The authors also note that the salts of the Muskeg Formation have been extensively leached from the 2-10 well site, apparently during the deposition of the upper Beaverhill Lake Group. They indicate that the area of extensive leaching is proximal to the more-or-less circular basement high and suggest that the dissolution was focused by this underlying structure. Their conclusions are supported by a suite of plan view maps, geologic sections and seismic control from the region.

We have followed up our earlier work in an effort to elucidate some of the large-scale mechanisms of leaching in the Trout area. Our preferred thesis is that the dissolution at the 2-10 well site was triggered and/or accentuated by two principal causes: centrifugal flow and localized fracturing/pressure dissolution. Our rationale is as follows.

- 1) During the early Late-Devonian, the transgressive sediments of the Beaverhill Lake Group were being deposited on a regional scale. As a result of burial and the associated diagenetic changes, interstitial fluids were being expelled from the relatively thin veneer of

underlying Elk Point strata.

2) Contemporaneously, at the Trout site and elsewhere, significant differential compaction was occurring between crystalline basement structures (2-10 well) and the off-structure, infilling clastic/carbonate/evaporite facies. We suggest that the process of differential compaction resulted in the localized pressure dissolution of the Muskeg salts and stress and/or collapse-related fracture permeability in the vicinity of the 2-10 well site. This zone of increased permeability provided conduits for the over-pressured, interstitial waters within the underlying Elk Point strata, thereby facilitating additional leaching.

Rainbow area: north-west Alberta

The Muskeg Formation in the Rainbow area is subdivided into the basal Black Creek Member salt and the upper anhydritic member. The basal salt attains thickness of about 80 m, and is described as light-grey, semi-translucent, coarsely crystalline, and containing thin stringers of anhydrite. These salts are thought to have been widely distributed and uniformly deposited within the Rainbow area. As a result of extensive post-

depositional dissolution the distribution of these salts is not what it once was (Figure 17).

According to several authors including Anderson et al. (1989), Brown et al. (1989), and Anderson and Brown (1991b) the dissolution of the Black Creek salt in the Rainbow area initiated shortly after deposition and continued into the post-Mississippian. Their concept is supported by the geologic section of Figure 17. Specifically, note that the salt collapse features decrease in amplitude going upward in the section, but that the rate of decrease in amplitude varies laterally. This implies that dissolution has occurred at varying times in different places even on this local scale, and supports the thesis that leaching has occurred, in places, more-or-less continuously since deposition.

Anderson et al. (1989), Brown et al. (1989), and Anderson and Brown (1991a) suggest that the dissolution of the Black Creek salt in the Rainbow area was initiated about the peripheries of the isolated reefs and along the margins of the reef-fringed Black Creek sub-basin shortly after deposition (upper Muskeg time). These authors suggested that leaching was initiated at those places where the salts were proximal to relatively porous and permeable reefal carbonates. These authors concluded that salt dissolution is, at least in some instances, a self-perpetuating process and

that these salt dissolution fronts, once established, would migrate laterally. These authors also indicated that they had mapped a NNE-trending, salt-dissolution lineament on seismic data in the Black Creek area. They state that the lineament effectively parallels the Hay River fault, and that it is characterized by both a relatively narrow zone of extensive leaching and vertical displacement of post-salt strata. They concluded that some of the leaching in the Rainbow area, could have been caused by the reactivation of pre-existing planes of weakness.

These postulated processes of dissolution in the Rainbow study area, are consistent with two of the previously cited large-scale mechanisms of dissolution: centrifugal flow and regional fracturing/faulting.

- 1) The observation that the earliest phases of leaching occurred in proximity to reef is most easily attributed to centrifugal fluid flow through these porous and permeable carbonates. During upper Muskeg time in the Rainbow area, anhydrites and carbonates were being deposited in the inter-reef areas. Diagenetic processes at depth would have resulted in the expulsion of interstitial waters. It is very conceivable that the reefs acted as a conduit for such fluids, and that such fluids dissolved the proximal salts. These established salt-dissolution fronts could have migrated away from the reefs in a

self-perpetuating manner.

2) The presence of a single, 12 km long, NNE-trending salt-dissolution lineament on seismic data is strong (though not conclusive) evidence of regional faulting/fracturing, particularly in that it is consistent with the orientation of the Hay River fault. The observed pattern could also have been caused by preferential pathways along an advancing salt-dissolution front.

SUMMARY

There are six main Devonian salts in Alberta, those of the Lotsberg Formation, Cold Lake Formation, Prairie Formation (and equivalents), Beaverhill Lake Group, Leduc Formation and Wabamun Group. Each of these salts is different: some are thick (>160 m) - others are thin (<45 m); some are massive - others are bedded; some are areally extensive - others are areally restricted. Yet, each of these salts have one common characteristic; they have all been extensively dissolved in places.

The leaching of these salts is of significant interest 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 such as topographic highs that are controlled by salt edges or remnants; 3) structural traps can form where reservoir facies are draped across salt remnants or collapse features; and 4) salt remnants can be misinterpreted as reefs, faults or other structural features.

In an effort to elucidate the process of leaching, we have conducted a number of regional and local studies of the Devonian salts. On the basis of both our work and a review of the published literature, we have concluded that salt-dissolution, in western Canada, is generally attributable to one or more of the following seven principal processes: 1) the centrifugal flow of unsaturated groundwater from the basin interior and towards the basin margin; 2) the near-surface exposure of salt as a result of erosion; 3) the centripetal (basinward) flow of unsaturated waters from the basin margin and towards the basin interior; 3) regional faulting/fracturing; 4) pressure dissolution/localized fracturing; 5) glacial loading and/or unloading; 6) dissolution of the underlying salt; and 7) salt flow. In addition we have concluded that leaching self-perpetuating; a process whereby fractures, created by the collapse of overlying strata, provide conduits for water thereby facilitating further dissolution.

In support of our premise that these seven principal large-scale mechanisms initiate and/or accentuate the leaching of subsurface salts in western Canada, we have presented three dissolution case histories. In each case, the observed leaching can attributed to one or more of our proffered causes.

REFERENCES

Anderson, N.L., and Brown, R.J., 1991a, Reconstruction of the Wabamun Group salts, southern Alberta, Canada: Tulsa Geophys. Soc. spec. publ., in press.

Anderson, N.L., and Brown, R.J., 1991b, Black Creek and Wabamun salt collapse features, Western Canadian Sedimentary Basin: Geophys. 56, 618-627.

Anderson, N.L., Brown, R.J., Gendzwill, D.J., Hinds, R.C., and Lundberg, R.N., 1989, Elk Point Group reservoirs, *in* Anderson, N.L., Hills, L.V., and Cederwall, D.A., Editors, The geophysical atlas of western Canadian hydrocarbon pools: Can. Soc. Expl. Geophys. and Can. Soc. Petr. Geol. spec. publ., 27-66.

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

Anderson, N.L., Brown, R.J., and Hinds, R.C., 1988b, A seismic perspective on the Panny and Trout fields of north-central Alberta: Journ.

Can. Soc. Expl. Geophys. 24, 154-165.

Brown, R.J., and Anderson, N.L., 1991, A re-examination of lateral velocity variations over Leduc and Rainbow reefs of Alberta: Journ. Can. Soc. Expl. Geophys., in press.

Brown, R. J. and Anderson, N. L., 1992, An overview of salt dissolution and related hydrocarbon trapping potential in western Canada: Bull., Am. Ass. Petr. Geol., in revision.

Brown, R.J., Anderson, N.L., and Hills, L.V., 1990, Seismic interpretation of Upper Elk Point (Givetian) carbonate reservoirs of western Canada: Geophys. Prosp. 38, 719-736.

Cederwall, D.A., and Anderson, N.L., 1991, Westhazel General Petroleum Sand Pool, east-central Alberta, Canada: SEG annual meeting expanded technical program abstracts, 184-187.

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

Perrodon, A., 1983, Dynamics of oil and gas accumulation: Elf Aquitaine, France, 369 p.

Figure 1. Stratigraphic chart for northeastern Alberta (modified after AGAT Laboratories, 1988). Devonian halites occur within several stratigraphic intervals: Elk Point Group (Lotsberg, Cold Lake and Prairie formations), Beaverhill Lake Group, Woodbend Group (Leduc equivalent), and Wabamun Group.

Figure 2. Schematic illustration of centrifugal flow. According to Perrodon (1983), in normally-pressured sediment in a juvenile basin, interstitial water is progressively expelled from the deepest zones subjected to the highest pressures, and migrates towards zones with a weaker potential, laterally towards the edges and vertically through the beds into the surface layers.

Figure 3. Sketch illustrating how the dissolution of the salt could be triggered by near surface exposure as a result of erosion. Near surface exposure could also occur as a result of salt flow.

Figure 4. Schematic illustration of centripetal flow. According to Perrodon (1983), in a mature basin of great structural stability and relatively low geothermal gradient, hydrological flow will be from the highland areas towards the basin center.

Figure 5. Sketch illustrating how the dissolution of the Wabamun salt could have been triggered by a near orthogonal pattern of regional faulting/fracturing during the mid-Late Cretaceous. On the suite of reconstructed salt distribution maps prepared by Anderson and Brown (1991a), the dissolution fronts exhibit a pronounced orthogonal trend: NNE and WNW. Similar mechanism may have influenced salt dissolution of the other Devonian salts; however, evidence presented to-date in the literature is much less conclusive.

Figure 6. Sketch illustrating the differential compaction of reef and off-reef strata. The overlying salt could be selectively leached above the reef as a result of fracture permeability and pressure dissolution.

Figure 7. Sketch illustrating differential compaction on and off a crystalline basement structural high. The overlying salt could be selectively leached above the structure as a result of fracture permeability and pressure dissolution.

Figure 8. Sketch illustrating how the dissolution of subsurface salt could have been triggered by glacial loading and unloading. This process could account for the observation that many lakes in areas of salt dissolution are generally situated adjacent to thick remnant salts and above zones which

have been extensively leached.

Figure 9. Sketch illustrating how the dissolution of the salt could be triggered by the leaching of the underlying evaporites.

Figure 10. The movement of salt can enhance the permeability of the adjacent strata and/or juxtapose salt and permeable sediment. In either case, the rate of salt dissolution can be significantly enhanced.

Figure 11. 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 12. Distribution of the Prairie Evaporite Formation and its equivalents within the western Canadian interior plains (modified after Belyea, 1964; Meijer Drees, 1986).

Figure 13. Geologic section across the main dissolutional edge of the Leofnard salt. The Leofnard salt has been totally leached from the 3-27 and 10-23 wells; about 145 m of salt is preserved at the 10-15 and 6-1 locations.

Figure 14. Schematic cross-section of the east-central part of the Western Canadian Sedimentary Basin prior to the deposition of the thin veneer of Quaternary glacial sediment.

Figure 15. The data suggest that some movement of the Leofnard salts may have occurred in the vicinity of the main salt edge during or after the mid-Late Cretaceous. Such movement (envisioned by the authors as analogous to growth-fault type slumping/salt flow) could have been caused by excessive overburden pressure and/or glacial loading. This process could have been triggered by regional faulting/fracturing and enhanced by pre-existing fault/fracture planes and/or an influx of meteoric water.

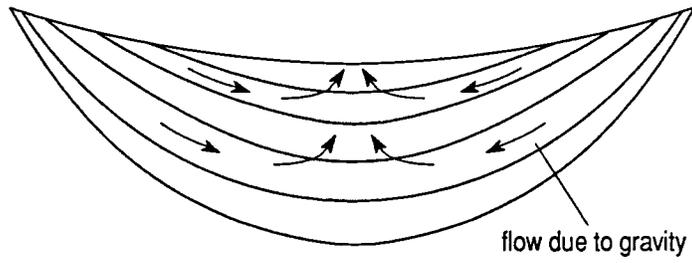
Figure 16. Geologic section across the crystalline basement structural high in the Trout study area. Thick remnant Muskeg salts are preserved in the 1-31 and 5-22 wells; these salts have been leached at the 2-10 location.

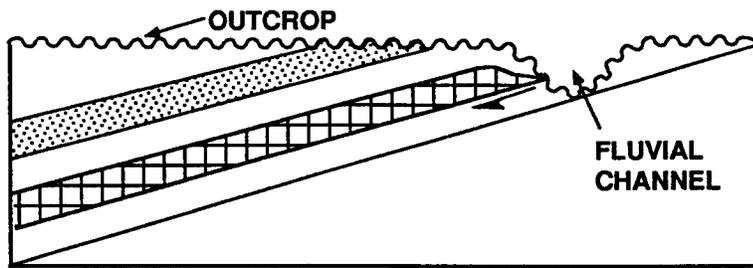
Figure 17. Geologic section across the Keg River reef (Rainbow Member) at Rainbow A pool. Remnant Muskeg salts (Black Creek Member) are preserved in the 9-24, 2-28, 2-31, and 10-27 wells; these salts have been leached at the 12-28 and 6-34 locations.

Alberta		AGE # 10 YRS.	SERIES	PERIOD	ERA	
Northeast Plains						
L. Drift		1.6				
		5.3		TERTIARY	CENOZOIC	
		23.7				
		36.6				
		57.8				
		66.4				
Bearpaw			Upper	CRETACEOUS	MESOZOIC	
Belly River		1st White Speckled Shale	/			
Lea Park						
Colorado Shale						
Colorado Shale		2nd White Speckled Shale				
Colorado Shale						
Viking/Pelican		Viking/Pelican Joli Fou 97.5				Late
Fish Scale Zone						Lower
Colony						
McLaren		144				/
Waseca						
Sparky						
GP						
Rex						
Lloyd						
Cummings						
Dina						
McMurray						
Grand Rapids						
Clearwater						
Wabiskaw						
Mannville Group						
		208	U L	JURASSIC		
			Middle			
			L E			
		245	U L	TRIASSIC		
			Middle			
			L E			

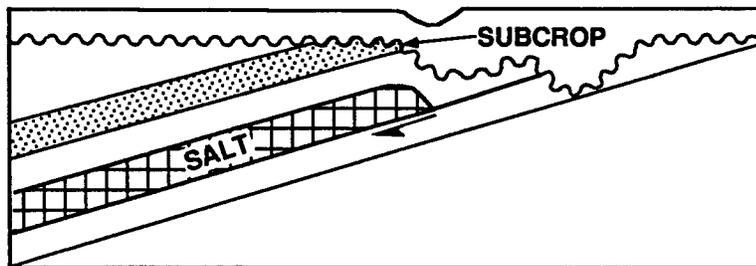
		286	PERMIAN		
		320	PENNSYLVANIAN		
			U L	DEVONIAN	PALEOZOIC
			L E		
Banff		360	Upper		
Exshaw					
Wabamun					
Winterburn		1 Hondo 2 Grosmont 3 Tathlina 4 Twin Falls 5 Leduc	/		
Woodbend Group	1 2 3 4 5				
Ireton					
Hay River					
Waterways					
BHL		374	Late		
		387	/		
				408	Lower Early
		438	Silurian		
			U L	ORDOVICIAN	
			Middle		
		505	L E		
			U L	CAMBRIAN	
			M		
		570	L E		

Centripetal Flow

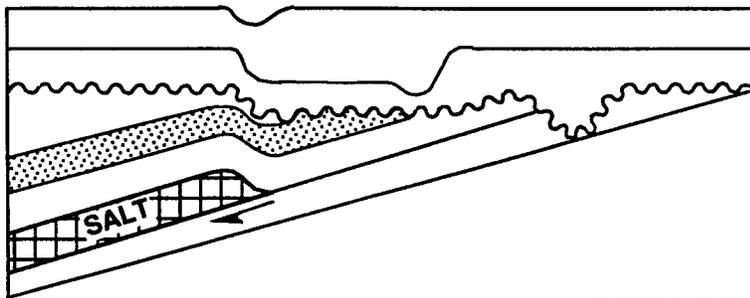




STAGE 1

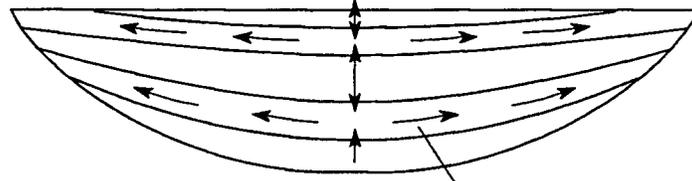


STAGE 2

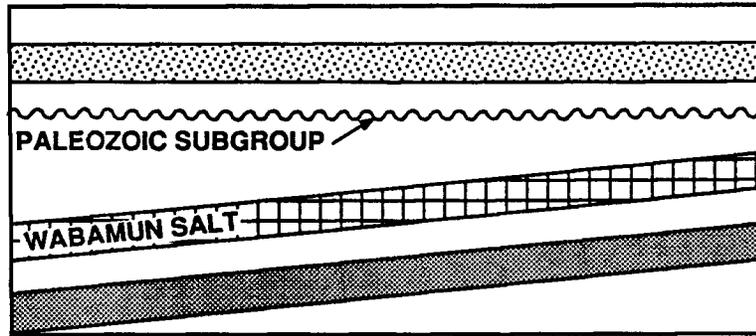


STAGE 3

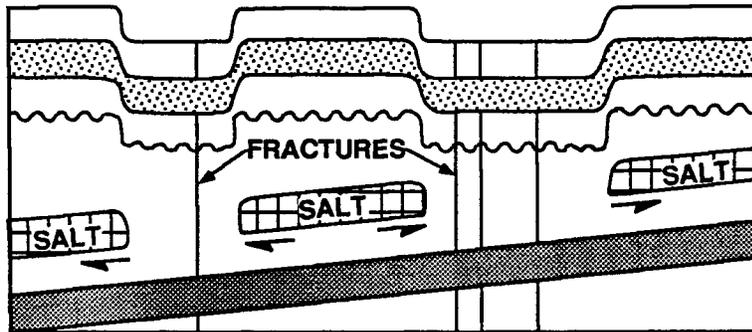
Centrifugal Flow



flow due to expulsion
of interstitial water

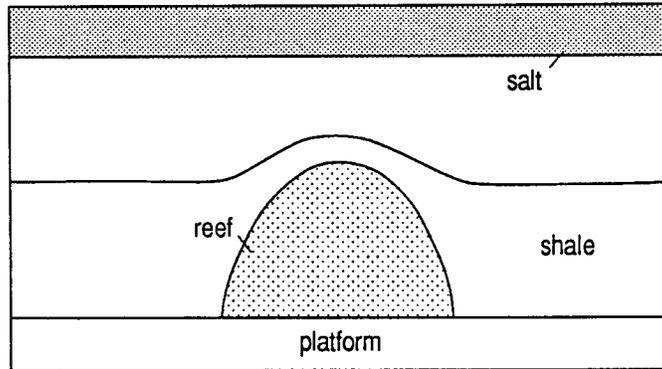


STAGE 1

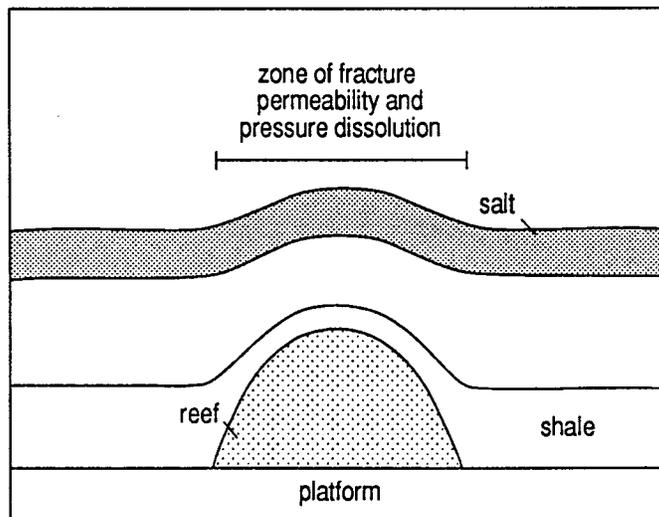


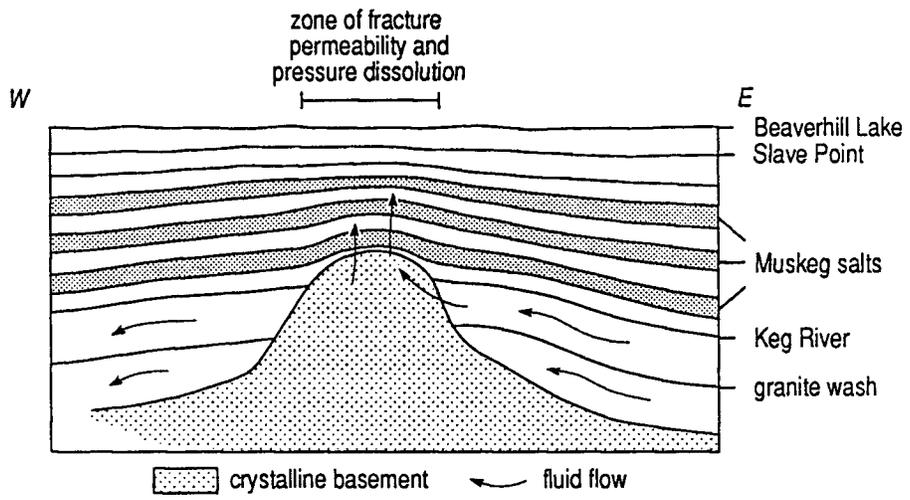
STAGE 2

Time 1

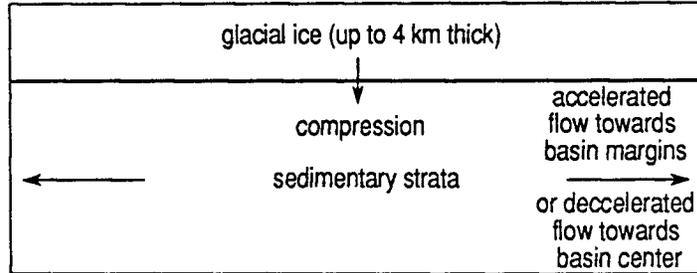


Time 2

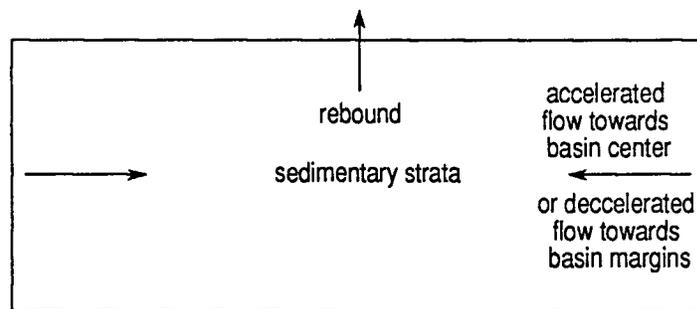


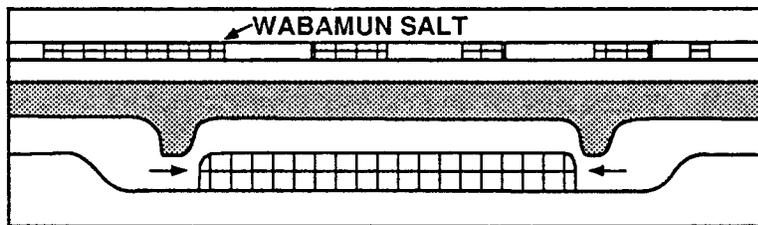


Glacial Loading

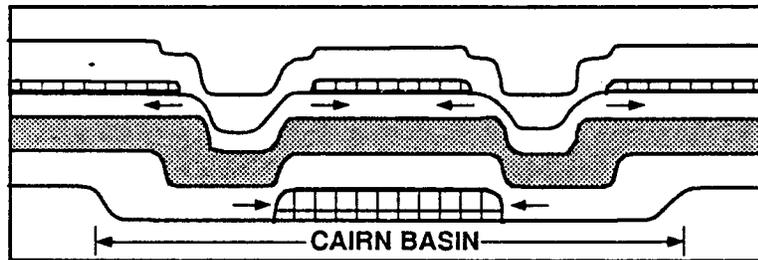


Glacial Unloading



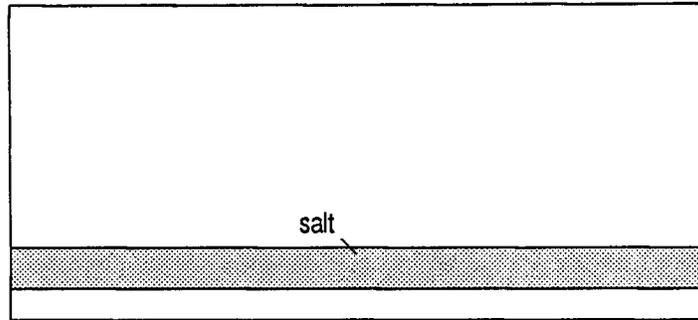


STAGE 1

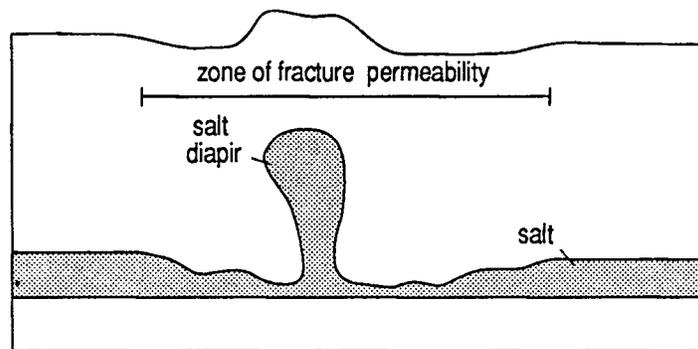


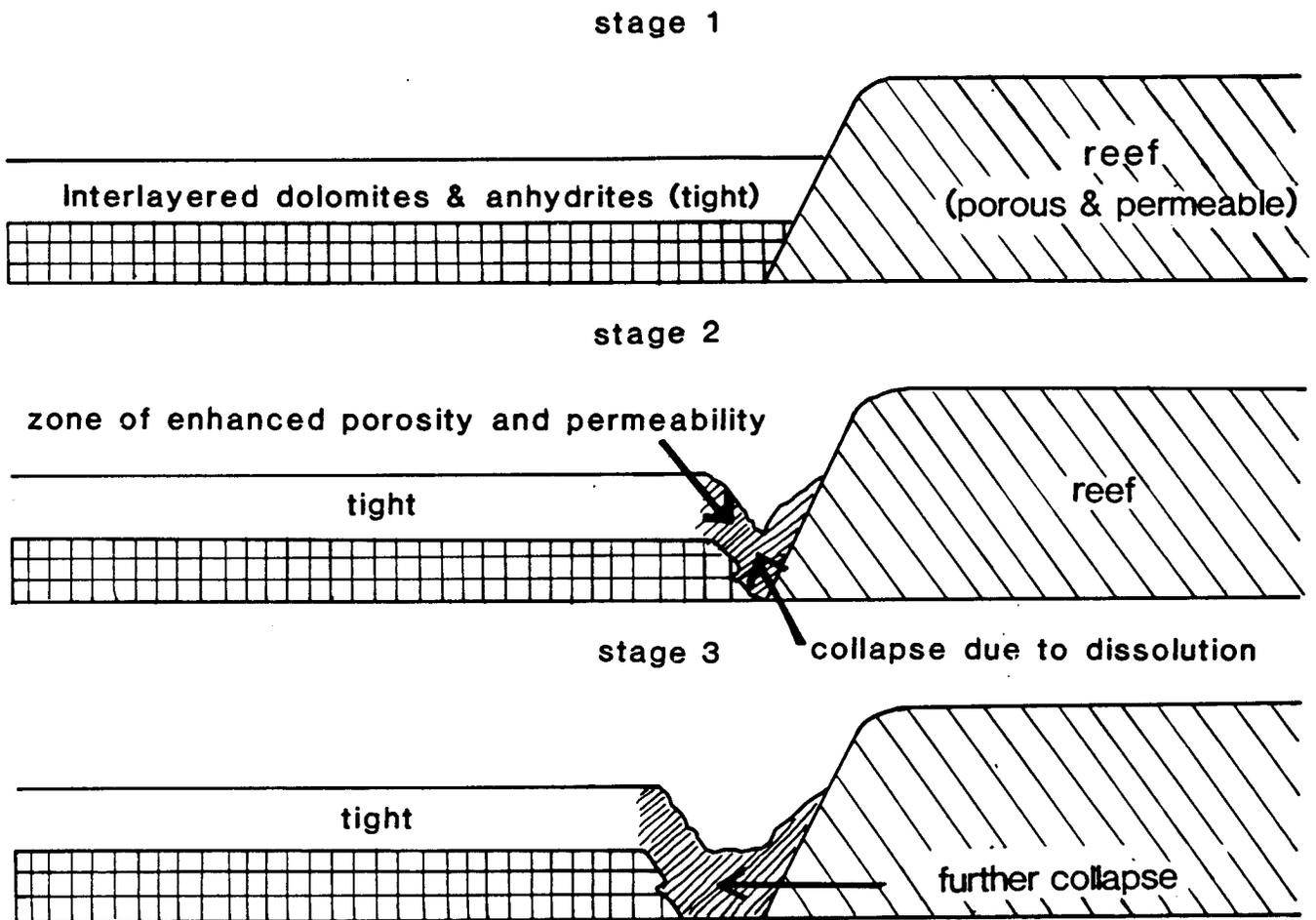
STAGE 2

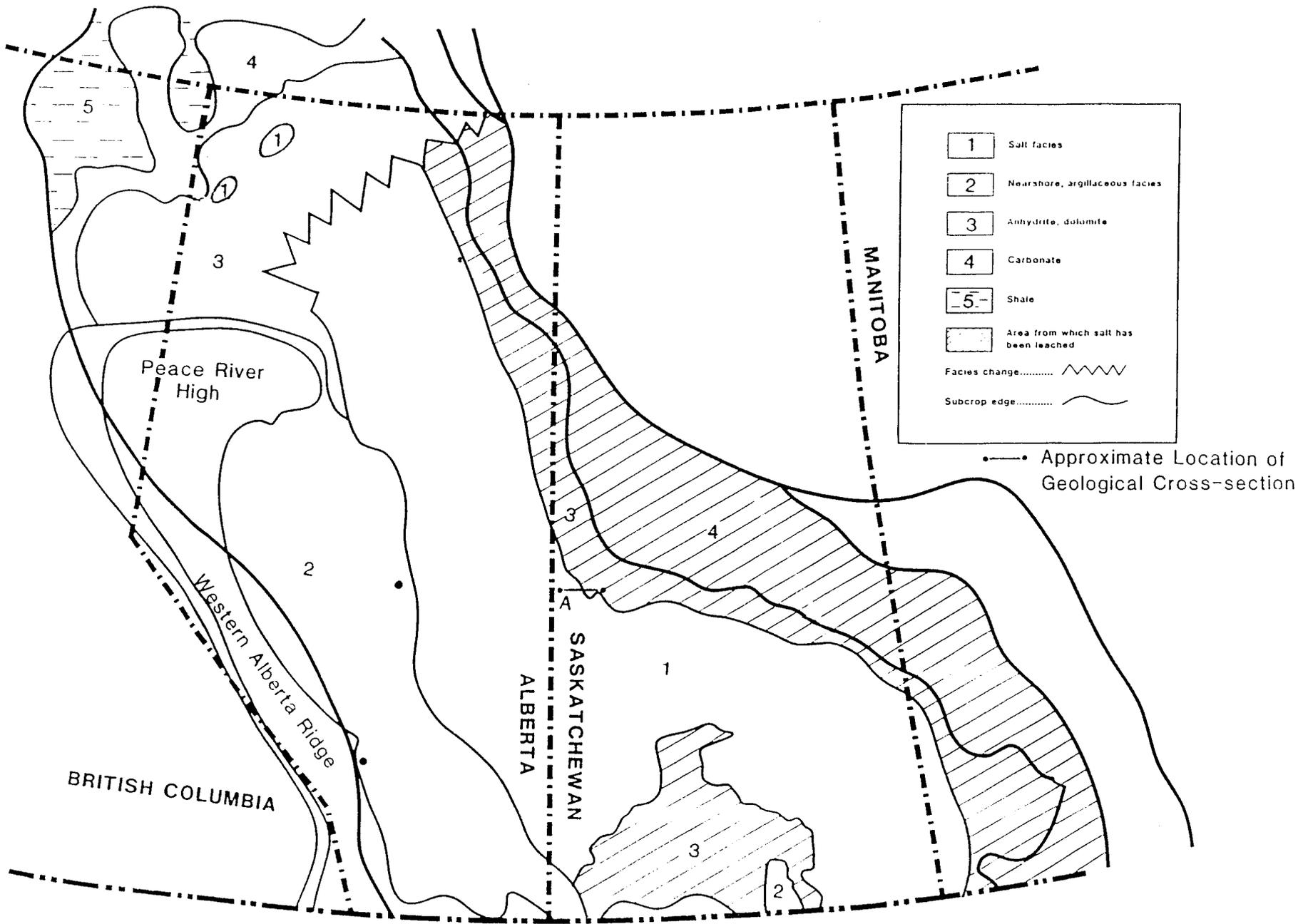
Time 1

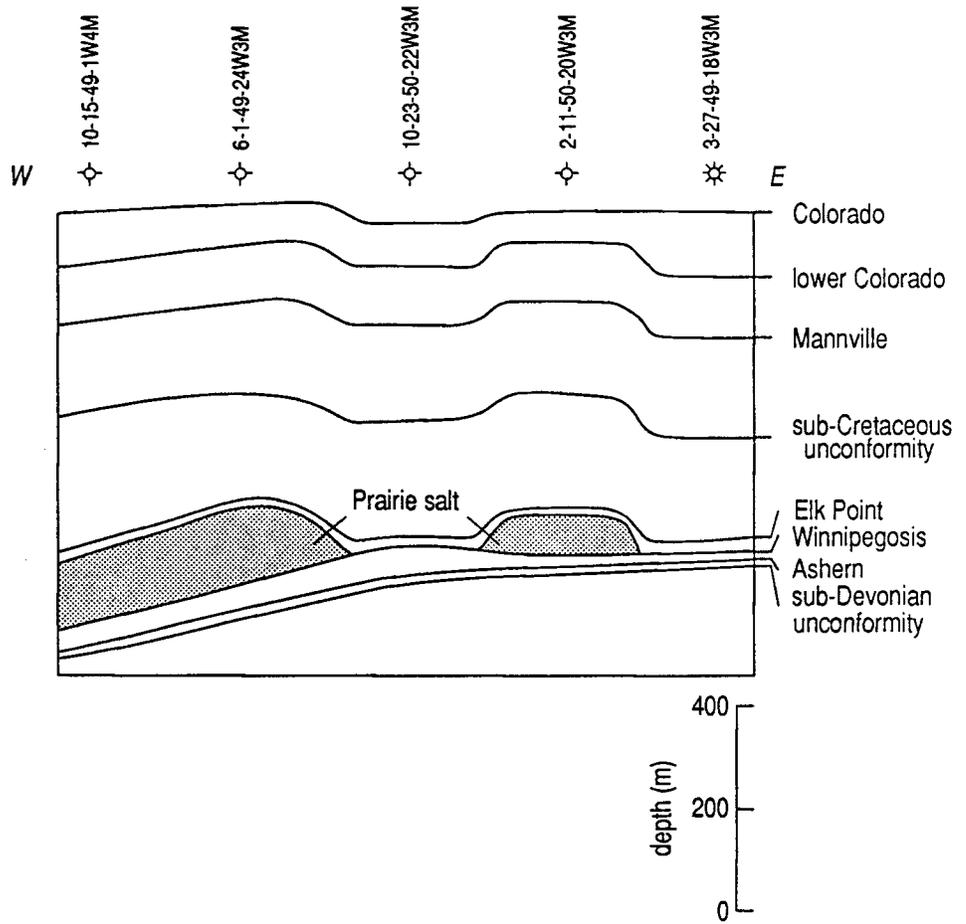


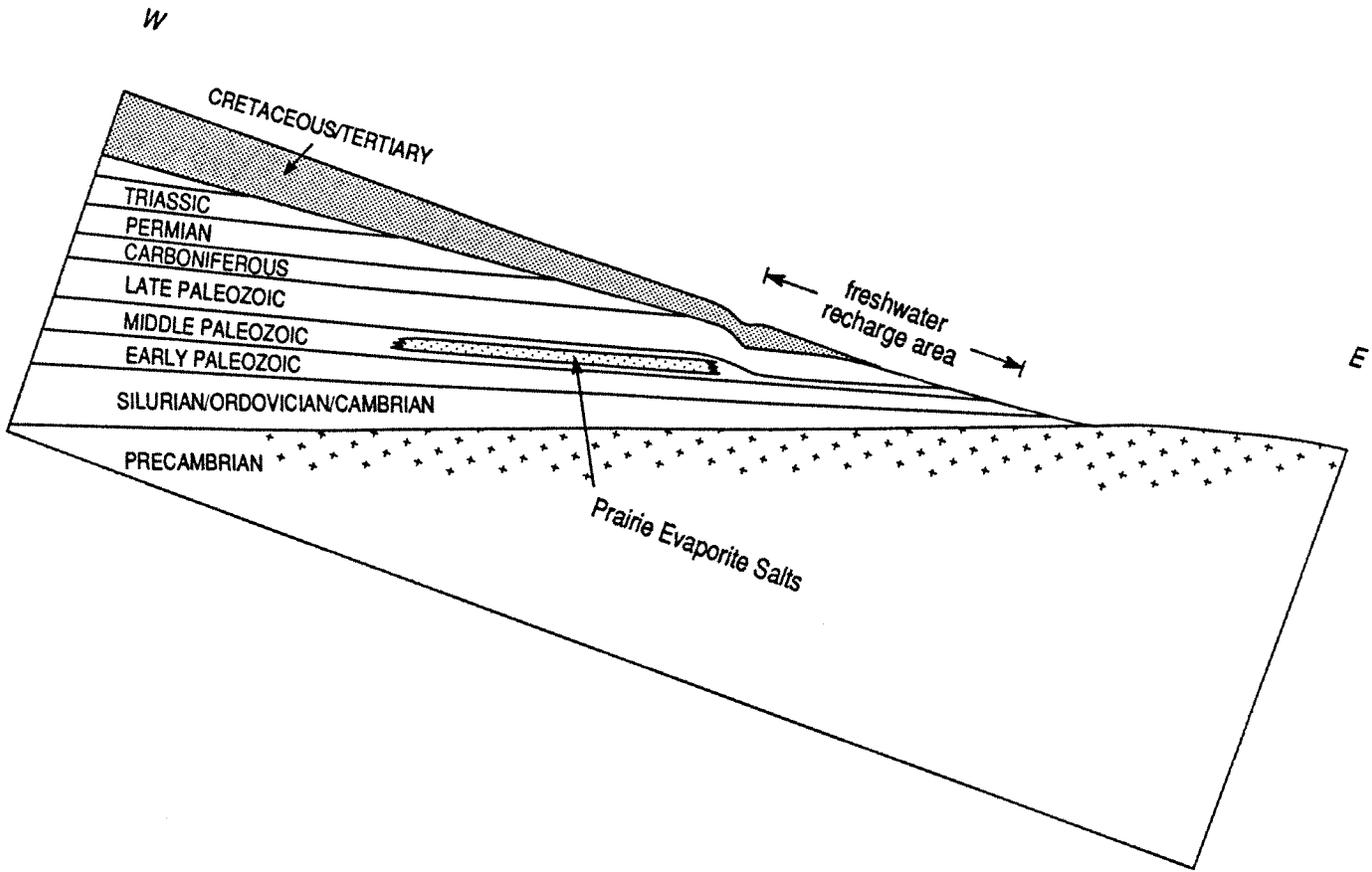
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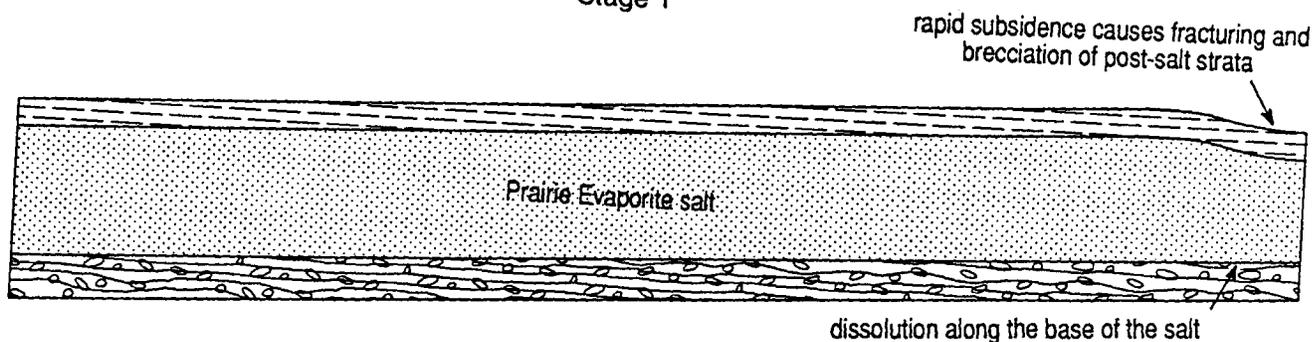




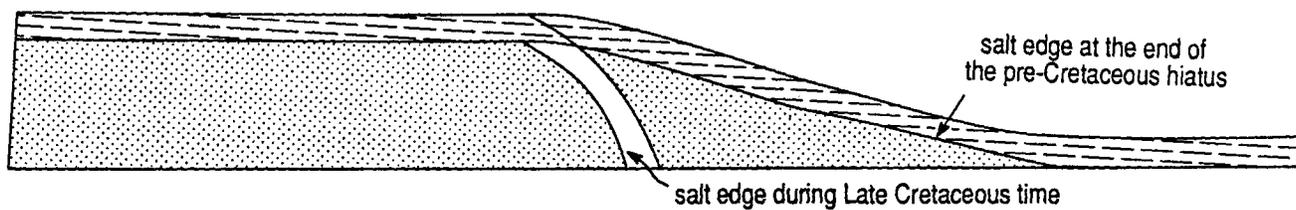




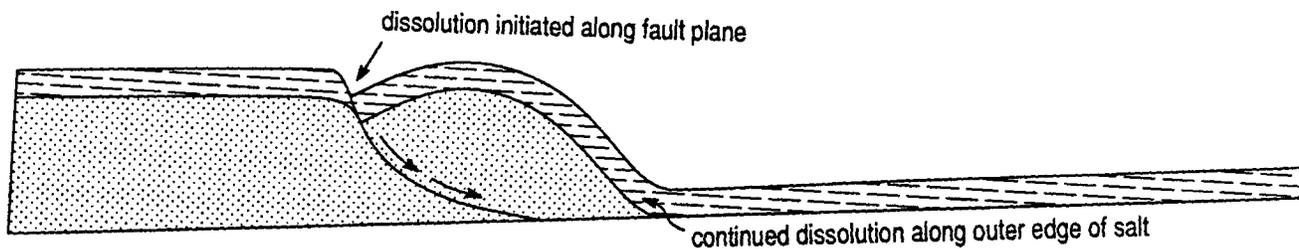
Stage 1



Stage 2



Stage 3



Stage 4

