Geological Problems in Saskatchewan Potash Mining Due to Peculiar Conditions During Deposition of Potash Beds

C. A. Baar
Consultant
169-330 Canterbury Drive S.W.
Calgary, Alberta, Canada
T2W 1H6

ABSTRACT

The depositional environment during the formation of the Devonian potash deposits in Saskatchewan was unique among all known potash deposits of commercial value. Peculiar conditions resulted from—

a) dolomite reefs which built up within the Prairie Evaporite Basin prior to the first cycle of evaporation; the reefs may have risen close to, or even above the levels, at which the first potash beds were deposited during subsequent evaporation cycles in several sub-basins separated by reefs;

b) lowering of the brine levels with increasing concentration, resulting in repeated exposure of deposited salts, in particular potash salts, as the lowest brine levels prevailed during potash deposition.

Anomalies due to such depositional conditions were preserved as the sub-basins suffered very little tectonic disturbance.

Several types of anomalies encountered in potash mines could be attributed to events during, or shortly after deposition of potash beds.

1) Occasional rainstorms caused isolated local dissolution of salts at exposed surfaces. The resulting brines subsequently evaporated and/or seeped into the deposits.

2) Inflow of less concentrated brines raised the brine levels, and resulted in salt and/or potash dissolution in larger areas. Subsequent evaporation yielded mainly rock salt until the concentration required for potash deposition was reached again.

Local pinnacle reefs within the sub-basins grew to known heights of 350 feet above the basis of the Prairie Evaporites with a maximum thickness of about 600 feet. They have been targets for oil and gas exploration, and constitute a serious safety hazard particularly in mining the lowermost potash bed.

INTRODUCTION

Recently, the following short description of potash deposition appeared in a publication dealing with the development of Saskatchewan's newest potash mine. The Prairie Evaporites "were deposited in a Devonian Basin which had a cyclic recharged outlet to the sea. The constant recharge and evaporation produced in the Saskatchewan Evaporite beds a textbook example of the normal Evaporite sequence where limestone and dolomites are overlaid by Anhydrite, Halite and the Bittern Salts in sequence. This very large basin or series of basins extending across the province from East to West and having a width of more than 50 miles, accounts for the relative uniformity and extensive area covered by the ore beds.

When one considers the potash-enriched zone as a blanket approximately 8 ft thick extending for miles in every direction, then the method of mining becomes apparent."

The mining equipment to be used "could be very large and heavy with little consideration given to irregularities in the ore bed. The mine could develop and produce simultaneously" (Schultz, 1971, p. 39). Figure 2 (Holter, 1969) shows such potash bed blankets in two North-South sections of the basin. Figure 3 (Gorrell and Alderman, 1968) shows a longitudinal section from Alberta to Manitoba with some more potash beds, and additional features like salt solution areas, and thick dolomite accumulations at certain locations. The significance of these features will be dealt with later.

The figures and the quoted description obviously are based on the classical model of potash deposition in an intracontinental basin in which the brine level never fell substantially below sea level, i.e., that the evaporation controlled the inflow of sea water; when the brine concen-

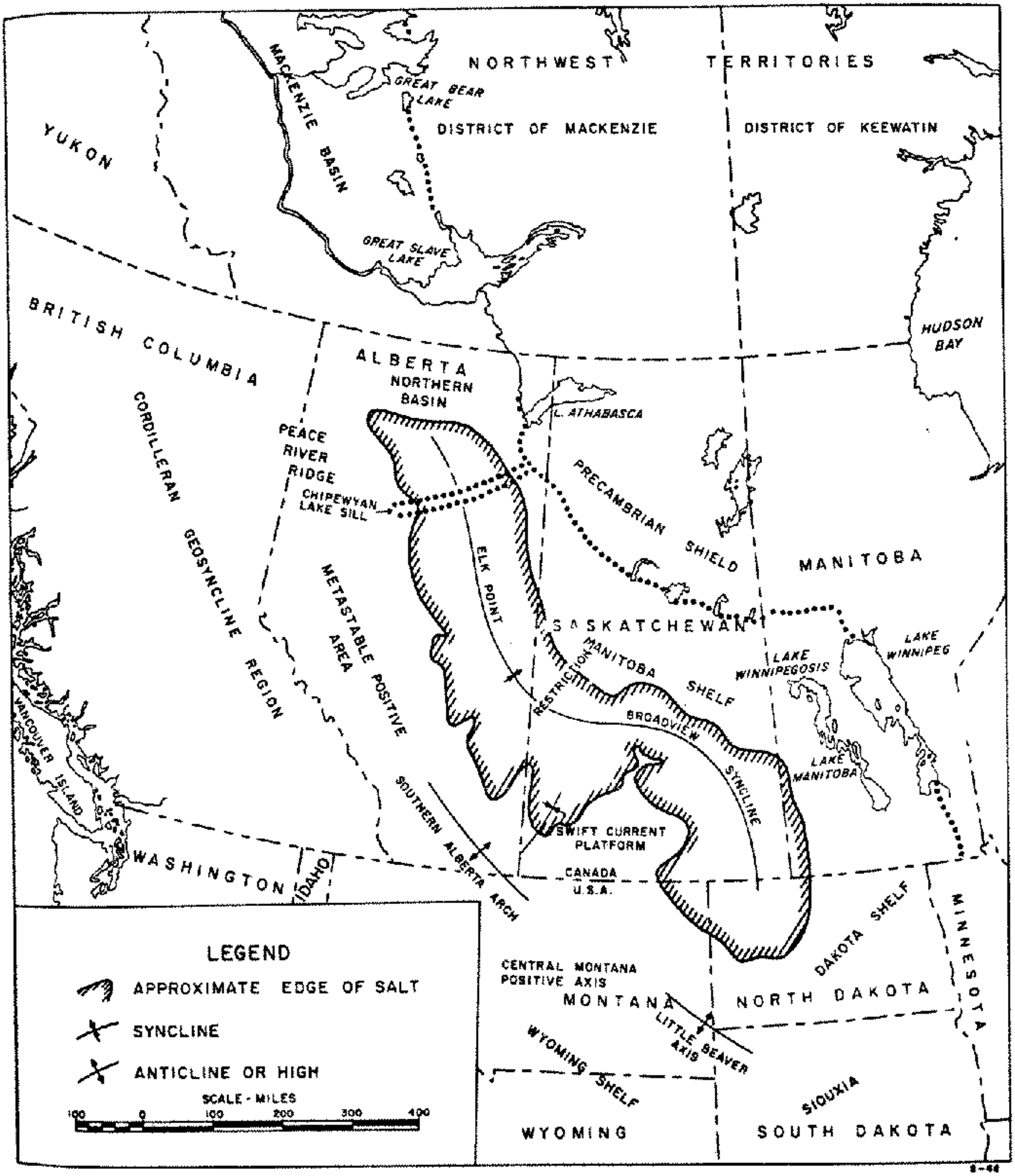

Figure 1. Location map, Prairie Evaporite Basin (Pearson, 1963). In Saskatchewan, the word "BROADVIEW" covers approximately the locations of 6 potash mines in the Saskatoon district. 3 potash mines in the Esterhazy district are located between "SYNCLINE" and the Manitoba border.

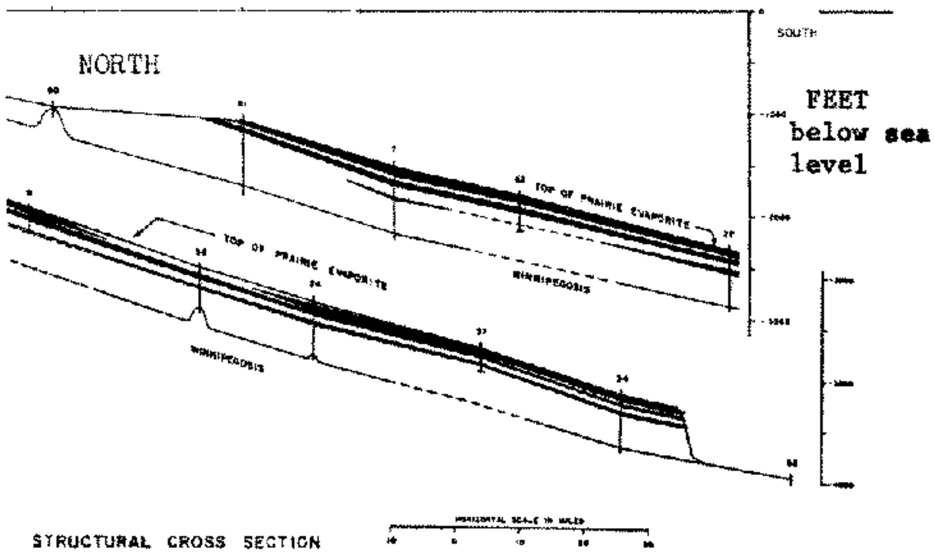

Figure 2. Schematic sections (after Holter, 1969) between "BROADVIEW" and "SYNCLINE" in Figure 1.

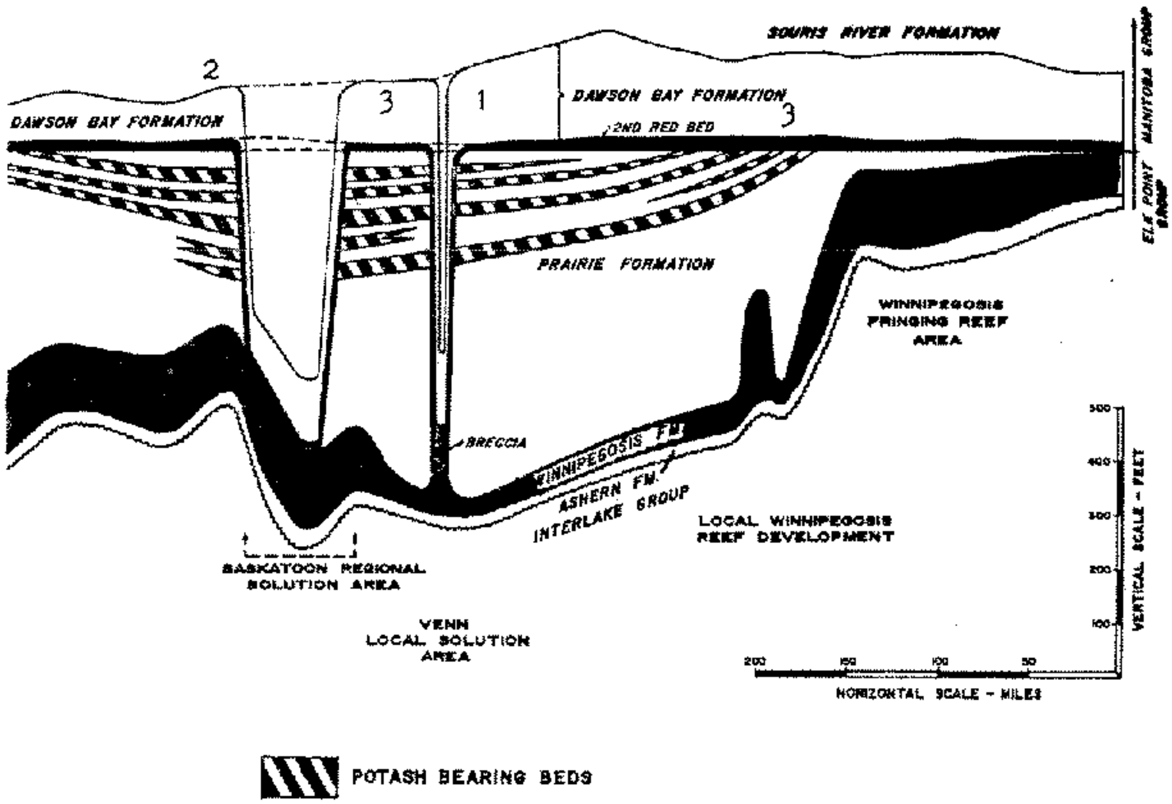

Figure 3. Longitudinal section, Prairie Evaporite basin (after Gorrell and Alderman, 1968). 1,2,3 = Location of respective numbers of potash mines.

tration in the basin reached the point of potash precipitation, huge amounts of concentrated brines were present. In the classical example of the European Zechstein the average depth of brines after deposition of the Stassfurt potash bed was about 150 m.

In such cases of progressive sea water evaporation, the bromine contents of the halite sequence below a potash bed are reliable indicators of the brine concentrations. This has been shown for the Zechstein deposits in Europe, and for the Paradox basin deposits in Utah (Baar 1954, 1966; Schulze 1958; Raup 1966; Raup et al, 1970; Kuehn, 1968).

However, the classical textbook model of potash deposition is not applicable to the Devonian potash deposits of Saskatchewan. On the contrary, its application has proven misleading in many regards. Some writers who applied classical concepts to the potash deposits in Saskatchewan, soon experienced that they had to change their views from publication to publication.

All potash companies too, sooner or later after starting to mine the potash beds, found that they had to change original concepts. There will be no exception to the newest mine. Possibly, the situation will become even worse inasmuch as a location has been chosen which offers the worst conditions among all potash mines operating in Saskatchewan.

The reason why the conditions for potash deposition in Saskatchewan were unique among all known potash deposits under exploitation, is outlined in the following sections and the resulting peculiar features will be shown by a number of figures.

EXPLORATION DRILLING REVEALED FREQUENT LOCAL CHANGES TO THE MINERALIZATION OF VARIOUS POTASH ZONES

Every company engaged in exploration drilling for potash found that there is a variety in potash mineralization in Saskatchewan which hardly can justify assumptions as quoted above. Figures 4 and 5 (after Wardlaw, 1968) demonstrate the situation in two adjacent townships in the centre of the basin; here abrupt lateral and vertical changes from red carnallite to red sylvinite occur. In Figure 4, the sylvinite in the borehole next to the one with high carnallite would not meet the economic requirements for ore grades in Saskatchewan. In Figure 5, the changes are even more obvious; in one borehole, potash is almost entirely missing; its remnants occur immediately below the Second Red Bed.

Figure 6 shows similar changes to the mineralization of zones 1 and 2 in the Yorkton area of Eastern Saskatchewan. Three potash mines are operating in that area, mining the lowermost potash zone. All exploration holes drilled in the area show similar changes from location to location.

A number of companies discontinued their exploration activities in that area, at least partly on account of vertical and horizontal changes to the potash mineralization of zone 1.

Figure 7 shows similar abrupt changes to the clay content in the roof of the upper potash bed in the Saskatoon area.

Figure 8 should be given particular emphasis. It shows several more depositional cycles including salt beds above the potash deposits in Central Saskatchewan. These salt beds provide for a tight seal against any water action from above *if* they are still present, and if they are being protected by careful mining methods.

Locally, particularly along the margins of the basin, these salt beds are missing due to non-deposition, or due to later dissolution as indicated in Figure 3.

DOLOMITE REEFS IN THE PRAIRIE EVAPORITE BASIN

After some famous discoveries in N.W. Alberta, the oil and gas industry became very much interested in dolomite accumulations which rise from the basis of the Prairie Evaporite sequence. These so-called reefs are similar in Alberta and in Saskatchewan.

The stratigraphic relationship is shown in Figure 9 (Fuller and Porter, 1969b).

Fuller and Porter (1969b, p. 920) particularly stressed the point that "much of the halite (infilling the interreef depressions) shows the chevron structure described by Wardlaw and Schwerdtner (1966)." They arrive at the "further conclusion that "subaqueous" may mean only an inch or two of water," in contrast to the considerable water depths postulated by Wardlaw and Schwerdtner (1966). Fuller and Porter's conclusion appears to be in agreement with Valyashko's (1957) findings: The same type of chevron crystals in recent salt deposits in Russia was attributed to daily changes in temperature in the so-called dry-lake stage of deposits. In this stage the mother brines disappear between the mush of salt crystals during time periods of high evaporation. Valyashko's findings match conditions which controlled the potash deposition in the Prairie Evaporite basins.

With regard to Figure 9, it may be emphasized that the Zama level indicates the level at which the reef growth stopped in the terminal southeastern part of the basin. The reef tops remained at the outside sea level, while the interreef depressions were infilled with salt. The brine levels kept falling during time periods of evaporation in excess of inflow. The time required for salt infill of the interreef depressions may well agree with Wardlaw and Schwerdtner's (1966) figure of only a few thousand years. It may

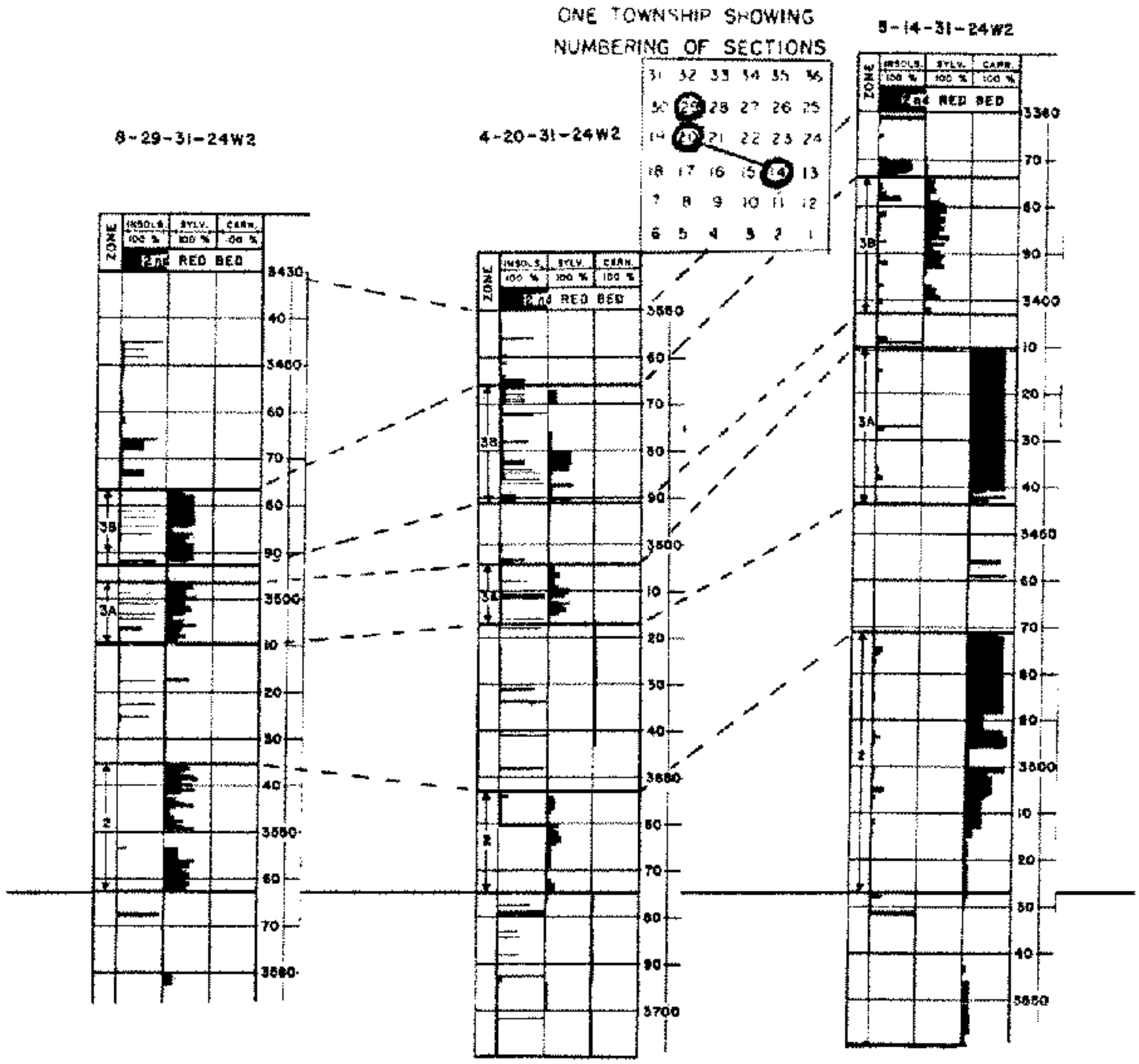

Figure 4. Potash beds in neighboring drill holes, central area (after Wardlaw, 1968).

even have been a shorter period. Subsidences of central areas of the basin as shown in Figure 10 (Shearman and Fuller, 1969) appear to be questionable.

Exploration drilling has confirmed that the reefs in Central Saskatchewan reached top levels of at least 350 ft above the salt basis.

This leaves only about 200-250 ft for salt and potash beds to the Second Red Bed. Wardlaw and Reinson (1971, see also Reinson and Wardlaw, 1972) show the top of the reefs at the level of the first potash zone. They also assume that the reefs resumed growing when the basin was flooded by sea water from which the basin-wide anhydrite beds deposited, similar to the development in N.W. Alberta.

However, it must be considered that the situation in N.W. Alberta was different as the reefs were located near the main barrier reef where the sea water inflow took place. After a thousand miles of flow across a salt basin, the inflowing sea water probably was too saline to allow organic reef growth in the terminal basin. However, the fact that the reefs reached heights of 350 ft above the salt basis appears to be confirmed by all investigators.

Figure 12 and 13 (Jones, 1965) show an evaluation of the Winnipegosis reef situation in Central Saskatchewan which differs considerably from the evaluation offered by Wardlaw and Reinson (1971, 1972). Figure 14 (Fuller and Porter, 1969a) shows another differing picture of the location of reefs.

Although the Winnipegosis reef development in the Prairie Evaporite basin has been the subject of various

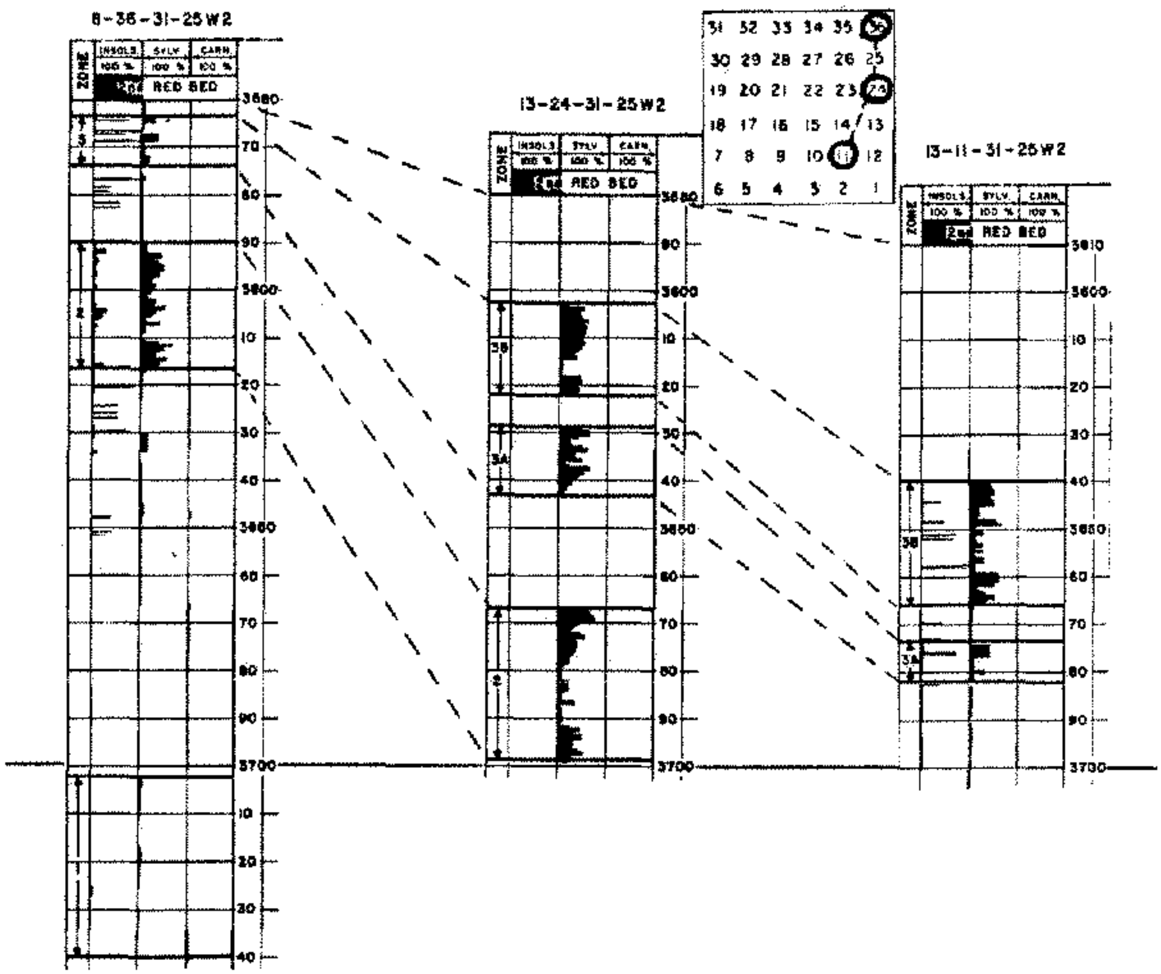

Figure 6. Potash zones in neighboring drill holes, central area, Prairie Evaporite basin (Wardlaw, 1968).

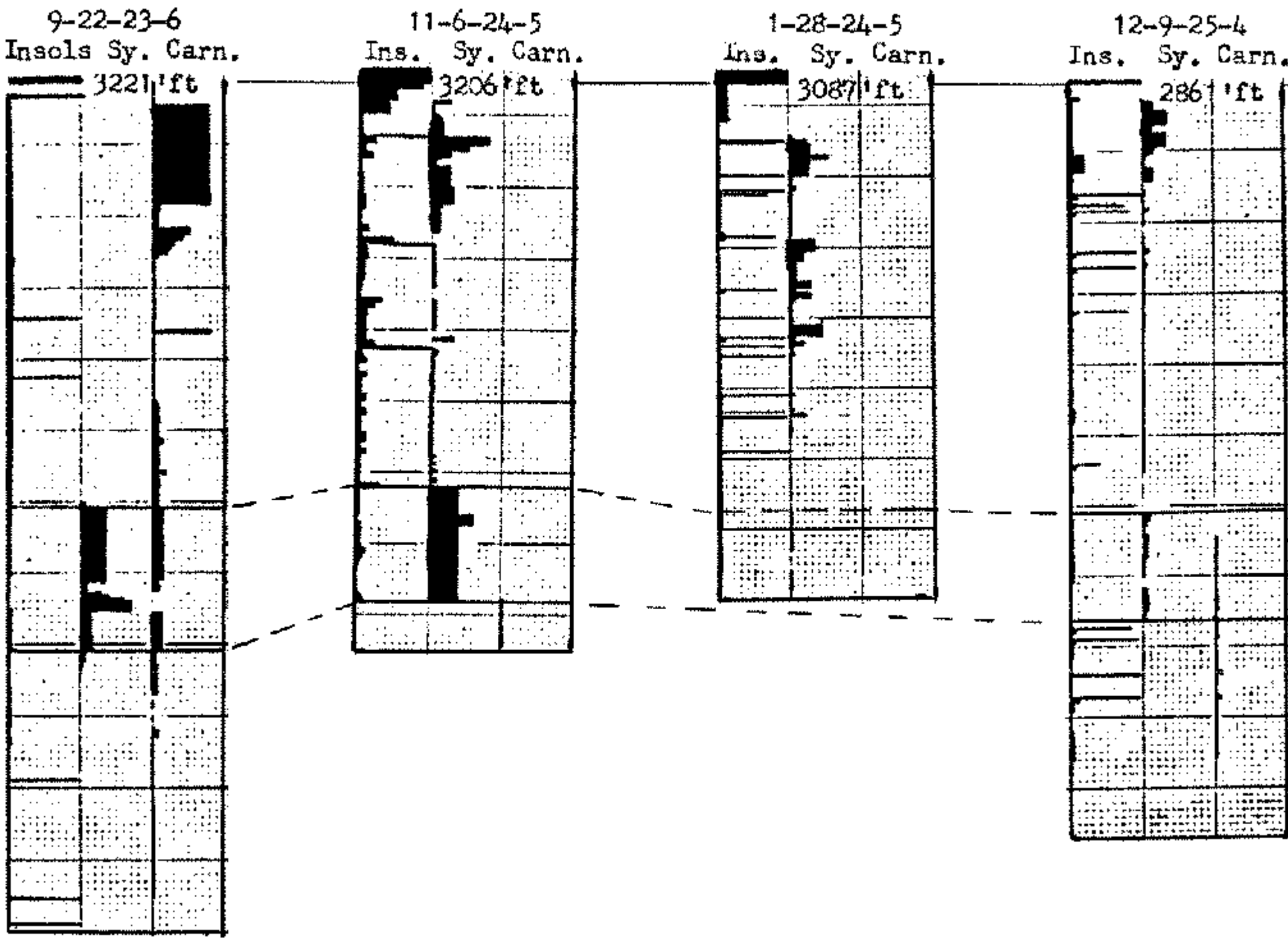

Figure 6. Potash zones in neighboring drill holes in the marginal area of the Prairie Evaporite Basin south of Yorkton. The 4 boreholes were drilled at nearly equal distances between the locations of the two holes at the ends of a 15 mile stretch.

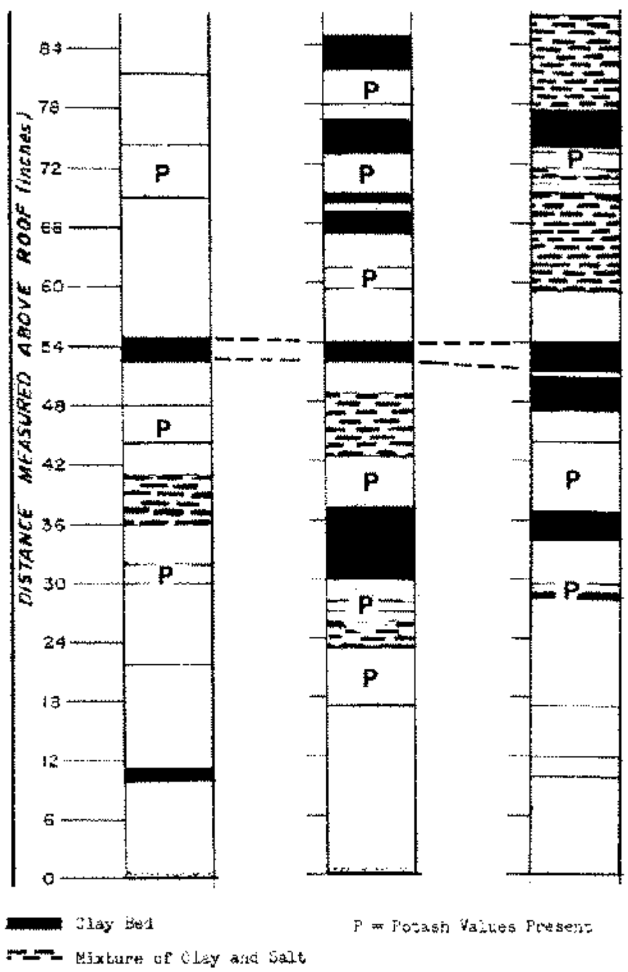

Figure 7. Borescope clay seam logs at 7.5 ft distances. Central Canada Potash Co.

controversial publications, the matter apparently has not yet been clarified. It appears to be necessary to deal with this question not only on the basis of what is believed to represent petrographic evidence from drill cores. Clear evidence of falling and rising brine levels before and during potash deposition has been found in potash mines, and will be presented in the following. This evidence may help in clarification of some of the controversial questions.

POLYGONAL CRACK SYSTEMS PROVIDE PROOF OF REPEATED EXPOSURE OF SALT AND POTASH SHORTLY AFTER DEPOSITION

Figure 15 shows the IMC K-1 shaft section. Polygonal crack systems filled with clay and/or carnallite occur about 40 ft below the first potash bed. Similar systems were observed in the K-2 shaft section. At both locations inclined drifts from the potash level down to the shaft sumps exposed the systems in all three dimensions. The cracks start at greatest widths of several inches at certain levels of clay bands, diminishing in width downward for total depths of up to 5 ft.

Similar crack systems filled with clay and/or potash minerals were observed in the central area of the basin in the Cominco mine near Saskatoon above and below the uppermost potash bed.

These crack systems clearly demonstrate temporary exposure of the deposits in statu nascendi. The exposed surfaces were subsequently covered due to rising brine levels. In the Esterhazy area, about 200 ft of salt were deposited above the lowest observed level of surface exposure, indicating the order of magnitude of possible changes to the brine levels in marginal areas. Considering the gentle slope of the basin floor, it becomes apparent that very large areas must have been exposed temporarily when the brine level fell due to excess evaporation. The resulting potash deposition took place in local depressions which were still covered by brines, and between salt and potash crystals near the surface of the deposits which solidified in this way. Ample petrographic evidence of intercrystalline formation of various mineral generations has been presented by Wardlaw and Schwerdtner (1966, and various other publications).

OCCASIONAL RAIN STORMS CAUSED LOCAL ANOMALIES IN POTASH BEDS NEAR EXPOSED SURFACES

In a huge salt basin like the Prairie Evaporite basin, there is no possibility of natural transportation of fresh water to isolated localities except for precipitation from occasional rain storms. Such storms are known to occur every few years or so in present arid areas. The following features are attributable to Devonian rain storms which hit locally exposed surfaces of the salt basin.

Figure 16 shows a typical example of a sink area where the brines resulting from a rainstorm seeped into the deposited salt. The channels dissolved by the fresh water run from all sides to the central sink.

The channels were subsequently filled with salt. Often, they exhibit a layer of clay at the channel floor. Most of the clay residue of dissolved salts, however, was flushed into the central sink. Fractures caused by the incision of these channels often run parallel to them. These fractures also were infilled with salt. In cases, where the original potash bed was carnallitic (with carnallite up to 10%), the fractures often are filled with carnallite.

These features were described by Keyes and Wright (1966) with reference to Schwerdtner (1964). Keyes and Wright correctly explained some observed features as fractures and incised channels filled with salt. McIntosh and Wardlaw (1968) gave a different explanation on the

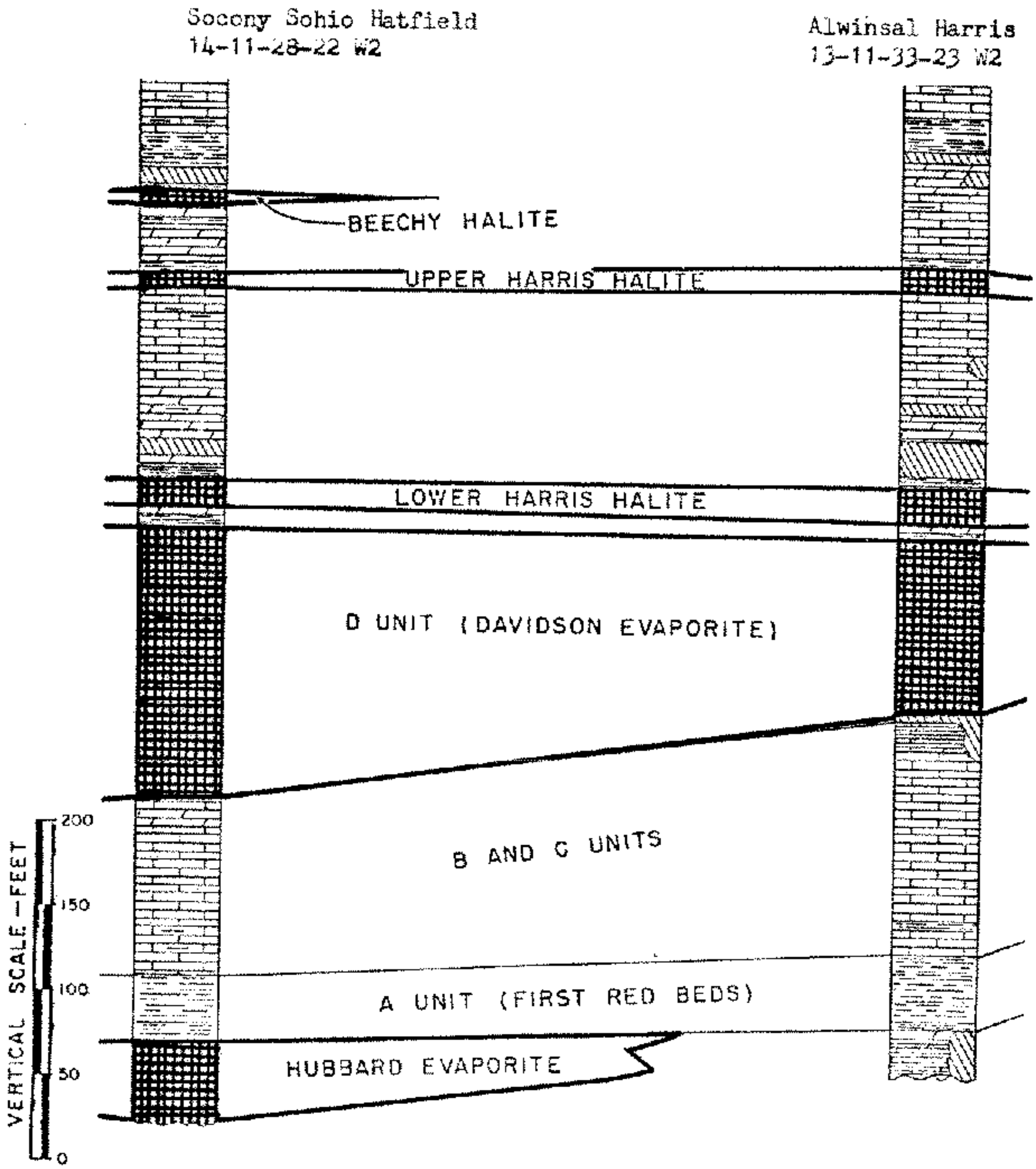

Figure 8. Evaporite cycles with salt beds above the Prairie Evaporite, Central Saskatchewan (after Lane 1964).

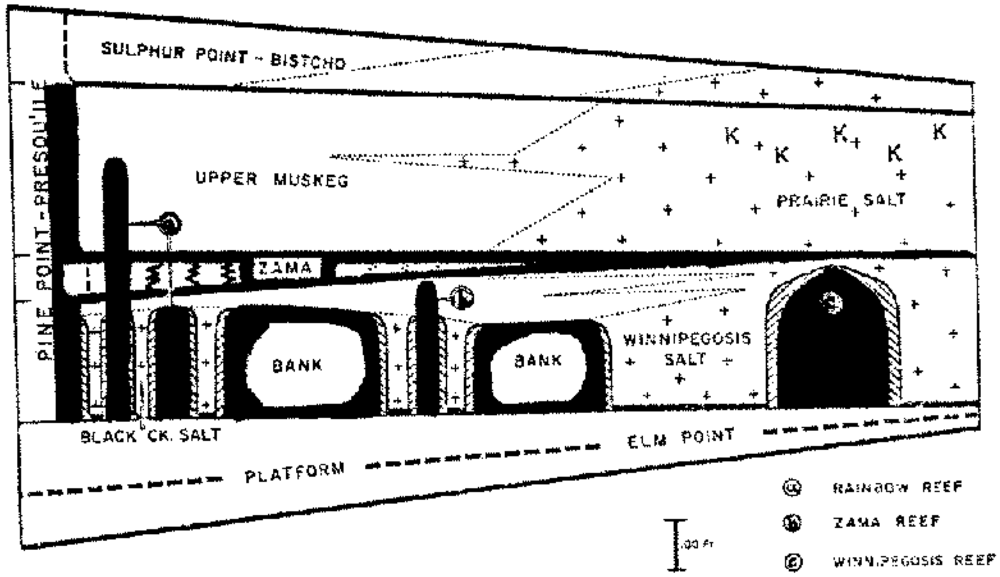

Figure 9. Relationship of reefs to Zama horizon, N.W. Alberta, Saskatchewan (after Fuller and Porter, 1969).

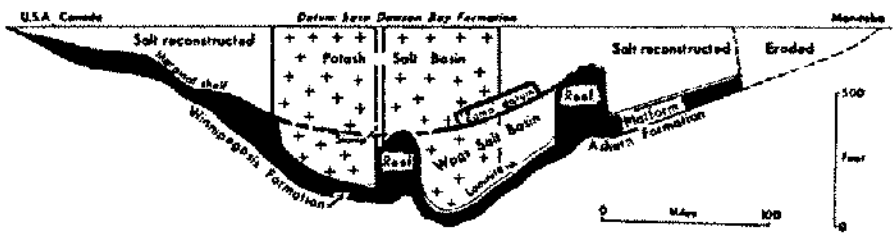

Figure 10. S.W.-N.E. section, Prairie Evaporite basin (after Shearman and Fuller, 1969).

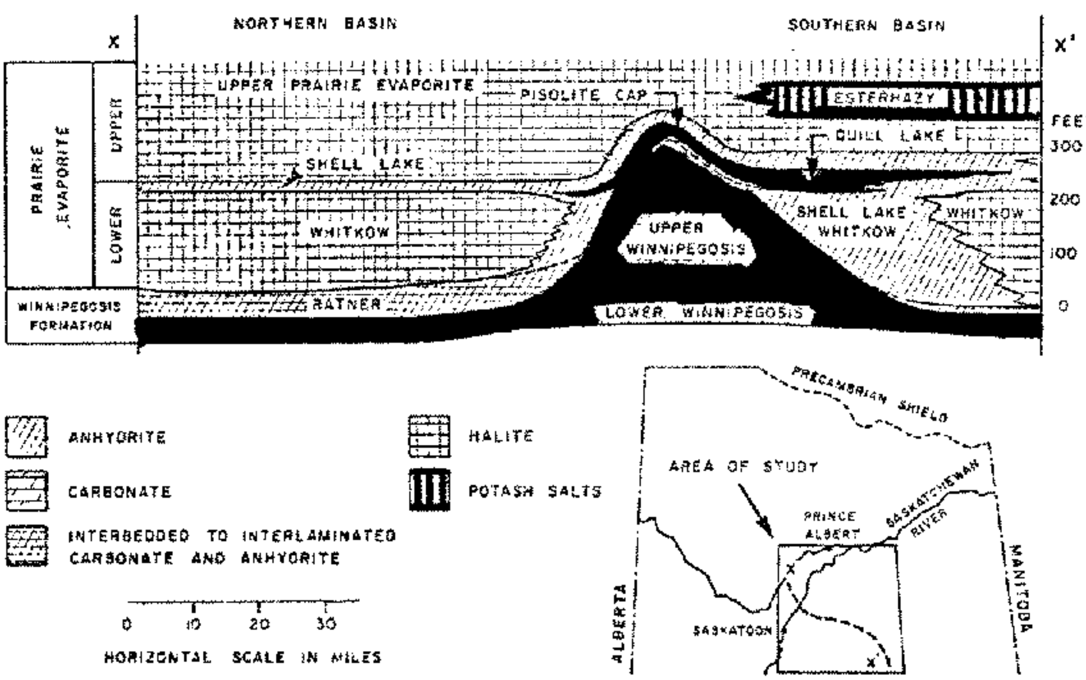

Figure 11. Scheme of Winnipegosis reefs (after Wardlaw and Reinson, 1971).

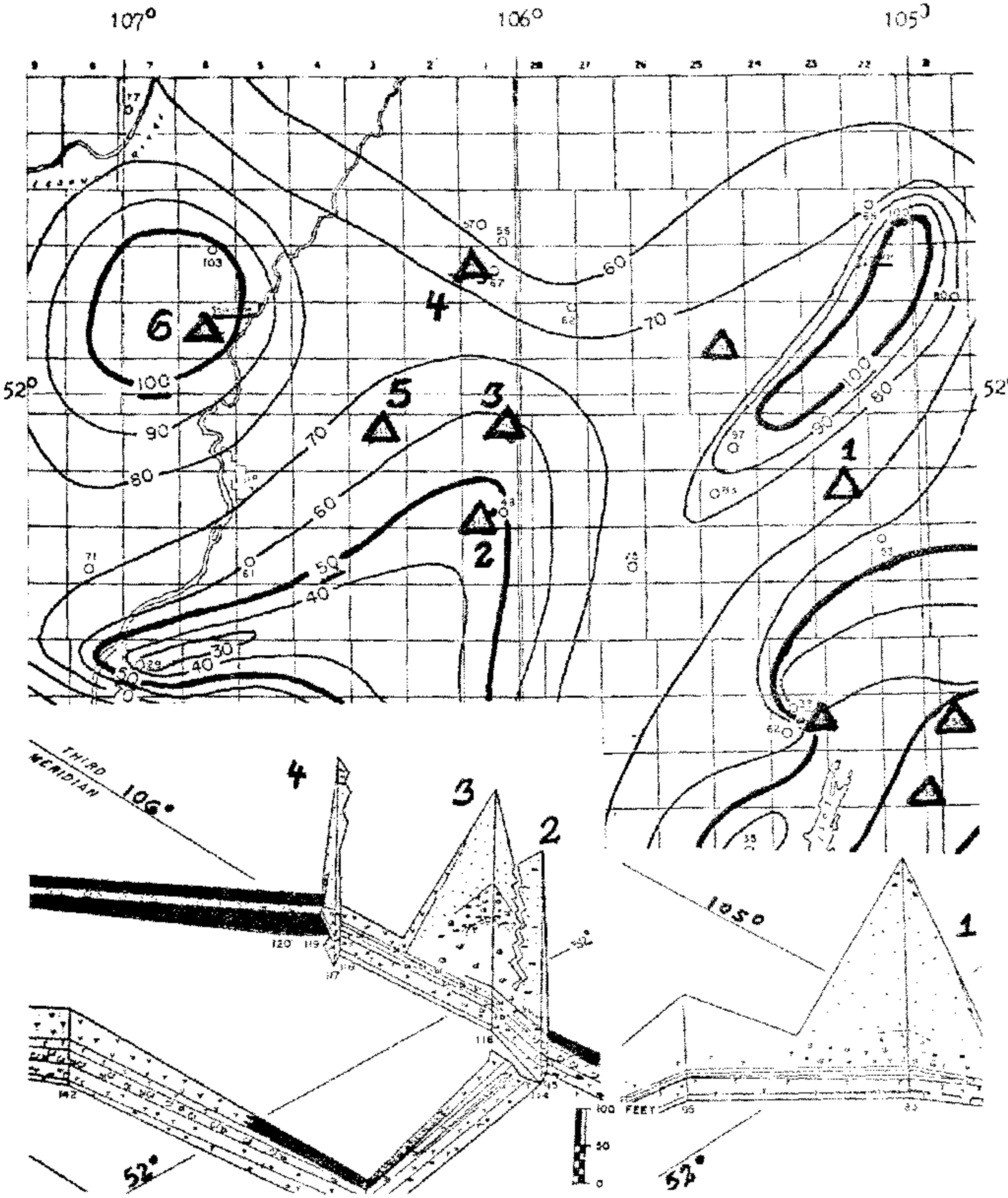

Figure 12 and **Figure 13.** Sections with Winnipegosis reefs, and location map, Central Saskatchewan (after Jones, 1965).

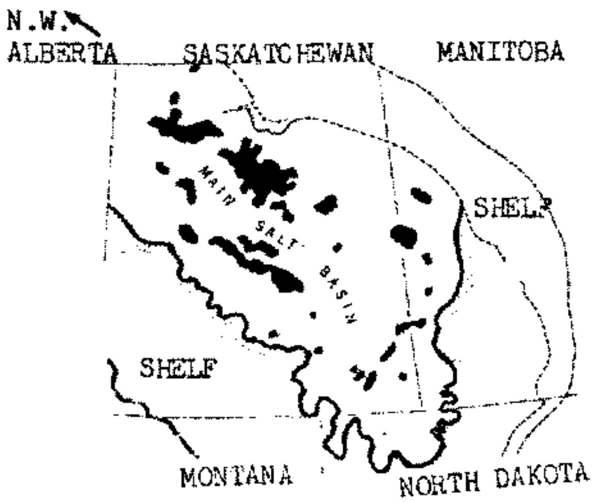

Figure 14. Location map, Winnipegosis reefs (after Fuller and Porter, 1969).

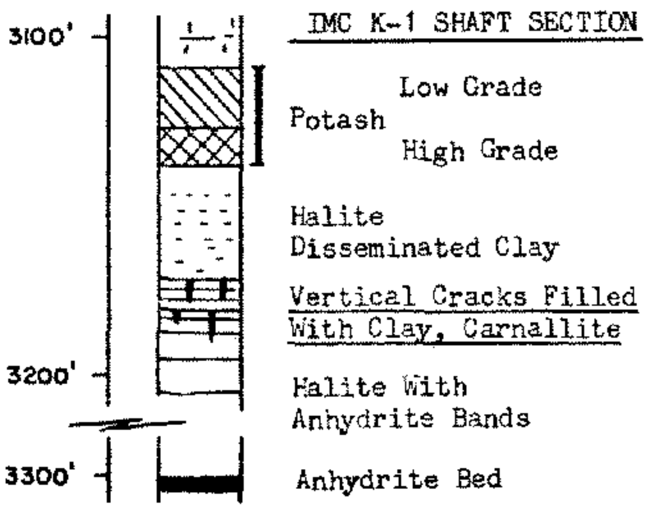

Figure 15. IMC K-1, shaft section.

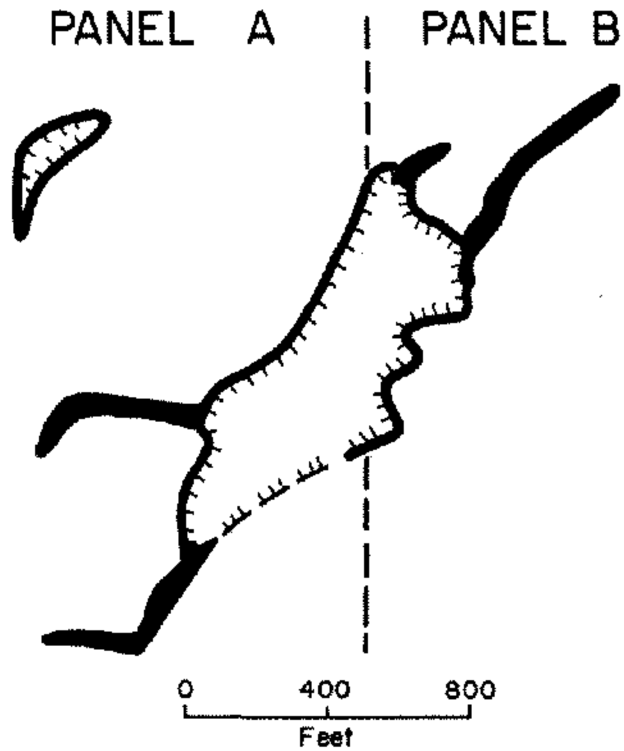

Figure 16. Small anomaly encountered in potash bed at IMC K-1.

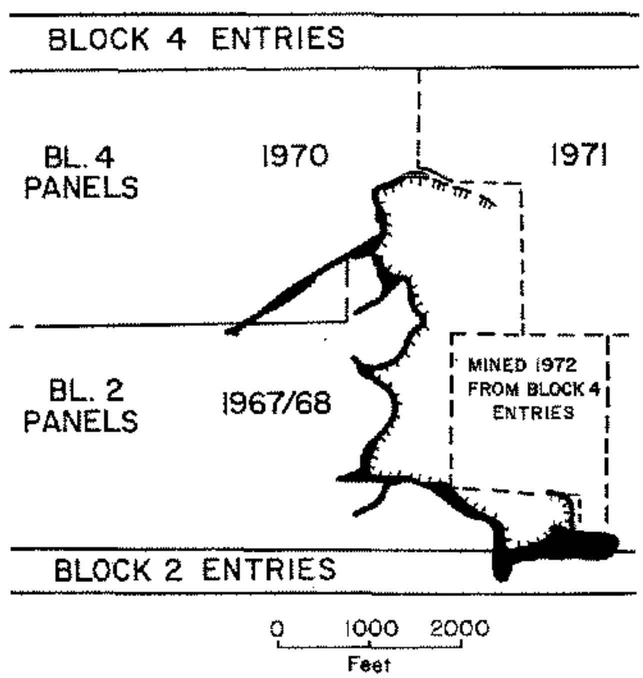

Figure 17. Mining around anomaly at IMC K-1.

basis of bromine investigations. They also described carnallite pods and carnallitic sylvinite masses near what they also termed salt horses with reference to similar salt bodies in the New Mexico potash beds. As the genesis of the New Mexico salt horses is different, the term salt horses is no longer used in Saskatchewan.

Figure 17 shows a larger sink area in the IMC K-1 mine. McIntosh and Wardlaw's investigations partly refer to this anomaly which was hit in the block entry system connecting the two IMC mines, and in a panel mined-out in 1967–68. For a couple of years, a large salt horse was shown on the mine maps covering several panel areas. In 1970, when the block-4-panels were mined, as shown in Figure 17, it was found out that various channels run to the sink, one of them over 1000 ft long, but only 10–20 ft wide. An exploration entry disclosed that there was no large salt horse. The area was then mined from the block-4-entries in 1971 and 1972 as shown in Figure 17.

It might be of interest that a peculiar type of rock salt was found in abundance at the bottom of the long channel seen in Figure 17. This type of rock salt, often in large cubes with edges several inches long, is yellow in situ. As soon as it is brought to surface and exposed to light, it begins to turn blue. After a couple of hours, that process results in beautiful blue crystals which then remain blue.

That type of rock salt often occurs also in carnallite pods near anomalies caused by rainstorms, and in fractures filled with carnallite and large halite crystals which are blue or purple in situ. Results of detailed investigations on the peculiar yellow halite which turns blue have been reported elsewhere (Baar *et al,* 1971). In conclusion, the peculiar colors of the halite were attributed to radio-active material brought into the salt basin by rainstorms which also brought the fresh water to dissolve the salt. As a result of subsequent terminal evaporation, the described carnallite pods were formed.

It appears to be obvious that bromine contents of salt minerals forming by evaporation of relatively small amounts of brine can cover the whole theoretical range. That exactly was found in detailed investigations also reported by Baar *et al.* (1971). This is the reason why bromine investigations are of little value under depositional conditions like those in the Devonian Prairie Evaporite basin in Saskatchewan.

Yellow halite which turns blue, blue and purple halite have also been found in potash mines in which other potash zones are being mined. Their occurrence is related to similar local anomalies in which quite often pods of nearly pure potash minerals occur.

In Figure 18, such an anomaly at Central Canada Potash is outlined by contour lines.

Figure 19 shows an abundance of isolated anomalies in another potash mine near Saskatoon. The following Figures 20 and 21 show some sections through such anomalies, indicating the variability of features and minerals.

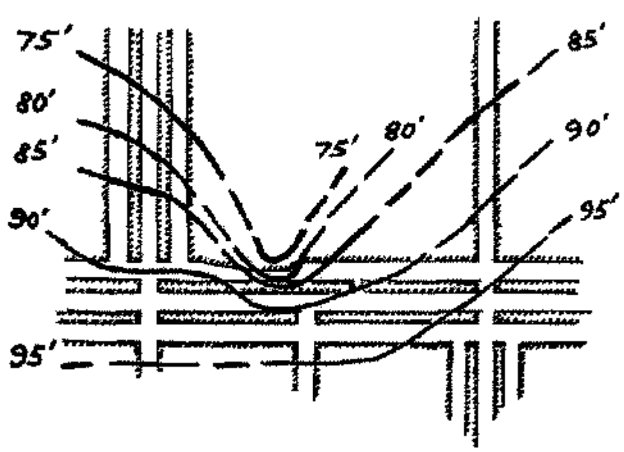

Figure 18. Local depression, Central Canada Potash Co.

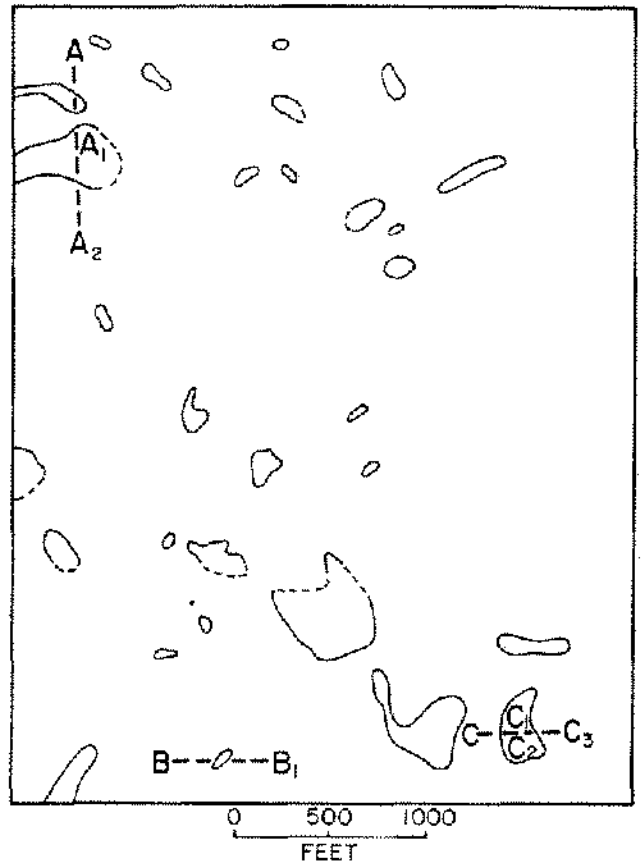

Figure 19. Mine map showing locations of small anomalies.

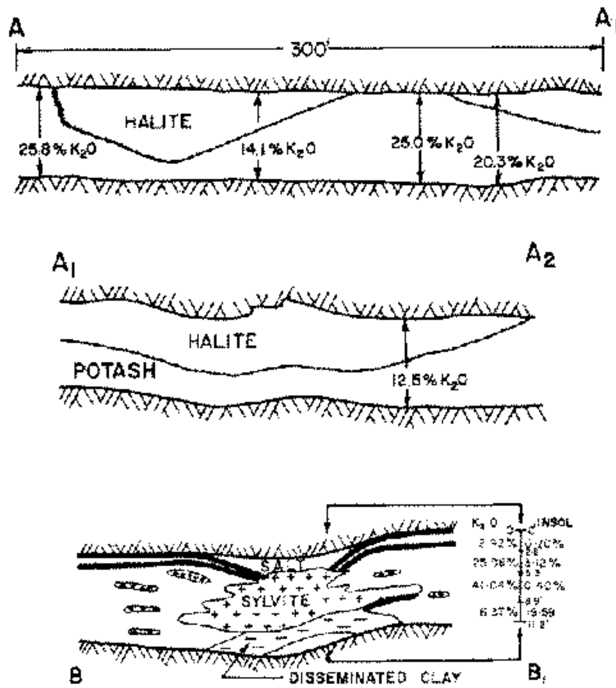

Figure 20. Sections through small anomalies.

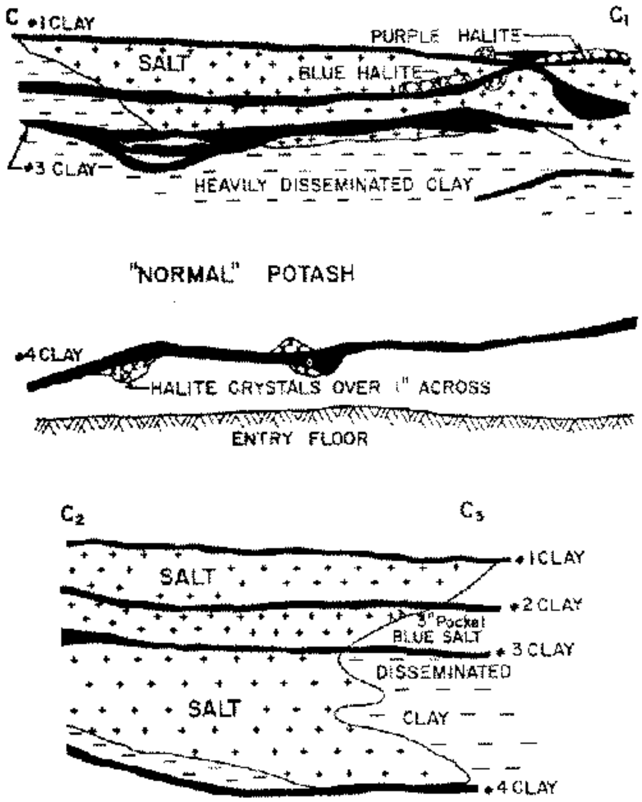

Figure 21. Sections through small anomalies.

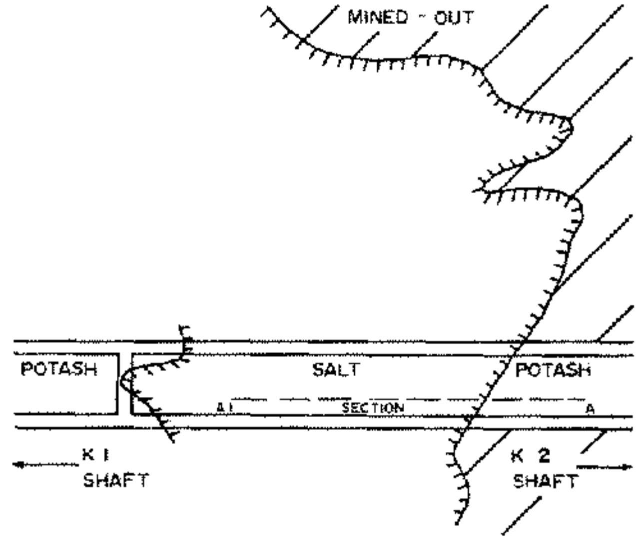

Figure 22. Large anomaly, IMC.

INFLOW OF DILUTED BRINES CAUSED LARGE ANOMALIES

In the Esterhazy area, up to 150 ft of salt were deposited on top of the potash bed in which the features resulting from rainstorms occur. Deposition of 150 ft of salt with clay bands and some thicker clay beds requires inflow of possibly pre-concentrated sea water to raise the brine levels accordingly.

Several observations indicate that the brine levels rose only slowly and intermittently; some density layering within the rising brine apparently was consistent; as a result, diluted surface brine layers reached marginal areas and dissolved deep channel-like troughs out of the surface of the solid deposits.

Figure 22 shows such an anomaly in plan; the extent of the anomaly has not yet been outlined.

Figure 23 shows a section. The salt infilling the trough

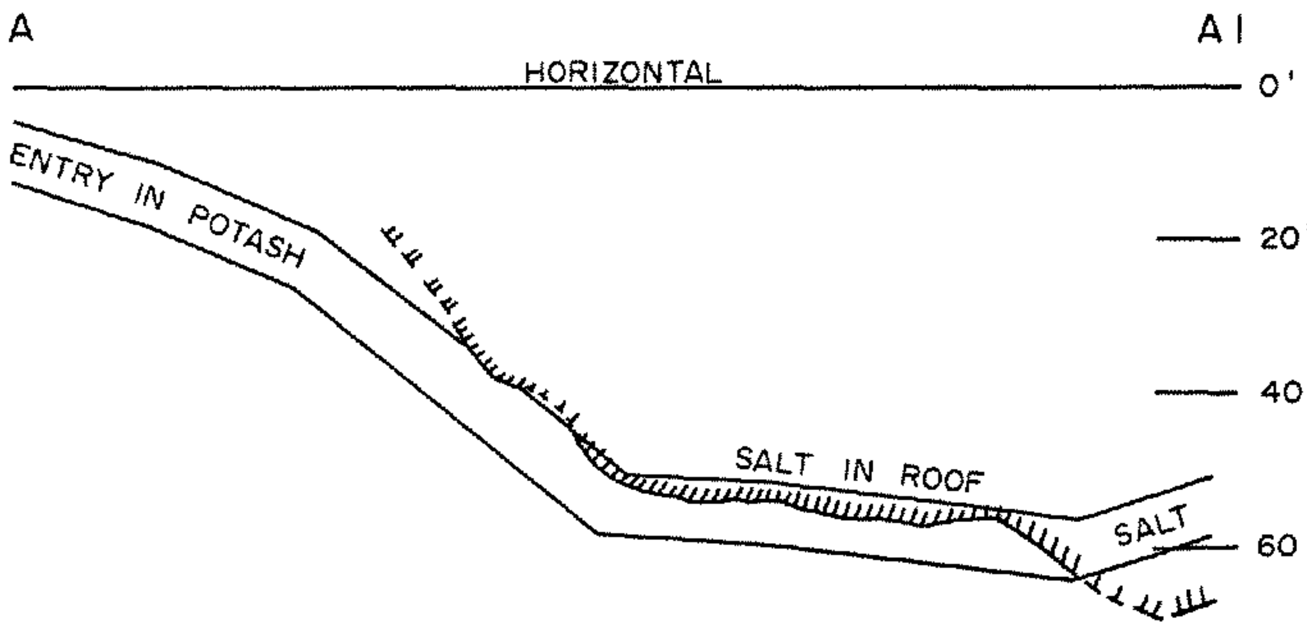

Figure 23. Section through the anomaly shown in Figure 22.

is about 60 ft thick. It is clean salt in contrast to the salt-clay mixture in small, isolated anomalies as described above. Some years ago, another anomaly of that type was encountered at the western boundary of the mining area, all along the last mined-out panels of a block. Attempts to cut an exploration entry through the trough had to cease because of its width. It was decided to get around or through it when the adjacent block would reach it.

The bottom of that salt trough was encountered at the level of the polygonal crack systems shown in Figure 15. The same polygonal crack systems were encountered; some systems below the salt were still filled with carnallite. The salt itself, however, exhibits similar systems filled with brown clay, indicating that the floor of the trough too was intermittently exposed after the trough had been incised. Roof holes drilled to lengths of 80 ft indicated salt of various varieties. Some thick brown clay beds also were intersected. Apparently, this trough had been cut after at least 80 ft of salt and potash had been deposited above the horizon indicated in Figure 15. The potash bed had been removed completely.

Similar troughs encountered within the upper potash beds around Saskatoon may be attributed to similar removal of potash from lower beds. Conversion of carnallite to sylvinite in underlying beds would have had similar effects as it causes a loss of about 50% of the rock volume. Figure 24 may provide one example.

There are some indications that channels or troughs may have been incised when the basin finally was flooded after sedimentation of the Second Red Bed. Figure 25 shows a small block of Dawson Bay limestone at the normal potash level of the Duval mine.

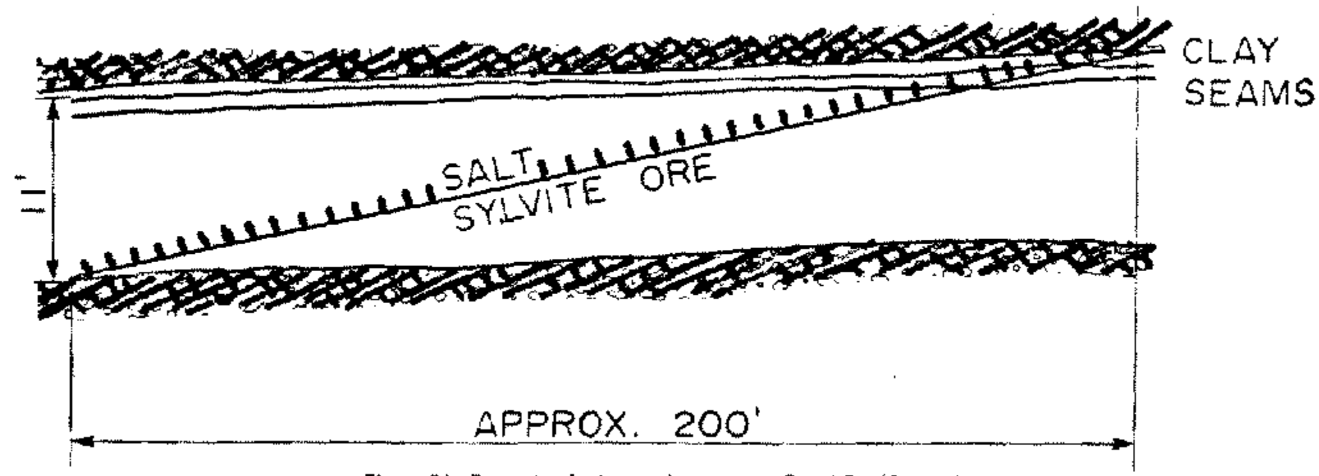

Figure 24. Example of salt-potash contact at Duval Co. (Canada).

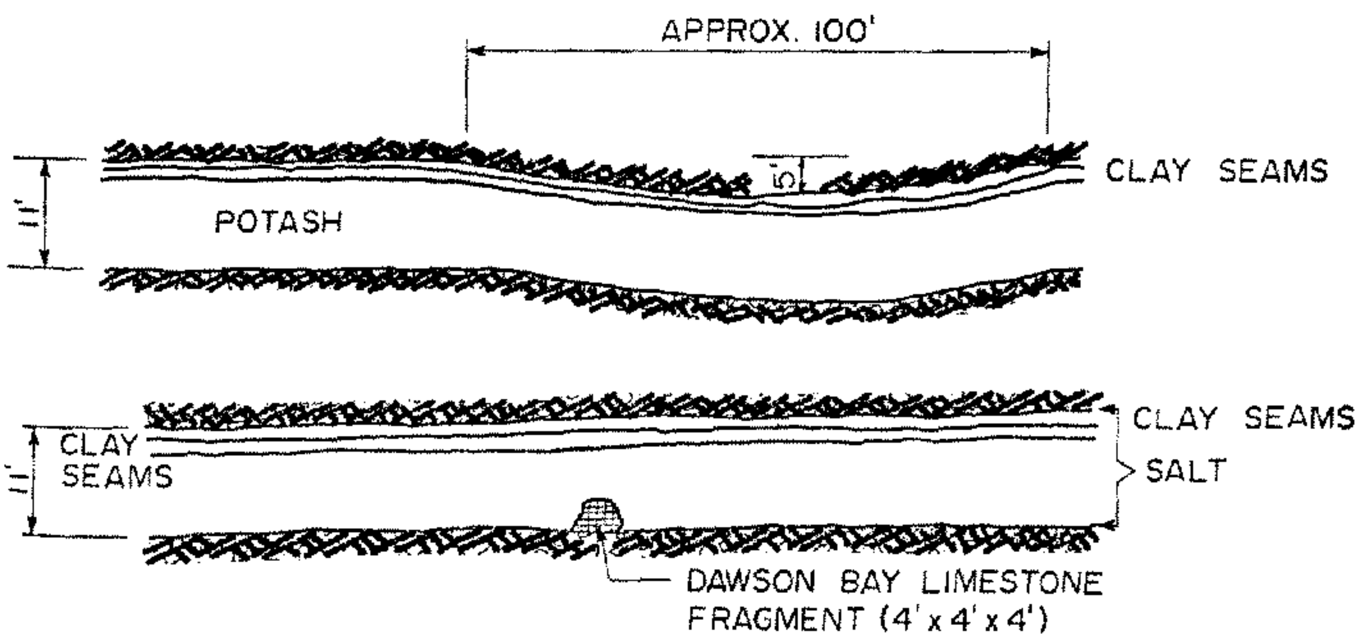

Figure 25. Anomalies encountered at Duval Co. (Canada).

Under normal conditions as shown previously in Figure 8, with several salt beds above the Dawson Bay limestone, such anomalies and many similar ones, called sink holes or wash-outs or break-ins in other potash mines around Saskatoon, cause no concern with regard to potential water inflow from the Dawson Bay. The situation is different near solution areas where all the protecting salt beds have been removed, and the Dawson Bay formation is known as waterbearing.

DEVONIAN BRINES LOCALLY CONSERVED IN THE POTASH BEDS

Some brine inflows into potash mines in Saskatchewan caused initially considerable concern. One example is shown in Figure 26. In 1968, brine seepage from the roof started in a panel in which a local anomaly of the first type described above had been encountered (isolated local anomaly with increased clay contents). The inflow rate decreased considerably over the following years. The inflow did not stop completely, so a detailed investigation was initiated.

At the faces marked x in Figure 26, large intercrystalline cavities were found, representing the space which is often filled with carnallite. The same cavities were found in the core from the borehole Y-8 in a salt bed about 10 ft thick, replacing most of the potash bed.

The brine outflowing in the panel was too high in $MgCl_2$ and in bromine to be derived from dissolution of carnallite (the resulting so-called Q-brine is relatively richer in KCl). So it was concluded that the brine represents a terminal brine from Devonian evaporation. Similar brines with $MgCl_2$ in excess of the $MgCl_2$ in Q-brines have been reported from other potash deposits. The Devonian brine at IMC had been trapped for some reason or another within the deposit.

On the basis of these findings, it was concluded that the brine occurrence was harmless. However, the possibility that the brine lense encountered in the panel would extend to the borehole had to be accounted for.

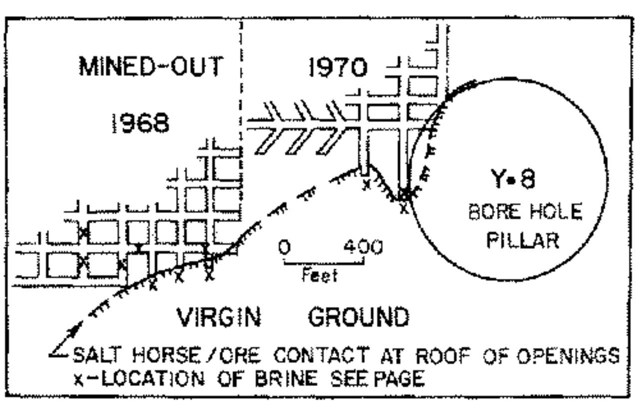

Figure 26. Location of brine seepage, IMC K-1.

Indeed, similar inflows were encountered in a panel developed in 1970, as shown in Figure 26.

Figure 27 shows a situation in which brine with excess $MgCl_2$ and $CaCl_2$ was encountered in a roof borehole in a mine in the Saskatoon area. It could also be classified as harmless.

NO INDICATIONS OF ASCENDING BRINES ENCOUNTERED IN POTASH MINES IN SASKATCHEWAN

To this writer's knowledge, indications of brines ascending from below have not been encountered in any of the potash mines in Saskatchewan.

Some writers have suggested that the reefs shown in various figures initiated local salt solutioning by ascending formation waters. Tectonic events would have triggered such upward flow by causing fractures and creating the required permeability.

This is certainly a conclusive course of events, similar to those observed in other potash deposits. For very good reasons, however, the present potash mines in Saskatchewan keep away from solution areas.

On the other hand, regarding the widespread occurrence of reefs below the mining levels, the inevitable conclusion in the case of missing evidence of ascending brines is that the reefs still contain their original content, including the gasses which were the targets of exploration drilling.

The potential of gas and brine inflows from such reefs requires careful exploration by means of underground seismic, and careful mining methods which do not allow floor upheaval.

CONCLUSION

Only a rough outline of problems encountered in the new potash mines in Saskatchewan could be presented. Much work remains to be done to determine in detail how big the problems really are, and how they possibly can be resolved.

One lesson must be learned: potash deposits are chemical precipitates; their precipitation and alteration was controlled by physico-chemical laws which are known; these laws must be adequately considered in any theory on how a particular potash deposit may have developed. Unfortunately, many textbooks and publications written by geologists do not meet this basic requirement in potash geology.

Another lesson learned in Saskatchewan is that decisive answers to certain questions in potash deposits cannot be found by investigations on a few samples. The whole picture must be considered carefully, and much more geological work is required in the mines to provide for a sound background of facts.

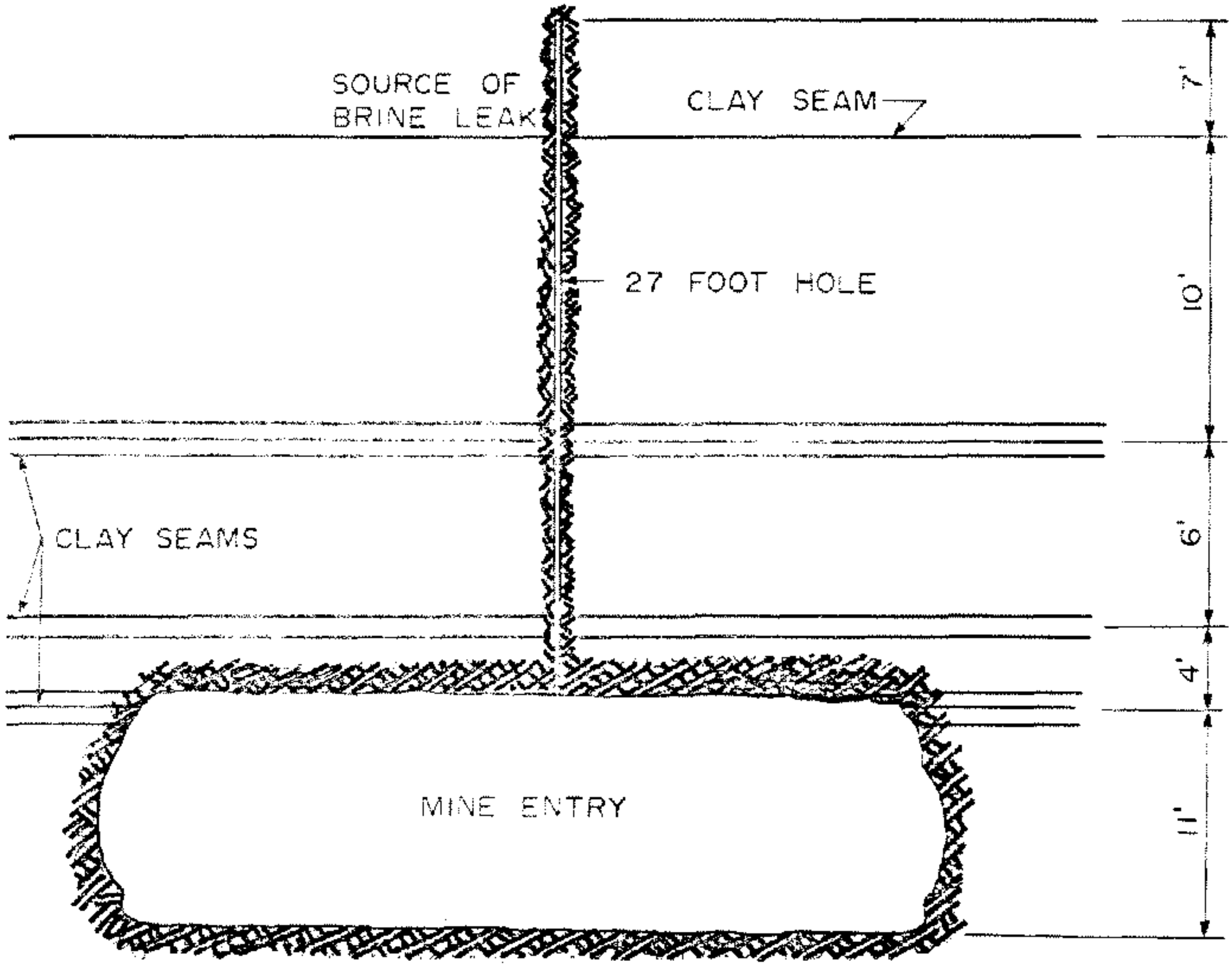

Figure 27. Section, brine seepage at Duval Co. (Canada).

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