

# Bromine Investigations on Eastern Canada Salt Deposits

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## ABSTRACT

*In order to obtain reliable information on the possibilities of potassium deposits, the bromine contents have been determined in series of rock salt samples from several salt sequences occurring in the Upper Mississippian in Eastern Canada.*

*Earlier investigations on various salt deposits have proved the bromine contents of halite (Br/NaCl) to indicate the concentration degree of evaporated ocean water. In a marine salt sequence, the normal bromine contents rise from 0.007 wt. % Br/NaCl at the bottom to approximately 0.02 wt. % at the beginning of potassium precipitation.*

*Rock salt samples from two smaller sub-basins in Nova Scotia are very low in Br/NaCl indicating an evaporation rising only slightly over the concentration at which rock salt begins to crystallize from ocean water. Since samples were only available from areas close to the former basin boundaries, no final conclusions can be drawn. The paleogeographical environment favoured potassium deposition which would have occurred in deeper central areas of these two basins.*

*Thick evaporites in the Cumberland basin extended throughout Northern Nova Scotia from New Brunswick to Prince Edward Island. Potassium salts have been encountered in the former Malagash mine as well as in the Pugwash rock salt mine. Bromine contents of the Cumberland basin rock salts also confirm the high concentration of evaporated sea water.*

*The results of bromine determination challenge further exploration by drilling, since Nova Scotia's favourable geographical position would compensate an ore quality even far below the famous Saskatchewan potash.*

## INTRODUCTION

Canada is going to be the world's largest potash producer, over half a billion dollars are being invested in exploiting Saskatchewan's famous deposits. However, the first potash in Canadian salt deposits was found as early as 1919 in the Malagash rock salt mine in Nova Scotia.

Potash in commercial quantity was not found in that mine which was closed in 1959. Rock salt mining continued with the exploitation of the Pugwash deposit some 20 miles northwest of Malagash. Again, potassium mineralization has been encountered in the mine as well as in some boreholes drilled in the Pugwash area.

With the objective of finding commercial potash deposits, the Nova Scotia Research Foundation, for the past ten years, has been conducting systematic geophysical and geological investigations in those parts of the province which are underlain by marine evaporites.

During 1964-1965, geochemical studies were made on the salt deposits of Nova Scotia, attention being concentrated on the bromine contents of rock salt. For the past fifteen years, the

bromine method has been used in large-scale practical and scientific application in salt deposits, particularly in Germany and Russia. This technique provides evidence of the conditions under which marine chlorides were originally deposited and eventually altered after consolidation.

The author wishes to express his appreciation to the N. S. R. F. for sponsoring these geochemical investigations.

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### SUMMARIZED GEOLOGY OF EASTERN CANADA SEDIMENTARY BASINS

The geological history of sedimentary basins in Eastern Canada has recently been described by Roliff, 1962; Howie and Cumming, 1963; and Pearson, 1963. These publications contain numerous references to the work of previous authors.

For the purpose of this paper, an abstract may be given following Roliff, 1962: The Maritimes Carboniferous Basin comprises parts of the provinces of New Brunswick, Nova Scotia, Prince Edward Island, Newfoundland, and Quebec (Magdalen Islands), the greater part underlying the Gulf of St. Lawrence.

The basin had its origin in early Mississippian time as a result of crustal adjustments following the Acadian orogeny. Throughout much of its history, the basin was unstable; differential movements of basement blocks created a number of small linear sub-basins of deposition that varied in magnitude and position from time to time resulting in complex stratigraphical and structural conditions (Fig. 1).

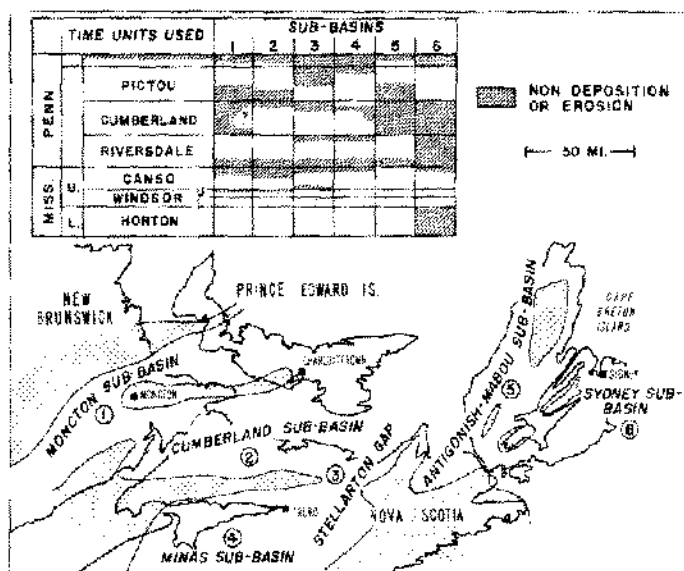


Figure 1. Sub-basins of the Maritimes sedimentary basin, and time units (after Roliff, 1962).

The rocks are of Mississippian and Pennsylvanian age, the former being chiefly brackish-water and marine deposits, and the latter largely nonmarine deposits.

Sedimentation was controlled to a large extent by the presence and differential movement of a number of basement blocks within and bordering the basin, with the result that individual subdivisions of the stratigraphic column are often locally separated by unconformities. Figure 2 shows the Horton sedimentation of Lower Mississippian.

Structurally, the rocks in the basin were subjected to faulting and folding during Mississippian and Pennsylvanian time. Locally, folding of the Mississippian strata was accompanied by diapiric movement of salt and anhydrite (Fig. 3).

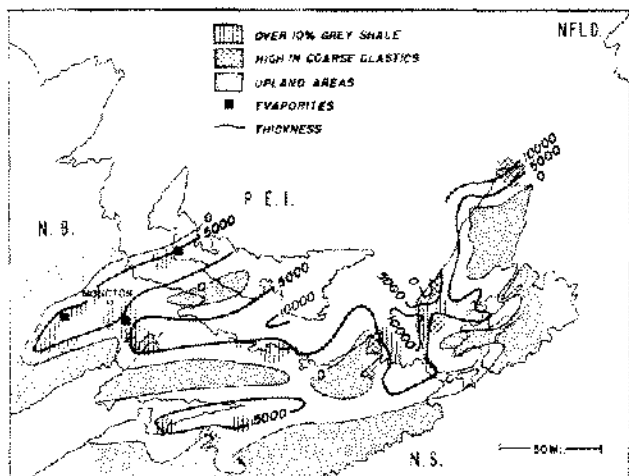


Figure 2. Horton sediments (Lower Mississippian) (after Roliff, 1962).

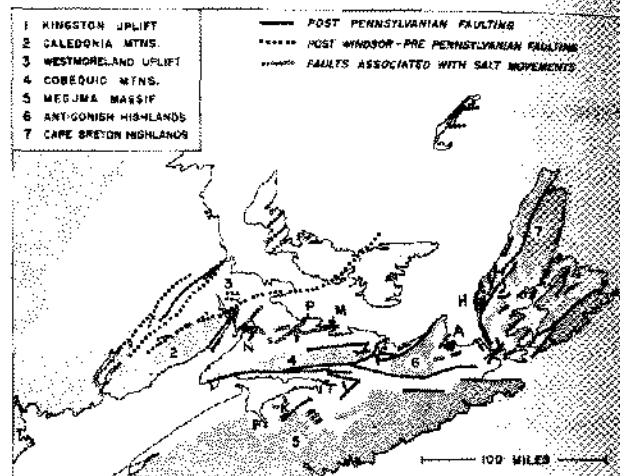


Figure 3. Major fault zones (after Roliff, 1962)

A Antigonish, H Port Hood, F Falmouth, K Kennetcook, M Malagash, N Nappan, P Pugwash, T Truro.

Fold axes and most of the major fault systems parallel the borders of Pre-Mississippian positive areas. Several major fault zones dominate the structural pattern of the Maritimes, block faulting being the most common structural feature in the region.

Similar conclusions have been drawn by Howie and Cumming, 1963: Fragmentation and subsequent tilting of basement blocks initiated isostatic adjustments accompanied by erosion and sedimentation in localized narrow troughs during Carboniferous time.

Such crustal movements favoured restriction of sub-basins and deposition of evaporites if the sea advanced into the Maritimes basin. Salt deposits have been found in the Albert Formation of the Lower Mississippian in New Brunswick and in the sub-zone B of the Lower Windsor (Upper Mississippian) throughout all sub-basins in Nova Scotia.

In Fig. 4, the sub-basins dealt within this paper are numbered as follows:

1. Antigonish-Mabou sub-basin
2. Minas sub-basin
3. Cumberland basin

#### COMPARABLE DEPOSITIONAL CONDITIONS IN OTHER SALT DEPOSITS

No large uniform salt sequences can be expected in the Maritimes basin, such as are known for example, in the Prairie Evaporites of Saskatchewan or in the Zechstein of Europe.

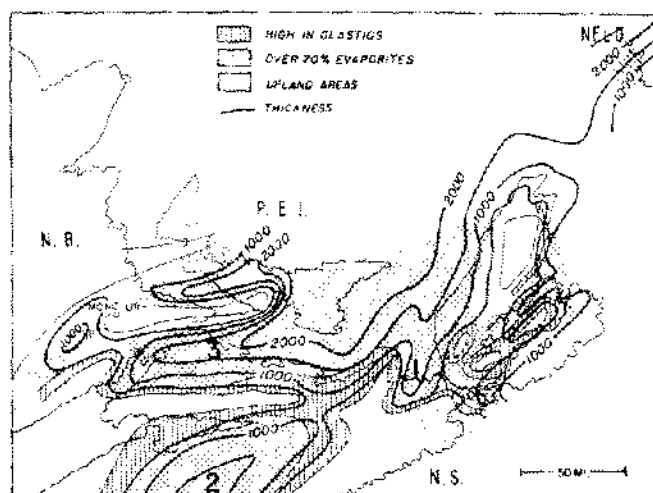


Figure 4. Lower Windsor sediments (Upper Mississippian) (after Roliff, 1962)

- 1 Antigonish-Mabou sub-basin
- 2 Minas sub-basin -- 3 Cumberland basin.

Since large upland areas surrounded the small evaporating basins of the Windsor sea in Nova Scotia, a great deal of terrestrial material sedimented together with evaporites, intercalated clay or shale layers representing seasonal fresh water influx from the upland.

Comparable salt deposits have frequently formed under similar conditions, the best known example being the Tertiary Upper Rhine Valley deposits (Fig. 5). The sea advanced several times into this subsiding area, and although evaporation was often interrupted by influx of seasonal fresh

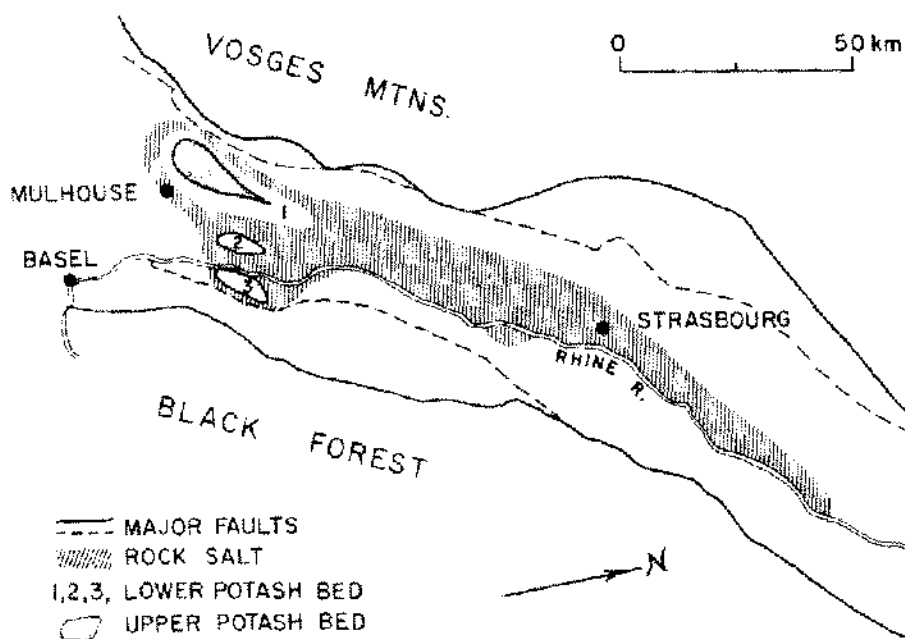


Figure 5. Tertiary salt deposits. Upper Rhine Valley.

water, two potassium beds were precipitated in the deepest parts of this basin. Obviously, the brine level was lowered with increasing concentration, the highly concentrated solutions finally occupying small areas only where potassium salts crystallized.

Similar paleogeographical conditions controlled the evaporation of Windsor sea sub-basins in the Maritimes. Final precipitation from inflowing sea water should have left potassium salts in the deepest parts of subsiding troughs.

Potassium deposits of this type apparently were protected from dissolving in dilute inflows by intercalated marl or clay layers. In particular, if thick clay layers sedimented shortly after potassium precipitation, concentrated solutions still covered the soluble salts. Throughout the Maritimes salt deposits, intercalated shale beds are common features favouring conservation of soluble potassium salts.

Another phenomenon often associated with salt deposition of this type also occurred during Windsor sea evaporation in Nova Scotia: No magnesium sulfates (only sylvite and carnallite) have been found in these salt successions, obviously due to loss of  $\text{SO}_4$ , the inflowing sea water interacting with calcium carbonate water coming in from the hinterland.

In the full development of such an alteration process, sea water will lose all its magnesium sulfate, the final evaporation resulting in a crystallization path starting at point 5, Fig. 6 (after Valyashko, 1957).

Salt sequences resulting from gradually increasing loss of  $\text{SO}_4$  are shown in Fig. 6. Magnesium sulfate gradually disappears from the normal sylvite zone and then from the carnallite zone. Since alterations by incoming fresh water would easily reach high grades under conditions controlling the Upper Rhine deposits as well as the Maritimes salt deposits, precipitated salt successions should represent the sequences 4 or 5 of Fig. 7.

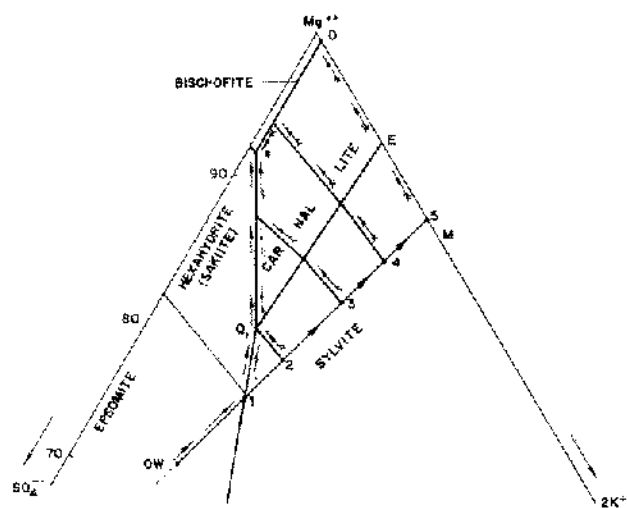


Figure 6. Crystallization from unaltered sea water (composition represented by point SW) and from sea water the composition of which is gradually altered by loss of  $\text{SO}_4$ , as indicated by the points 1, 2, 3, 4, 5 (after Valyashko, 1957).

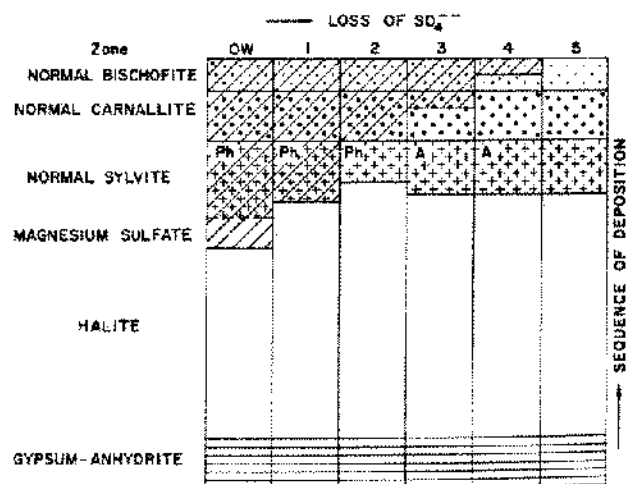


Figure 7. Salt sequences resulting from sea water evaporation after alterations as shown by Figure 6 (after Valyashko, 1957).

## THE BROMINE METHOD IN SALT DEPOSITS RESEARCH

The bromine ion occupies a special place among the approximately 40 trace elements found in sea water: bromine enters into crystallizing chlorides replacing a definite amount of chlorine

ions. This replacement is controlled by so-called distribution factors (see Fig. 8) which are different from each chloride.

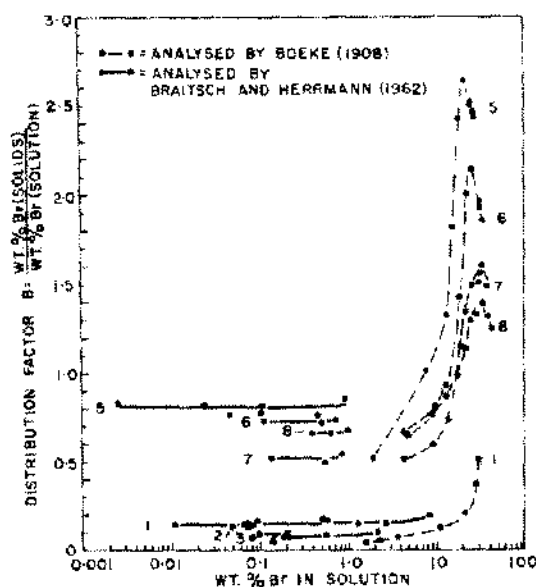


Figure 8. Bromine distribution between solutions and chlorides crystallizing at 25° C (after Braitsch and Herrmann, 1963).

- 1 - 4 Halite crystallizing from the following systems:
  - 1 Na, Cl, Br, and H<sub>2</sub>O
  - 2 Na, Mg, Cl, Br, and H<sub>2</sub>O, the MgCl<sub>2</sub>-concentration equaling that of sea water at the beginning of halite crystallization
  - 3 Na, Mg, Cl, Br, and H<sub>2</sub>O, the MgCl<sub>2</sub>-concentration being approximately 11 wt. %
  - 4 Na, Mg, Cl, Br, and H<sub>2</sub>O, the solution being nearly saturated with respect to MgCl<sub>2</sub>
- 5 - 6 Sylvite crystallizing from the following systems:
  - 5 K, Cl, Br, and H<sub>2</sub>O
  - 6 K, Mg, Cl, Br, and H<sub>2</sub>O, the solution being nearly saturated with respect to carnallite
- 7 Carnallite crystallizing from the system K, Mg, Cl, Br, and H<sub>2</sub>O
- 8 Bischofite crystallizing from the system Mg, Cl, Br, and H<sub>2</sub>O.

Since all distribution factors for chlorides crystallizing from evaporating sea water are less than 1, the remaining solution becomes progressively enriched in bromine. This enrichment, on the other hand, is reflected in progressively increasing bromine contents in a salt sequence precipitated by evaporation, provided that the amount of evaporated water at least equals the influx, and progressive concentration takes place in an evaporating basin.

The bromine content of a given amount of sea water increases with concentration as shown by Fig. 9. The distribution factors cause the very first halite to have a bromine content of approximately .007 wt. %, a continual increase taking place to approximately .023 with the concentration at which the first potassium mineral crystallizes. It is kainite under conditions assumed in that graph (after Braitsch, 1962).

Continual influx of sea water will delay the bromine content increase in the evaporating basin as well as in the precipitated salt sequence. In the Stassfurt rock salt sequence, for example, the normal bromine contents increase very regularly from the basal anhydrite to the Stassfurt potash bed as shown by Fig. 10 (Baar, 1954).

From these bromine profiles it became apparent that the main rock salt precipitation initially took place in the deepest part of the Stassfurt basin, due to the negative temperature coefficient for sodium chloride in marine solutions until the magnesium chloride concentration has reached 25 moles of MgCl<sub>2</sub> in 1000 moles of water. During rock salt precipitation in the deeper parts of the basin where temperatures were lower at the basin floor, calcium sulfate was the main precipitate in shallower areas. This is a true facies change which may be found in all evaporites deposited under comparable conditions.

The regular bromine contents shown in Fig. 10 could be used in large-scale practical application for stratifying the very uniform rock salt succession of the Stassfurt cycle (Baar, 1954, 1955). Similar bromine stratification was possible in other Zechstein rock salt sequences (Schulze, 1959 and Dittich, 1962). However, it is advisable to make large-scale bromine determinations in order to recognize irregular single bromine contents caused by post-depositional alteration (Baar, 1961).

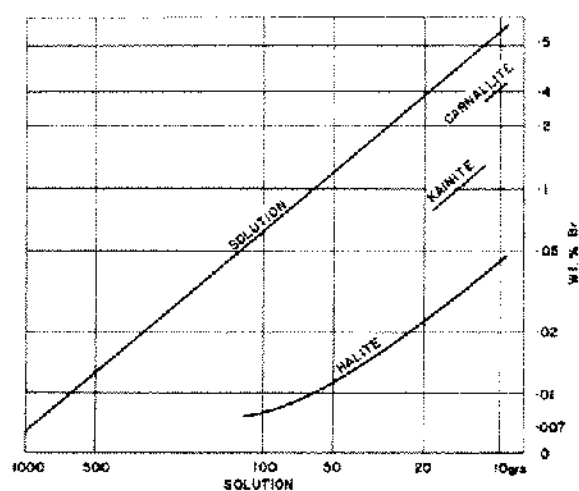


Figure 9. Bromine distribution calculated for evaporation of a given amount of sea water at 25° C (after Braunsch, 1962).

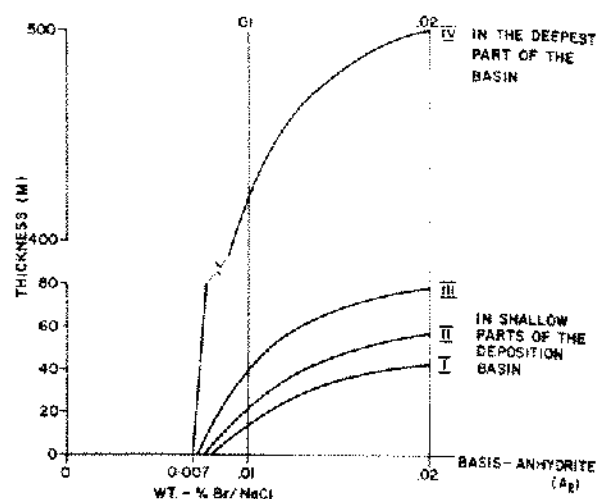


Figure 10. Normal bromine contents of the Stassfurt rock salt sequence, South Harz district, Central Germany (after Baar, 1954)

- I Bismarckshall mine near the Eichsfeld swell
- II Bleicherode area
- III Sondershausen area
- IV Rossleben mine near the centre of the depositional basin.

Salt minerals as well as their bromine contents readily undergo alterations if contacted by solutions which do not meet the equilibrium conditions. The bromine content of a chloride may alter even if during recrystallization a solution is present which has a bromine content not in equilibrium with respect to the distribution factor. Depending on the bromine content of a contacting solution, bromine contents of recrystallizing or replacing chlorides may increase or decrease. Many examples of both have been found in nearly all the deposits in which bromine investigations have been made.

First of all, lowered bromine contents are usually found in the basal strata of a rock salt sequence; the decrease in bromine is believed to have been caused by less concentrated brines infiltrating from below in an early diagenetic stage of consolidation. The same often happened in top salt strata when dilute brines entered from above; as a consequence, bromine contents in thinner salt beds were lowered throughout the whole section.

On the other hand, dilute solutions infiltrating salt deposits from above before consolidation may cause irregular high bromine contents of floor strata if enriched in bromine by dissolving potassium salts. This apparently occurred in the Prairie Evaporites, irregular bromine contents being encountered below the potassium beds where the primary carnallite has been dissolved, syl-vite ore being left. In consolidated salt sequences, fissure fillings crystallizing from migrating solutions also have irregular bromine contents (Baar, 1954; Kühn, 1955).

In the salt domes of Northern Germany, severe alterations of original bromine contents in halite were caused by salt flowage in which solutions were involved. According to Borchert and Muir, 1964, salt flowage is believed to be accompanied by continuing recrystallization, the bromine contents being subjected to alterations controlled by the distribution factors. Since at least three primary potassium beds were deposited in the Hanover area, any solution involved in salt flowage would easily become saturated with respect to potassium salts and enriched in bromine. Recrystallizing halite contacted later by these solutions, altered its bromine content so that no "bromine stratification" was possible in the Hanover area, contrary to other areas where the same rock salt strata have not been subjected to heavy flowage, and alteration of bromine contents (Baar, 1961).

In salt deposits precipitated by evaporation of small intercontinental basins, such as the Upper Rhine and the Maritimes basins, bromine contents of rock salt may be used in particular

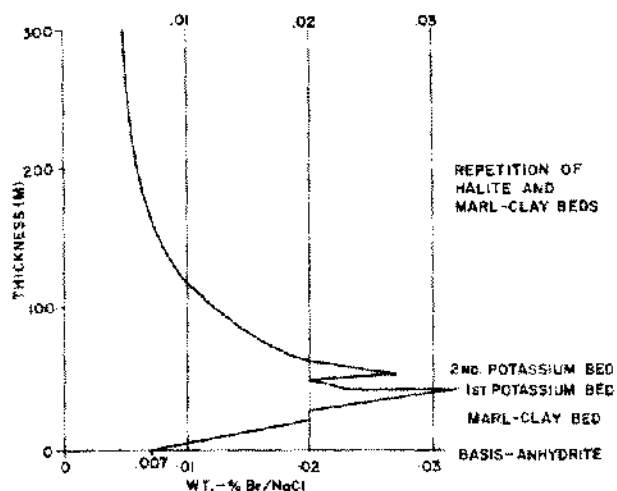


Figure 11. Average bromine contents of the Tertiary Upper Rhine Valley salt deposits (compiled after Baer and Külls, 1962, and Manger, 1961).

to find horizons of possible potassium precipitation. A great many individual evaporation cycles occurred in the Upper Rhine trough, but potassium salts were only left in the two first cycles as shown by Fig. 11. During the following salt deposition, decreasing average bromine contents indicate lower concentration degrees which finally rose only slightly above the concentration at which sodium chloride begins to crystallize.

In such cases, the volume of solutions involved in influx and evaporation was small in comparison to large evaporating basins; so that the concentration needed for potassium precipitation was reached much sooner, i. e., after precipitation of a much thinner rock salt sequence, particularly if the solutions shrank by evaporation and finally occupied only a small area of potassium precipitation.

The upper part of Fig. 11 has been compiled from large-scale bromine determinations which were made in order to recognize the potassium horizons in some boreholes in which strata correlation by other means had failed (Manger, 1961).

#### SAMPLING AND ANALYSING METHODS

From experience gained by using the bromine method in Western Europe, and after considering the similar experience Russian workers obtained in Asian and Russian salt deposits, the bromine contents of Nova Scotia salt deposits are expected to indicate the concentration degrees reached in different sub-basins.

However, it was difficult to obtain suitable sample series of Nova Scotia salt sequences since there is no drilling program at the present time. In wells drilled for other purposes, salt beds have not been cored. The usual drilling fluids leave little undissolved salt with the cuttings, and if cutting samples were washed before being stored, the salt was washed out.

Fortunately, no large quantities are needed for bromine determination in rock salt. Thanks to the kindness of Dr. Caley, Geological Survey of Canada, a few grams of each salt containing sample listed by Howie and Cumming, 1963, Table 1, could be used for bromine determinations.

Cutting samples which have previous histories which are largely unknown, are certainly not the best sample material for geochemical investigations on an element such as bromine which is known to readily undergo alteration with recrystallization of its carrier. However, cutting samples were the only available material of most of the wells intersecting Windsor salt in Nova Scotia.

A complete core was available from a well drilled in the Antigonish area. The Pugwash salt mine afforded unlimited sampling.

All samples obtained from cores or from exposures in the mine were selected, eliminating large halite crystals which obviously formed secondarily not representing the normal sequence. Since bromine contents of potassium salts are up to ten times higher than contents of paragenetic halite, potassium contamination, if any, has also been eliminated.

In order to remove any possible potassium contamination and any adherent solution which would also falsify the bromine contents of halite, the samples were washed with distilled water and alcohol after being ground. As an added precaution, potassium was determined spectrographically in each sample; sodium was determined flame-photometrically, and all bromine contents were calculated as per 100 % NaCl.



TABLE 1  
Analyses of Core Samples -- Port Hood No. 1 Well

DEPTH	% K	% Br	% NaCl	% Br/100% NaCl
6105	.052	.0031	99.1	.0032
6111	.080	.0020	96.0	.0021
6283	< .05	.0027	100.0	.0027
6284	< .025	.0030	100.0	.0030
6284A	< .025	.0032	99.6	.0032
6286	.025	.0037	99.6	.0037
6288	.035	.0030	100.0	.0030
6289	.033	.0034	100.0	.0034
6291	.047	.0034	100.0	.0034
6292	.028	.0035	99.6	.0035
6640	.031	.0052	99.6	.0052
6655	.043	.0085	96.5	.0088
7002	.043	.0025	93.0	.0027

Bromine was determined following the method of Van der Meulen, 1931, improved by d'Ans and Hoefer, 1934 (see Schwerdtner, 1963, English summary).

Sufficient material was not available for all these determinations in the "cutting samples," so they were prepared by the following procedure: picking out the impurities, almost pure halite was obtained for bromine determinations. Nevertheless, sodium was determined by flame-photometer for calculating the bromine per 100% NaCl.

#### ANTIGONISH -- MABOU SUB-BASIN SALT DEPOSITS

The Antigonish-Mabou sub-basin extends northeastward between the Antigonish and Cape Breton Highlands, the greater part underlying St. George's Bay of the Gulf of St. Lawrence (Figs. 3 and 4).

Rock salt beds are known from two series of boreholes, one situated south of Antigonish Harbour, the second between Port Hood and Mabou, Cape Breton Island.

Figure 12 shows a cross section of the Antigonish area, gypsum-anhydrite beds under- and overlying the salt sequence and outcropping to the west. The bromine profile of this salt bed is shown in Fig. 13; the samples have been taken from a core of borehole No. 2.

The normal bromine contents indicate low concentration degrees of evaporating sea water persisting through the whole sequence. However, some irregular bromine contents found in secondary halite indicate that higher concentrated solutions migrated through that succession. According to this conclusion, the potassium contents of these secondary halites are somewhat higher (.11 -- .28% K) than the normal K-contents which are less than .07%.

Comparing the situation of the Upper Rhine salt deposits (Figs. 5 and 11) and considering a probable facies change of anhydrite-gypsum to halite following the eastward dipping, solutions higher in bromine should have originated from deeper parts of that basin which were occupied by evaporating solutions shrinking with concentration. Precipitation from such brines should have taken place in easterly situated areas now covered by St. George's Bay.

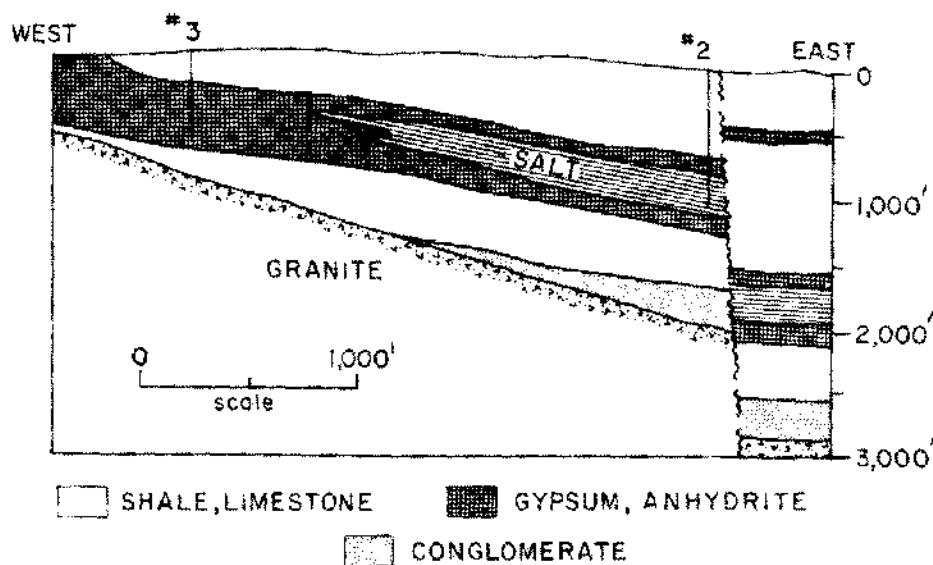


Figure 12. Cross section South Side Antigonish Harbour.

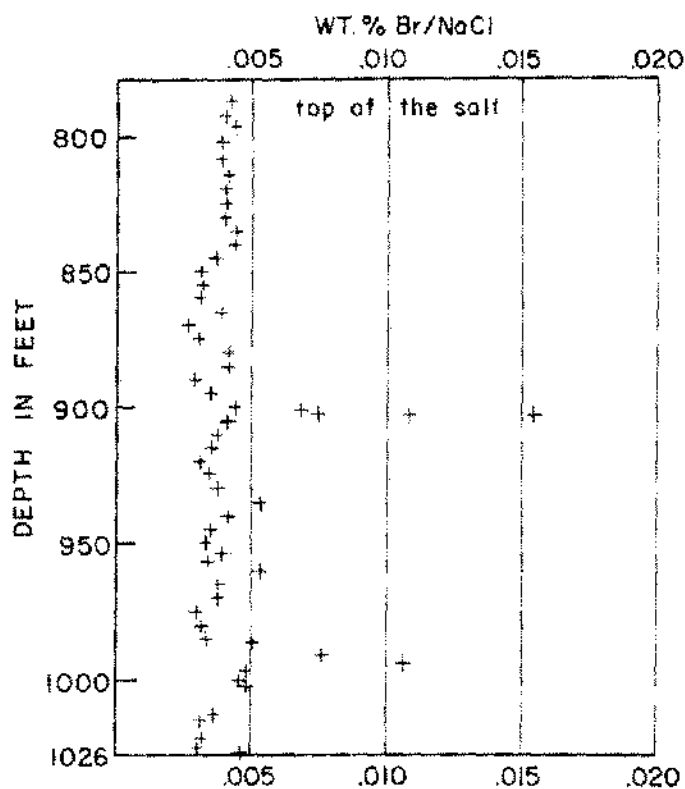


Figure 13. Bromine Contents Core of Borehole No. 2, South Side Antigonish Harbour.

Figure 14 is a cross section through the opposite eastern side of that sub-basin; the wells revealed several faults and severe distortion of Windsor Evaporites; the salt was probably accumulated by flowage.

Some short core sections were available from the Port Hood No. 1 well. The results of analyses are listed in Table 1.

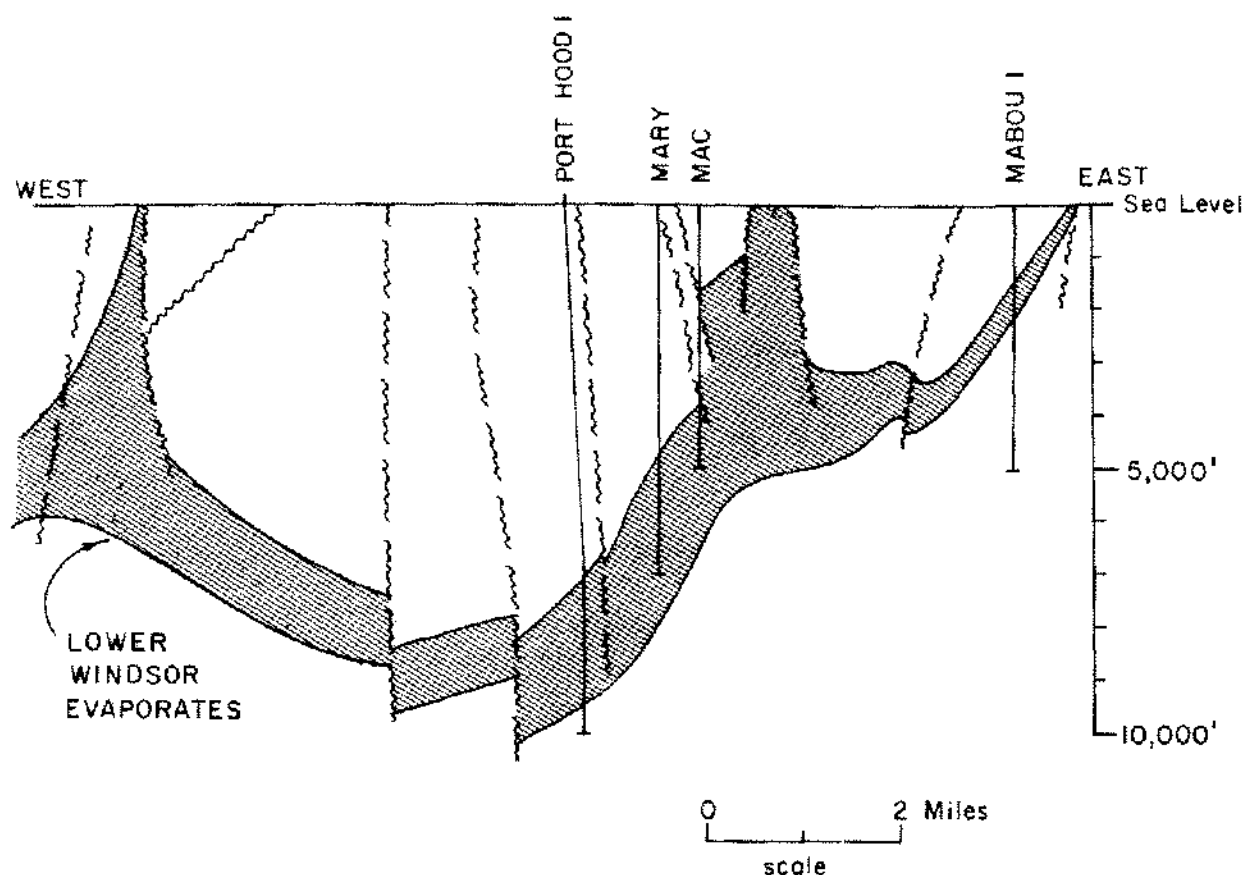


Figure 14. Cross section Port Hood -- Mabou, Cape Breton Island (after Roliff 1962).

Results of cutting samples analyses are compiled in Table 2. The Mary No. 1 samples are generally lower in bromine, only four values rising slightly over .005 wt. % Br/NaCl.

Although all bromine contents probably are altered, an increase is indicated from Mary No. 1 to Port Hood No. 1 towards the basin centre.

TABLE 2

Bromine Contents (wt. % Br/100% NaCl) of cutting samples  
 Port Hood No. 1 between 7800 and 9420 feet  
 Mary No. 1 between 5300 and 6800 feet

Wt. % Br/100% NaCl	Number of Samples	
	Port Hood No. 1	Mary No. 1
.003 - .0039	-	11
.004 - .0049	5	21
.005 - .0059	3	4
.006 - .0069	1	-

## MINAS SUB-BASIN SALT DEPOSITS

Three earlier wells drilled south of the recent Minas Basin have intersected thin rock salt beds: Two wells near Falmouth in the vicinity of Windsor (Fig. 3) each encountered 11 feet of rock salt, another one near Kennetcook about 30 miles to the northeast some 50 feet, both salt beds being accompanied by thick gypsum-anhydrite beds.

The results of analyses of available cuttings are listed in Table 3. The lowermost sample from Kennetcook contained as much as .0195 wt. % Br/NaCl, which is of major importance:

TABLE 3  
Bromine Contents of Cutting Samples, Minas Sub-basin

LOCATION	DEPTH IN FEET	WT. % Br/NaCl
Falmouth	554	0.0056
Kennetcook	1366	0.0050
Kennetcook	1375	0.0057
Kennetcook	1383	0.0053
Kennetcook	1405	0.0195

In large areas of the sub-basin, thick gypsum beds are known. These were deposited during Windsor B Time, and are the basis of an important gypsum industry. During the preceding Horton time, the basin rapidly subsided and received approximately 5,000 feet of terrestrial sediments (Fig. 2). Since no noteworthy Post-Windsor sedimentation occurred, the area probably became stabilized.

The Windsor sea probably entered through the Stellarton Gap from the main Maritime basin, and restriction of influx resulted in a large deposition of evaporites. Obviously, depositional environments favoured evaporation of sea water, the shrinking solutions covering only deeper parts of the sub-basin during temporary cutoff of sea water influx and possible potassium precipitation. For these reasons, some thick salt bodies indicated by gravity anomalies are of greater interest.

One of those gravity lows is located near Kennetcook. The above mentioned well intersected a thin salt bed extending to the left from the main salt body as shown in Fig. 15.

Since undisturbed salt beds are impervious if buried by thick overlaying sediments, solutions pressed out of or contacting the main salt body would not ascend through the salt, but would migrate along the floor of the salt sequence causing recrystallization. Therefore, the high bromine content of the lowermost sample of the Kennetcook borehole should indicate migrating solutions enriched in bromine, derived from the main salt body. Since high bromine contents indicate the probability of potassium precipitation, investigation of the main salt body by drilling was recommended.

Although this recommendation is based on a single bromine determination, and it was not possible to check on more sample material, the favourable paleo-graphical situation controlling the Windsor sea evaporation in the Minas Sub-basin seems to justify further drilling work.

The same is true of another large gravity low situated in the eastern part of the Minas sub-basin south of the town of Truro (Fig. 3).

The salt body which is assumed to occur at suitable depths has not yet been investigated by drilling.

The Nappan area structure differs somewhat from the Pugwash structure, the Nappan salt beds are probably dipping steeply from the gypsum outcrop at the syncline crest.

Several boreholes drilled in that area since 1931 penetrated the top of the salt at depths between 772 and 1360 feet. Some cutting samples were available from the Sunoco No. 1A well which intersected several salt beds between 1105 and 6072 feet. Bromine contents of available sections are shown in Fig. 18.

In the two uppermost sections, the bromine contents run from .006 to .009 wt. % Br/NaCl, except one sample with a content of .0172.

In the third section all bromine contents are over .007 and in the fourth section, all are less than .007 wt. % Br/NaCl.

In the deepest section, all contents exceed .011 wt. % Br/NaCl. Unfortunately, no more samples were available from that section. The bromine contents increase with depth and probably reach values, which indicate concentration degrees of evaporating sea water which enabled potassium to precipitate in that sub-basin.

Similar high bromine contents have also been found in cutting samples from the Pacific Fox Harbour well situated east of Pugwash (Table 4).

Further east, in the Hillsborough well of Prince Edward Island, four cutting samples between 13,695 and 14,250 feet depth have Br/NaCl contents from .0097 to .0145 wt. %.

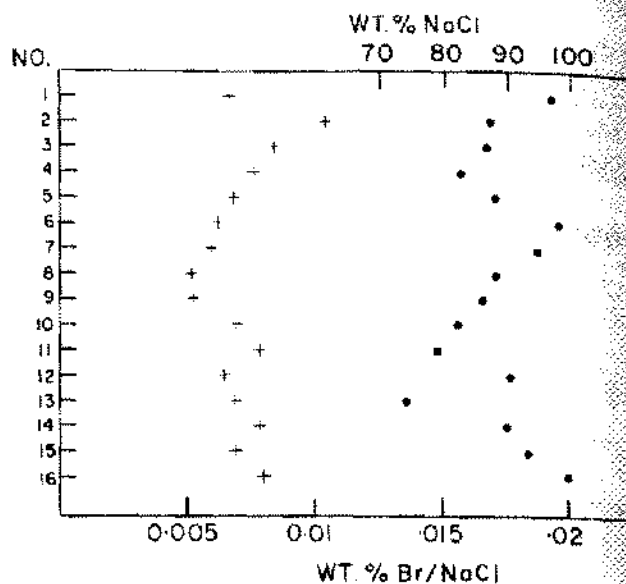


Figure 17. Bromine contents of halite, samples taken along a definite horizon over approximately 1000 feet, Pugwash mine, 635 feet level.

TABLE 4

Analyses of Cutting Samples -- Pacific Fox Harbour Well

DEPTH (Ft.)	% K	% Br	% NaCl	% Br/100% NaCl
8860	.046	.0101	99.1	.0102
8890	.082	.0106	98.6	.0108
8915	.125	.0140	94.9	.0147
8945	.142	.0132	92.5	.0142
8975	.062	.0132	97.5	.0135
9065	.068	.0132	99.9	.0132
9085	.149	.0132	97.5	.0135
9110	.097	.0107	99.9	.0107
9135	.082	.0101	99.9	.0101
9210	.134	.0126	99.1	.0127

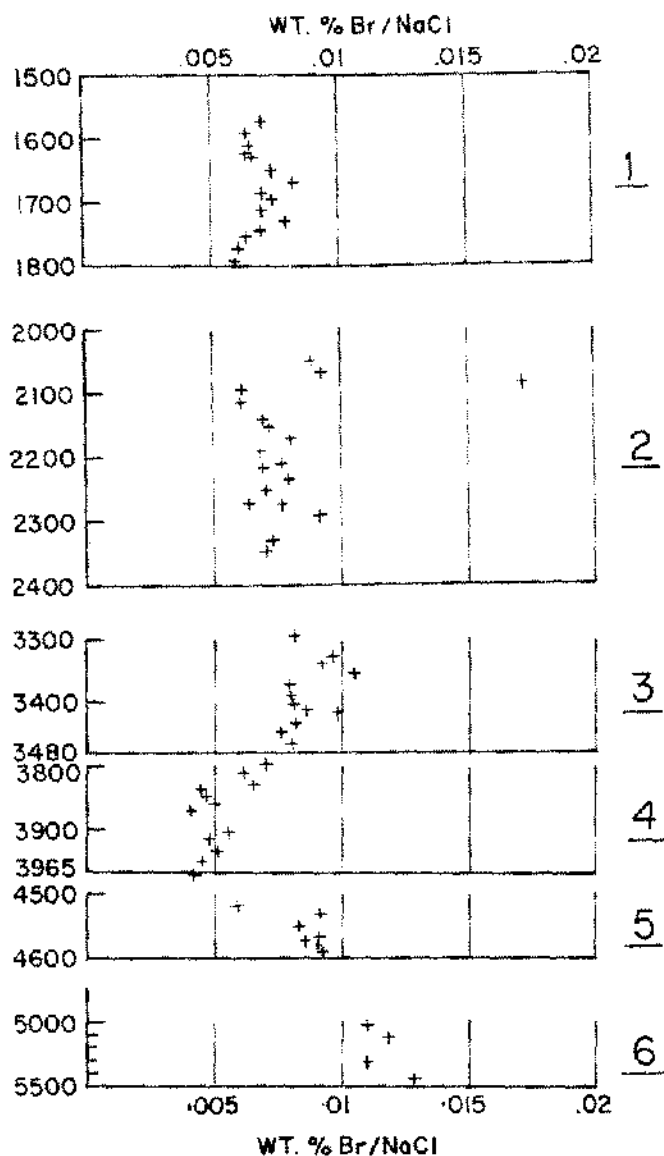


Figure 18. Bromine contents of halite (cuttings), Sunoco No. 1A well, Nappan.

The bromine contents found throughout the Cumberland basin indicate that high concentrations of evaporating sea water have been attained in all parts of that basin.

No correlation of salt beds intersected by boreholes at various locations was possible. This is attributable to the small number of wells drilled and to a lack of coring in that large basin which was probably subdivided into several sub-basins each controlled by different restriction and influx conditions.

More drilling work is required; the salt sections should be cored in order to obtain suitable samples.

### CONCLUSIONS

Normal bromine contents of rock salt core and cutting samples from the Antigonish-Mabou and the Minas sub-basins are very low, indicating an evaporation degree rising only slightly over

# CUMBERLAND BASIN SALT DEPOSITS

The Cumberland basin extends through Nova Scotia north of the Cobequid mountains from New Brunswick to Prince Edward Island and beyond into the Gulf of St. Lawrence. Some faults and anticlinal structures parallel the Cobequids, Windsor strata outcropping in several areas.

A number of gravity lows indicate salt bodies near the surface. Such salt bodies are exploited commercially by the Pugwash mine and by the Nappan solution mining operation (Fig. 3). The Malagash salt body also appears as a negative gravity anomaly. Figure 16 demonstrates the Pugwash gravity low and two others located south of Pugwash in the cross section. (See Pearson, 1963, for geological maps and more details.)

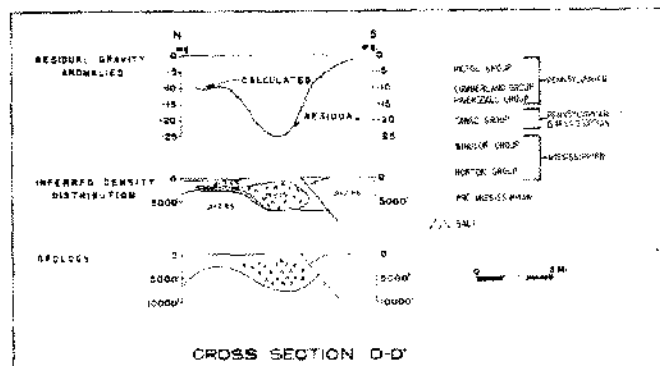


Figure 15. Cross section Kennetcook gravity anomaly.

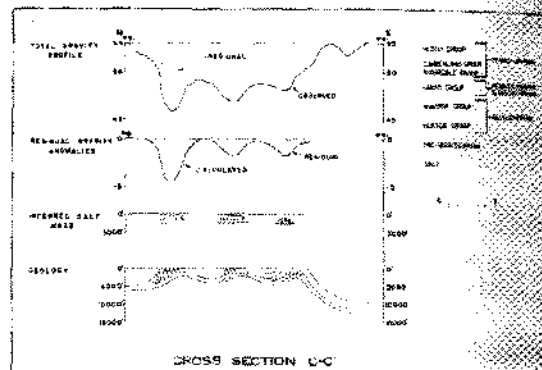


Figure 16. Cross section Pugwash gravity anomaly.

Earlier observations in the former Malagash mine and recent structural investigations carried out in the Pugwash mine have demonstrated that the salt deformation is not comparable to diapiric salt flowage which has occurred, for example, in the Gulf Coast salt domes. Although intensive local flowage of salt beds is indicated by innumerable small folds exposed in the Pugwash mine workings, block faulting and tilting accompanied by lateral stress seems to have been the major cause of salt deformation. The clay beds became slide planes and enabled solutions to enter deforming salt beds.

Rock salt recrystallization and secondary crystallization of chlorides from migrating solutions is indicated by large single crystals, such as blue halite and red carnallite which occur predominantly in former fissures or bed separations.

The following bromine contents were found in single crystals:

blue halite	.0184 wt. % Br.
white halite	.0239 wt. % Br.
red carnallite	.1245 wt. % Br.

These bromine contents confirm secondary crystallization from migrating solutions which contacted primary potassium salts. Similar bromine contents have been found in minerals crystallized under comparable conditions in other salt deposits, for example the Stassfurt deposits (Kühn, 1955; Baar, 1954, 1955; Kühn and Baar, 1955).

In order to discover the range of alteration which bromine contents of halite have undergone during recrystallization in contact with migrating solutions, bromine contents were determined in a series of halite samples taken along a definite horizon exposed in the Pugwash mine. The results, plotted in Fig. 17 vary from .005 to 0.011 wt. % Br/NaCl and indicate remarkable alterations. Further investigations are pending which will determine whether bromine contents can be used to stratify the Pugwash salt sequences.

e concentration at which halite begins to crystallize from sea water. However, some high bromine contents indicate crystallization from migrating solutions rich in bromine probably originating from salt beds located nearby which may have been deposited by final evaporation of shrinking brines in narrow, deeper parts of the sub-basins.

In the Cumberland basin potassium mineralization has been found in the Windsor salt deposits of the Pugwash-Malagash area. High bromine contents in salt beds penetrated by boreholes throughout the basin give evidence of the possibility of potassium precipitation in favourable local sub-basins. Suitable locations for further drilling work should be investigated by seismic observations, rock salt beds usually giving excellent seismic indications. Coring salt beds intersected by exploration wells is indispensable.

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