ONTARIO
DEPARTMENT OF MINES

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SALT IN ONTARIO

By

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Industrial Mineral Report No. 6

TORONTO
Printed and Published by Frank Fogg, Printer to the Queen's Most Excellent Majesty
1962

The Series

Industrial Mineral Circulars

has been re-named

Industrial Mineral Reports.

Therefore

Industrial Mineral Circular No. 5

is followed by

Industrial Mineral Report No. 6

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SALT IN ONTARIO

BY

D. F. Hewitt[1]

I—Introduction

Extensive beds of rock salt are found in the Salina formation of Silurian age in parts of southwestern Ontario, west of London. Figure 2 indicates the areas of southwestern Ontario underlain by salt. The uppermost salt beds are found 900–1,600 feet below the surface. The shallowest salt beds occur at Kincardine at 900-foot depth. In the Sarnia area the uppermost salt beds occur at about 1,600-foot depth, and the lowermost salt at about 2,700-foot depth. The Salina formation may be as much as 1,500 feet thick. The number and thickness of salt beds varies from place to place in the salt basins, with the maximum aggregate thicknesses of salt beds being 700 feet in the Sarnia area. Salt beds thin to the eastward and pinch out in the vicinity of London.

As indicated in Figure 2, there are three main areas in southwestern Ontario underlain by salt. Windsor area, Chatham area, and Sarnia-Goderich area.

The salt beds in the Windsor and Sarnia-Goderich areas form the east margin of the Michigan salt basin. The salt beds of the Chatham area may join those of the Ohio area, beneath Lake Erie.

Rough estimates of the areas underlain by salt, the average salt thickness, and the possible tonnages of salt present in southwestern Ontario are as follows:

Area	Area Underlain by Salt	Average Thickness of Salt	Estimated Amount
	square miles	feet	millions of tons
Windsor	150	150	30,000
Chatham	600	150	200,000
Sarnia-Goderich	3,000	300	2,000,000

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The estimated indicated reserves of salt present in the Salina formation in southwestern Ontario exceeds 2,000,000 million tons. Some idea of the amounts involved may be obtained from the fact that a salt bed contains about 2,000,000 tons per vertical foot for each square mile of area, or roughly 3,000 tons per vertical foot to the acre.

Salt is recovered either by underground mining or by brine-well operation. In Ontario in 1960 the production of salt amounted to 3,007,599 tons valued at $13,994,545, produced by two underground mines and six brine operations. The two salt mines in operation are the Ojibway mine of Canadian Rock Salt Company and the Goderich mine of Sifto Salt (1960) Limited. Brine operations are carried out by Brunner Mond Canada Limited near Amherstburg, Canadian Salt Company Limited and Canadian Brine Company Limited at Windsor, Sifto Salt (1960) Limited and Dow Chemical of Canada Limited at Sarnia, and Sifto Salt (1960) Limited at Goderich. The locations of these mining and brine operations are shown in Figure 2.

The largest consumer of salt is the chemical industry, in which it is mainly used in the manufacture of chlorine and soda ash. Large amounts are used in food processing and allied industries including meat packing, tanning, fishing, dairying, canning, baking, and flour and feed production. Table salt also accounts for a substantial amount. Salt is used in the pulp-and-paper, textile, dyeing, soap, metallurgical, ceramic, rubber, and oil-refining industries. It is also used in water softeners, and in ice- and cold-storage plants. In recent years increasing amounts have been used for snow removal from highways and streets in winter.

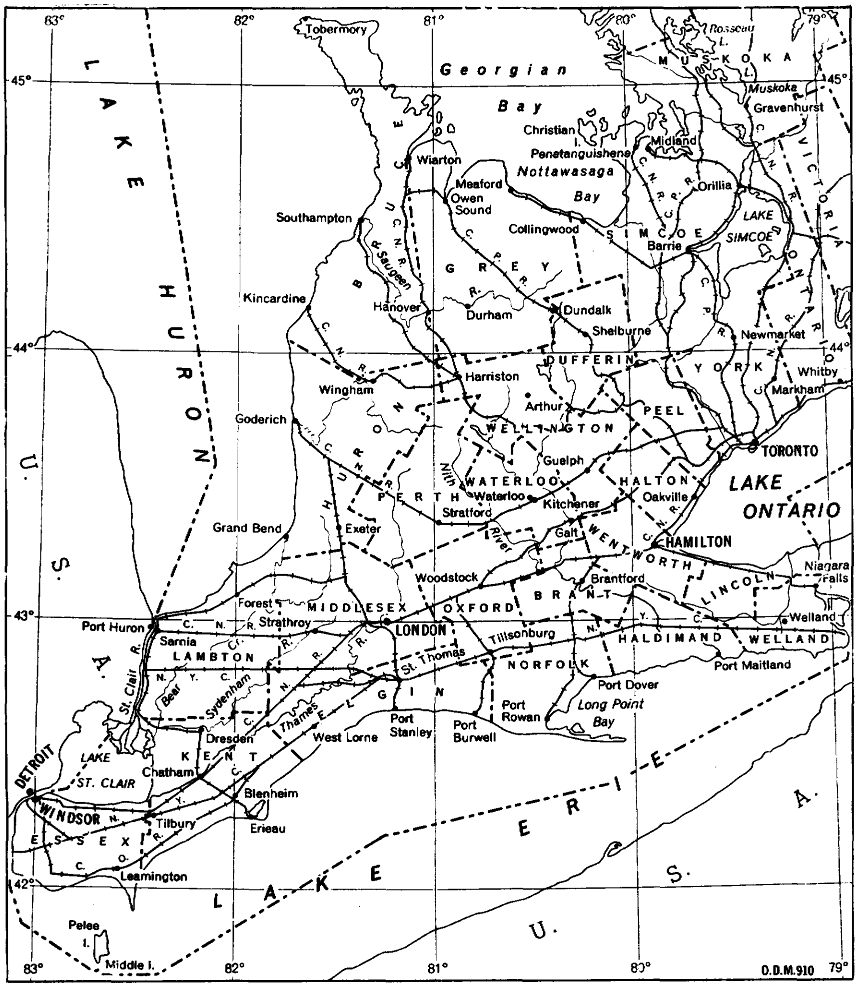


Figure 1 – Southwestern Ontario, showing the locations of areas and centres referred to in the report. Scale, 1 inch to 50 miles.

II—Salina Stratigraphy and the Distribution of Salt

In Figure 2, which shows the distribution of salt in southwestern Ontario, the main structural features are also shown. To the northwest lies the Michigan basin, to the southeast the Appalachian basin. These are separated from one another by the northeast-trending Cincinnati arch and its northeastward extension, the Algonquin arch. The axis of this arch, which separates the two major structural basins, strikes northeast. In the Chatham area a minor east-west-trending syncline, the Chatham sag, lies across the axis of the arch.

The salt deposits of the Windsor and Sarnia-Goderich areas are on the east flanks of the Michigan basin and form part of the Michigan basin salt deposits. However, the salt deposits of the Chatham area possibly form the westward extension of the Ohio-New York salt deposits of the Appalachian basin and represent deposits laid down in an arm of the sea extending westward into the Chatham sag. It is probable that the Chatham salt beds form a link between the Michigan and Ohio salt basins.

The regional geology of southwestern Ontario is shown in Figure 3. Figure 4 is a generalized columnar section of the geological formations of southwestern Ontario. For a detailed description of the stratigraphy the reader is referred to two memoirs of the Geological Survey of Canada describing the Windsor-Sarnia area (Caley 1945: Sanford and Brady 1955).

THE SALINA FORMATION

As shown in Figure 3, the Salina formation is exposed in a band from 5 to about 16 miles wide, extending southeast from Southampton on Lake Huron, through Hanover, Mount Forest, Kitchener, and Paris to Brantford; thence east through Caledonia and Welland to the Niagara River. Since the formation dips to the southwest, it is found in the subsurface at various depths throughout southwestern Ontario.

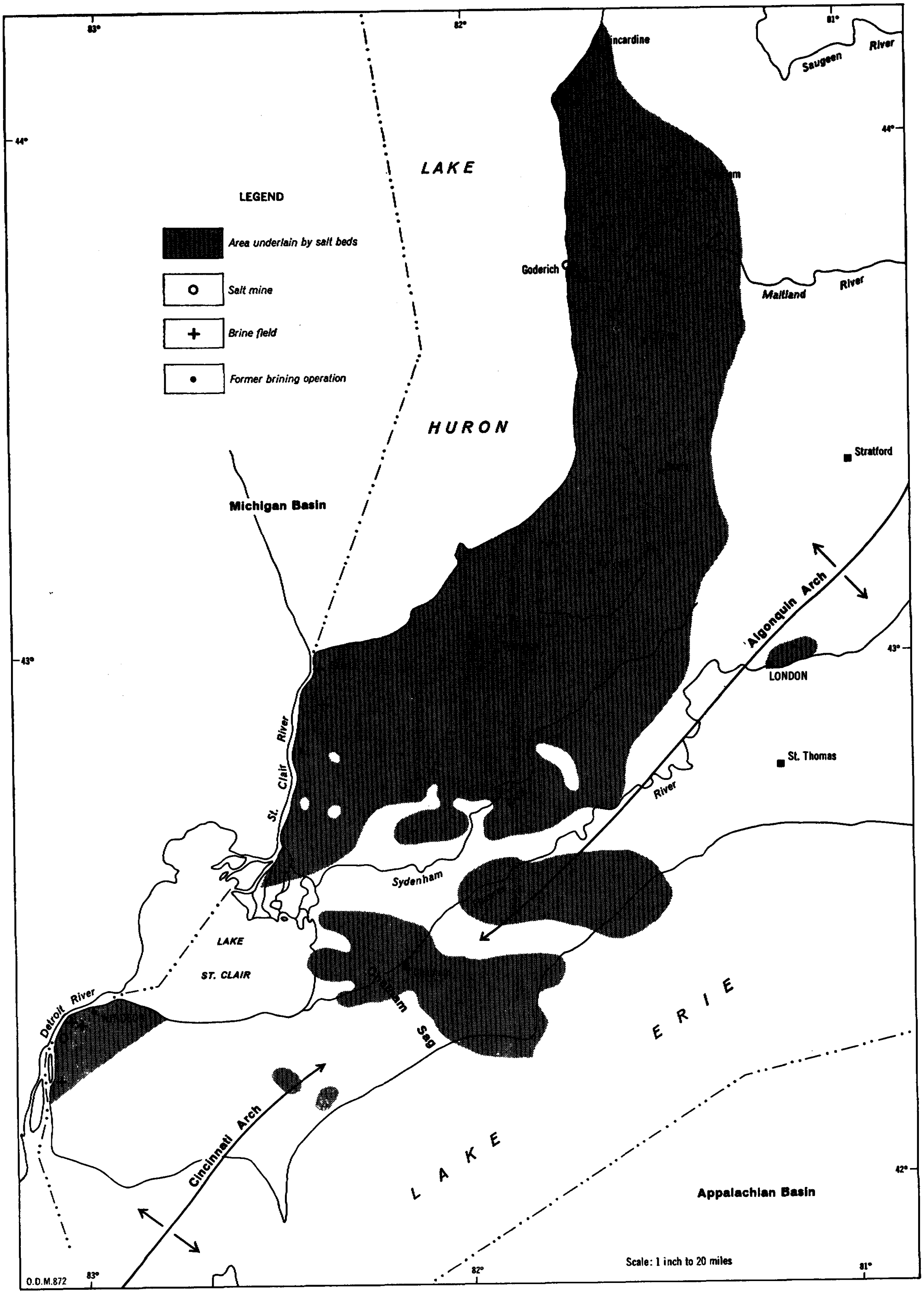


Figure 2 – Distribution of salt in southwestern Ontario.

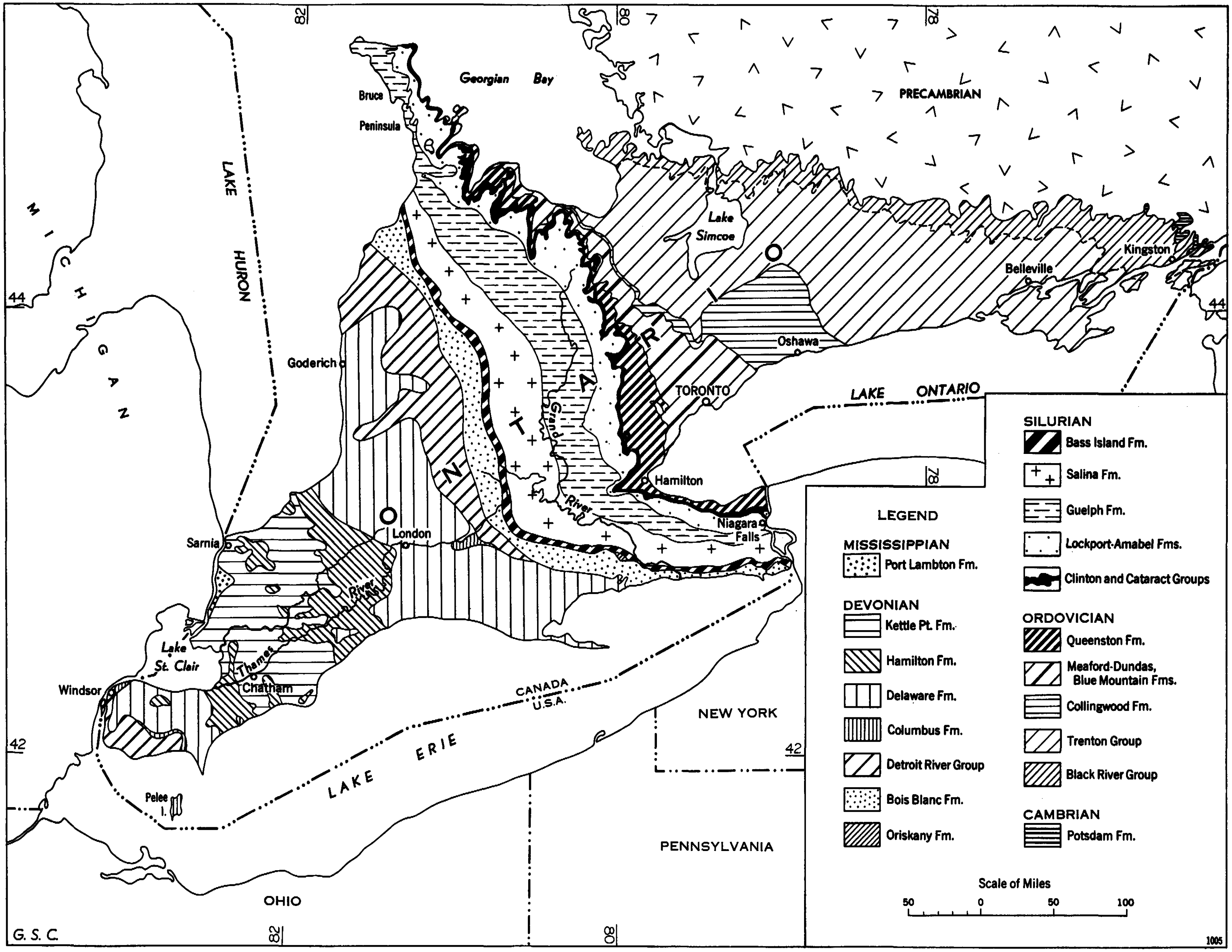


Figure 3 – Regional geology of southwestern Ontario.
(*Courtesy Geological Survey of Canada*)

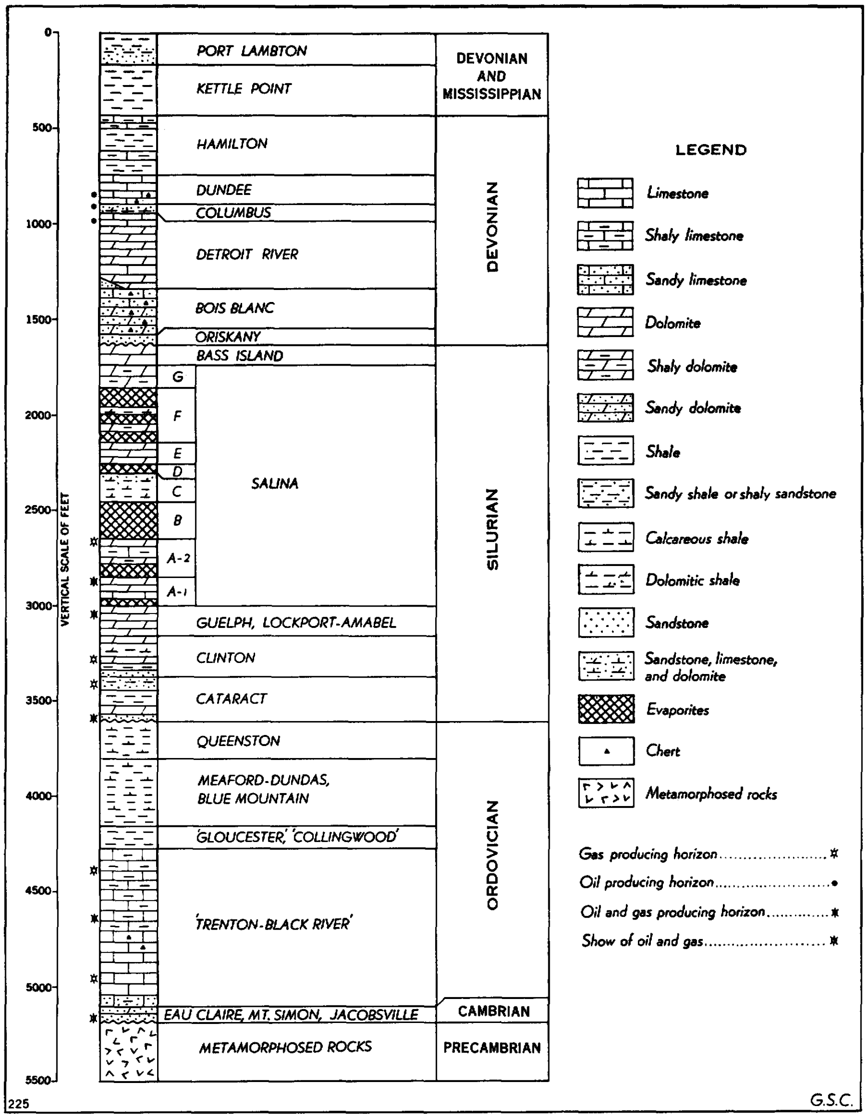


Figure 4 – Generalized columnar geological section for southwestern Ontario.
(Courtesy Geological Survey of Canada)

Lithology

As indicated in the generalized columnar section, Figure 4, the Salina formation is underlain by the Guelph-Lockport dolomite, and overlain by the Bass Island (Bertie-Akron) dolomite. The Salina formation is described by Roliff (1949, pp. 159–60) as follows:

> The Salina formation consists of thin-bedded, fine-grained, gray, buff, and brown dolomites and limestones, shaly dolomites and limestones, dolomitic and calcareous shales, beds of gypsum and anhydrite, and in many places, beds of salt. There is practically no pure shale in the entire succession, and the dolomitic shale may, perhaps, be more accurately defined as an argillo-calcareous mud rock, the nearest approach to true shale being some thin zones of gray and greenish gray and reddish argillaceous rock in the southwestern part of the province, and in wells and outcrops in the Walkerton-Kincardine area. In general, the succession consists of alternating gray dolomitic shale or argillo-calcareous mud rock, and intervals of brown-coloured fine-grained to dense dolomite, rarely with dark bituminous streaks, and commonly with thick beds of salt, particularly in the area west of London. Small quantities of white anhydrite and gypsum are present throughout practically the entire formation, although perhaps more prevalent in the gray shaly intervals.

Contacts

It is difficult to fix definite and sharp demarcation between the Salina and the Guelph-Lockport below. In general, the base of the Salina is placed where there is a marked increase in size of grain to sugary-textured dolomites, from the dense shaly dolomites that lie below the lowest anhydrite bed of the Salina. Its relation to the Guelph-Lockport in general appears to be conformable, but locally at least, there is definite evidence of erosion at the end of Guelph-Lockport time. The top boundary of the Salina is placed just above the highest shaly dolomite containing anhydrite or gypsum.

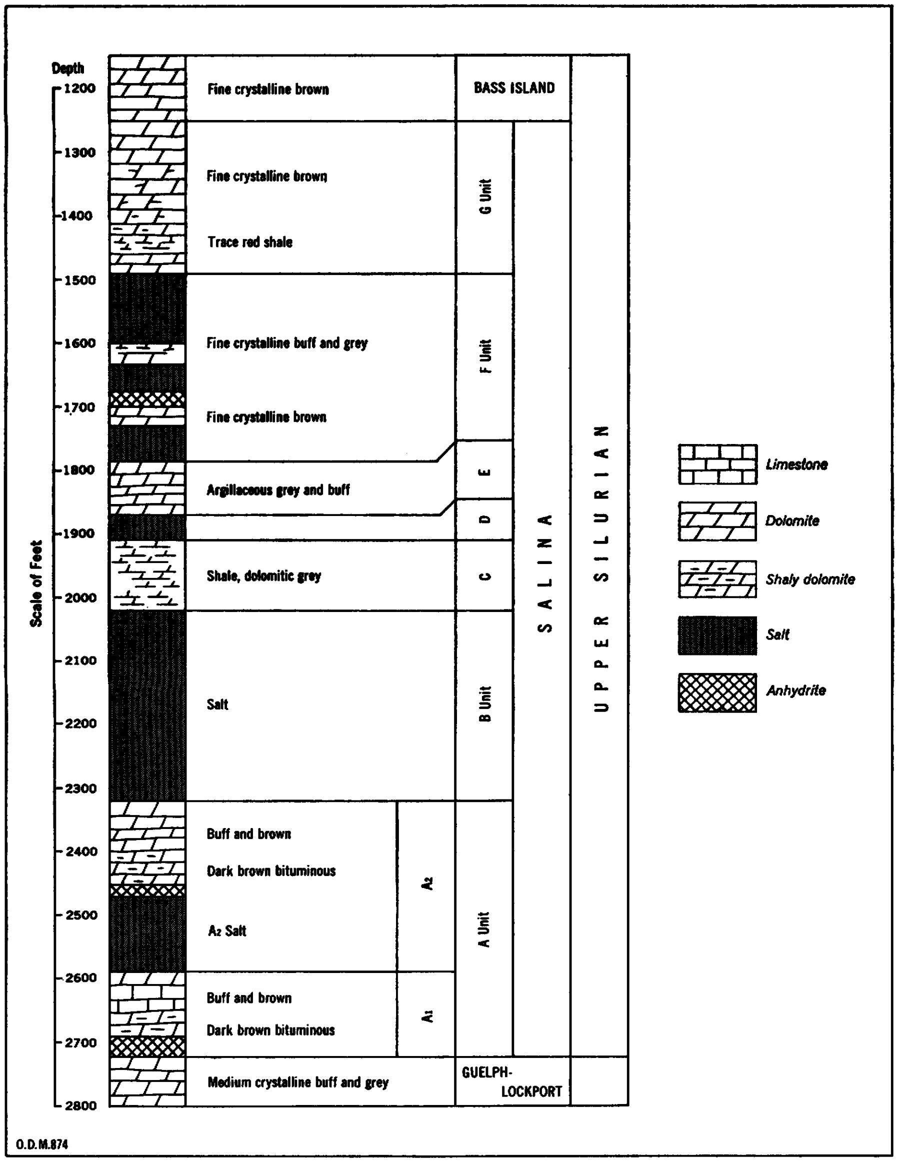


Figure 5 – Subdivision of the Salina Formation. (After R. O. Grieve.)

Thickness

Grieve (1955, p. 12) describes the thickness of the Salina formation as follows:

> The Salina formation increases in thickness in a northwesterly direction from as thin as 350 feet east of London, where no salt is present, to nearly 1,500 feet near Sarnia, where the aggregate thickness of the salt beds is approximately 700 feet.

Roliff's paper gives several series of cross-sections, compiled from well records, showing the thickness of the Salina in southwestern Ontario and indicating, graphically, the thicknesses of salt present. (Roliff 1949, Figures 5, 6, 7, and pp. 162–65.)

Caley (1945, p. 27) gives a table of data from 35 wells in the Windsor-Sarnia area showing thickness of total Salina, thickness of salt, and thickness of Salina without the salt. This table indicates that much of the local variation of the Salina is due to the thickening and thinning of the salt beds. However, Caley notes that after deducting the total thickness of salt from each well, there appears to be a general thickening of the formation northward across the area, from a minimum of 460 feet in Anderdon township to a maximum of 897 feet in Sarnia township.

Evans (1950, p. 58) points out:

> Total Salina thickness statistics demonstrate that the total thickness, less thickness of salt, produces a more or less uniform, gradually changing thickness of non-salt bearing strata. Thus, locally in an area, say of 20 square miles, the total thickness of Salina, less the thickness of salt, will give

TABLE I—SUBDIVISIONS OF THE SALINA FORMATION

Formation	Unit		Description
Upper Salina			Top of Salina Formation.
		G	Fine crystalline brown dolomite, shaly dolomite, some anhydrite, red shale.
	Upper Salt Beds	F	SALT, in thick beds separated by beds of shale, shaly dolomite, grey and buff and brown crystalline dolomite; anhydrite nearly always present.
		E	Thin shaly unit, argillaceous grey and buff dolomite.
		D	SALT, nearly pure; thin partings of buff dolomite.
		C	Dolomitic grey shale.
		B	SALT, thick salt beds with thin dolomite layers. (Main upper salt unit.)
Lower Salina		A2	Fine to medium brown to brownish grey dolomite; Fine grey to dark-grey dolomite, some dark bituminous shale; SALT (Lower salt) up to 140 feet thick; where salt is absent the base of A2 marked by anhydrite.
		A1	Fine- to medium-grained, buff to brown dolomite; Fine to dense, brown-grey and dark-grey dolomite with dark-grey bituminous shale; Anhydrite at base.

a fairly uniform thickness of limestones and dolomites. In other words, when salt was being deposited little or no other sediments were being deposited.

Subdivision of the Salina Formation

The work of K. K. Landes on the Salina formation in Michigan led to the subdivision of the Salina into seven lithological units (designated A to G in ascending order), which can be traced in the subsurface (Landes 1945a.) Work done mainly by Union Gas Company and Imperial Oil Limited indicates that this subdivision can be extended into southwestern Ontario. The subdivision of the Salina is illustrated by Figure 5 and Table I.

These units of Landes have been traced into Ontario; salt beds occur in units A2 and F and make up nearly all of units B and D. Since this subdivision depends largely on the stratigraphic position of several traceable salt beds, it is difficult to apply where salt is absent. (Sanford and Brady 1955, p. 5.)

Sanford and Brady (1955, p. 5) state:

> Petroleum and natural gas production from the Salina formation in Ontario is confined to unit A. Unit A in Ontario is divided into two traceable units, A1 and A2 (Evans, 1950). There units are commonly referred to as the "upper" and "lower" pays of the lower Salina. Both A1 and A2 are buff or light brown, granular dolomite at the top becoming darker in colour and more argillaceous and dense towards the base. The lower part of A2 may contain a thick bed of salt (lower salt), up to 125 feet in thickness, or in its absence a thin bed of anhydrite, making the two units easy to distinguish.
> Unit A2 is present throughout the entire (Windsor-Sarnia) area, but A is recognized only in the north half . . .

W. A. Roliff (1949, p. 167) points out:

> With the possible exception of a few wells in the Dawn oil and gas field, Unit A is present in all wells west of the outcrop belt that reach sufficient depth to encounter it. It ranges in thickness from 50 feet to 450 feet and is composed of calcareous or argillo-calcareous rocks with a middle salt member in the area east and south of Lake Huron [*see* Charts A and B, map case]. In much of this latter area, these calcareous rocks are predominantly limestones that grade laterally outwardly into a belt composed of limestones and dolomites, thence into dolomites, and finally into dolomites and shaly dolomites. Unit A is overlain in the western part of the province by the thick unit B salt, and in the eastern part by the argillo-calcareous beds.

Some descriptions of Salina stratigraphy in the Windsor-Sarnia area are given in various publications and papers. Caley (1945, pp. 22–26) includes a table describing Salina stratigraphy in one well in each of nine townships in the Windsor-Sarnia area. Logs of three wells in Lambton county, which cut salt-bearing Salina strata, are given by Sanford and Brady (1955, pp. 8–16).

Salt Deposition and Distribution

The isopach maps (Charts A, B, map case) show the distribution and thickness of the lower and upper salt units in southwestern Ontario.

LOWER SALT

The lower salt bed in the A2 unit occurs only within the Sarnia-Goderich salt area. It is not present in the Windsor or Chatham salt basins. The lower salt underlies the area shown in Chart A (map case) within the Sarnia-Goderich area. The salt bed has a maximum thickness of 140 feet in the Sarnia area and extends as far south as Wallaceburg where it pinches out. To the east of Sarnia it extends almost to Strathroy before pinching out. As indicated on the map, the lower salt thins or is absent over a number of "pinnacle" reefs in the Guelph formation southeast of Sarnia.

UPPER SALT BEDS

The upper salt beds include units B and D, and parts of unit F. Units B and D are almost entirely salt, and several salt beds may occur in unit F. Unit B is the thickest salt bed and in places exceeds 300 feet in thickness. Chart B (map case) is an isopach map showing the aggregate thickness of the upper salts in southwestern Ontario.

Windsor Area

As indicated on Chart B, salt beds underlie an area of about 105 square miles in the Windsor area. The upper salt beds have a maximum total thickness of about 300 feet along the Detroit River south of Windsor; they thin to the southeast and pinch out about 12 miles to the south and east of Windsor. The B and D salt units are present, as are salt beds of the F unit. The Ojibway mine is in the F unit. Brine wells have been operated in B, D, and F salt beds in this area.

Chatham Area

Chart B indicates a salt-free area, extending eastward from Lake St. Clair through Dresden and Bothwell, which separates the salt of the Chatham basin from the extensive salt deposits of the Sarnia-Goderich area to the north. Evans (1950, p. 63) suggests that this salt-free band "apparently existed as a ridge over which no salt ever was deposited." This ridge might then have separated the Chatham salt of the Appalachian basin from the Sarnia-Goderich salt beds of the Michigan basin.

The salt beds of the Chatham area underlie a land area of over 300 square miles and extend for an undetermined distance under Lake Erie.

Grieve (1955, p. 12) states that only the B salt is present in the Chatham salt basin. In the vicinity of Chatham, as indicated on Chart B, the salt thickness in places exceeds 200 feet. A thick salt zone extends east-west through Chatham. A second thick salt zone extends east-west through Thamesville and Rodney, with a salt-free area between that divides the Chatham salt area into two minor basins.

Sarnia-Goderich Area

The most extensive salt deposits in Ontario are those of the Sarnia-Goderich area. As indicated on Chart B, salt beds underlie a land area of more than 3,000 square miles. Salt beds occur in the A2, B, D, and F units of the Salina formation in the Sarnia-Goderich area. As shown in the generalized structure section eastward from Sarnia (Chart C), the salt beds thin to the east of Sarnia, with the F, D, and A2 salt beds disappearing first. In the Sarnia area the upper salt beds have an aggregate thickness of over 550 feet, while the lower salt (A2) has a thickness of over 140 feet, giving a total salt thickness of about 700 feet.

Chart D is a section eastward from Goderich, showing the progressive thinning and pinching out of the salt beds to the east. The B salt horizon persists farthest.

In addition to the regional changes in thicknesses of salt beds due to their position in the salt basins, there are minor local variations, apparent on Chart B, which are due to local thinning or non-deposition or removal of salt beds. These local variations in salt deposition are apparently due either to thinning or non-deposition of salt over buried hills on the Guelph floor of the lower Salina sea or to later leaching and removal of salt by solution.

NON-DEPOSITION OF SALT OVER GUELPH REEFS

Evans (1950, p. 67, Figure 10) has published a sketch map showing contours on top of the Guelph formation. On this map a number of small circular hills appear; these are Guelph reefs, which stood up in relief as hills on the sea floor at the time of early Salina sedimentation. Some of these buried hills had relief of as much as 400 feet. While Salina sediments, including salt beds, were being laid down on the flanks of these hills, there was little or no deposition on the hills themselves. Thus the circular areas of non-deposition of salt in the area south of Sarnia (*see* Chart B) are due to non-deposition of salt over buried Guelph reefs, which stood up as hills during early Salina times.

Figure 6 is based on Figure 7 of Grieve (1955, p. 13) showing a structure section across the Corunna gas field 6 miles south of Sarnia. It is described as follows by Grieve:

> Production in this pool is from a Guelph-Lockport reef which has an amplitude of over 400 feet. The structure of the reef is not reflected on horizons higher than the base of the B salt. Thinning of the A1, A2, and B units appears to compensate entirely for the reef. It is of interest to note that a relatively thick bed of anhydrite which has been traced laterally into the A2 salt was deposited over the reef crest. This suggests that the reef was not exposed to subaerial erosion during the deposition of the A2 salt.

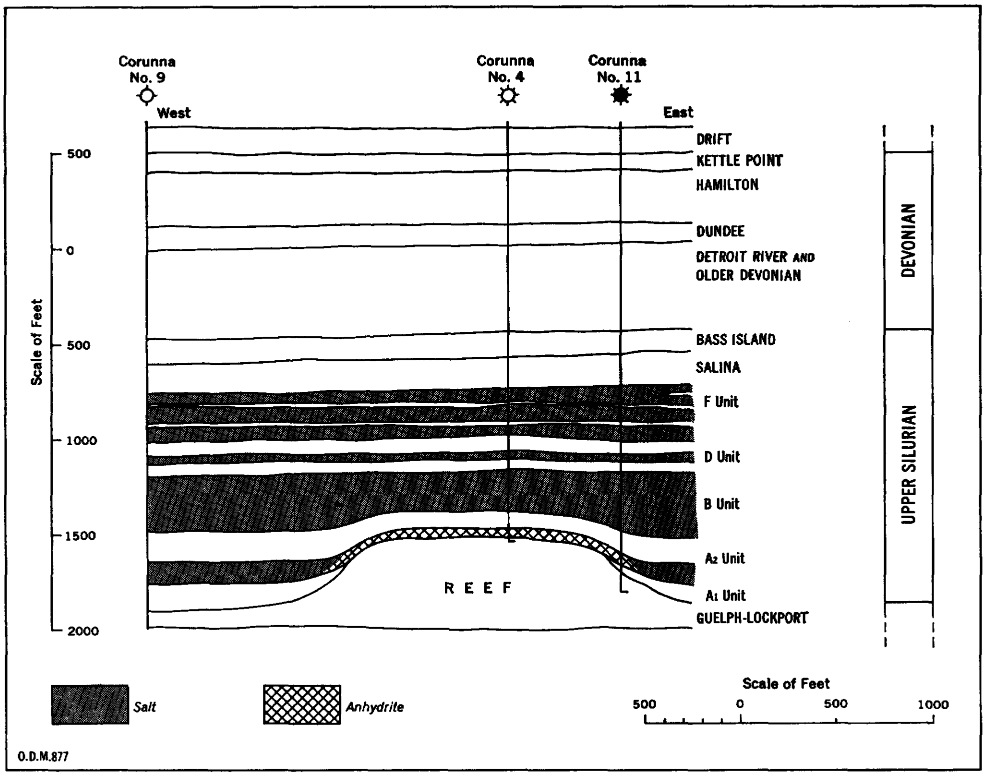


Figure 6 — Structure section showing non-deposition of A_2 salt, Corunna pool reef. (After R. O. Grieve.)

In discussing the Guelph reefs, Evans (1950, p. 76) states:

So far 13 "pinnacle" type reefs have been found . . . . . In all but three of these the relief above the surrounding Guelph ranged from 150 to 400 feet. Eleven of these reefs occur where the surrounding Guelph-Lockport is from 80 to 180 feet thick. The reef with the greatest relief (400 feet) shows thicknesses of 74 feet, 88 feet, and 95 feet of Guelph-Lockport around it. Two others with relief of 300 feet occur further south, where the Guelph-Lockport around them has a total thickness of 90 to 125 feet. Still further south two reefs with a relief of 150 feet have Guelph-Lockport thicknesses of about 150 feet around them. This suggests to the writer that these reefs, more resistant to erosion than the non-reef Guelph-Lockport dolomites, were etched out by pre-Salina erosion.

LEACHING AND SUBSIDENCE

Within the Sarnia salt basin (*see* Chart B) north of Dresden in Dawn and Enniskillen townships, there are two narrow bands of little or no salt extending in an east-west direction. Evans (1950, p. 63) points out that these two bands of little or no salt correspond with depressions in the surface of the Dundee formation above them and postulates that "along the narrow bands, one of which coincides with a known fault, salt migration, whether by pressure or solution probably took place." Evans (1950, p. 71, Figure 14) gives a north-south structural section 19 miles long across Plympton, Enniskillen, and Dawn townships, showing the thinning or absence of the B salt over the two narrow east-west bands already mentioned in Enniskillen and Dawn townships. (Figure 7, *this report.*)

Evans (1950, p. 71, 72) states:

The depression shown on this section in the Dundee extends east and west for over 30 miles before it acquires a northwesterly trend and disappears into Michigan. Even bedrock elevation, the top line in the section, is low over the depression caused by rapid thinning of salt. This fact implies that the beds overlying the salt, which were removed by solution or pressure, caved in. However, since all drilling was done by cable tools, in the use of which no apparent crevices were disclosed, and since the cuttings could give little evidence of crevices or brecciation, it remains just an implication.

K. K. Landes (1945b, pp. 123–98) in his study of the origin of the Mackinac breccia of Michigan suggests that this breccia is formed as a collapse breccia due to leaching of salt beds in northern Michigan in pre-Dundee times. In the area of the Mackinac straits, pipes of breccia several hundred feet high occur in the Devonian above the Salina beds. Faulting and brecciation caused by the dissolving of underlying salt beds is described as probably widespread in Michigan, the basin margins being particularly affected.

Grieve (1950, p. 10), from subsurface studies of the Salina in southwestern Ontario, states:

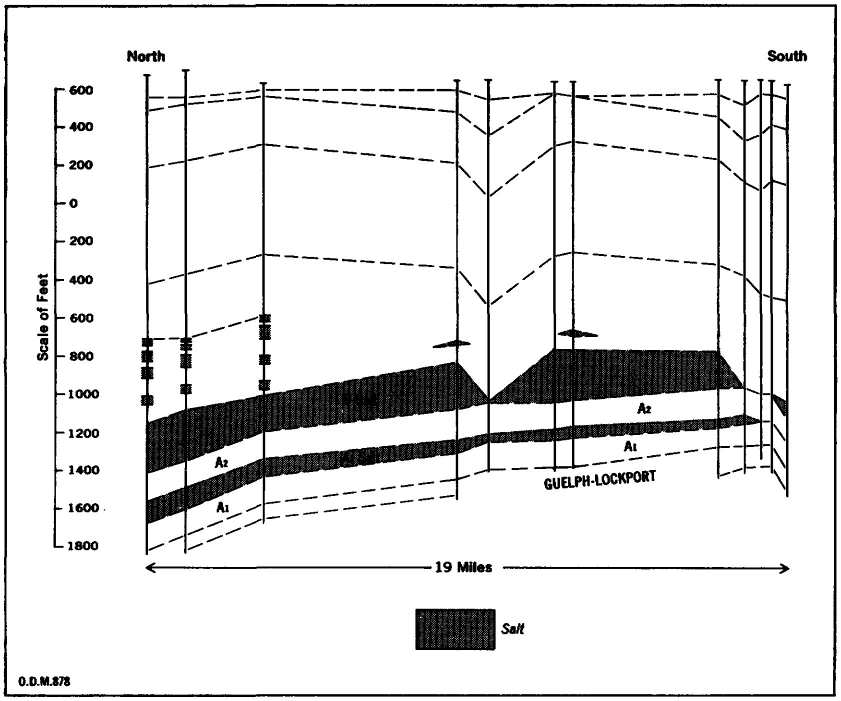


Figure 7 – North-south section, Plympton, Enniskillen, and Dawn townships. (After C. S. Evans.)

Within the salt basin(s) numerous areas, which range from a few hundred acres to many square miles, are noted for the complete absence of, or a marked thinning of, salt beds. Subsurface data from many of these areas indicate that salt was deposited and later removed. Subsidence of the overlying strata is attested by the structural features now present.

Locally, removal of salt appears to have been related to flexures or faults which, through fracturing, may have provided access to the salt-beds for solvent waters. Subsidence occurred as early as late Salina time and continued intermittently until after Hamilton time.

Structures apparently due to subsidence are described by Grieve (1955, pp. 15, 16):

A structure section through three wells drilled by Imperial in an area about three miles east of Sarnia is shown in Figure 8 [Figure 8, *this report*.] Here, as in the vicinity of the Corunna pool, salt beds usually are present in the A2, B, D, and F units. In the Imperial Sarnia 13-5 well, however, no A2 salt and only traces of the D salt were penetrated. The absence of these salt beds is reflected in the structure higher in the Salina formation. The complete lack of relief on the horizons below the A2, and the absence of thick anhydrite beds in the place of the A2 salt, strongly contrast with the conditions illustrated by the Corunna pool [Figure 6]. The uniform thickness of the non-saliferous rocks of units A1 to E suggests that no structure existed in this area before F unit time. It is obvious, therefore, that the A2 and D salt beds were deposited and subsequently removed, presumably during the time represented by units F and G, which are thicker in the Sarnia 13-5 well than in the adjacent wells by an amount comparable to the normal thickness of the A2 and D salts.

Grieve gives evidence of similar subsidence structures in the Kimball and Northwood areas. There is no evidence to support the view that the thinning of salt is due to flow of salt under pressure, or to non-deposition of salt beds. Grieve (1955, p. 17) concludes:

It is apparent that removal of the salt beds and subsidence was a process not confined to one particular interval of geological time. In the features illustrated . . . subsidence took place at times ranging from before deposition of the higher Salina salt beds until after the Devonian. The number of instances where two or more dates of subsidence are evidenced is so great that it is suspected that subsidence progressed laterally with time. In this event, however, it is difficult to visualize emergence and leaching by circulating ground waters as a prerequisite, for a large number of heretofore unsuspected unconformities would have to be postulated. Instead, it is suggested that circulation of normal marine waters in sub-sea fissures could remove the salt and produce those subsidence structures not effectively explained by the conventional theory of leaching [by ground waters in a period of emergence] which has been adopted by Landes and others. (Landes, 1945; Bishop, 1953).

Sources of Information on Salina Stratigraphy

A general description of the Salina formation is given by Caley (1945, pp. 21, 22), and logs of the Salina formation are given for one well in each of nine townships in the Windsor-Sarnia area. Sanford and Brady (1955, Figure 1, sheets 1–4) give an excellent series of columnar sections from the Windsor-Sarnia area showing salt thicknesses. Roliff (1949) gives a very useful series of generalized stratigraphic sections of the Salina formation. Evans (1950) gives a general description of the Salina, several useful isopach and contour maps of members of the Salina formation, and a number of sections showing salt thicknesses. The information in the foregoing part of the report is largely derived from these sources and from Grieve (1955). Logs of

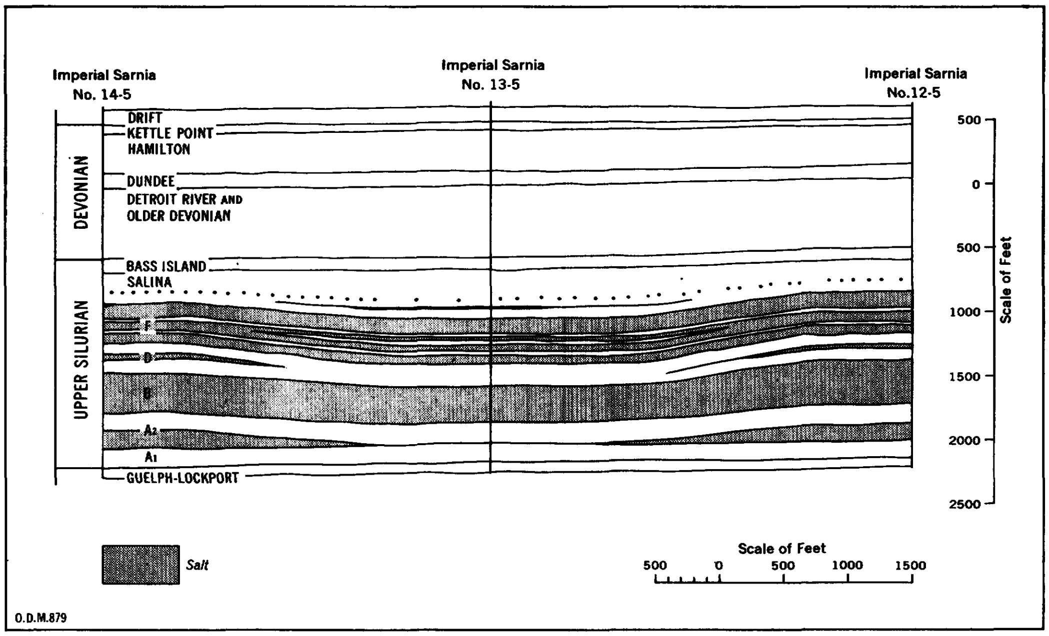


Figure 8 – Structure section showing removal of salt and subsidence, Sarnia area. (After R. O. Grieve.)

oil and gas wells drilled in southwestern Ontario are on file at the offices of the Ontario Department of Energy Resources and are an important source of information on salt in the Salina formation.

Characteristics of Salina Salt Beds

The characteristics and origin of the Salina salt beds of Michigan are described by Dellwig (1955, pp. 83–110): salt layers, 3–8 centimetres thick, alternate with tissue-thin laminae of anhydrite and dolomite; the anhydrite is generally darker in colour. Dellwig reports that some quartz, pyrite, celestite, polyhalite, and carbonaceous material may be present. Complex salts are rare, and precipitation apparently terminated before the development of the polyhalite phase in the theoretical sequence of salt deposition.

It is pointed out that the thickening of the Salina salt toward the centre of the Michigan basin, together with the great salt thickness present, indicates subsidence during Salina deposition. These features also necessitate addition of brine during salt deposition. Contemporaneous salt and gypsum beds are found in eastern Ohio and New York states, and this presents the possibility that there was brine replenishment in the Michigan basin from the New York basin. Apparently a delicate balance was maintained between sinking, evaporation, and supply so that at no time did evaporation approach completion.

Dellwig describes the banded salt as composed of three units: carbonate and sulphate laminae, clear salt, and cloudy salt. Cloudy zones contain abundant liquid inclusions, while the clear salt is comparatively inclusion-free. Pyrite and carbonaceous material are localized along the anhydrite-dolomite laminae and indicate a reducing environment. At the Detroit mine, dolomite is mainly concentrated in crude, discontinuous layers. The low percentage of insolubles in the salt beds indicates evaporation and deposition from a concentrated brine.

Dellwig points out that for deposition of banded salt certain conditions must be established: the main mass of brine must be concentrated to a point at least near saturation, so that most of the dolomite and anhydrite deposited with the banded salt must come from the inflowing water intermittently added to the basin. Before the saturation point of NaCl is reached, all the $CaCO_3$ and about 90 percent of the $CaSO_4$ are precipitated in that order. Underlying the salt, therefore, layers of dolomite and anhydrite might be expected.

Thick salt beds represent periods of influx of brine nearly depleted in $CaCO_3$ and $CaSO_4$. The deposition of anhydrite-dolomite laminae is completely independent of the deposition of salt and may be considered due to an influx of brine into the basin of deposition. The presence of pyrite and carbonaceous material with these laminae is indicative of this influx.

Conditions governing the deposition of $CaSO_4$ were studied by Posnjak (1940, pp. 247–72). Anhydrite rather than gypsum will precipitate above 42°C. regardless of the brine concentration of NaCl; if sea water has an NaCl concentration of 4.8 times normal at 30°C., then anhydrite will deposit instead of gypsum. Dellwig points out that although dolomite-anhydrite laminae may be accounted for by an influx of water into the basin, the alternation of dolomite and anhydrite is not readily explained. Increases in salinity or temperature will cause a decrease in carbonate solubility.

A study of inclusions in the salt indicates a range of temperature of deposition for the halite of 32°–48.4°C.

An earlier paper by Kaufmann and Slawson (1950, pp. 24, 25) describes features of the Salina salt beds in Michigan as follows:

> A feature to be emphasized is the varvelike stratification of the salt beds . . . Each of the individual stratification bands is very persistent throughout the entire [Detroit] mine, showing only minor variations of spacing or intensity . . . The bands range from an almost imperceptible brown tint to dark brown or black . . . If the face of the salt is sprayed with water and slowly dissolved away, the core of the dark bands begin to protrude. This core consists of either a single layer or several layers of paper-thin lamellae of white or gray anhydrite, separated by narrow zones of salt of variable thickness. The lamellae are in some cases crowded so close together as to be almost indistinguishable. A group of four or five may occur in a centimeter of vertical distance . . . Clear bands of white salt also contain thin anhydrite lamellae. The presence of . . . laminae of anhydrite in the main mass of . . . salt as well as in the dark bands indicates [frequent environmental changes] . . . There is no regularity in vertical spacings of the dark bands.

This same paper describes ripple marks in the salt of the Salina formation at the Detroit mine (Kaufmann and Slawson 1950, pp. 27, 28):

> The ripples [apparently] formed in a layer of fine granular, poorly coherent massive salt crystals . . . Because of the continuity, uniformity, and well developed character of these ripples, and the nature of the salt in which they were formed, the authors are of the opinion that they represent the development of ripples by wave action upon unconsolidated salt resting on a bed of consolidated salt. The uniformity of the entire rock salt formation suggests the action took place some distance from a shoreline.

A more recent paper (Briggs 1958, pp. 46–56) gives the results of facies analyses in the Michigan basin. These indicate that:

> 1) The Michigan and Ohio–New York basins were separate evaporite basins, connected across the Findlay (Algonquin) arch, through the Chatham sag.
> 2) The principal inlet to the salt basins was in the vicinity of Georgian Bay in Ontario which connected the Michigan basin with the Arctic seaway.
> 3) A subsidiary channel flowed northward into the Michigan basin through an inlet in the vicinity of Clinton, Michigan, connecting the basin with the southern Appalachian seaway, principally during Middle Salina times.
> 4) A persistent river flowed eastward into the Michigan basin in the vicinity of Ludington, Michigan.

This paper also includes informative maps of the distribution of evaporite facies in the Michigan and Ohio–New York basins; it also indicates replenishment of brine in the Ohio–New York basin from the Michigan basin via the Chatham sag.

III—Salt Production

In 1960, Ontario salt production amounted to 3,007,599 tons valued at $13,994,545 from two salt mines and six brine well operations. This was 95 percent of the total Canadian production. Other Ontario production figures for salt, back to 1895, are given in Table II.

MARKETING SALT

The largest consumers of salt are the chemical industries, who use salt in the manufacture of soda ash and chlorine. In Ontario in 1959, Brunner Mond Canada Limited, Canadian Brine Limited, and Dow Chemical of Canada Limited who produce brine wholly for chemical purposes, accounted for 52 percent of the total Ontario output. In addition, some of the production of the other salt companies is used by the chemical industry.

The amount of salt used for de-icing streets and highways has increased greatly in recent years, and this use now accounts for a substantial quantity of coarse-mined rock salt. In 1959, the Ontario Department of Highways used about 170,000 tons for this purpose; the municipality of Metropolitan Toronto used more than 20,000 tons; Hamilton municipality used 12,000 tons; and other municipalities used proportionate amounts.

Table III, from the Dominion Bureau of Statistics publication on the Salt Industry in 1958, gives figures of salt consumption for various specific industries. It will be noted that the food processing industries, including meat packing, fish processing, baking, dairy, canning, brewing, and confectionery are major users of salt. Salt is also used in the tanning, pulp and paper, soap-making, metallurgical, rubber, and oil-refining industries.

A large quantity of salt is now used in water softeners.

Table IV, also from the Dominion Bureau of Statistics, gives statistics on imports and exports of salt.

TABLE II—ONTARIO SALT PRODUCTION[1]

Year	Tons	Value	Operators	
			Mine	Brine Well
1960	3,007,599	$13,994,545	2	6
1959	3,036,230	13,228,977	[2]2	6
1958	2,126,483	10,204,472	1	6
1957	1,538,805	9,478,587	1	5
1956	1,347,729	7,932,294	1	6
1955	998,789	5,845,340	1	6
1954	733,066	4,440,418	....	7
1953	749,046	3,919,810	....	7
1952	757,025	4,401,780	....	7
1951	772,585	4,789,990	....	7
1950	696,582	4,639,867	....	7
1949	607,206	3,477,583	....	6
1948	619,598	3,265,654	....	6
1947	633,766	3,132,165	....	6
1946	441,679	2,408,279	....	6
1945	578,697	2,920,973	....	6
1944	603,806	2,906,117	....	6
1943	594,889	2,892,839	....	6
1942	558,407	2,793,328	....	6
1941	447,170	2,512,166	....	6
1940	412,401	2,371,780	....	6
1939	370,843	2,200,189	....	6
1938	388,130	1,637,140	....	6
1937	407,701	1,539,599	....	6
1936	350,044	1,557,078	....	7
1935	320,003	1,698,508	....	7
1934	276,751	1,734,196	....	6
1933	244,107	1,755,087	....	5
1932	231,138	1,789,752	....	6
1931	231,329	1,760,388	....	5
1930	248,637	1,558,405	....	7
1929	302,445	1,420,424	....	7
1928	279,841	1,377,629	....	9
1927	254,180	1,510,777	....	9
1926	252,345	1,388,672	....	10
1925	226,470	1,466,450	....	11
1924	203,428	1,337,311	....	11
1923	197,917	1,674,365	....	11
1922	176,741	1,573,657	....	10
1921	161,987	1,649,626	....	11
1920	206,612	1,544,867	....	10
1919	148,112	1,395,368	....	11
1918	131,726	1,287,039	....	10
1917	138,909	1,047,707	....	8
1916	128,935	700,515	....	9
1915	116,648	585,022	....	9
1914	104,774	498,383	....	10
1913	96,799	474,372	....	11
1912	90,986	450,251	....	10
1911	88,689	430,835	....	11
1910	84,071	414,978	....	11
1909	77,490	389,573	....	10
1908	79,112	488,330	....	10
1907	62,806	432,936	....	7
1906	50,414	367,738	....	8
1905	60,415	356,783	....	7
1904	55,877	362,621	....	7
1903	58,274	388,097	....	8
1902	62,011	344,620	....	9
1901	60,327	323,058	....	7
1900	66,588	324,477	....	10
1899	56,375	317,412	....	11
1898	59,385	278,886	....	10
1897	54,686	249,880	....	11
1896	44,816	204,910	....	....
1895	51,009	188,101	....	....

(1)Ontario Dept. of Mines statistics.
(2)The Goderich mine of Sifto Salt (1960) Ltd. began production in October, 1959.

TABLE III—CONSUMPTION OF SALT IN SPECIFIED CANADIAN INDUSTRIES

(From Dominion Bureau of Statistics, "Salt Industry in 1958")

Industry	1956		1957	
	Quantity Used	Cost at Works	Quantity Used	Cost at Works
	pounds		pounds	
Acids, alkalies and salts:				
Brine (salt content)	1,040,831,700	$1,012,722	1,600,811,727	$3,571,008
Dry salt	508,111,567	2,669,866		
Artificial abrasives	382,000	3,995	230,000	2,000
Slaughtering and meat packing	(2)	(2)	(2)	(2)
Sausage and sausage casings	2,704,316	33,859	2,152,513	32,171
Animal oils and fats	(2)	(2)	(2)	(2)
Fish processing	54,752,000	632,800	47,156,500	534,600
Foods, breakfast	1,958,338	24,094	2,132,299	25,834
Biscuits	2,735,167	43,729	2,619,921	43,590
Bread and bakery products	24,902,251	419,069	25,897,855	439,927
Macaroni, vermicelli, etc.	99,404	3,020	112,295	3,138
Miscellaneous food preparations	15,545,995	239,593	17,516,023	280,304
Butter and cheese	(2)	342,433	(2)	259,615
Cheese, process	821,778	12,212	980,784	13,708
Concentrated milk products	(2)	7,329	(2)	6,242
Starch and glucose(1)	(1)	(1)	(1)	(1)
Fruit and vegetable preparations	23,166,973	305,000	26,897,267	354,013
Breweries	2,405,479	35,567	1,946,029	31,935
Malt and malt products(1)	(1)	(1)	(1)	(1)
Stock and poultry foods, prepared	45,798,000	560,997	45,324,000	561,953
Leather tanneries	14,850,113	147,185	14,127,260	146,365
Soaps and cleaning preparations	4,436,311	55,026	3,875,201	33,717
Dyeing and finishing of textiles	3,890,343	48,221	3,902,081	46,898
Artificial ice	594,320	7,202	522,400	4,781
Pulp and paper mills	98,012,000	554,062	90,966,000	556,464
Vegetable oil mills	(2)	(2)	(2)	(2)
Confectionery, cocoa, etc.	709,098	13,396	747,787	13,886
Miscellaneous chemicals	28,385,691	66,379	30,505,165	70,192
Feed mills	2,468,000	28,284	(2)	(2)

(1) Combined under "Miscellaneous food preparations."
(2) Not applicable.

TABLE IV—PRODUCTION, IMPORTS, EXPORTS, AND CONSUMPTION OF SALT

(From Dominion Bureau of Statistics, "Salt Industry in 1958")

	1956		1957		1958	
	Amount	Value	Amount	Value	Amount	Value
	tons		tons		tons	
Producers' shipments	1,590,804	$12,144,476	1,771,559	$13,989,703	2,375,192	$14,989,542
Imports:						
Table salt	45	28,278	94	36,288	41	34,342
Salt for the use of fisheries	58,985	330,012	80,178	308,081	56,977	247,374
Salt, in bulk,	242,133	962,505	269,681	1,023,114	267,423	946,159
Salt, in bags, barrels, etc.	17,961	284,951	17,527	281,734	16,445	275,123
Total imports	319,124	1,605,746	367,480	1,649,217	340,886	1,502,998
Exports	333,935	2,286,830	457,888	3,241,119	(1)406,707	2,917,269
Apparent consumption	1,575,993	....	1,681,151	....	....	....

(1) Excluding salt in brine exported.

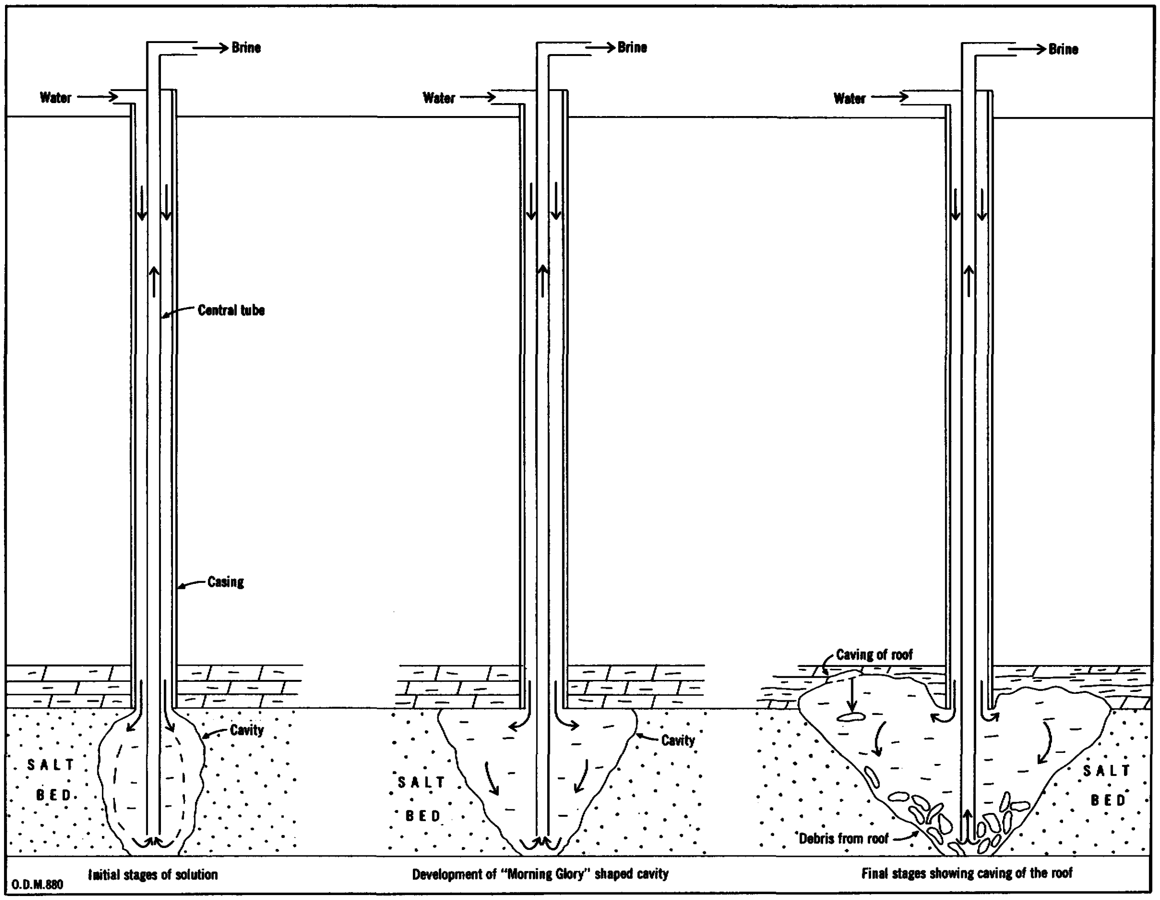


Figure 9 — Tully method of brine-well operation.

The following companies produced salt in Ontario in 1959:

Company	Type of Operation	Location
Canadian Rock Salt Co........	mine	Windsor
Sifto Salt (1960) Ltd..........	"	Goderich
Brunner Mond Canada Ltd....	brine field	Amherstburg
Canadian Salt Co.............	"	Windsor
Canadian Brine Ltd...........	"	Windsor
Dow Chemical of Canada Ltd..	"	Sarnia
Sifto Salt (1960) Ltd..........	"	Sarnia
Sifto Salt (1960) Ltd..........	"	Goderich

Canadian Rock Salt Company Limited and Canadian Brine Limited are associated companies of Canadian Salt Company. The production of Brunner Mond Canada Limited is wholly used by the company for the manufacture of soda ash. The brine production of Dow Chemical of Canada Limited is used by this company at its Sarnia caustic soda-chlorine plant. The brine production of Canadian Brine Limited is piped across the Detroit River to the Detroit plant of the Solvay Process Division of Allied Chemical and Dye Corporation. Canadian Salt Company and Sifto Salt (1960) Limited sell on the open market.

BRINE-WELL AND BRINE-FIELD OPERATION

A large part of Ontario salt production is obtained from artificial brine wells by solution mining. Wells are drilled into the salt bed, water is injected to dissolve the salt, and the brine is pumped out. The oldest method of brine-well production, still used in some small plants, is the single-well type of operation, in which water is injected and brine produced from a single well by means of a central tube in the well (used either to introduce water or to provide exit for the brine). The single-well operation gives only a limited rate of production, depending on the thickness of the salt bed, the size of the salt cavity, the proportion of salt surface available for solution, and the rate of pumping.

Modern methods of brine production involve multiple-well brine-field operations in which two or more wells are joined in series. Water is injected into one well, and brine is recovered from one or more of the adjacent wells, which are joined to the injection well. Much larger rates of production can be achieved in this type of brine-field operation involving this use of multiple wells in series. It is also possible to exercise some control of the size and shape of cavities produced.

There are two main types of single-well operation, the Tully method and the Detroit method; and two main types of multiple-well brinefield operation, the Trump or Air Pad method (Trump 1944) and the hydraulic fracturing or "Hydrofrac" method.

In each case, wells are drilled by normal churn-drill or rotary-drill methods used in oil-well drilling. At the surface the wells generally have a diameter of 10–14 inches. The casing is generally 6–10 inches in outside diameter.

Single-Well Operation

In the Tully method of single-well operation, water passes down the annular space between the casing or wall of the hole and the centre tube, and the brine rises in the centre tube. In the Detroit method, water passes down the centre tube, and brine rises in the annular space between the centre tube and the casing.

TULLY METHOD

In the Tully method the well is drilled to the base of the salt bed and may be cased and cemented to the top of the salt bed. A centre tube, 3–4 inches in diameter, is placed in the well extending to the bottom of the salt bed as shown in Figure 9. Water is forced down the well between the casing and the centre tube, and the brine is raised in the centre tube by hydraulic pressure. In some cases a small air-line is dropped down the centre tube to the brine level, and compressed air is injected. This addition of air decreases the specific gravity of the brine column, and the brine is raised in the centre tube by this "air-lift" method.

As shown in Figure 9, an inverted conical or "morning glory" type of cavity gradually develops, mushrooming outwards towards the roof of the salt bed. Anhydrite or shaly material interbedded with the salt falls to the bottom of the cavity and blankets the salt surface, limiting the area available for solution to the upper exposed parts of the salt bed. When the cavity reaches and extends outward along the roof of the salt bed as shown in Figure 9, trouble begins owing to caving of the roof. Blocks of falling roof-rock may cut off the tubing; when this happens, production from the well is cut off until the tubing can be re-established. This may necessitate re-drilling in the caved section. Excessive caving may force the abandonment of the well.

Taft (1946, p. 246), in describing salt wells at Hutchison, Kansas, states:

> The life of a well may not be more than a year but some of those at Hutchison have a reported average life of 14 years. Cave-ins at the bottom of the well which may occur as frequently as twice a year, necessitate the difficult and expensive operation of re-drilling the well through loose rock and pumping out the mud which blankets the bottom of the 'salt bed.'

Plastic tubing has been tried in place of iron tubing since it is easier to re-drill in the debris pile in the well cavity. Total production from this type of well may be small, depending on the thickness of the salt bed.

In the Goderich-Kincardine area of Ontario, a variation of the Tully method was used and is still used in the older wells of Sifto Salt (1960) Limited at Goderich. These wells are drilled to the base of the salt bed, and the centre tube installed. The wells are cased to bedrock and are uncased below; underground water in an upper aquifer provides the solvent water. It flows down between the uncased walls of the hole and the centre tube. Brine is raised by air lift in the centre tube. New regulations requiring the casing of wells have made this type of well obsolete.

DETROIT METHOD

In the Detroit method (Figure 10) the well is drilled to the base of the salt bed, cased and cemented to the top of the salt bed, and the centre tube is placed in the well extending to the bottom of the salt bed. Water is injected via the centre tube, and brine passes up the annular opening between the casing and the centre tube. Trump (1944, p. 1) describes the operation of this type of well as follows:

> Initially this flow forms a pear-shaped cavity in the bottom of the salt bed, but this cavity soon changes in shape to that of an inverted cone, as under the Tully plan, with the attendant disadvantages inherent in that plan. Application of the Detroit plan is limited to salt beds 300 feet thick as a minimum. This depth of bed is necessary to prevent fresh water of lower specific gravity than the brine from rising in the brine thus producing an unsaturated solution.

The diameter of the cavities produced in single-well operation will vary greatly depending on the life of the well and the thickness of the salt bed. However, if caving does not occur, the cavities of

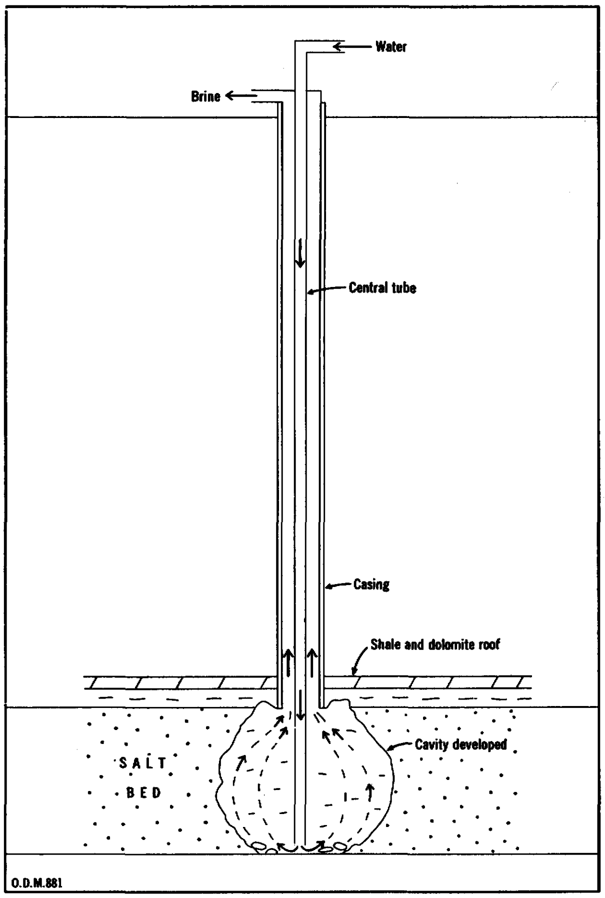


Figure 10 – Detroit method of brine-well operation.

two or more adjacent wells may join. In this event it is common practice to inject water at one well and to pump brine from the adjacent connected well or wells. In older fields many wells may become connected. This is desirable from a production standpoint as it enables higher production. When further production is required, a new offset well may be drilled a few hundred feet, possibly 300–500 feet, from the nearest adjacent well and may be operated as a single well until its cavity breaks through to join the system.

Multiple-Well Brine-Field Operation

Recently brine-well producers have had success in planning brine-field operations to give a higher percentage extraction from the whole salt bed, with control of the size and shape of cavity, and to get away from the old "morning-glory" type of salt-well development, with its attendant caving problems.

These newer methods of brine-field design depend on laying out the wells in series on 300- to 500-foot centres, joining the salt wells for production at the base of the salt bed early in the production cycle, and then establishing a linear flow generally in a series of three wells in line, with one water-injection well and two brine-producing wells.

TRUMP OR AIR PAD METHOD

The Trump or Air Pad Method (Trump 1944) was developed by E. N. Trump of the Solvay Process Division, Allied Chemical and Dye Corporation, Syracuse, N. Y. In this method a series of three or more holes is drilled in a line on 300-foot centres as shown in Figure 11. The holes are cased and cemented to the top of the rock salt bed, and the centre tube is put in place to the base of the salt bed. Trump (1944, p. 2) describes the method as follows:

> A horizontal undercut is dissolved at the bottom of the salt bed. Mud and impurities fall on top of the underlying shale, and the disadvantages of the conical cavity produced (in the Detroit and Tully methods) are thereby avoided. The solvent (water) is held down by an air cushion provided by air bubbles carried down in the water. A constant level of the solvent is maintained by provision for the escape of surplus air that is not dissolved in the brine . . . The solvent is permitted to rise to a height of four feet during undercutting operations

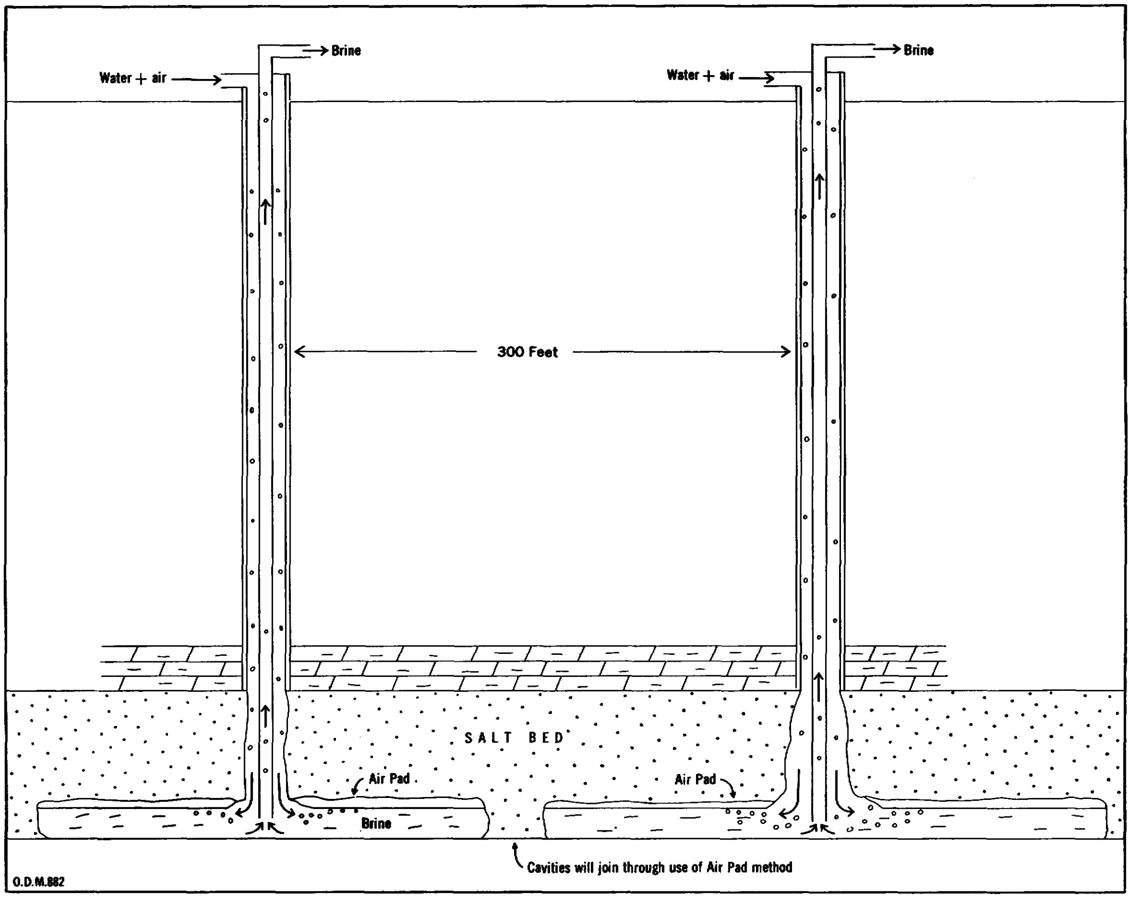


Figure 11 — Use of air pad method of joining two nearby wells.

by provision of an outlet for the surplus air in the form of holes drilled in the center tube at that height from the base of the saline bed . . . Air is added to the solvent water in the form of small bubbles, which decrease in size as pressure increases during the passage of water down the well. The heat of compression is absorbed by the water and the air dissolved, the weight of the water decreasing in weight by the volume displaced by the air. The water, moreover, will dissolve four times as much air as the saturated brine and sufficient air is added to the water to provide a surplus over that which is absorbed in the brine. This surplus air is then liberated to produce the air cushion, which in turn holds down the solvent.

As brine rises in the centre tube, the air dissolved therein is released in the form of bubbles, which increase in size as they move upward to the top of the tube. These bubbles decrease the weight of the brine by one eighth. To prevent dilution of the brine a bell may be placed above the surplus-air holes in the center tube. This arrangement permits the surplus air to be removed without taking water into the brine and prevents its entry with the brine into the center tube. To raise the brine in the center tube, the water, and air added to the water, at the top must be pumped into the annular space between the center tube and casing at a pressure equal to the difference in specific gravity between that of the brine and that of the water and air. Moreover, the loss of pressure resulting from friction in the pipes must be taken into consideration.

The air pad allows the undercut to be extended in an expanding horizontal circle until the three wells are joined. The wells may then be operated by injecting water into an end well and pumping brine from the other two. It is assumed that the resulting cavity will have a linear form between the wells, resulting in an elongate room being dissolved out as solution progresses.

The air-pad method has the disadvantage that air introduced into the system speeds corrosion of brine lines and pipes. The pressures needed to operate the air pad at depth of 1,300–1,700 feet are difficult to handle. Oil pads have also been used with varying success.

Although the air pad is used to connect wells by undercutting on initiating brine production, it is not often used during later production. About 12–14 months is the normal period taken to join two wells 300 feet apart.

HYDRAULIC FRACTURING (HYDRAFRAC) METHOD[1]

A second method used to join wells in multiple-well operations is the hydraulic fracturing method. A typical brine-field layout for this method is shown in Figure 12. Wells are drilled three in a line on 500-foot centres; the distance between lines may be of the order of 800 feet. The wells are drilled to the base of the salt formation and then cased and cemented. The casing is perforated in the lower 3–5 feet of the salt bed to ensure that circulation begins at the bottom of the bed.

After perforation, water pressure is applied to the well. Fracturing will normally occur when the pressure reaches about one pound per foot of depth. This hydraulic pressure is thought to act by

[1]Since the writing of this report, a comprehensive article has been published: C. A. Bays, W. C. Peters, and M. W. Pullen, "Solution Extraction of Salt using Wells Connected by Hydraulic Fracturing"; A.I.M.E. Trans., Vol. 217, 1960, pp. 266–77.

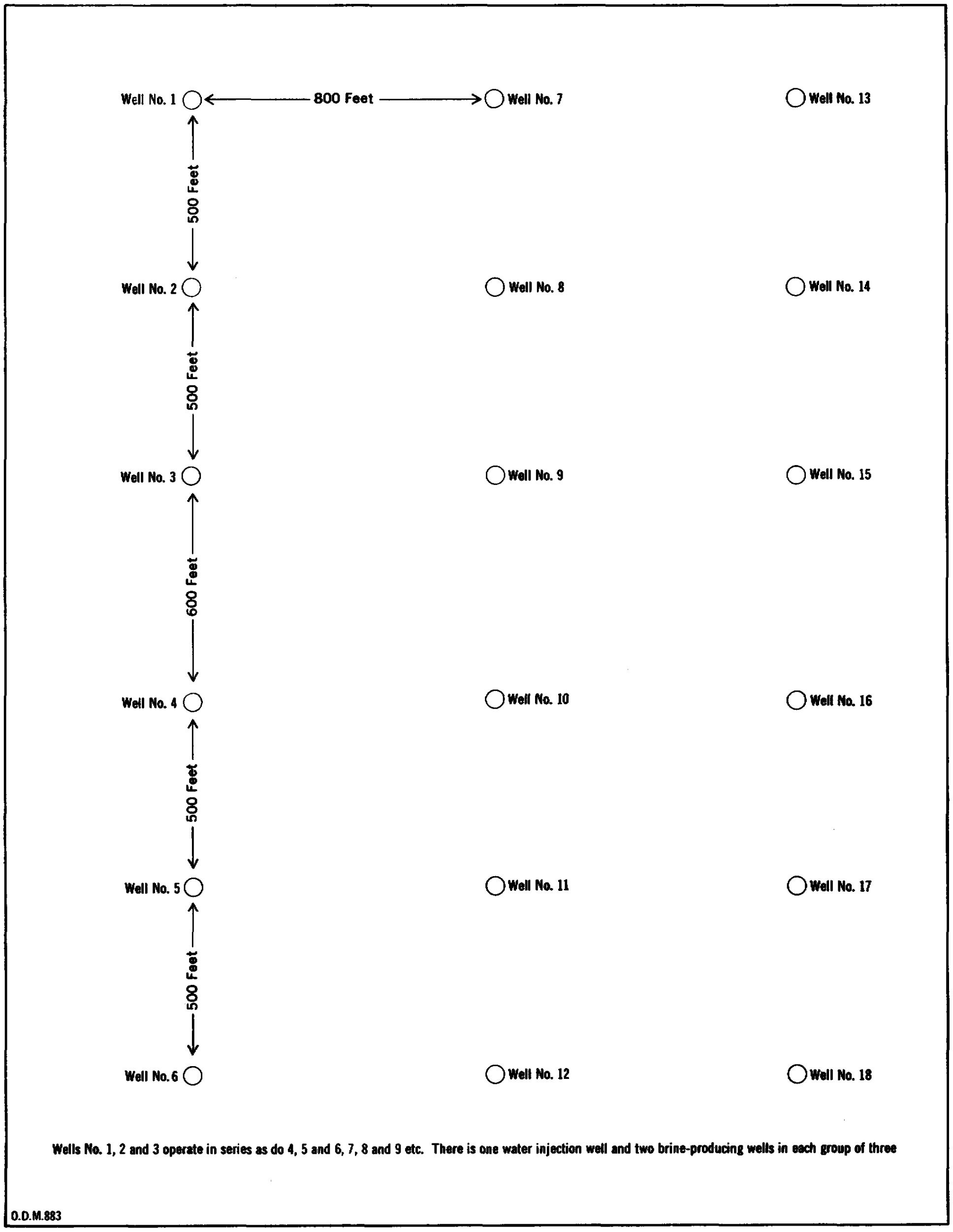


Figure 12 – Brine-field layout for series of wells joined by hydraulic fracturing.

hydraulic jacking of the strata along horizontal fractures. Loss of pressure may indicate that an open fracture system has been reached. The fracturing between two wells 500 feet apart under ideal conditions may occur in 2–4 hours, and the join will be indicated by a dropping-off of the hydraulic pressure.

When three wells in a linear series are joined, water is introduced in one well (often the centre one) and brine pumped from the two adjacent wells. The join having been made at the base of the salt bed, the cavity is supposed to develop as a linear gallery between the three wells. Ideally it is hoped that a pillar of salt will be left between adjacent lines of wells.

If wells produce 100-percent saturated brine, this will have a specific gravity of 1.208 and will contain 2.6 pounds of salt per gallon or 1.3 tons per 1,000 gallons. All producing wells are metered, and the tonnage of salt produced from each group of three wells can be calculated. Knowing the thickness of the salt bed and assuming a cavity 300 feet wide, an approximation of the life of the series of three wells can be made.

No good method has been developed to determine the size and shape of the cavity. The volume of the cavity is known from the tonnage produced; the area of the cavity per foot of depth can only be ascertained by pumping it out. Before casing the well, radioactive tracers can be fired into the walls of the salt bed at various levels. As the cavity eats its way upwards these tracers will fall out one by one. A gamma-ray survey of the hole at any time will give an indication of the height of the cavity at the time of survey.

Some experimentation has been done on sonar surveys of well cavities, but so far the method has not had a wide application.

Rates of production vary, but the average is about 100 gallons per minute per well.

SALT MANUFACTURE FROM BRINE

Methods of salt manufacture are described in the following sources from which this section is largely derived (MacMillan 1960, pp. 727–28: Cole 1930, pp. 81–9: Hester and Diamond 1955, pp. 672–83: Badger and Standiford 1955, pp. 173–77, 180–83: Phalen 1949, pp. 834–37).

In Ontario, evaporated salt has been produced both by grainer and vacuum pan. The grainer, which produces coarse or flake salt most suitable for certain food-processing industries, consists of elongated shallow open pans or troughs heated by steam pipes. Salt is produced by slow and quiet evaporation, and the hopper-shaped salt crystals form at the surface. The type of salt recovered is determined by the temperature and the brine composition. The salt that sinks to the bottom of the grainer is recovered by mechanical rakes. It may be centrifuged to reduce moisture content. The average production from a 120-foot grainer is 10 tons of salt per 24 hours. Fuel consumption is high, and production of grainer salt is limited. Grainer coils must be frequently cleaned of calcium sulphate scale, and maintenance time is said to amount to about one hour per ton of salt.

Nearly all evaporated salt is now made in vacuum pans, which produce fine cubic salt crystals. MacMillan (1960, pp. 727–28) describes the vacuum pan operation as follows:

> Most evaporated salt is a product of the vacuum pan—a large cylindrical vessel, which may be 18 feet in diameter and 60 feet high, having a conical top and bottom. A steam-heated calandria encircles the vessel just below mid-section and a large impeller helps circulate the brine upward through the tubes of the heater and down through the central downtake. Crystallized salt collects in the conical bottom and is removed in a slurry. The pans are operated under partial vacuum to lower the boiling point of the brine.
>
> Economy is increased substantially by operating several pans in series, using the vapor produced in one to heat the brine in the next; each succeeding pan operates on a slightly higher vacuum. This procedure is known as multiple effect evaporation and three or four effects are common in the salt industry.
>
> Over the years many improvements in both design and operation of vacuum pans have been evolved. Calcium sulphate scale which formerly crusted the heat exchange tubes of the calandria and had to be drilled out each week is no longer a problem. It is now largely controlled by maintaining a considerable concentration of fine calcium sulphate crystals in the evaporator brines. The dissolved calcium sulphate which precipitates in the pans as the temperature increases is thus provided with small, circulating nuclei on which to grow, and the heating tubes are not encrusted. Excess calcium sulphate and fine salt crystals are washed from the salt slurry with saturated brine and a portion is returned to the evaporators.

Calcium sulphate has an inverted solubility curve and precipitates at high temperatures.

Vacuum pans produce salt at the rate of about 2 tons per day per square foot of evaporator cross-section (Wilson 1947, p. 530). About 2,600 pounds of steam is required per ton of salt in triple-effect vacuum pans.

Salt is removed from the vacuum pans as a slurry and goes to a rotary vacuum filter. This step is followed by drying, screening, and packaging.

Treatment of brine is often necessary to remove impurities before evaporation. Phalen (1949, p. 834) states:

> The brine coming from wells contains soluble impurities, chiefly hydrogen sulphide gas, iron compounds probably as

carbonate, and calcium and magnesium salts. For the purest grades of salt used in the food industries and for special purposes, these are largely removed by chemical means. The brine may be aerated, treated with lime or lime and soda ash, caustic soda and soda ash, and possibly alum, and allowed to settle a few days. Some manufacturers chlorinate the raw brine for the removal of sulphides and oxidation of the iron. The brine is then aerated to remove the excess of chlorine and the chemicals added. In the manufacture of vacuum pan or grainer salt for the most exacting trade, the brine may be purified by the lime–soda ash process, and for this trade, largely the dairy, some manufacturers consider the cubical grained or granulated salt as good as the flake grainer salt.

The addition of such chemicals as lime and soda ash should be under close chemical supervision, chemical dosage and control may be based on pH value, or, preferably, on actual chemical analysis or alkalinity of the purified product .

In discussing salt manufacture, Badger and Standiford (1955, pp. 173–77, 180–83) state:

Salt is almost always made from brine saturated with calcium sulphate and containing appreciable amounts of calcium and magnesium chlorides. Few operators in this country find it possible to chemically purify the brine. The consumption of sodium carbonate to remove completely the calcium sulphate results in excessive costs. Consequently practically all salt evaporators today run on unpurified brine. However the calcium and magnesium chloride content of the mother liquor is watched and a sufficient bleed is taken off the evaporator to hold this concentration of soluble impurities at a desired level. This level is such that washing in the elutriation leg, washing in the settling tank, and washing in the top filter are enough to keep the calcium and magnesium chloride contents of the final salt in the desired limits. It is possible by such methods to make the salt considerably purer than 99.5 percent in day to day operations.

Other processes of salt manufacture such as the Alberger, Morton, International, and Richards processes are also used. The last two require solid salt as starting material. The Richards process is described in *Chemical Engineering* (Richards 1952, p. 140). This process is used in New York state.

An article by W. L. Hardy (1957, pp. 59, 60) is reviewed by the United States Bureau of Mines in the chapter on salt in their *Minerals Yearbook for 1958*, as follows:

The investment cost of a small plant capable of producing 35 tons per day of pure dry salt was estimated at $426,000, divided about equally between equipment and buildings. Equipment and costs were itemized as follows:

1) Salt evaporator and accessories, $85,000;
2) Rotary filter and accessories, $16,000;
3) Salt drier, $50,000;
4) Pumps, $4,000;
5) Settling tanks, $8,000;
6) Storage bins, $10,000;
7) Piping and miscellaneous items, $25,000.

The refining costs in a plant of this capacity were estimated at $12 to $17 per ton of finished salt exclusive of brine costs.

A small salt unit manufactured by Manistee Iron Works for refinining 20 tons of salt per day is described in *Chemical Engineering* (Jan. 1952, p. 230).

ONTARIO BRINE-WELL OPERATIONS

History of Salt Production in Ontario

An interesting account of the discovery of salt in Ontario is given by L. H. Cole (1915, pp. 30–32):

The discovery of salt in Ontario dates back to 1866. In that year, when the oil excitement was at its height in western Ontario, due to oil having been discovered to the south, a company was formed at Goderich, organized by a Samuel Platt, with the object of drilling for oil. This company, with a subscribed capital of $10,000, commenced drilling on the north bank of the Maitland river, to the east of the bridge. The drill passed through a series of layers of greyish limestone of varying hardness, to a depth of 686 feet, without encountering any indications of oil; so the stockholders decided to abandon the enterprise. Mr. Platt, however, decided to continue drilling at his own expense, especially since the County Council had offered a bonus of $1,000, and the city a bonus of $500 providing drilling was continued to a depth of 1,000 feet. His efforts were amply rewarded, for, at a depth of 964 feet from the collar of the hole, he encountered a solid bed of rock salt into which he bored for a distance of 60 feet, thus completing 1,000 feet, and securing the above-mentioned bonuses.

Upon encountering salt, the shareholders who previously had abandoned the work, expressed a desire to pay up their assessment and were allowed to do so by Mr. Platt. The capital of the company was increased to $14,000, and was incorporated as the Goderich Petroleum Company, and in September, 1866, pumping of brine commenced. The salt made from this brine was sold to George Rumball & Co., who marketed it.

. . . .

As soon as the well was in shape for pumping the brine, the Goderich Salt Company [as it was then called] constructed two blocks of 52 kettles each: the kettles ranging in capacity from 120 to 140 gallons. Thus the total capacity of the plant was in the neighbourhood of 100 barrels per day.

The salt produced found a ready market, so that at the end of the first year's operation the profits were considerable, dividends totalling 51 per cent, having been distributed among the shareholders. The price then obtained for the salt was $1.25 per barrel at the works.

The kettle method was soon found to be expensive, hence it was discarded in favour of the pan method of evaporation.

The success attending this pioneer company gave great impetus to this infant industry, so that by the next summer the valley of the Maitland from the bridge to the town was the scene of extensive drilling operations. About the year 1872, the following blocks, with the enumerated capacity in barrels per day were in full operation: "The Goderich" 200 bbls. (this was the pioneer well); "Maitland" 100; "Prince," 100; "Victoria," 100; "Huron," 100; "Dominion," 200; "Ontario," 150; "Tecumseh," 150; "Hawley's," 200; "Inniskillen," 200; "International," 600; and "Platt's," 150 (Platt having severed his connexion with the original company and erected works of his own).

In the meantime, drilling operations had been carried on with good success at Clinton and Seaforth, and at both places salt was encountered, and plants erected. The fact that wood fuel was cheaper at these latter places enabled them to supply the Canadian market at lower prices than from the Goderich wells, and in consequence a number of the plants at the latter place were forced to close down.

In the year 1879, there were only four of the Goderich plants in operation: namely: "Platt's"—making 150 barrels per day; "Tecumseh"—owned by A. Hodge, 75 barrels; "Hawley's"—200 barrels; and the "International"—600 barrels. This last mentioned Company was operated by the Seaforth Syndicate and was, up to that time, the largest salt works in Canada.

TABLE V—ONTARIO BRINE PRODUCERS

	Location	Dates of Production	Total Wells	Well Depth	Wells in Current Production	Total Production to 1958 (approximate)
				feet		tons
A. PRESENT PRODUCERS						
1. Brunner Mond Canada Ltd.	Amherstburg	1919–	32	....	15(?)	7,099,675
2. Canadian Salt Co. Ltd.	Sandwich	(1)1910–	32(?)	....	3(?)	5,136,333
3. Canadian Brine Company Ltd.	Sandwich	1958–	18	....	18	488,549
4. Dow Chemical of Canada Ltd.	Sarnia	1950–	12(?)	....	6	1,305,241
5. Sifto Salt Ltd.	Sarnia	1910–	10	....	3	2,038,411
6. Sifto Salt Ltd.	Goderich	1880–	4	....	3	(2)1,485,730
B. PAST PRODUCERS OVER 100,000 TONS						
1. Canadian Salt Co. Ltd.	Windsor	1893–1928	(?)	....	....	1,292,310
2. Purity Flour Mills	Goderich	1908–1954	(?)	....	....	387,686+
3. Western Salt Co.	Courtright	1917–1930	(?)	....	....	119,909+
C. OTHER PAST PRODUCERS						
1. Ontario Peoples Salt & Soda Co. (Kincardine Salt Co.)	Kincardine	1897–1930, 1935–1936	....	935	....	....
2. Grey, Young & Sparling Co. of Ontario (Wingham Salt Works, Western Salt Co.)	Wingham	1898(?)–1925	....	1,185	....	....
3. Stapleton Salt Works (J. Ransford)	Stapleton	1898(?)–1916	....	1,300	....	....
4. North American Chemical Co. (J. Ransford)	Goderich	1880–(?)	....	1,200	....	....
5. Exeter Salt Co.	Exeter	1898(?)–1928	....	1,225	....	....
6. Parkhill Salt Co.	Parkhill	1898(?)–1911	....	1,300	....	....
7. Elarton Salt Co. (Warwick Pure Salt Co.)	Warwick	1908–1926, 1933–1956	....	1,460	....	....
8. North American Chemical Co.	Clinton	1914–1916	....	....	....	....
9. Western Salt Co.	Mooretown	1898(?)–1913	....	....	....	....

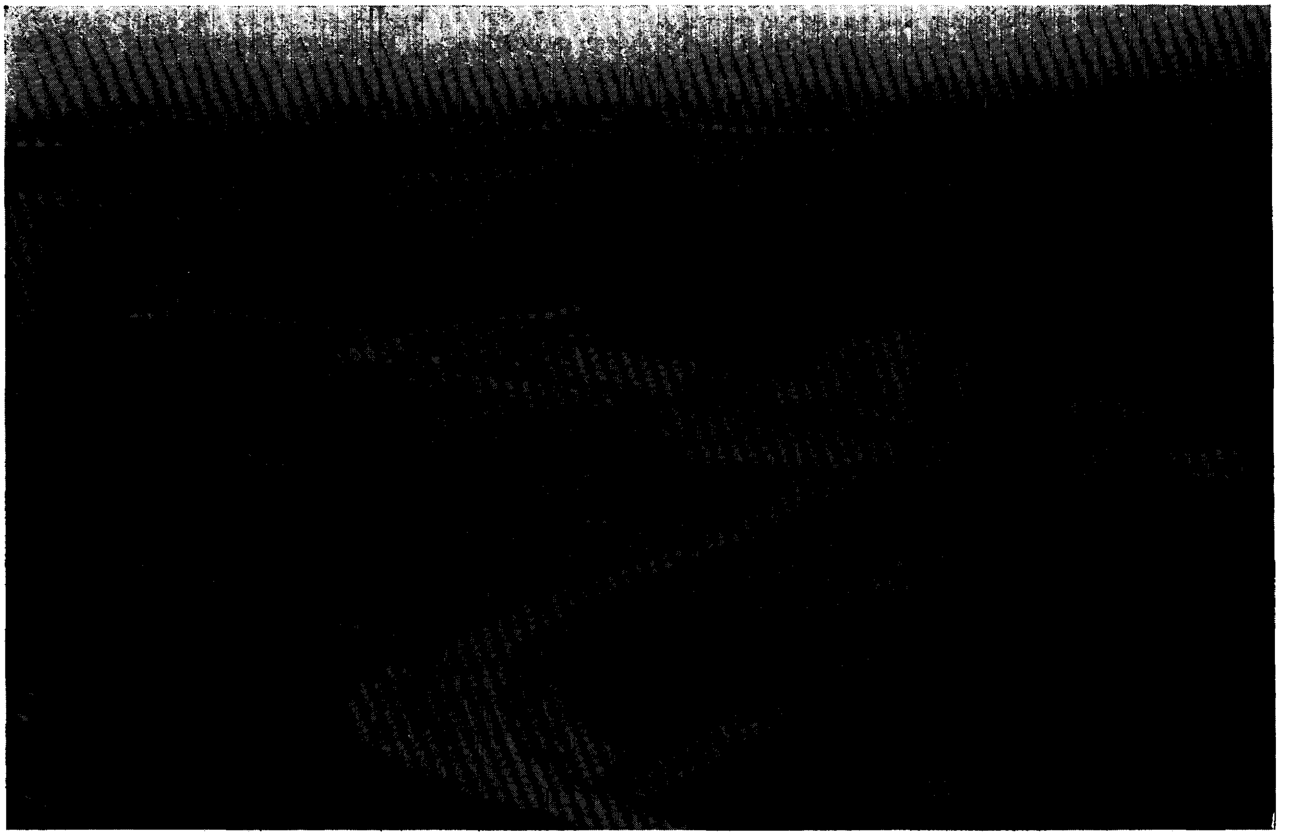
(1)The Windsor works of the company began operation in 1893.
(2)1919 to present only.

In 1900 there were nine salt works operating in Ontario: Coleman Salt Company at Seaforth; R. & J. Ransford's Stapleton Salt Works, near Clinton; North American Chemical Company at Goderich; Goderich Salt Works of Peter McEwen; Grey, Young and Sparling Company of Ontario (later Wingham Salt Works) at Wingham; Ontario People's Salt and Soda Company at Kincardine (later Kincardine Salt Company); John Fox and King Hodgkin's Salt Works (later Parkhill Salt Company) at Parkhill; Sarnia Salt Company at Sarnia; and Windsor Salt Works (later Canadian Salt Company) at Windsor.

In 1914, at the time of L. H. Cole's first report on the salt industry, the following eleven companies were producing:

1) *Ontario People's Salt and Soda Company.*—In 1914 this company operated a brine well 935 feet deep at Kincardine. This plant operated until 1930; it reopened in 1935 and 1936 but has been inactive since.
2) *Grey, Young and Sparling Company of Ontario Limited.*—This company operated a brine well 1,185 feet deep with 30 feet of salt, at Wingham; it operated until 1925 as the the Wingham Salt Works.
3) *Stapleton Salt Works.*—This plant near Clinton, operated by J. Ransford, had one brine well 1,300 feet deep; it operated until 1916.
4) *Western Canada Flour Mills Company Limited.*—This company operated a well 1,150 feet deep, at Goderich. The company and its successor, Purity Flour Mills Limited, operated at Goderich harbour until 1954 when it was taken over by Sifto Salt Limited. It ceased production in 1954.
5) *Exeter Salt Company.*—This company operated one well, 1,225 feet deep, at Exeter, in 1914; it ceased production in 1928.
6) *Parkhill Salt Company.*—One well, 1,300 feet deep, was operated in 1914, at Parkhill.
7) *Elarton Salt Company.*—This plant in 1914 operated one brine well, 1,460 feet deep, in which 130 feet of salt was reported. The Elarton Salt Company operated until 1926. Its successor, Warwick Pure Salt Company, operated from 1933 to 1954 and was one of the last of the small independent producers.
8) *Dominion Salt Company.*—This company, which in 1914 operated three wells at Sarnia, was the predecessor of Sifto Salt Company's Sarnia operation.

Photo by Sid. Lloyd, Walkerville



The Ojibway mine, Canadian Rock Salt Company.

9) *Western Salt Company.*—This company in 1914 operated one well at Courtright with a depth of 1,700 feet. The company ceased operation in 1930. It also operated at Mooretown.
10) *Canadian Salt Company.*—In 1914 this company operated five wells at Windsor. The Windsor operation was closed in 1928 when the whole operation was concentrated at the Sandwich works of this company.
11) *Canadian Salt Company.*—In 1914 this company operated a brine field and chemical plant at Sandwich on the outskirts of Windsor.

Table V gives a list of present brine-well producers, with their location, time of production, number of wells, and total salt production to 1958. Some other substantial past producers are included on the list.

Present Producers

BRUNNER MOND CANADA LIMITED

Brunner Mond Canada Limited operates a brine field in lots 29, 30, and 31, concession I, Anderdon township, Essex county. The brine field has been in operation since 1919 to supply brine for the manufacture of soda ash at the Amherstburg plant of Brunner Mond Canada Limited. The brine is piped from the brine field to the plant, a distance of about 3 miles.

By 1959 a total of twenty-six wells had been drilled in lots 29 and 30 of which nine were in operation. In the older wells, salt is produced from salt beds at 1,030–1,130 feet and 1,140–1,196 feet, a total thickness of 156 feet of salt. In 1959 a new brine field of six wells was laid out and drilled in lot 31, and production began in 1960 from this new unit. The Trump (Air Pad) method is being used to connect these six new wells, which are in line on 300-foot centres. The wells are 1,210–1,220 feet deep.

CANADIAN SALT COMPANY LIMITED

A short history of early operations of the Canadian Salt Company is given by L. H. Cole (1930, pp. 40, 41):

In the year 1891 a well drilled near the Canadian Pacific Railway station at Windsor encountered a 30-foot bed of rock salt at a depth of 1,138 feet, thus greatly extending the area in Ontario known to be underlain by salt. Construction of a plant for the manufacture of salt was soon commenced under the name of Windsor Salt Company and production started late in the year 1893. The original plant consisted of open pans and grainers, but soon two 12-foot, single effect, vacuum pans were installed and these were the first vacuum pans operating on salt brine in Canada. In April 1901 the Canadian Salt Company was incorporated and took over the assets of the Windsor Salt Company. Under the new management a third vacuum pan was added, larger than the other two, the two smaller ones being run alternately as first effect, with the larger one as second effect. An additional plant for this company was later built at Sandwich, Ont., where four grainers were operated.

In 1911, this company commenced the operation of its chemical plant at Sandwich, for the manufacture of caustic soda and bleaching powder, later additions being made to produce liquid chlorine and hydrochloric acid.

In 1928 excavations were started for a new and modern salt plant adjacent to the chemical plant at Sandwich and this plant was put into operation early in 1929.

During the fall of 1928 the Canadian Salt Company was purchased by the Canadian Industries Limited, and operations are now carried on (1930) by the Salt and Chemical Division of that company.

The original salt plant at Windsor is completely dismantled and all operations are conducted at Sandwich.

Early in 1951 the assets of the Salt Division of Canadian Industries Limited were purchased by an independent group to reincorporate Canadian Salt Company Limited.

In 1952 a subsidiary, Canadian Rock Salt Company, was formed to mine rock salt at Ojibway, 2 miles south of the Canadian Salt property at Sandwich. Production from the mine began in August 1955. This operation is described later in the report. In 1952 a controlling interest in Canadian Salt Company was acquired by Morton Salt Company of the United States. In 1957, Canadian Brine Limited was formed as a subsidiary of Canadian Salt Company to export brine to the Detroit plant of the Solvay Process Division of Allied Chemical and Dye Corporation. Production began in 1958.

Canadian Salt Company operated a brine field adjacent to the Canadian Industries plant on a 56-acre property on the shore of the Detroit River. Twenty-nine wells were drilled on this property. Production ceased from this field after the subsidence of February 1954 when a sink-hole 400 feet in diameter and 24 feet deep occured on the property.

The new brine field operated by Canadian Salt Company consists of three wells east of highway No. 18, east of the plant. These wells are joined in a series of three, with one water-injection well and two brine-producing wells.

The brine is pumped to storage tanks. From the storage tanks it is pumped to three 18-foot vacuum pans operated in series. The salt slurry from the evaporators goes to a brine washing tank where it is washed by a current of fresh brine to remove calcium sulphate. The slurry then goes to an Oliver filter for drying. The product from the filter is conveyed to a rotary dryer. The dried salt is then conveyed to the packing plant where the required additives are added. The salt is packaged, bagged, made into blocks, or shipped in bulk.

CANADIAN BRINE LIMITED

The new brine field of Canadian Brine Limited went into production in 1958. The company has a 150-acre property, east of the Canadian Salt Company plant, bounded on the south by the Windsor city limits and on the east by Matchette Street. Twelve wells have been laid out on this property in north-south rows of six wells each. An additional six wells have been drilled on the east side of Matchette Street on City of Windsor property on which the company has rights to recover salt.

The completed brine field consists of eighteen wells drilled on a rectangular pattern in three rows of six wells each. The wells in each row of six are spaced about 500 feet apart, and the distance between adjacent lines of six wells is 800 feet.

The wells are 1,600 feet deep and 6–8 inches in diameter. The hydraulic fracturing method of interconnecting wells was used in establishing the field. The wells are operated in three groups, one group of two wells, one of five, and one of eleven. In the two smaller groups, one water-injection well is used in each group. In the largest group, three water-injection wells are used.

DOW CHEMICAL OF CANADA LIMITED

In 1950, Dow Chemical of Canada Limited began production of brine to supply their caustic soda-chlorine plant at Sarnia. Ten wells were drilled on the company property, in lots 22–30, River Front, Sarnia township. Salt beds were encountered in hole No. 1 at 1,540–1,680 feet, 1,755–1,782 feet, 1,820–1,877 feet, and from 1,972 feet to the bottom of the hole at 2,010 feet.

Production now comes from a new 400-acre brine field in lots 25 and 26, concession XII, Moore township, about 2 miles from the Dow plant. Eight wells have been drilled in the new field; they operate in pairs, located 500 feet apart, and are about 2,500 feet deep. A surface casing, 16 inches in diameter, is seated on bedrock, and the hole is cased with 10¾-inch casing to within 17 feet of the bottom of the hole and is cemented throughout.

SIFTO SALT (1960) LIMITED—SARNIA

The Sarnia plant and brine operation of Sifto Salt (1960) Limited is on a 30-acre property bounded approximately by Front Street, London Road Extension, Exmouth Street, and Sarnia Bay in the City of Sarnia. Fifty acres of adjacent water lots are also held.

Ten salt wells have been drilled on the property, which has operated since 1903. Six wells have been abandoned. Three wells are operated at present, one water-injection well and two brine-producing wells. The wells are 1,800–2,100 feet deep, and salt beds occur at depths between 1,550 and 2,000 feet. The wells are pumped at the rate of 130–150 gallons per minute.

The brine from the wells goes to storage tanks, from which it is pumped to the vacuum pans. There are three vacuum pans, 10 feet in diameter, run in series. The salt slurry from the evaporators goes to washing tanks and then to an Eimco filter for drying. The dried salt goes to the packing house where it is packed in packages or bags, or made into blocks, or shipped in bulk. Additives such as potassium iodide and magnesium carbonate are added at this stage.

SIFTO SALT (1960) LIMITED—GODERICH

The Goderich brine operation of Sifto Salt (1960) Limited is located in the eastern part of the town of Goderich, south of the Maitland River. The company, which formerly operated under the name Goderich Salt Company, is one of the pioneers of the Canadian salt industry, having operated at this location since 1880 (Cole 1930, p. 36).

The first well, drilled in 1880, has a depth of 1,168 feet. The second well, drilled in 1919, is 1,270 feet deep. Wells Nos. 3 and 4, drilled in the 1930's, are about 1,200 feet deep. Two wells are operated at the present time. The wells are uncased, the water being supplied by a flow of water from aquifers in the uppermost 300 feet of the rock formations penetrated. The brine is raised in a central pipe in the wells by the air-lift method. Well capacities are 90–100 gallons per minute.

The brine goes to a 300,000-gallon brine-storage tank where lime is added. From the storage tank the brine is pumped to three vacuum-pan evaporators operated in series. The product from the evaporators goes to two washing tanks where the salt slurry passes against a countercurrent of fresh brine to wash out the calcium sulphate. The salt slurry is then charged on to a rotary top-feed filter dryer.

Dry salt is discharged to a belt conveyor and transported to storage. Salt is packaged, bagged, or shipped in bulk, or made into blocks. Additives that may be required for particular uses are added at this stage.

In 1960 two new salt wells were drilled in lot 1, Maitland Concession, ¼ mile east of the plant. This new brine field is expected to be in operation in 1961.

SALT MINES

Two companies are now engaged in mining rock salt in Ontario. They are Canadian Rock Salt Company Limited, operating the Ojibway mine near Windsor, and Sifto Salt (1960) Limited, operating the Goderich mine at Goderich.

CANADIAN ROCK SALT COMPANY LIMITED

Canadian Rock Salt Company Limited was formed in 1952 as a subsidiary of Canadian Salt Company, to engage in underground mining of rock salt in the Windsor area. The rock salt mine of Canadian Rock Salt Company Limited is located in lots 40–49, concession I, Sandwich West township, Essex county, on the shore of the Detroit River, 2 miles southwest of the Windsor city limits. The mine workings extend westward under the Detroit River.

The development and operation of the Ojibway mine are described in several papers (Gail 1954: Mamen 1956, pp. 37–43: O'Day 1958, p. 107: Rice 1960).

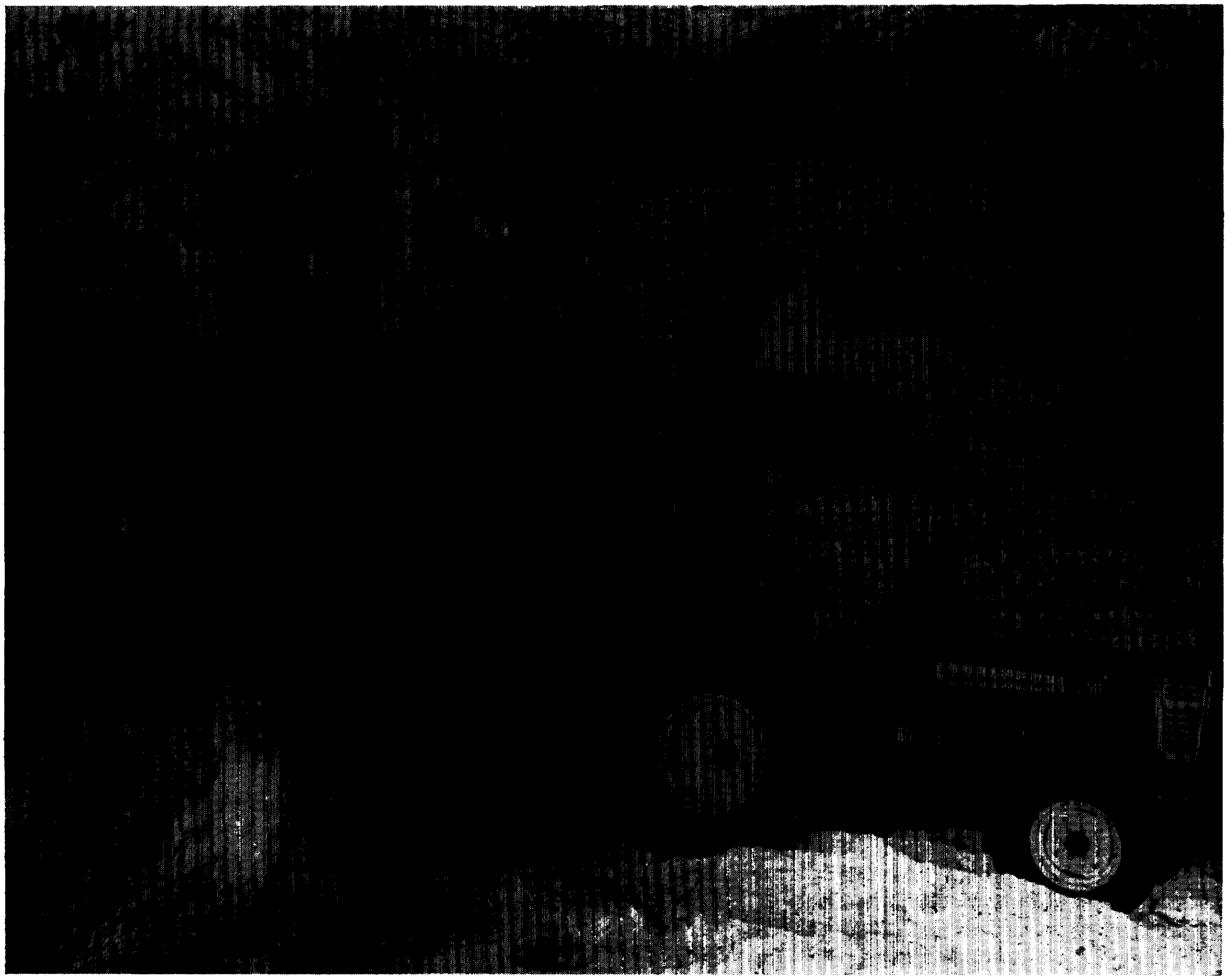
Much of the material in the following description is drawn from these papers.

History of Development

Diamond-drilling carried out in 1952 on the property indicated a mineable bed of very pure salt 27 feet thick, 948–975 feet below the surface, and this bed is now being mined. A second bed of salt occurs 30 feet above this bed. These salt beds belong to the F unit of the Salina formation. A geological section of the mine shaft was prepared by B. V. Sanford (1957, p. 212) of the Geological Survey of Canada, and is reproduced in Chart E.

Preliminary drilling indicated about 90 feet of overburden, mainly sand and gravel, clay, and till. Below this, strong aquifers were found in the Detroit River limestone and dolomite, in the Sylvania sandstone, and in the Bois Blanc limestone, to a depth of about 710 feet. Hydrogen sulphide

Photo by Sid. Lloyd, Walkerville



Loading holes in the salt face at the Ojibway mine, Canadian Rock Salt Company. Note the well-bedded character of the salt horizon.

was also encountered in some of the strata. Owing to the difficult water conditions and the presence of hydrogen sulphide gas, it was decided to sink the shaft by the Poetsch method of freezing the ground prior to sinking.

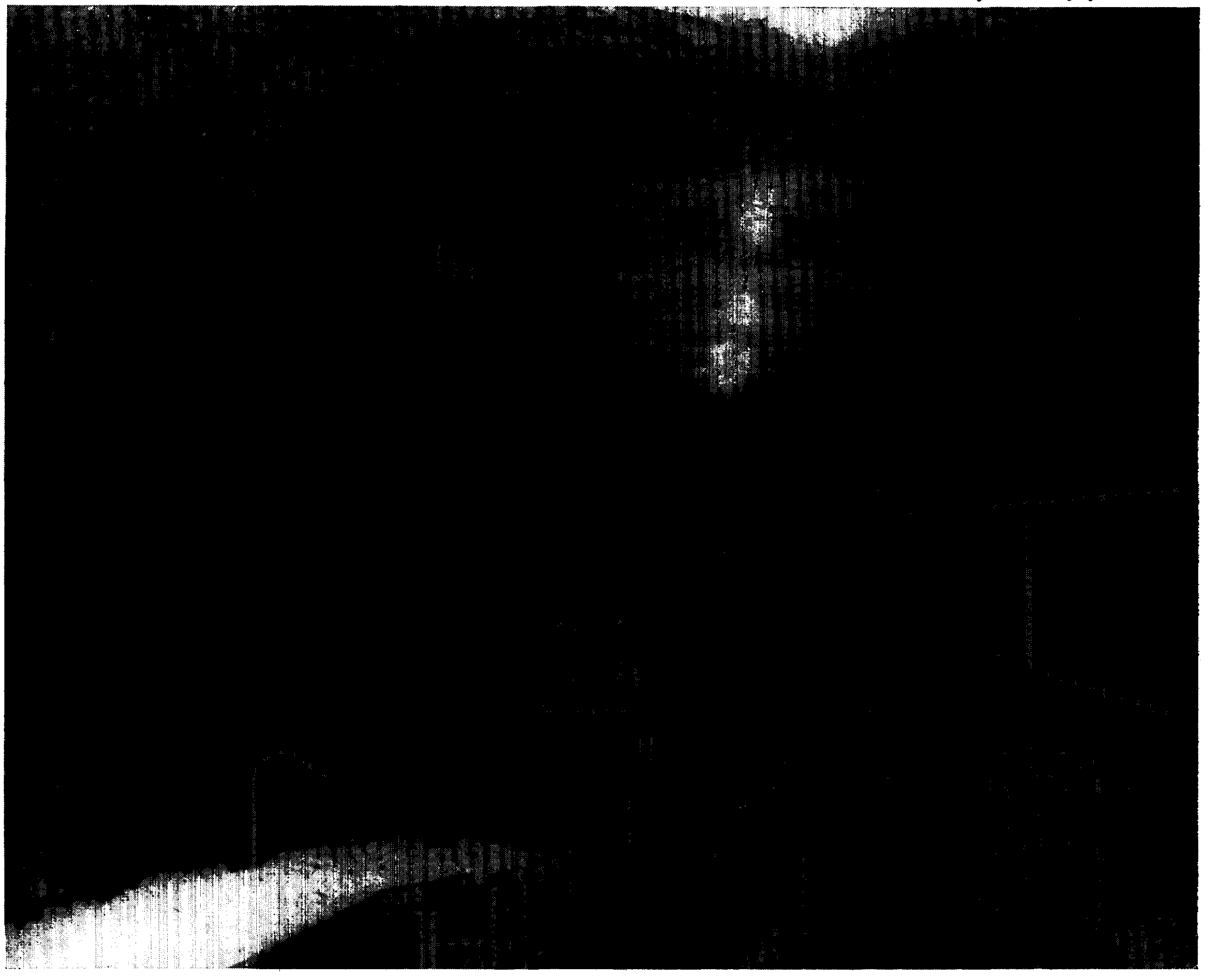
The production shaft, with an inside diameter of 16 feet, was sunk to a depth of 1,100 feet. The ground was frozen to a depth of 750 feet, below the lowermost aquifer, by means of a series of freeze holes drilled 3 feet apart on the circumference of a circle of 32-foot diameter. The concrete shaft-lining ranges from 16 to 30 inches in thickness depending on ground and water conditions. The lining was grouted after the shaft was completed. After the ground thawed, additional grouting was carried out, as required, to seal leaks.

Some interesting information on water conditions in the central pilot hole, drilled to examine the formations and water conditions and to provide a pressure-relief hole, are given by C. P. Gail (1954, p. 3):

In drilling the centre hole, the following water data was obtained: The sand and gravel strata at about 8 feet was found to carry a moderate flow of water. This was probably surface water. The clay and other stratas down to 87 feet were wet, but no pronounced water veins were indicated. As the hole was drilled below 87 feet in the rock, the static level of the water rose to the surface and overflowed the 10-inch casing.

The artesian water flows, as measured while drilling, were as follows: at 137 feet, 200 g.p.m.; 175 feet, 250 g.p.m.; 203 feet, 500 g.p.m.; 207 feet, 750 g.p.m.; and at 210 feet a flow of 1,150 g.p.m. overflowed the 11-inch casing. Therefore it was evident that a water vein of considerable capacity existed at the 210-foot depth.

Photo by Sid. Lloyd, Walkerville



Primary crushing at the Ojibway mine, Canadian Rock Salt Company.

As the hole was drilled below the 210-foot depth, the overflow decreased, so that at 625-foot depth the overflow was about 390 g.p.m., which remained fairly constant down to 710 feet. At 710 feet another water vein was tapped which, when isolated from the upper flows, had a static level of approximately minus 27 feet. By an injection test and the observance of the draw-down while pumping, the capacity of this water vein was calculated to be about 625 g.p.m.

A survey of the vertical water flows was made after the center hole was drilled down to 785 feet, and the following deductions were made: inasmuch as the overflow water decreased after the hole was drilled below the 210-foot depth, a part of the water from that zone passed down into the other strata to 710 feet which are believed normally dry, but possibly porous. A vertical flow survey indicated that at 230 feet 195 g.p.m. was flowing downward from 210 feet, and at 365 feet 120 g.p.m. was flowing downward. After the 710-foot water vein was tapped the survey indicated about 30 g.p.m. flowing from above into the 710-foot vein.

This evidence on the flow of water from strong aquifers into normally dry, but porous, strata penetrated during drilling, indicates the necessity of plugging drill holes after abandonment, in order to ensure that water, brine, oil, or gas are retained in their original formations.

Work on the production shaft began in the fall of 1952, and the property began operating in August 1955. An access shaft, 12 feet in diameter, also sunk by the freezing method, was completed in 1959 to a depth of 1,025 feet.

Mining Methods

The salt bed being mined lies at an elevation of 975–948 feet below the shaft collar. The bed averages 27 feet in thickness and, being flat-lying, is mined by the room-and-pillar method. A thickness of 18–21 feet of salt is mined, leaving some 6 feet of salt in the roof for extra stability.

Photo by Sid. Lloyd, Walkerville

Drilling jumbo at the Ojibway mine, Canadian Rock Salt Company.

Rice (1960, p. 9) states that:

> Extraction to date has been in the range 57 per cent leaving 43 per cent as pillars. Panels 2,000 feet on all sides are worked by a 30-foot wide twin entry system with lateral rooms on either side. Each new panel is transverse to the preceding to distribute weight over a greater area.
>
> The width of the rooms is 50 feet and the pillars between rooms are also 50 feet.[1] The rooms have narrow points of entry to provide extra protection to the roadways.

The mining operation consists of undercutting, drilling, blasting, and loading. Undercutting to a depth of 11 feet is carried out by electrically powered, hydraulically controlled undercutters, which travel across the 50-foot face at an average speed of 7 inches per minute. Drilling is done by a jumbo mounting four hydraulic auger drills. The 11-foot drill-round consists of 72 holes spaced horizontally at 4½ feet apart. The upper holes are horizontal, the lower holes are slanted downward to draw the break towards the undercut.

Rice (1960, p. 10) states that:

> The blasting, after undercutting and drilling are completed, requires a combination of 40 and 50 per cent Stopeite with electric millisecond delay caps. The break of salt from one blasted face amounts to 650 tons or one ton for each half pound of explosive used. There is very little secondary blasting required and the break size can be controlled very readily to suit production needs. Scaling is carried on from the muck pile before the loading operation. Any subsequent scaling is done from special trucks with hydraulically extensible platforms.

The salt is loaded by Joy loaders on to 18-ton diesel Le Tourneau rear-dump haulage units for

[1]The pillar width has now been changed to 60 feet.

haulage to the crusher stations. At the crusher station the salt is dumped on a 12-inch grizzly. The throughs go to the primary crusher, a 36 by 54-inch single-roll crusher. The product goes via 2,000-foot conveyors to the skip-loading pockets at the production shaft. These conveyors have a rated capacity of 700 tons per hour. Rice states that the hoisting facilities are designed to handle 500 tons per hour using 10-ton bottom-dump skips. Some fine salt is screened out underground for use in road maintenance in haulageways.

Milling

Rice (1960, pp. 11–13) describes the mill operations as follows:

The processing of the salt after it leaves the mine is relatively simple; it consists of crushing, screening and storing functions. The run-of-mine product as it enters the mill is —2½-inch, and after being elevated, flows by gravity through the various screens and crushers for disposition to storage areas and to subsequent bag or bulk movement. The primary screening is carried out on a series of Dillon vibrating screens, the secondary screens of the finer fractions by Rotex screens.

The screened products are carefully analyzed for purity and screen size. The bag filling and bag handling operations are completely mechanized and permit the movement of 5,000 tons per day with relative ease. The individual storage bins hold 200 tons of each product and act mainly as a surge preceding the dispatching of the product to truck or railroad car or to the boat loading facilities. To provide for the large volume of bulk movement encountered, we store 20,000 tons of product in covered storage which moves by conveyor to the dock loading tower 750 feet in the Detroit River. Our facilities will handle the largest boats the new St. Lawrence Seaway accommodates. Boat loading is carried out at the rate of 750 tons per hour and to eliminate the products of attrition involved in handling, a final clean-up screening to ensure the quality of the product is located in this area.

We maintain a laboratory for quality control in the mill for testing products before entering the loading areas. Two boxcar loading points and three truck loading points are included, coupled with scales to provide quick, efficient service and to facilitate movement of boxcars, we use trackmobiles for switching and tending. Outside storage areas will accommodate 100,000 tons of sized product and may be recovered at the rate of 500 tons per hour which duplicates the normal expected speed of flow in the mill. Duplicate process lines coming from the run-of-mine bins permit repairs to our mill processing equipment without disrupting operations and permits custom hoisting of product on a single side, for an indefinite period, if circumstances require it. To assure continuity of movement during the winter season, barges carrying 1,700 tons move daily to storage depots.

Compaction Process

As an integrated segment of our milling process, we recently initiated a compaction program. In the course of mining and crushing and screening, the resulting fractional proportion of fine salt particles produced by attrition is not in balance with the present market requirement. To control, within limits, the ratio of saleable tonnage to the total amount of salt processed, the compaction program has been designed to provide for the recovery and reconstitution of the fine salt. This method of compaction of granular solids is an allomorphic process which upgrades the fines to a particle size more acceptable to the trade. At present, related methods now employed for this purpose such as briquetting and extruding are unsuited to high capacity low cost production requirements.

The nucleus of this process is the compacting mill which consists of two 24″ x 24″ face smooth rolls both driven, turning at 28 r.p.m. In operation, the fines passing through the nip are subject to a sufficient high pressure to emerge as a ribbon of material, which after a short period of curing, may be granulated to the required particle size. By feeding the mill with an aggregate preheated to a minimum of 200°F., the curing period is effectively shortened and the amount of power required to achieve plastic deformation of the granules is also reduced.

The roll shafts are mounted in pressure lubricated sleeve bearings designed for an operating force of 250,000 lbs. Pressure on the rolls is maintained hydraulically, and power to the rolls is supplied by a 150 h.p. motor. A head of the material to be compacted is introduced into an inverted type hopper above the mill. This ensures a positive choke feed by gravity into the nip of the rolls.

The process of reconstitution as we have initiated it is capable of handling fines and multi-size particles, within the fines range, and of varying consistencies. Compaction subjects the material to a momentary line pressure of 21,000 lbs. per lineal inch, the object of the pressure being to eliminate voids by forcible rearrangement of the particles, and thus restore the compacted material to its original crystal density. The pressure must be great enough to actually deform the granular masses during this period of rearrangement. Experience to date indicates we are making a product with characteristics entirely suitable as a saleable product.

The Salt Bed

The 18- to 21-foot section of salt exposed in the mine consists predominantly of white to clear translucent, medium- to coarse-grained salt of 2–5 millimetre grain size. As shown in the accompanying photographs, the salt bed has a well-banded, almost varved, character. The bedded structure is indicated by dark-grey to yellowish-brown bands generally 3–8 inches apart in the white salt. Where moist air has scoured the salt pillars in airways, it may be seen that the dark bands in the salt contain paper-thin lamellae of anhydrite, which stand out on the "weathered surface" of the salt. Thin, individual 3- to 8-inch beds or units in the face are remarkably persistent in the mine for long distances and must represent a period of uniform deposition broken only by changes in salinity and precipitation, which allowed precipitation of anhydrite for short periods, perhaps owing to influx of less saturated brine into the basin of deposition. Shaly interbeds are lacking.

A noteworthy feature is the presence in many places of large patches of very coarse-grained "pegmatitic," clear crystalline salt replacing the bedded salt. The patches of secondarily crystallized salt range from a few inches to several feet in diameter and are completely surrounded by bedded salt on all sides with no disturbance of the bedding abutting the pegmatitic patch. No dark bands transect the coarse pure pegmatitic salt, but frequently at the bottom of the recrystallized patch of salt there will be an inch or more of medium-grey, aphanitic anhydrite; this suggests that the salt must have recrystallized in solution with a settling-out and concentration of the anhydrite and other impurites at the bottom of the recrystallized zone.

Courtesy Sifto Salt (1960) Limited

The Goderich mine, Sifto Salt (1960) Limited.

The salt is of remarkable purity, containing less than 2 percent of impurities. The following analysis is the average of a series of four chip samples taken down the 20-foot face by the author in 1957;

	Percent
Na	39.04
Cl	59.21
K	0.17
Ca	0.44
SO_4	0.26
Mg	nil
CO_2	0.13
Insolubles	0.47
	99.72

The absence of potash salts indicates that the precipitation sequence was never completed in this series of beds, and that there must have been a balance between evaporation and replenishment of the brine, which never allowed complete evaporation in this part of the basin.

SIFTO SALT (1960) LIMITED

The rock salt mine of Sifto Salt (1960) Limited is located in Goderich harbour within the Goderich city limits. As shown in the accompanying photo, the shaft, mill, and dock facilities are on an 8-acre site largely built up from fill in Goderich harbour at the mouth of the Maitland River. The property consists of about 2,700 acres lying mainly under Lake Huron. The salt rights are leased from the federal and provincial governments.

After a program of diamond-drilling had disclosed a mineable 80-foot bed of rock salt at depths of 1,675–1,755 feet, Sifto Salt Limited let a contract in 1957 for shaft-sinking. The shaft was completed, and production began in November 1959.

History of Development

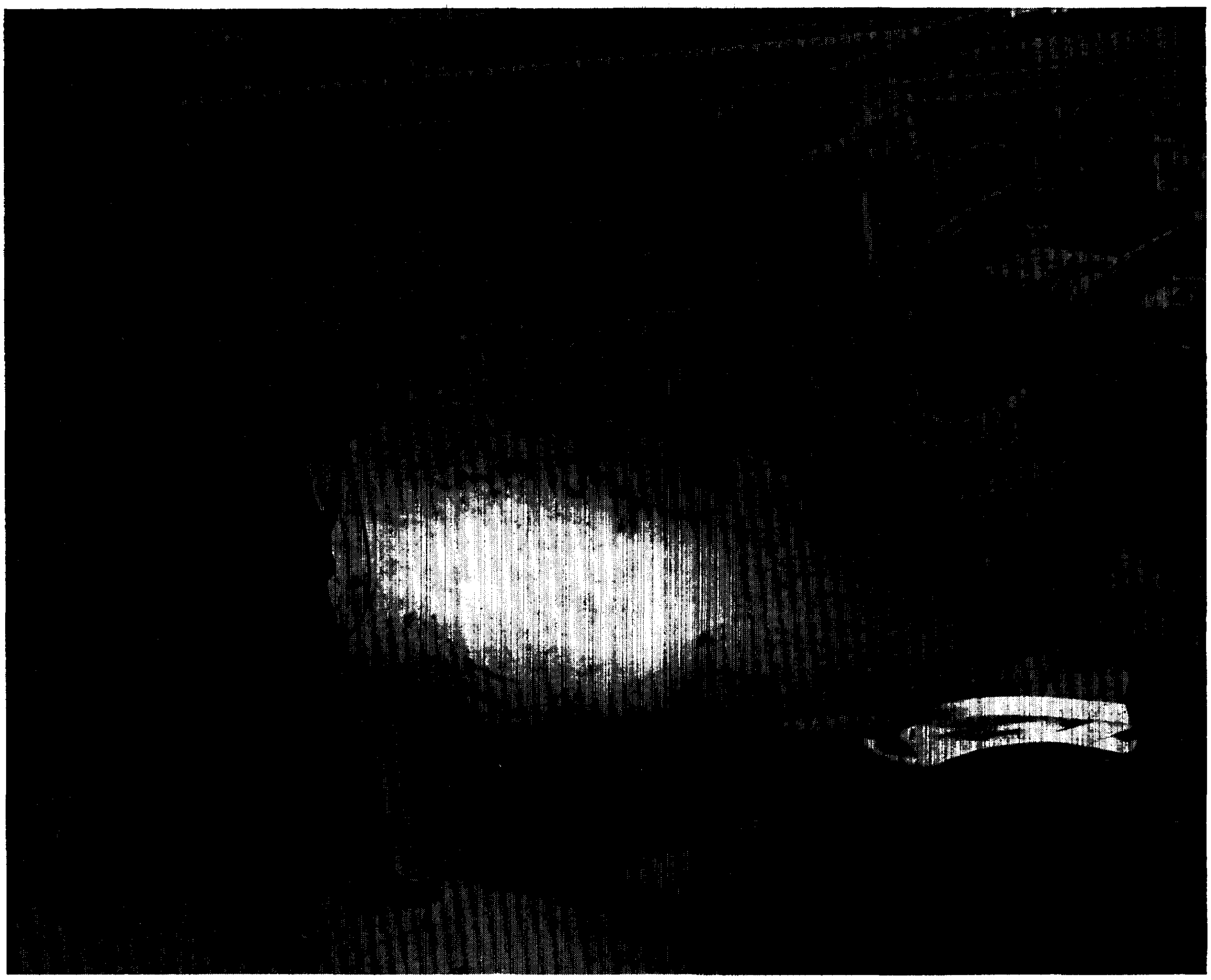
Although Sifto Salt (1960) Limited and its predecessors, Dominion Salt Company and Goderich Salt Company, had operated brine wells in the Goderich area for many years, it was not until the early 1950's that the company began exploration work that led to the development of an underground rock salt mine. Initial drilling was done at Erieau on Lake Erie and at Sarnia in 1952. At Goderich nine diamond-drill holes, totalling over 16,000 feet, were drilled in 1955 and 1956. The log of a typical drillhole near the present shaft site is shown in Table VI.[1]

[1]Log supplied by Sifto Salt (1960) Limited.

After proving up the salt deposit by drilling, the contract for shaft-sinking was let to Cementation Company (Canada) Limited in 1957. The initial problem was to collar the shaft through 30–40 feet of water-bearing gravels at lake level. This work was carried out by Icanda Limited. A series of 24-inch holes was drilled into bedrock around the circumference of a 24-foot-diameter circle. These were filled with concrete to form a waterproof concrete wall around the shaft site. The sand and gravel was excavated to bedrock, and a 4-foot-thick concrete collar was poured inside the waterproof concrete retaining wall.

In sinking the shaft, major flows of water were encountered in the upper 350 feet of the Detroit River dolomite, and for an additional 157 feet in the next 500 feet of sinking; strong aquifers were

Courtesy London Free Press



Undercutting salt at the Goderich mine, Sifto Salt (1960) Limited.

Courtesy London Free Press

View of the underground salt beds at the Goderich mine, Sifto Salt (1960) Limited.

present to depths of 800 feet. The Cementation Company handled the water entirely by grouting, well ahead of the sinking. Water-flows as large as 10,000 gallons per minute at pressures up to 300 pounds per square inch were encountered. About 200 tons of chemical grout and cement were pumped into the rock formations at high pressures to seal off the water-flow in advance of sinking. The 16-foot-diameter shaft, sunk to a depth of 1,867 feet, was lined with concrete to a thickness of 12–33 inches throughout.

Mining Methods

The main station was cut at 1,764 feet. During the early stages of underground operation, the primary crusher, a single-roll impact crusher, was set up directly over the ore passes. Two Joy Universal undercutters, one equipped with an auger drill, are used to undercut the salt. Drilling is done by a Joy drill jumbo fitted with four drills capable of drilling a face 45 feet high and 30 feet wide in one set-up. The explosive used is 40-percent Stopeite. Haulage is by three 25-ton capacity, diesel-driven rock wagons.

Crushing, screening, and storage facilities are to be set up underground in 1961. The planned capacity of the underground screening plant is 400 tons per hour.

Mining is carried out by the room-and-pillar method. Rooms are 60 feet wide, and pillars are 210 feet square. Extraction is about 40 percent.

Screening is done at present on surface, by 6- × 12-foot and 6- × 16-foot triple-deck screens in closed circuit with an impact crusher. Sized products are minus ½ inch in size. The separate-sized products are stockpiled for bulk shipment or bagged as required. The surface screening plant has a capacity of about 150 tons per hour.

Two grades of salt are produced, chemical grade and highway grade.

An analysis of the salt, provided by the company, is as follows:

	Percent
Insolubles (acid)	0.01
Calcium carbonate	0.23
Calcium sulphate	0.80
Magnesium carbonate	0.07
Magnesium chloride	0.04
Calcium chloride	0.06
Sodium chloride (dry basis)	98.79

TABLE VI—LOG OF TYPICAL DRILLHOLE—GODERICH MINE

Depth	Formation	Description
feet		
0–31	Overburden	Sand and gravel.
31–291	Lucas (Detroit River Group)	Dolomite.
291–390	Amherstburg (Detroit River Group)	Dolomite.
390–632	Bois Blanc	Cherty limestone.
632–846	Bass Island	Dolomite.
	Salina (H unit)	Dolomite and shaly dolomite.
846–956	Salina (G unit)	
956–1,077	Salina (F unit)	956–972 ft., salt; shaly dolomite; 1,012–1,037 ft., salt.
1,077–1,158	Salina (E unit)	Shaly dolomite.
1,158–1,196	Salina (D unit)	1,158–1,190 ft. salt.
1,196–1,261	Salina (C unit)	Shaly dolomite.
1,261–1,531	Salina (B unit)	Salt, interbedded shale, dolomite and anhydrite.
1,531–1,915	Salina (A unit)	Mineable salt horizon, 1,675–1,755 ft; dolomite and shaly dolomite.

TABLE VII—MIDRIM MINING COMPANY LIMITED—ADELAIDE SALT LEASE DRILLING—FINAL ASSAY RESULTS 27 NOVEMBER, 1956

From Department of Mines & Technical Surveys—Industrial Minerals Division, Chemical Laboratory, Ottawa.

Hole No.	Core Footage	Core Width	Sodium Chloride (NaCl)	Calcium (Ca)	Sulphur (SO4)	Iron and Aluminum (Fe+Al)	Potassium (K)	Magnesium (Mg)	Acid (insoluble)	Remarks
		feet	percent	percent	percent	percent	percent	percent	percent	
Adelaide No. 2.	1,694–1,724	30	(1)99.34	0.16	0.28	0.01	trace	0.06	0.13	clean salt
	1,724–1,730	6	96.37	0.96	1.81	0.08	trace	0.11	1.60	....
Adelaide No. 3.	1,698–1,727	29	(1)99.38	0.19	0.35	0.02	0.04	0.02	0.02	clean salt
Adelaide No. 4.	1,700–1,737	37	(1)99.50	Not assayed						clean salt
Adelaide No. 5.	1,699–1,726	27	(1)99.60	0.12	0.23	0.01	trace	0.02	0.02	clean salt
	1,726–1,734	8	98.80	0.35	0.55	0.01	trace	0.04	0.02	....

(1)Sections to be mined.

SALT EXPLORATION

Salt Property of Midrim Mining Company[1]

Exploratory drilling has been carried out on a property near Strathroy, by Midrim Mining Company, with a view to establishing a salt mine. The company owns and holds under lease about 5,000 acres of land in Adelaide township, Middlesex county, north of the town of Adelaide, midway between Sarnia and London. The south boundary of the Midrim property adjoins highway No. 22, which is the main paved road between London and Sarnia. Canadian National Railway transportation is avilable at the village of Kerwood about 2 miles south of Adelaide.

The company states that diamond-drilling has indicated reserves of 37,000,000 tons of high-grade white salt in a 35-foot bed of salt of the A2 unit at a depth of about 1,700 feet.

[1]Data supplied by Midrim Mining Co.

Analyses of the salt bed encountered in four diamond-drill holes on the property were kindly supplied by the company. (*See* Table VII.)

The log of drillhole No. 5 in Adelaide township, located in lot 10, concession II, Northeast Range, is given in Table VIII. The mineable salt horizon occurs at depths of 1,699–1,734 feet.

DISPOSAL OF ATOMIC WASTES IN SALT MINES

The problem of disposal of atomic wastes has led to a study of the possibility of storing atomic wastes in salt mines. The Committee on Waste Disposal of the National Academy of Sciences and the National Research Council, Division of Earth Sciences, prepared a report on the problem (Chemical and Engineering News, 1958) at the request of the Atomic Energy Commission. Conclusions indicate that storage of waste in tanks is the safest and most economical method. Disposal of these tanks in salt mines is likely in the near future. Dis-

TABLE VIII—MIDRIM MINING COMPANY LIMITED—LOG OF DRILLHOLE NO. 5

Drillhole: Adelaide No. 5; depth 2,051 feet.
Location: lot 10, con. II, Northeast Range.
Ordinates: south 2070; west 60.
Elevation: 763.10 feet.

Formation	Depth	Thickness	Lithology and Remarks
	feet	feet	
Surface	0–194	194	
	0–686		Core missing; coring with NX bit commenced at 686 feet.
	All coring beyond this depth done with NX bit.		
Detroit River	686–838	152	Beds of various shades of buff and grey dolomite and magnesium limestone of same colour; fine grained; gypsum nodules, styolites and bituminous partings; grey chert nodules throughout, especially in lower beds where grey and cream coloured chert forms 30 percent of rock; rounded white quartz sand in bottom beds forming a 6-inch white sand strata at base (836 feet); pyrite specks and green chlorite mineral at 834 feet.
Bass Island	838–863	25	Light-buff dolomite; fine grained; oölitic in part; gypsum at 861 feet.
	863–905	42	Beds of grey-buff and brown dolomite, oölitic sections; bituminous partings; gypsum-filled fractures and nodules.
Salina	905–913	8	Gypsum 95 percent, dolomite 5 percent.
	913–940	27	Brown dolomite; fine grained; anhydrite and gypsum nodules (between 928 and 934 feet gypsum forms 25 percent of rock); bituminous partings.
	940–945	5	Anhydrite 90 percent, grey-buff dolomite 10 percent.
	945–975	30	Thin beds of grey and buff-grey dolomite; dense; fine grained with conchoidal fracture; anhydrite nodules and laminae.
	975–986	11	Anhydrite 95 percent, with grey dolomite 5 percent.
	986–992	6	Buff dolomite; dense, with bituminous partings; anhydrite laminae and nodules.
	992–1,008	16	Thin beds of grey dolomite; dense, with thin strata and nodules of anhydrite especially in upper part.
	1,008–1,065	57	Beds of grey dolomite; dense, carrying nodules and thin strata of reddish anhydrite; anhydrite 20 percent of rock.
	1,065–1,080	15	Dark-grey dolomite; dense, with nodules of reddish anhydrite; thin blue anhydrite strata in lower part.
	1,080–1,087	7	Brown and buff dolomite; dense; anhydrite spots and laminae; bituminous partings; anhydrite bed (15-inch) at 1,084 feet.
	1,087–1,096	8	Grey argillaceous dolomite; dense, anhydrite nodules and laminae.
	1,096–1,098	2	Buff-grey dolomite; dense.
	1,098–1,103½	5½	Anhydrite; grey dolomite laminae with argillaceous parting.
	1,103½–1,120	16½	Thin beds of buff and grey dolomite; dense; fine crystalline; argillaceous in sections; bituminous partings, anhydrite laminae.
	1,120–1,140	20	Thin beds of grey dolomite; dense, anhydrite laminae.
	1,140–1,145	5	Anhydrite.
	1,145–1,177	32	Thin beds of grey and various shades of buff dolomite; dense, anhydrite laminae, argillaceous and shaly partings.
	1,177–1,197	20	Buff and grey dolomite; dense; bituminous partings, anhydrite.
	1,197–1,204	7	Grey argillaceous dolomite; dense, anhydrite laminae.
	1,204–1,209	5	Dirty salt.
	1,209–1,214	5	Light-grey dolomite; dense; red salt, anhydrite.
	1,214–1,228	14	Dirty salt.
	1,228–1,314	86	Thin beds of grey dolomite; dense; nodules of, and fractures filled with, red salt in upper beds; anhydrite laminae; argillaceous sections with shaly partings.
	1,314–1,333	19	Dirty salt (85 percent); anhydrite (15 percent); 6-foot section (1,319–1,325 feet), clear salt.
	1,333–1,338½	5½	Buff dolomite; dense; nodules of salt and anhydrite; 18-inch anhydrite bed at 1,334 feet.
	1,338½–1,344	5½	Grey dolomite; anhydrite; 9-inch salt bed at 1,342 feet.
	1,344–1,351	7	Salt; 6-inch anhydrite strata at 1,350 feet.
	1,351–1,358	7	Grey argillaceous dolomite; salt and anhydrite.
	1,358–1,447	89	Dirty salt; 3 thin (1- to 1½-foot) grey shaly dolomitic sections at 1,365, 1,403, and 1,432 feet.
	1,447–1,452	5	Grey dolomite; fine grained; red salt nodules.
	1,452–1,564	112	Dirty salt; 4 thin (1- to 1½-foot) grey shaly dolomite sections at 1,494, 1,507, 1,549, and 1,553 feet. *(Top of Salina A2 unit at 1,564 feet.)*
	1,564–1,570	6	Thin beds of grey dolomite; dense, with anhydrite laminae; bituminous partings and salt nodules.

TABLE VIII—MIDRIM MINING COMPANY LIMITED—LOG OF DRILLHOLE NO. 5—*Continued*

Formation	Depth	Thickness	Lithology and Remarks
	feet	feet	
Salina (*Continued*)	1,570–1,600	30	Thin beds of buff and grey dolomite; dense; bituminous partings.
	1,600–1,604	4	Anhydrite.
	1,604–1,607	3	Olive-grey dolomite; dense.
	1,607–1,614	7	Dark-grey limestone; fine grained; salt nodules and anhydrite.
	1,614–1,617	3	Grey dolomite; dense.
	1,617–1,697	80	Thin beds, grey and dark-grey limestone; dense and highly indurated; shaly and argillaceous sections; dolomitic between 1,679 and 1,681 feet; salt nodules and anhydrite.
	1,697–1,699	2	Buff-grey dolomite; argillaceous; anhydrite laminae.
	1,699–1,734	35	Salt (clear) estimated 99 percent plus NaCl.
	1,734–1,741	7	Anhydrite (95 percent); salt nodules.
	1,741–1,744	3	Grey-buff dolomite; anhydrite 30 percent of section; bituminous partings.
	1,744–1,750	6	Dark-grey to black limestone; dense indurated; bituminous partings, conchoidal fracture.
	1,750–1,754	4	Thin beds of dark-grey and buff limestone; dense; argillaceous; bituminous partings.
	1,754–1,758	4	Buff laminated limestone; dense; small salt clusters.
	1,758–1,762	4	Olive-green limestone; dense; fine salt clusters.
	1,762–1,773	11	Thin beds of grey limestone; dense; argillaceous; styolites, bituminous partings.
	1,773–1,786	13	Thin beds of grey and grey-buff limestone; with anhydrite specks throughout; bituminous partings, especially in lower part.
	1,786–1,795	9	Beds, dark-grey and black limestone; dense; bituminous partings; small salt clusters.
	1,795–1,800	5	Grey dolomite; dense; bituminous partings.
	1,800–1,847	47	Thin beds of grey, dark-grey, and black limestone; dense; bituminous partings; small salt clusters between 1,800 and 1,804 feet, and fine salt-filled fractures at 1,828 and 1,837 feet; light oil blotches between 1,812 and 1,815 feet and at 1,817, 1,828, and 1,835 feet; specks and streaks of pyrite, especially in lower beds; narrow layer (1-inch) of anhydrite crystals at 1,841 feet.
	1,847–1,858	11	Laminated grey and dark-grey limestone; dense; bituminous partings.
	1,858–1,886	31	Anhydrite; bituminous partings.
	1,886–1,888	2	Grey dolomite; dense; anhydrite.
	1,888–1,893	5	Thin beds of buff and buff-grey dolomite; dense; highly indurated; salt blebs; styolites, bituminous partings, anhydrite.
Guelph Lockport	1,893–1,899	6	Buff-grey and grey dolomite; granular styolites, small salt aggregates.
	1,899–1,911½	12½	Greenish grey dolomite; granular salt nodules and bituminous partings.
	1,911½–1,913½	2	Grey dolomite; dense.
	1,913½–1,961	47½	Buff-grey mottled dolomite; argillaceous and bituminous partings; styolites; small salt clusters in lower part.
	1,961–1,970	9	Thin beds of grey and creamy grey dolomite; dense styolites.
	1,970–2,020	50	Beds of dark-grey and black dolomite; dense; specks and small aggregates of pyrite; shaly partings.
	2,020–2,033½	13½	Beds of grey, changing to creamy grey in lower part, dolomite.
Rochester	2,033½–2,035	1½	Two thin (2-inch and 9-inch) strata of oölitic hematite with shaly characteristics interbedded with greenish grey dolomite; shaly and clastic.
	2,035–2,051	16	Dark-grey shale with two thin (4-inch) dolomitic sections at 2,037 and 2,046 feet.
	2,051		End of hole.

TABLE IX—STORAGE OF LIQUID PETROLEUM GAS

Company	L.P.G. Wells	Brine Disposal Wells	Capacities	Location
			barrels	
Imperial Oil Ltd.	3	. . . .	80,000–100,000 (each)	lots 41–44, RF, Sarnia tp
Sun Oil Co.	5	1	61,900–216,700	lot 20, RF. Sarnia tp.
Dow Chemical of Canada	3	. . . .	not reported	lots 25–27, RF, Sarnia tp.
Polymer Corp.	6	1	not reported	lots 34–36, RF, Sarnia tp.
Canadian Oil Co.	1	. . . .	not reported	lot 67, RF, Moore tp.
Total	18	2		

posal in deep porous beds is the best distant-future possibility.

Since salt is impervious to water seepage, the mined-out spaces are dry. The relatively high thermal conductivity of salt and its high melting point would permit waste storage at moderate temperatures without effect on cavity walls. This assumes that salt plasticity is not increased by long-continued exposure to elevated temperatures. Since heat is generated by the wastes, there must be some provision for cooling.

STORAGE OF LIQUID PETROLEUM GAS IN SALT BEDS

In the Sarnia area, underground caverns for the storage of butane, propane, ethylene, propylene, etc., have been formed by solution of the B and A2 salt horizons. Petroleum products will not dissolve salt and are not contaminated by it. When hydrocarbons are removed from the top of the cavity, brine from a brine pit or brine disposal well is simultaneously injected into the bottom of the cavity, which is kept full of liquid at all times.

Imperial Oil Limited has three Liquid Petroleum Gas (L.P.G.) storage wells in Sarnia township for the storage of butane, ethylene, and other products. These cavities are reported to have capacities of from 80,000 to 100,000 barrels each. Sun Oil Company has five L.P.G. storage wells and one brine displacement well for the storage of butane, fuel oil, gasolene, etc., in Sarnia township. These cavities have capacities of from 60,000 to over 200,000 barrels each. Dow Chemical of Canada have three L.P.G. storage wells in lots 25–27, R.F., Sarnia township. The Polymer Corporation has six L.P.G. wells and one brine disposal well in lots 33-36, R.F., Sarnia township. The Canadian Oil Company has one L.P.G. well in Moore township.

This data is summarized in Table IX.

A comparison of costs of surface and underground storage has been made (Chemical and Engineering News 1958, pp. 104–6). In Louisiana, storage capacity for 1,000,000 barrels was established underground at a cost of $1.00 per barrel. Surface L.P.G. storage costs are reported in the neighbourhood of $12.00 per barrel.

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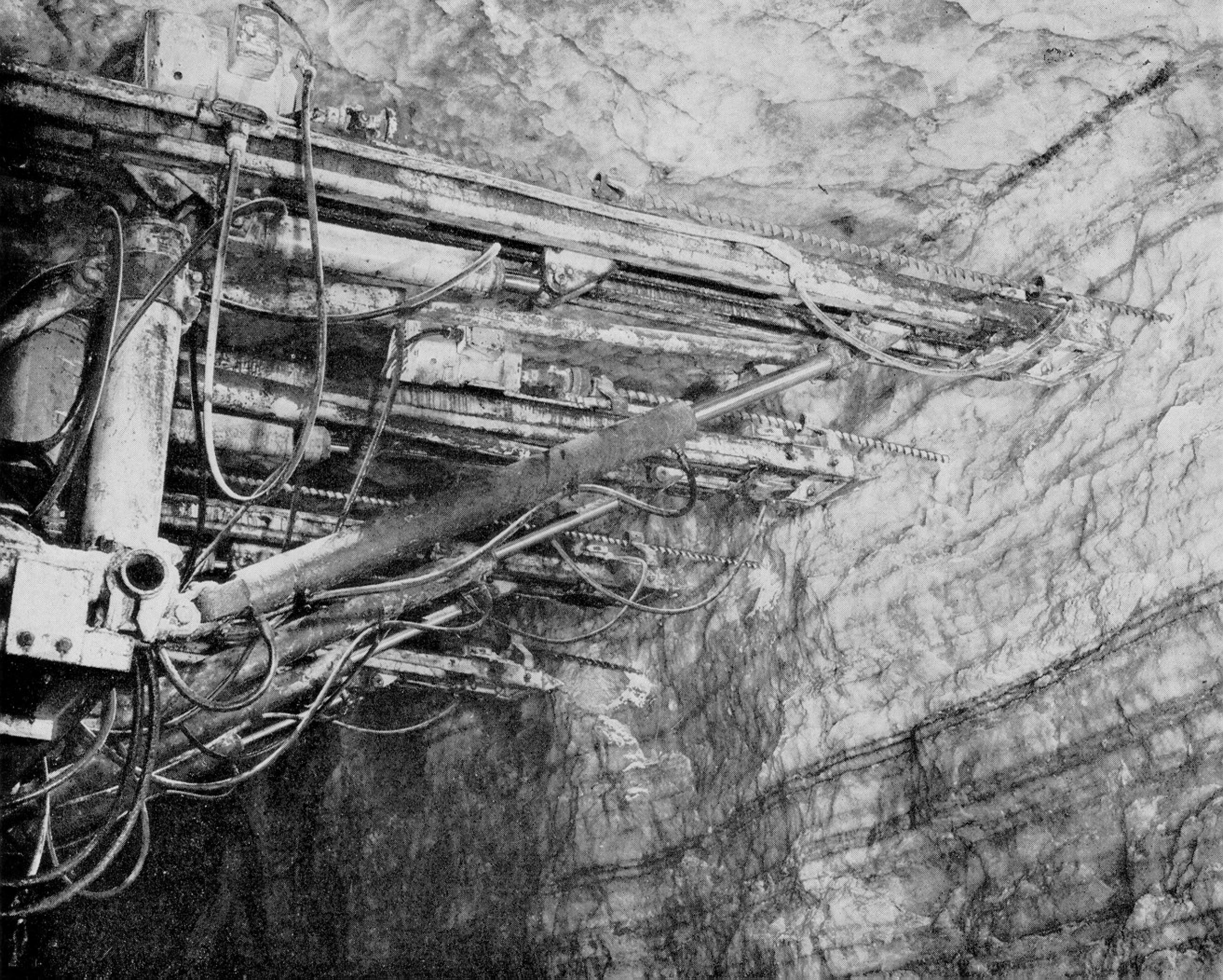

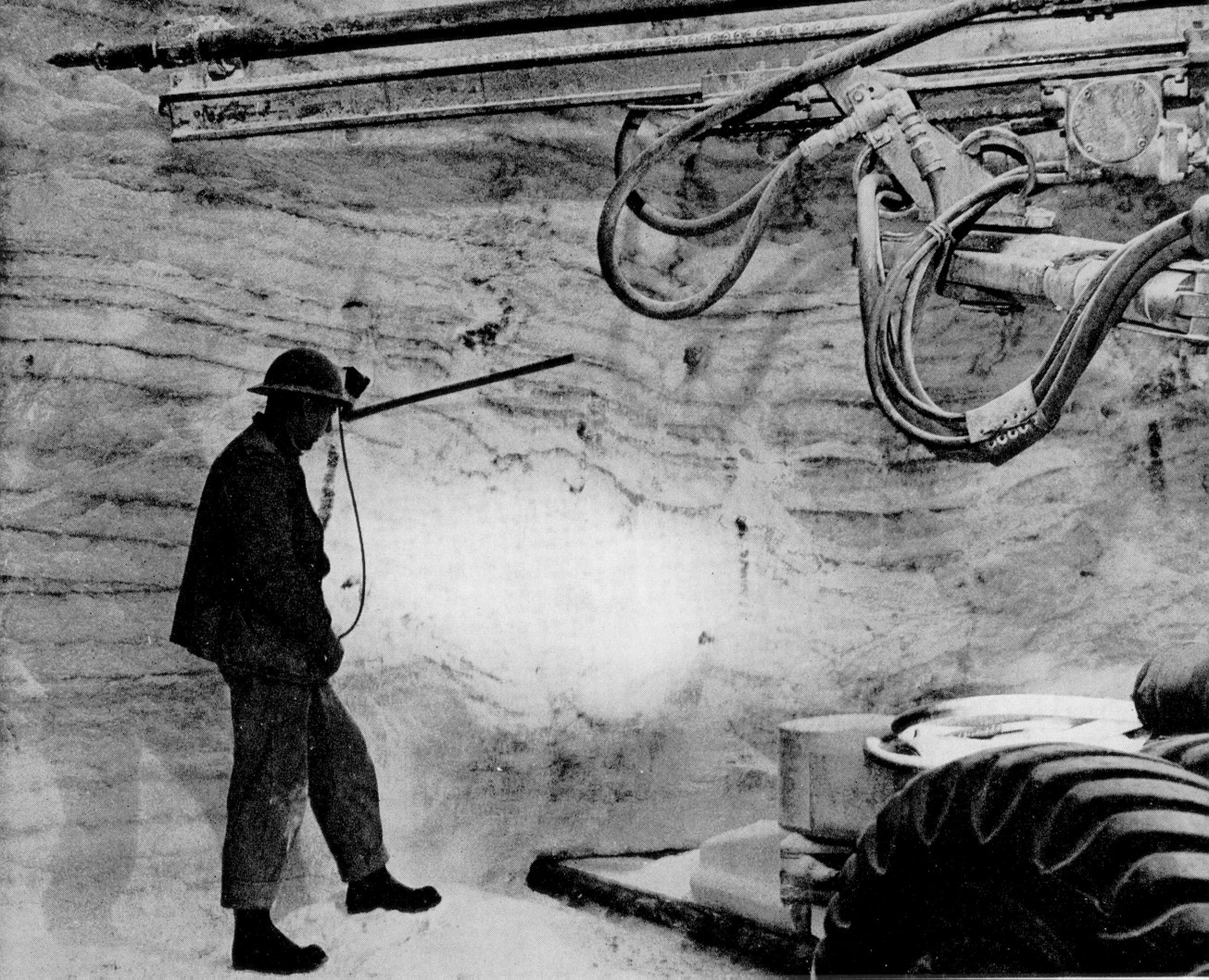

Chart C—Section from Sarnia eastward toward London showing thinning of salt beds.

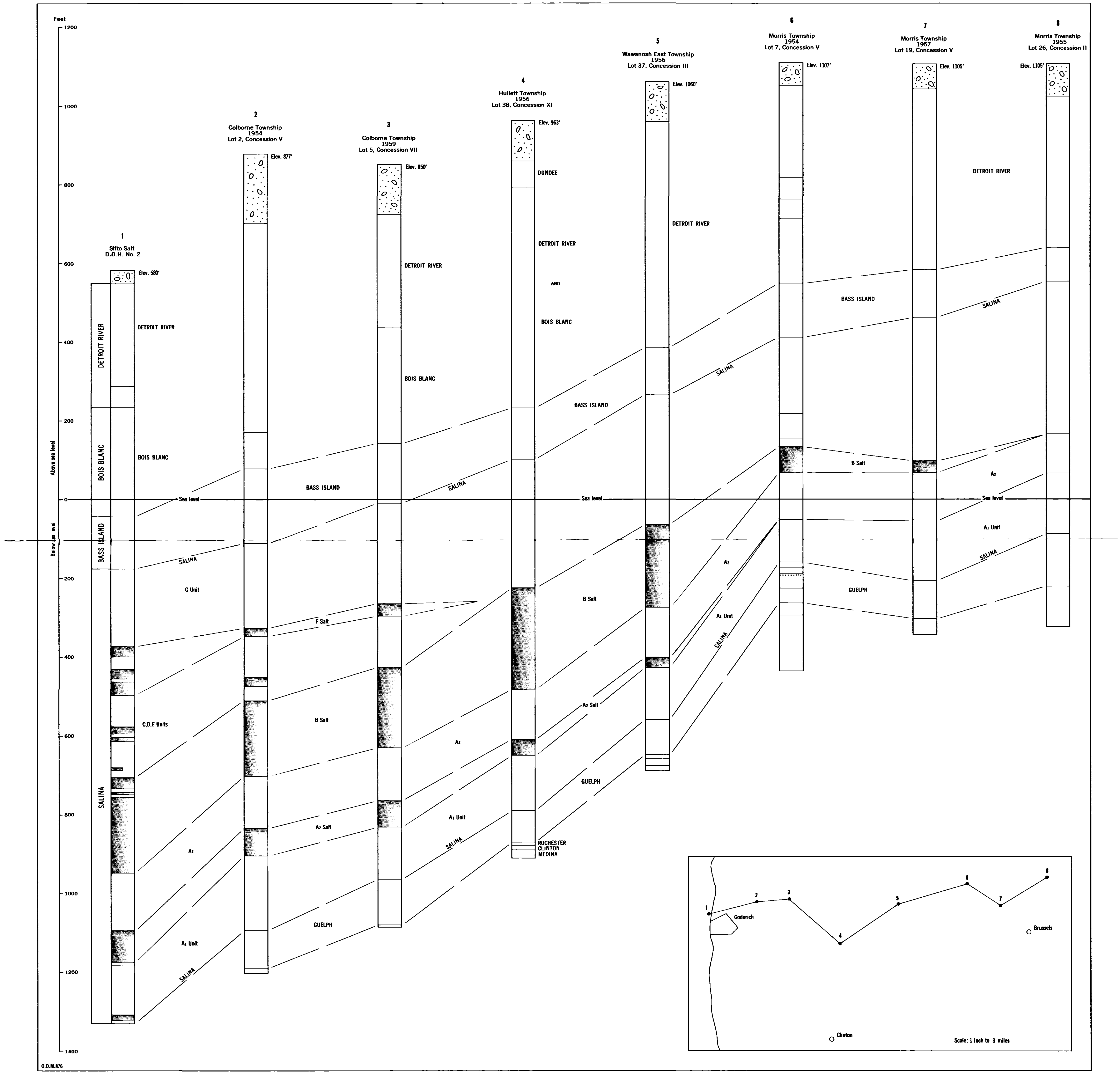

Chart D—Section eastward from Goderich showing thinning of salt beds.

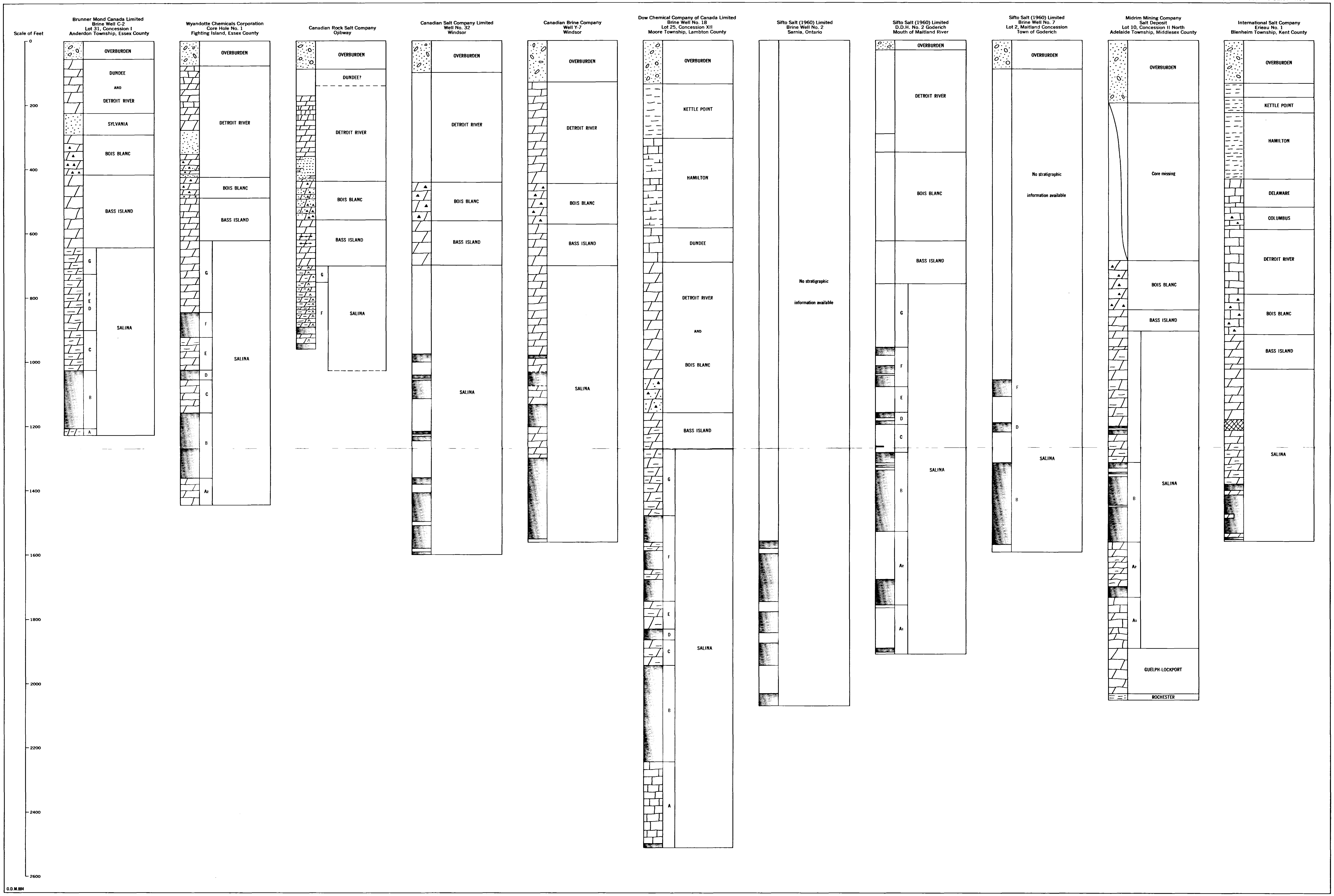

Chart E—Salt Well Sections—Southwestern Ontario.