All Evaporite Salt Deposits Are the Same. Or Are They?

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ABSTRACT

A brief outline of evaporite deposition is given as a basis to establish that the Canadian Salt Company mine at Pugwash, Nova Scotia and its Ojibway Mine at Windsor, Ontario have a similar origin. The general geology, mineralogy, petrology, structure and mining methods of both mines are summarized. Attention is drawn to their dissimilarity. A comparison is made of the geological differences and the mining problems that are produced and the advantages each mine enjoys. It is pointed out that the major difference is the salt thickness. The comparison is between a twenty-five-foot thickness at Ojibway and over one thousand feet at Pugwash. It is suggested there could be one twenty-five-foot horizon at Pugwash that would be comparable to Ojibway in quality, mineralogy and petrology. If we search deeply enough it can be shown that evaporite salt deposits, although varying markedly in physical appearance, are basically the same.

INTRODUCTION

The Canadian Salt Company operates mines at Pugwash, Nova Scotia, and the Ojibway Mine at Windsor, Ontario. Both deposits are considered to have been formed by the evaporation of seawater. One might naturally expect them to be similar but after visits to the two mines, one cannot help but feel that the only thing they have in common is that both mine salt (Photographs 1 and 2). This leads to a comparison of their origin and geological history to establish an explanation of the differences.

This brief outline of evaporite sedimentation is included as a basis to study whether the deposits are evaporites. As seawater is concentrated by evaporation its dissolved materials are deposited in the inverse order of their solubilities. Limestone is followed by calcium sulphate, either as gypsum or anhydrite, depending on the existing physical-chemical conditions. When the concentration is in the order of ten times normal seawater, sodium chloride will start being deposited and at still higher salinities potassium chloride and other salts will be laid down.

The climatic conditions must have been tropical or nearly so, in order to produce a significant amount of evaporation.

It is well established that in order to produce the thicknesses encountered, some mechanism must have existed to permit a rhythmic replenishment of seawater in the evaporite depositional basin. It is suggested this was a lagoon on the margin of a land mass with some connection to the sea. The Karabugas Gulf, east of the Caspian Sea, is a modern example of just such a basin.

Photograph 1. Main conveyor system, Ojibway Mine. Note regularity of the pillar pattern and banding on pillar walls.

If seawater is introduced into a lagoon that is in the calcium sulphate phase, the deposition of gypsum or anhydrite will be interrupted by a limestone layer from the calcium carbonate content of the new seawater. The amount

Photograph 2. Characteristically irregular pillars at Pugwash mine. This area has a roof height of 55 feet.

of anhydrite rock would depend on how long the lagoonal waters remained in this concentration, resulting from the dilution by new seawater, without reaching the rock salt phase.

If a sufficiently high concentration were reached to deposit sodium chloride, then each introduction of new seawater would lay down its limestone and calcium sulphate before it, too, reached the sodium chloride phase. This mixture is rock salt.

The lagoonal water, or parts of it, could remain in any depositional phase for varying periods, depending on dilution rate, temperature, evaporation, gravity layering, to mention but a few of the many variables. This would control thickness.

THE OJIBWAY MINE

The area is underlain by Paleozoic sediments which dip gently into the Michigan depositional basin. The source of the salt is the Salina Formation, which is Silurian in age. The Salina was divided by Landes (1945) into seven units, designated A to G from bottom to top. Significant rock salt horizons are the "B," two in "D," and three "F," salts. Production was started from the middle "F" salt member in 1955. The original mine floor had a depth of 297 meters.

Consideration of the paleogeography shows that in the Silurian this area had a latitude of 20°South. (Scotese, Bambach, Barton, Van der Voo and Ziegler, 1979.) This confirms a tropical climate favoring the production of evaporites.

Structure

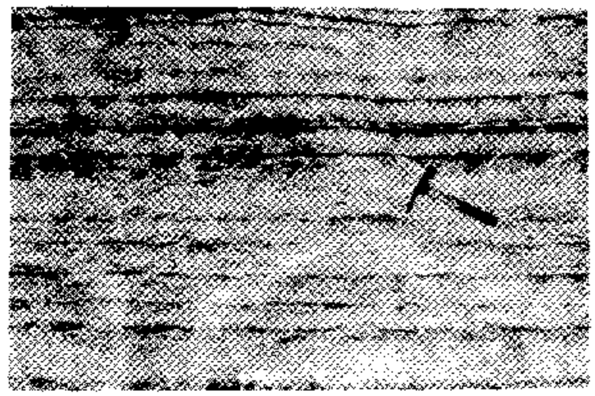
From the base of the shaft the salt horizon has a general dip of ½° slightly west of north. Minor localized steepenings of this have been encountered, with maximum dips of up to 10°. These represent irregularities of the depositional floor. No evidence of deformation other than that associated with lithification or secondary crystallization has been noted.

Mineralization

The rock salt is buff in color and has a number of thin, dark carbonate-anhydrite bands (Photograph 3). These are most persistent and some are recognizable over a number of kilometers. Although appearing as solid beds on pillar walls, in thin section they appear as roughly aligned but widely disseminated, irregularly shaped grains or small crystals of carbonate and anhydrite in halite, but they form a small percentage of the salt rock. They represent rhythmic replenishment of the basin with seawater. Every indication supports the view that this horizon originated by the evaporation of seawater.

Secondary crystallization occurs to some degree throughout the mine. This produces irregularly shaped masses of coarse, white salt (Photograph 4). It is of high purity, for the dark bands are expelled as the crystals grow and this material forms a dark margin at the bottom and sides of the secondary salt.

No unusual minerals have been identified.



Photograph 3. Carbonate-anhydrite bands on the pillar walls. Ojibway Mine. These three bands are called the "cutting lines" and are also readily recognizable at the International Salt Company mine in Detroit.

Photograph 4. Secondary crystallization. Ojibway Mine. Note the dark bands have been broken and there is a concentration at the base of the new, coarser crystals.

Thickness

The horizon thickness is measured with each face advance. The average is 7.5 meters, but thicknesses from 6.6 meters to 12.8 meters have been noted.

Mining

Room and pillar mining is used (Map 1). The only variations have been occasional alterations in the pillar dimensions and configurations for reasons such as equipment size and capabilities. The deepest workings in the mine are at 328 meters.

There are over 250 kilometers of drifts and crosscuts varying in width from 9 to 15 meters.

The mining stops at the United States border, which is vertically below the middle of the Detroit River. The salt continues, and five kilometers northwest the International Salt Company mines this same horizon. This is toward the basin center and is deeper. The salt has thickened to 8 meters and there is less evidence of depositional floor irregularities, but otherwise it is comparable to Ojibway and some dark bands are readily recognizable.

Roof Control

The horizontal attitude of the beds and the planes of weakness, coupled with lenses of secondary crystallization in the upper portion of the middle "F" salt, cause a slabbing effect. Careful scaling and constant monitoring help offset this condition.

Inherent weakness in the overlying shaley dolomite requires a sufficiently competent salt thickness acting as a beam to maintain the roof. This is measured and controlled with each face advance.

THE PUGWASH MINE

The mine produces salt from the Windsor Formation, which is Lower Carboniferous (Mississippian) in age. Paleogeographic studies show that in early Carboniferous times Nova Scotia, having a latitude of approximately 10° south, had a tropical climate (Scotese, Bambach, Barton, van der Voo and Zeigler, 1979). The identification of marine fossils in interbedded limestones leaves no doubt that the salts have been formed by a concentration of seawater as a result of evaporation. This is supported by the rhythmic repetition of beds.

Pennsylvanian times in Nova Scotia deposited thick coal measures and at the close of the Carboniferous, Hercynian mountain building (Appalachian) produced a major, lineated fault zone through Novia Scotia mainland and Cape Breton Island. Pugwash lies north of this line but well within its sphere of influence.

Earlier maps of the area show an elliptical Windsor inlier with a fault forming its contact with the surrounding, younger, Pennsylvanian sediments (Sketch 1).

Original drilling suggested a flat-lying salt deposit, and in 1959 production was started from the "630-foot level" (192 meters). At first a regular room and pillar configuration, similar to Ojibway, was used, but it was soon evident that the beds were anything but horizontal. They are steeply dipping throughout the mine. Vertical dips are common and dips of 30° are regarded as "flat-lying." The writer has never seen an area of truly horizontal bedding at Pugwash.

Structure

Folding. At the outset let it be stated that the folding is highly complex and, as yet, no straightforward picture can be presented. An absence of reliable, persistent marker beds has been a major problem in defining fold structures.

The deposit has been subjected to major compressive forces and the rocks have reacted according to the dictates of their relative strengths.

Thin anhydrites have been completely broken and are now merely limestone and anhydrite grains disseminated through the salt.

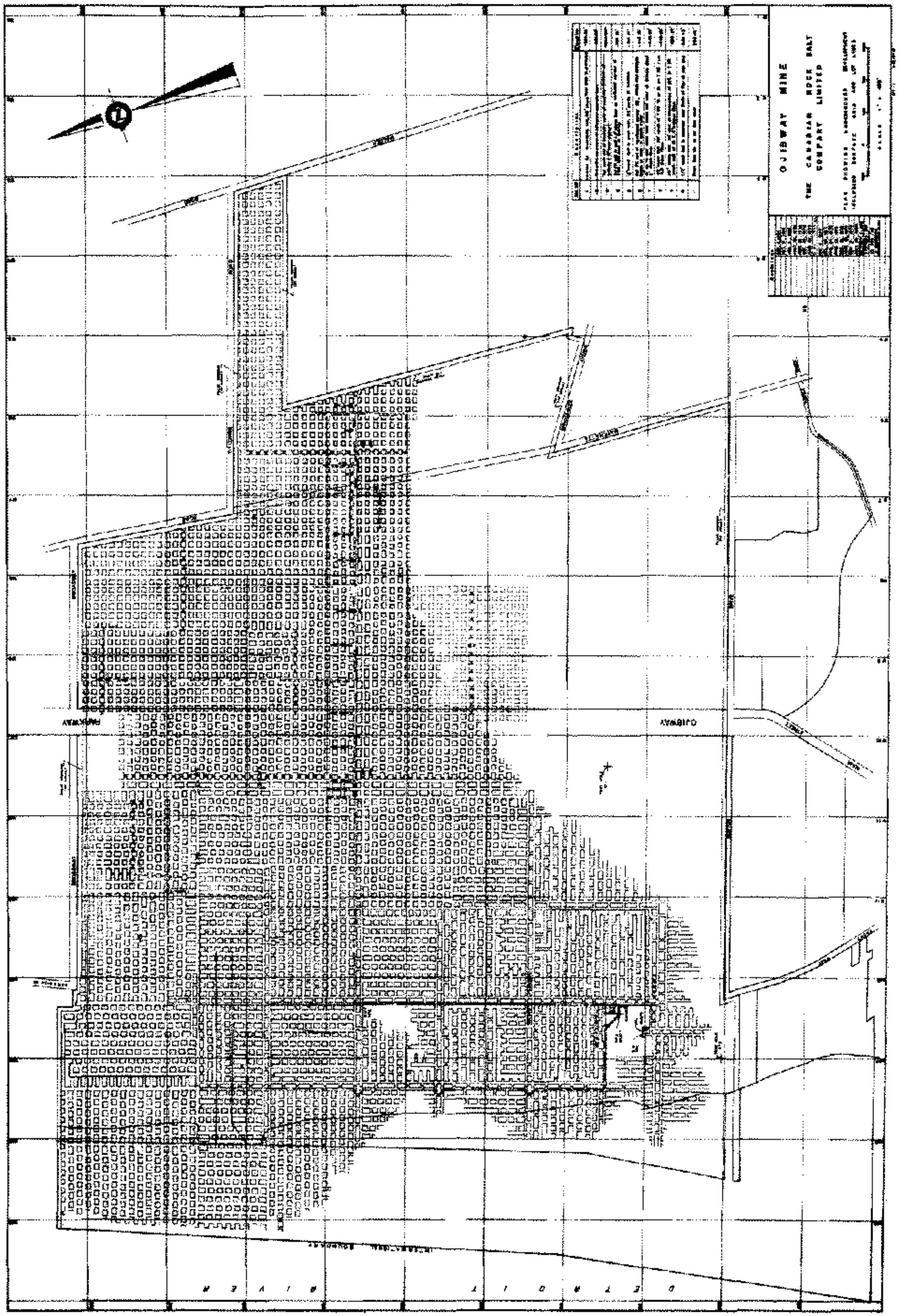
Anhydrites of an inch or two in thickness frequently show complex folding (Photograph 5). This type of structure has also been observed in the salt.

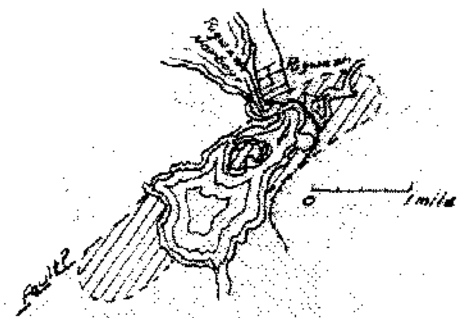
Thicker anhydrites are more brittle and resist folding, and blocks of head, desk or room size are found in the salt. The thickest anhydrite is 30 meters and, although relatively competent, has been contorted, thinned and broken. This member has been traced over 1200 meters horizontally and is present on all levels.

Faulting. The first project of a drilling program on the "630-foot level" (192 meters) was to confirm the presence of a fault as the north limit of the deposit, as suggested by Fletcher (Sketch 1,A). Drillholes into the fault have a tendency to be wet, and this undesirable characteristic curbs unnecessary drilling. Horizontal and inclined holes have established that the fault plane is sharp against arenaceous Pennsylvanian sediments. There is a small amount of light-colored gouge in the fault plane. The dip is 70° north. The younger sediments on the downthrow side indicate a normal fault. It is a contradictory situation to reconcile essentially compressive phenomena in the body of the mine with a tension type, normal fault forming the northern limit.

As the mine developed to the west the fault was traced for approximately 1400 meters with a constant strike slightly south of west. A second, younger fault system with a NE–SW strike has caused a number of minor offsets to the north fault (Map 2). Progressing west, the mining was forced to change direction and now the western limit strikes NE–SW. Either the north fault has changed direction or the second system has taken over. This direction is parallel to the minor offset faults and it is now evident that these two fault systems are the control on the size and shape of the deposit (Sketch 1,B).

Southern mining was stopped by a broad deformation


OJIBWAY MINE
THE CANADIAN ROCK SALT COMPANY LIMITED
PARKWAY
OJIBWAY
DETROIT RIVER



Sketch 1A. Tracing from Geological Survey of Canada Map 61, 1905 by Hugh Fletcher showing an elliptical inlier of Windsor sediments with a probable fault contact to the north.

Photograph 5. Folding of thin anhydrite member in salt, Pugwash Mine.

zone, which is a mixture of clay and evaporites. Drilling is difficult and it is not established whether it is faulting, folding or both. In any event, it is a limit to mining. The zone dips steeply south and strikes parallel to the north fault. It, too, has been offset by the younger fault system. As the mining went to the east the direction changed and the eastern limit has a NE-SW trend.

It is now apparent that the mine limits were the result of deformation and the shape was not an elliptical inlier but a block having the shape of a flattened parallelogram (Sketch 1). It is evident why this was originally interpreted as an ellipse.

The presence of the south zone and the knowledge that the active deformation forces came from the south resolved the seeming paradox of compression structures and tension faults. The answer is that the southern forces squeezed the evaporites against the competent, albeit younger, sediments which held firm, resisting the pressure, and finally rode up against the evaporites.

Mineralogy and Petrology

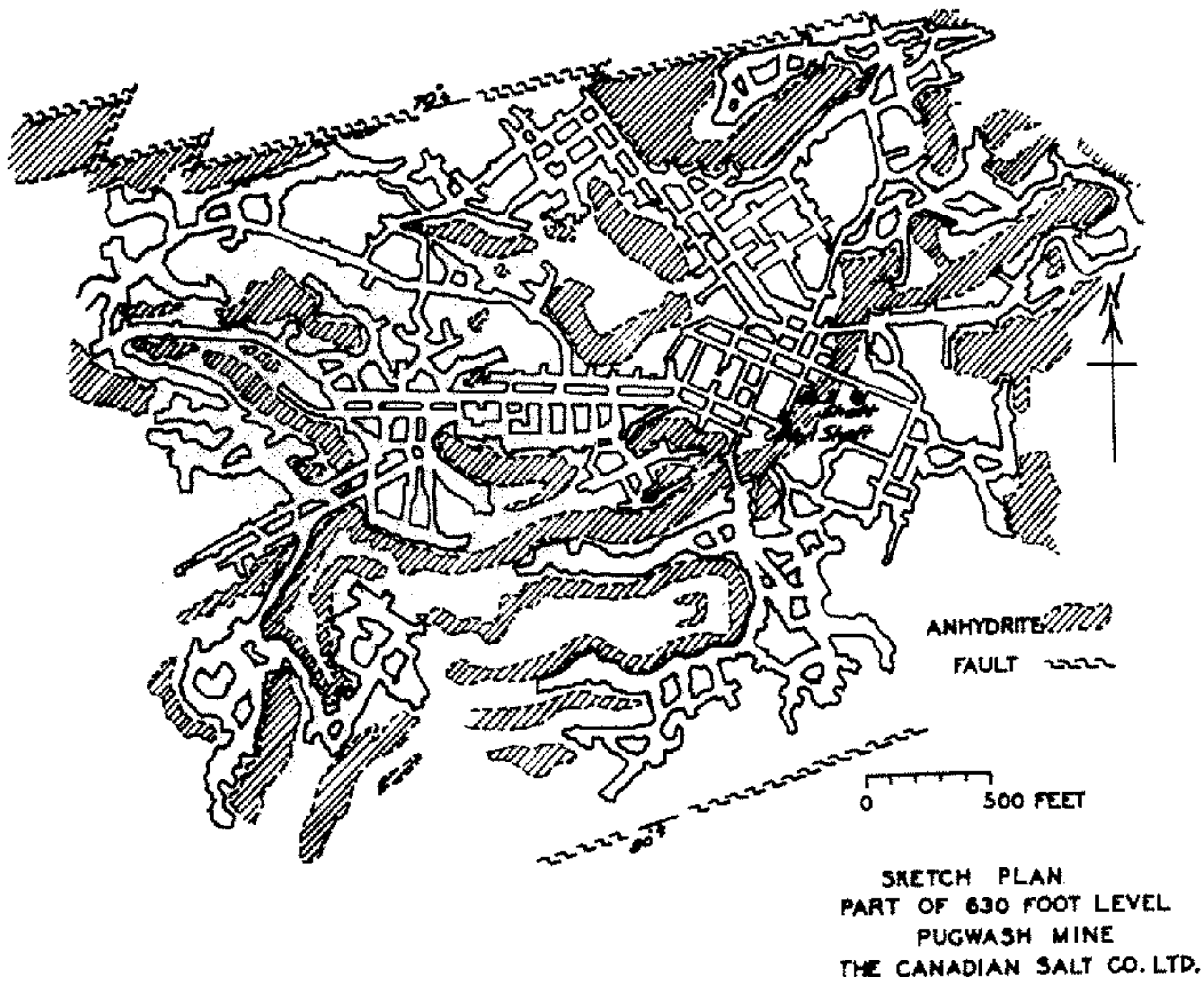
It is common practice to use the mineral name, anhydrite, when speaking of anhydrite rock. Similarly rock salt may be referred to as salt but the term halite is not used. Rather than make hair-splitting, academic issues, rocks and minerals are grouped together.

Salt. The salt rock is variable in color and is sometimes quite dark, but usually it is light buff in color (Photograph 6). It contains varying amounts of carbonate and anhydrite. Small pockets of colorless, cleavable, transparent crystals of secondary halite are occasionally encountered and rarely blue halite crystals are found. This secondary crystallization is sufficiently uncommon for specimens to be collected and kept in the underground office as samples for visitors. More common are iron-stained, coral-colored, small crystals of halite. These are thought to be secondary and are often associated with, and difficult to distinguish from, carnallite, which is the same color.

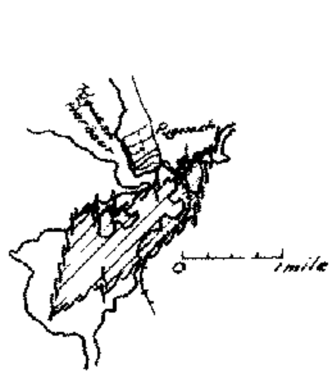
Anhydrite. Anhydrite rock varies from tiny broken bands to a member 30 meters thick. Any number of variations between these limits can be found.

It is evident that there were a number of prolonged periods of variable duration when the lagoonal waters were in the anhydrite depositional phase. We do not know if the beds are overturned, but if we assume they are not, then the oldest anhydrite is against the north fault. If we call this #1 and connect the broken pieces that suggest they are related, we find ten or more major anhydrite periods with the thickest member in this sequence being #5. The drilling program concentrated on delineating the anhydrite, for these were the areas that could not be mined and where-ever possible were incorporated into the pillars and, in effect, make a strong, skeleton-like structure which plays a big part in the safety of the mine.

Carbonates. Carbonates are ever present impurities. In a few instances the dark carbonate beds are an inch or two in thickness and when struck with a hammer give off an odor of bitumen. One horizontal drillhole hit a small oil



Map 2



Sketch 1B. Fault block of Windsor evaporites at Pugwash.

pocket and some gallons of oil gushed out and greatly startled a drill crew.

Potassium minerals. Sylvite has been reported but carnallite is the only common potassium mineral. It is iron-stained and coral red in color. The carnallite is widespread and associated with clay and mud zones. Field evidence suggests that it is secondary, perhaps related to potassium-rich connate waters able to permeate the mud horizons.

Danburite. Small nodules of danburite have been identified from one area of the mine. They have the characteristic appearance of white, unglazed porcelain.

Clays. Thin green clay bands are noted in anhydrites and are of some aid in correlation, but they are limited in their lateral extent. Thick clays and muds are intersected by drillholes and frequently contain carnallite.

Mining. At the start of the mine a conventional, regular room-and-pillar plan was attempted, but the steeply inclined, contorted beds made this impracticable. As a result, the mine plan developed to take maximum advantage of the deposit (Map 2). The anhydrite members act as strengthening ribs; there are no horizontal planes of weakness, and the interlocking nature of the rock salt crystal growth produces a safe, secure roof once it has been carefully scaled. Occasional roof spans of over 30 meters have caused no trouble and second cuttings have produced rooms over 15 meters in height. The limiting vertical factor is the height to which the "cherry picker" can reach for scaling (Photograph 7).

COMPARISON

A comparison of the mines must cover a broad spectrum. First, a consideration of the geological differences and secondly, the mining problems that these produce. Particular attention will be paid to the advantages that each mine enjoys.

Consideration of the two deposits establishes that they were formed by the evaporation of seawater under tropical conditions. It is possible that the depositional lagoonal basins were of comparable size, but there is no reliable information on the depths of deposition, or position relative to the shoreline. Nor is it known how the ocean salinity varied from Silurian to Carboniferous times. It is assumed that it did not vary sufficiently to make any significant alteration in the general principles of evaporite sedimentation.

Ojibway, being Silurian, would have an age in the order of 400 million years (Strachan, 1964), whereas Pugwash is Lower Carboniferous and some 75 million years younger (Francis and Woodland, 1964). It is interesting, that although Ojibway is the older salt, it has suffered little or no deformation. The post-depositional events at Pugwash have produced the complex folding, faulting and steeply inclined beds that are now mined.

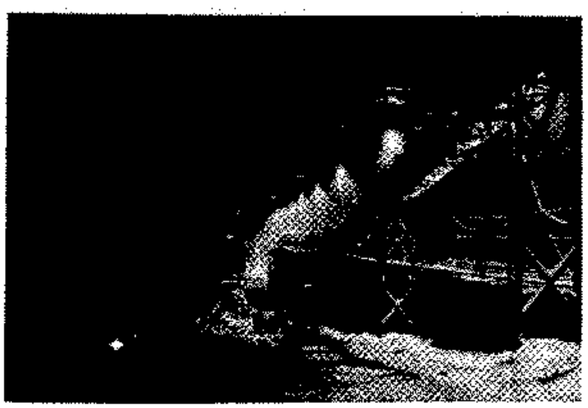
The primary salt at Ojibway is much the same throughout the mine, but at Pugwash there is more variety in appearance. Coarse secondary salt is rare at Pugwash, but it is common, in varying amounts, everywhere in the Ojibway Mine. A not-so-obvious difference is the moisture content. There is agreement that Pugwash, being drier, has dustier conditions during face preparations. One wonders if this moisture is related to the fluid cavities in the secondary salt which are so common at Ojibway. The Ojibway salt has a purity of 97%, but at Pugwash some quality control is necessary even to approach this figure.

Perhaps the major difference is the salt thickness. At Ojibway the middle "F" salt has an average thickness of 7.5 meters. No actual thickness can be established for Pugwash, but the evaporites exceed 300 meters. A drillhole 365 meters below the "630-foot level" (192 meters) was still in evaporites. This, of course, is not true thickness but does give some idea of the massive nature of the deposit. If it were possible to study in detail the over 300 meters of evaporites at Pugwash, surely we could find 7.5 meters that would be completely comparable to Ojibway in quality, mineralogy and petrology.

The flat-lying deposit at Ojibway has the advantage that the operation can be planned far in advance knowing that the quality will be constant, and the design readily followed. The mine layout can take full advantage of the economies of a conveyor belt system.

The horizontal attitude of the beds at Ojibway introduces planes of weakness which force constant roof control and continual monitoring to prevent troublesome slabbing. Although the deformation at Pugwash produces complications in quality and makes it difficult to plan future mine layout, it has the advantage that there are no planes of weakness; the anhydrite ribs give pillar strength, and the interlocking crystal growth produces a secure roof and permits an appreciably larger tonnage with each face advance.

The contrast in pillar configuration enforces different ventilation techniques. The regular pattern at Ojibway



Photograph 7. 830 foot level crusher station, Pugwash Mine. The maximum height of this opening is 83 feet. The roof span is 70 feet.

can avoid long, dead-ended rooms. The air stream is directed past the working panels by the strategic placement of brattices. The Pugwash air problem has always been one of developing a circular flow. Air must be directed into long entries by large, fan-fed, plastic ducts. This limits the number of working faces and adds to power costs.

As Ojibway develops, it rapidly expands laterally, which increases the distance of the working face from the shaft. Future expansion means obtaining mining rights and involvement of more people on the surface, which can increase social problems. Although it might some day be possible to extract bottom "F" salt, the feasibility of this has not yet been established.

The lateral extent of Pugwash is well known and future development will be with new levels. These are reached by a ramp so that machinery can be conveniently moved during the development stage, before the new level is ready to take over full production. When there was only the "630 foot level" (192 meters) this picture was essentially two-dimensional, and the apt analogy was that it was like a slice of a marble cake. The new levels add a third dimension; and, although far from exact, there is a great deal of clarification of the overall picture. The pillar strength has made it possible to start an intermediate level that can take full advantage of the anhydrite information from the upper and lower levels.

Apart from having a like origin, one might feel that a comparison is one of contrasts rather than similarities; but if we search deeply enough, we can establish that evaporite deposits are basically the same. Superficial differences can be explained by consideration of their geological history. It is left to the ingenuity of the mining industry to solve their problems and profitably take full benefit of such advantages as exist.

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