The Distribution and Diapiric Nature of Some Nova Scotia Evaporites—a Geophysical Evaluation

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ABSTRACT

Intrusive salt bodies cause localized negative anomalies in regional gravity surveys of Northern Nova Scotia and Cape Breton. The salt of Early Mississippian (Windsor) age has been forced upwards through overlying rocks towards the surface, in part controlled by regional geological structure. The vertical movement of up to 15,000 feet has been long continued, and may still be taking place. Bore hole data shows that the top of the salt commonly lies 500 to 1500 feet below the surface, is strongly folded, and is overlain by brecciated material with salt veining. Minor amounts of sulphur and potash minerals have been found associated with some of the salt intrusions.

Limited reflection seismic data provides evidence of fault control, and shows deformation of the surrounding rocks by the salt. Absence of diagnostic fossils and the imperfectly known stratigraphy of the Windsor Group makes geologic interpretation difficult. In two locations limited correlations have been possible between close spaced boreholes using geologic and gamma-ray bore hole logs.

A probably continuation of the salt intrusion into the offshore area east of Cape Breton may be significant in providing structural traps suitable for oil accumulation.

INTRODUCTION

In Nova Scotia evaporite deposits occur in the lower part of the Windsor Group which is of Early Mississippian Age. The stratigraphy of the Windsor is known only incompletely from outcrops. The rocks are generally incompetent and have commonly been folded and faulted; while the read solubility of the salt and potash minerals make them particularly sensitive to leaching by groun water. In the past the thickness of the Windsor ha been generally underestimated, and in particula the relative abundance of evaporite minerals ha not been appreciated.

Windsor evaporitic rocks outcrop in many part of Nova Scotia (Fig. 1) and probably extend nortl ward into Newfoundland where salt was proved i drilling in 1968. An eastward extension onto th Continental Shelf is suggested by seismic and gra ity work. (Loncarevik *et al.*, 1966)

Within Nova Scotia the lithology and thickne of the Windsor varies from a thin conglomerati near-shore facies, to thick sections of carbonat and evaporite rocks containing little terrigenou

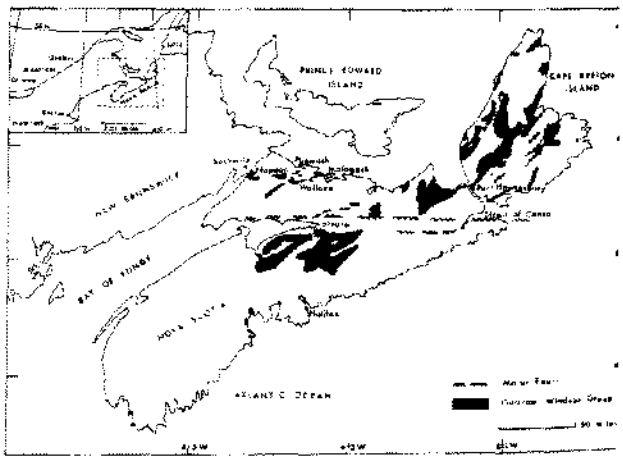

Figure 1. Windsor group outcrops in Nova Scotia.

material. In the past it has been the practice to speak of various basins and sub-basins of the Windsor, carrying implications of separate areas of deposition. The present imperfect knowledge of Windsor stratigraphy and the lack of correlation between salt sections make it difficult to confirm or deny the idea of separate basins. It is therefore important both for proper geological understanding and for economic exploitation that a satisfactory tool of stratigraphical correlation is found. Spore material seems to hold most promise, for it has been successfully used for correlation in saline deposits in other areas.

The Windsor deposits that occur in Cumberland County of northern Nova Scotia are the best known and also are exploited commercially, with a mining operation at Pugwash, and brine plant at Nappan. This paper is concerned with summarizing the available geophysical and geological information for that area, and making some provisional comparison with other parts of Nova Scotia.

GEOLOGY

Carboniferous rocks underlie most of northern Nova Scotia and are folded with an east-northeasterly trend (Fig. 2). Within the succession, the older Windsor age rocks occur in anticlinal cores associated with local faulting. The Windsor rocks can be traced in the northern structure from Nappan to Pugwash a distance of about thirty-five miles; in the southern structure from Springhill to Malagash, some forty miles. These two main axes are offset, en-echelon, by about seven miles. Along these axes the Windsor and overlying Canso Group have narrow elongate outcrops, with steep dips where these can be determined. Faulting is probably extensive but is not revealed in the poor surface exposures.

The sedimentary basin is bounded to the south by the large granite mass that forms the Cobequid Hills. The granites and associated rocks can be traced discontinuously for about one hundred miles east from Cape Chignecto towards New Glasgow. Older Ordovian and Silurian rocks outcrop south of the granite and within the main granite. The general trend is east-northeast, approximately parallel with the fold axes in the Windsor rocks.

The southern edge of the Cobequid Highlands is formed by the major Cobequid–Chedabucto fault system which extends across Nova Scotia and into

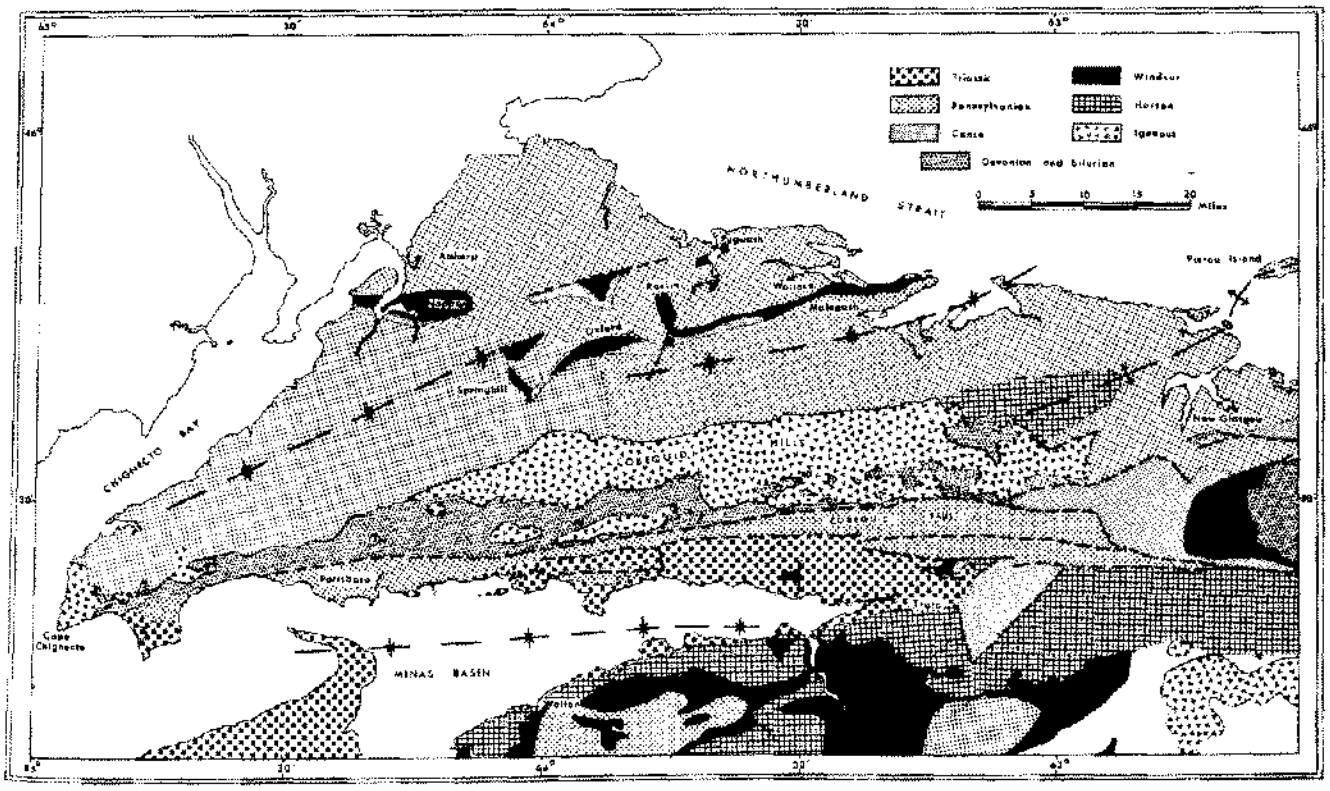

Figure 2. Geological map of northern Nova Scotia.

the Atlantic. South of this fault younger Triassic rocks occur around and underlie the Minas Basin.

GEOPHYSICS

Gravity.

In the past fifteen years the Nova Scotia Research Foundation has carried out a program of regional gravity surveys in the various areas where Windsor deposits occur. Stations were occupied at intervals of approximately one-fifth of a mile along existing roads and tracks. Gravity readings were made with either the Worden or Sharpe (Worldwide) gravimeters, and were tied to the network of gravity base stations established by the Dominion Observatory of Canada. Elevations determined by levelling were relative to the geodetic datum.

The data have been used to prepare Bonguer Anomaly maps on scales of 1 inch to 1 mile, or 1 inch to 2 miles. More recently the gravity data have been revised and are being stored in digital form using a system developed for the IBM 360-50.

The Bonguer Anomaly map for the Cumberland County (Fig. 3) area shows a number of negative anomalies which can be related to known Windsor rocks. These anomalies are attributed to diapiric salt structures which have penetrated upwards along faults and into fold axes. These structures have a vertical dimension up to 10,000 feet and widths ranging from 4000 to 40,000 feet.

The salt structure at Roslin (Fig. 4) is typical of the smaller bodies. The gravity anomaly has a magnitude of about 6 milligals and is nearly circular. Gravity data indicate a symmetrical body (Fig. 5) reaching to within 800 feet of the surface and extending to a depth of about 9000 feet. A bore hole located near the centre of this structure passed through a siltstone-salt section from 380 feet to the hole bottom at 1005 feet. The percentage of salt increased in depth.

The composite salt structure at Wallace and Malagash (Fig. 6) is the largest in the area. The gravity anomaly has a magnitude of about fourteen milligals, and is elongate in an east–west direction. There is evidence of at least two subdivisions: an elongate one in the east and a more prismatic one in the west. A gravity model study of the western part of the anomaly indicated a block about 7000 feet thick and reaching to within 900 feet of the surface. This has been confirmed in part by drilling. The eastern anomaly is narrower with steep gradients; the salt approaches to within fifty feet of the surface. This area was once the site of a mining operation.

Detailed gravity surveys over most of the negative gravity anomalies shown in Fig. 3 give a picture of a series of salt structures rising from depths of 8000 to 10,000 feet, to within 1000 to 500 feet of the surface.

Figure 3. Bouguer gravity map, Cumberland County.

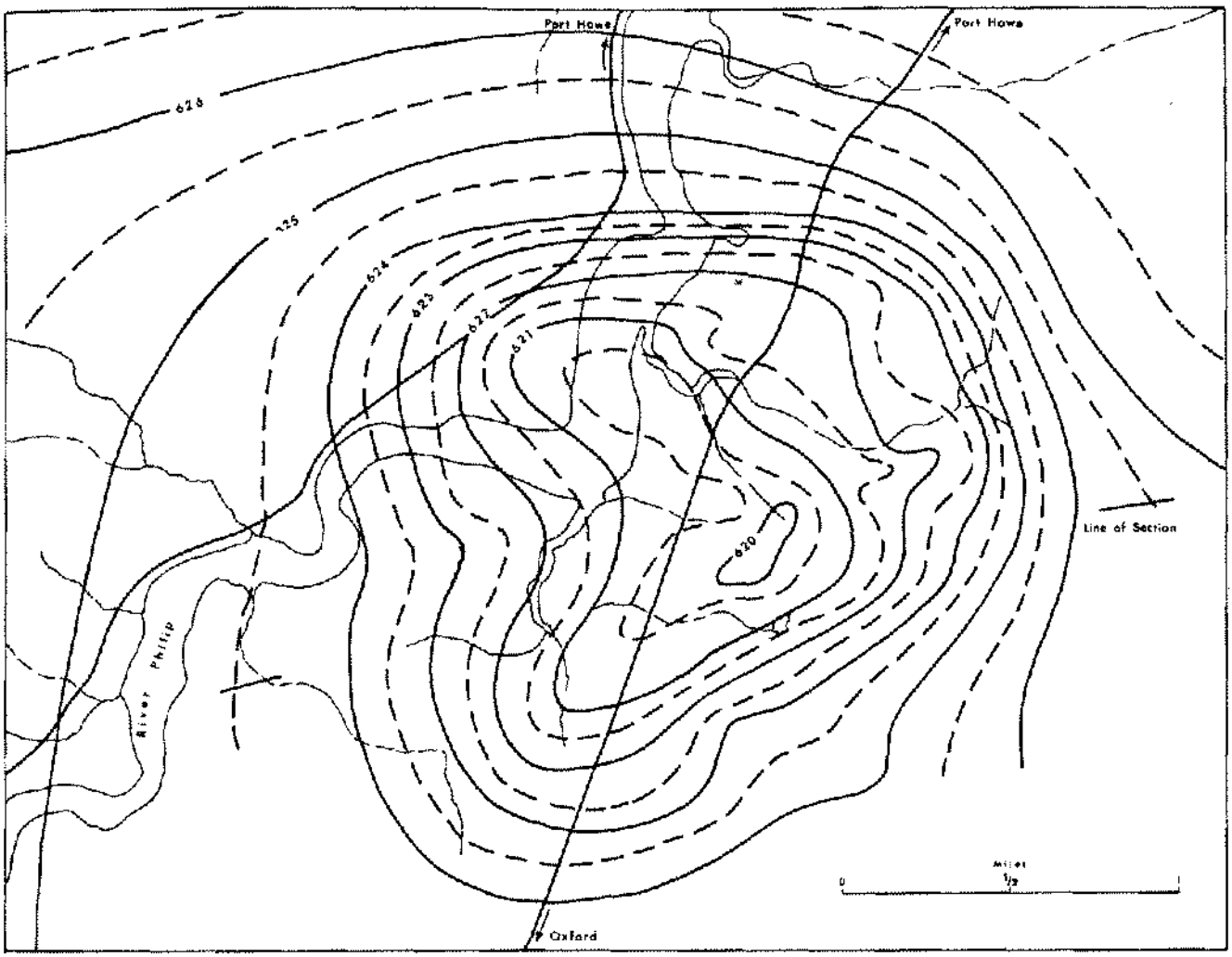

Figure 4. Roslin gravity anomaly.

The size of the gravity anomalies decreases northwards. Large anomalies tend to be on the two main axes and are commonly elongate in an east–west direction, while smaller more regular anomalies occur away from these axes.

Drilling.

Government and commercially sponsored bore holes have proved most of these negative anomalies to be associated with salt. However, drilling generally was stopped after penetration of a few hundred (at most 3000) feet of salt structure. This shallow penetration and lack of a satisfactory method of stratigraphic correlation have prevented detailed comparisons and complete structural studies. Drill cores commonly indicate dips in excess of fifty degrees, and there is every indication that the strong deformation described by Evans (1967) in the Pugwash mine is characteristic of all these structures. Some drill cores passed through thick anhydrite into salt with shallow dips, this relationship suggesting that the anhydrite has formed a stable cap and thus prevented deformation of the underlying salt.

Seismic.

Limited seismic work in the area gives information about the depth and dip of the undisturbed Windsor. Figure 7 is an interpreted uncorrected reflection profile for a line through the western end of the Wallace structure (A—A, Fig. 8). The Windsor has a shallow dip to the south, except in the immediate vicinity of the salt intrusion. Depths to the main salt horizon (assuming an average seismic

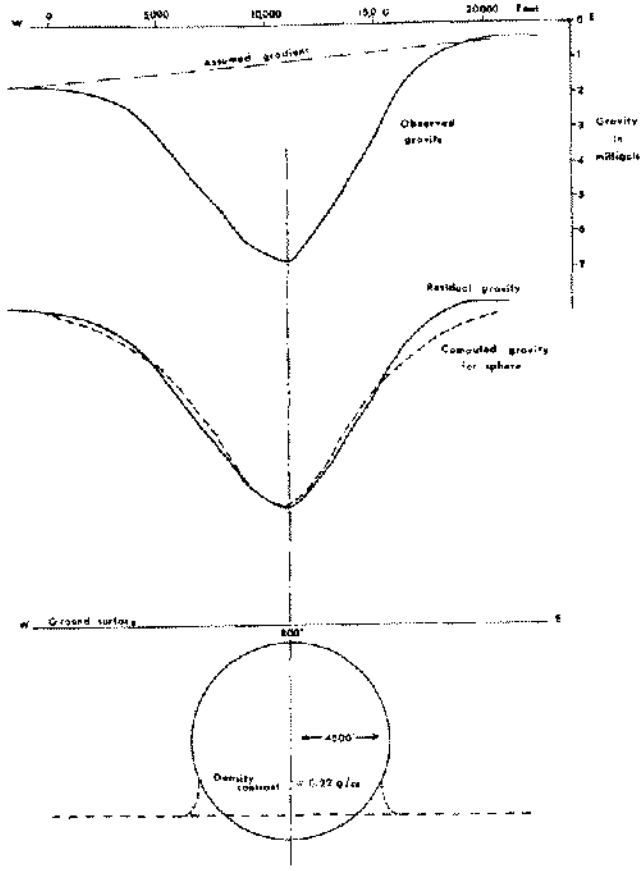

Figure 5. Interpretation of Roslin anomaly.

velocity of 11,000 feet/second) are about 7000 feet in the south and 6000 feet in the north. There is some indication that the salt intrusion is associated with a fault.

The second seismic profile (Fig. 8) is located south of Pugwash (B–B, Fig. 3). The Windsor again shows a dip to the south with a depth to salt of about 8000 feet at the south end of the profile and about 7000 feet at the north end. The salt structure deforms the Windsor and younger rocks on its flanks giving steepened dips. A low angle fault is shown passing into the salt horizon.

These two seismic sections across the southern anticline indicate a general southward dip of the Canso and Windsor rocks, except on the flanks of the salt intrusion where the uprising material has pushed aside the overlying rock. This has resulted in the development of steep dips on the flanks of the uplift. This suggests that this southern or Clairmont anticline which extends from south of Oxford through Malagash is salt cored, and may be fault controlled.

DISCUSSION

The area north of the Cobequid Granite is characterized by Mississippian and Pennsylvanian rocks locally folded into sharp anticlinal features trending east–west. A number of salt structures are known in the area from gravity, seismic and borehole data. The undisturbed Windsor evaporite

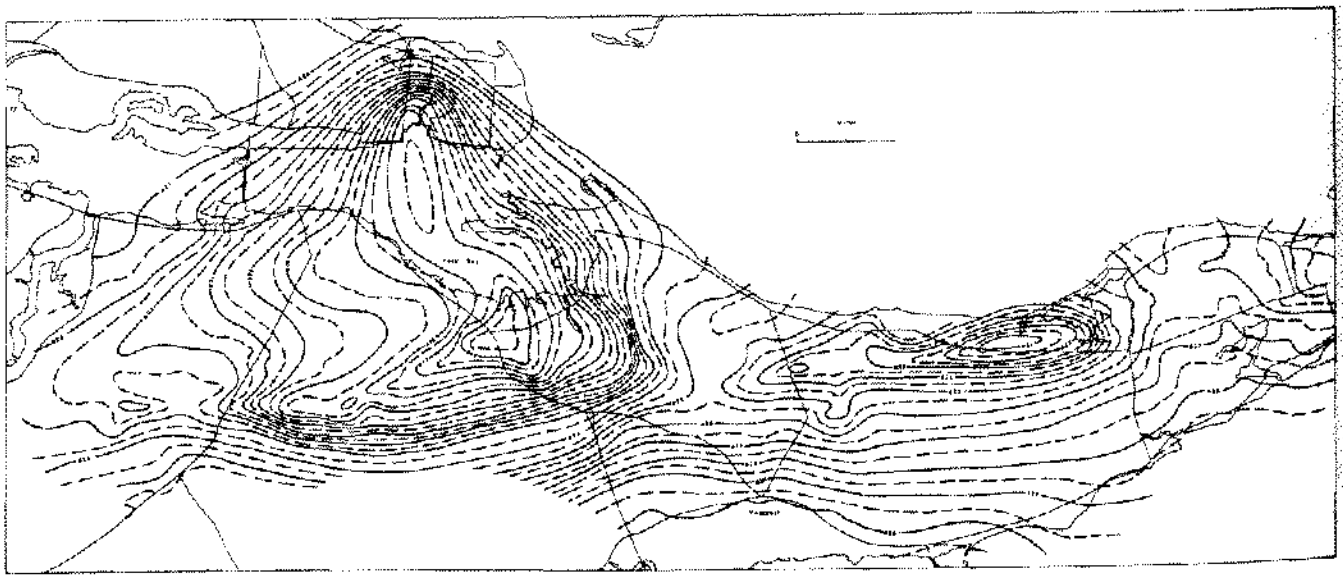

Figure 6. Wallace–Malagash gravity anomaly.

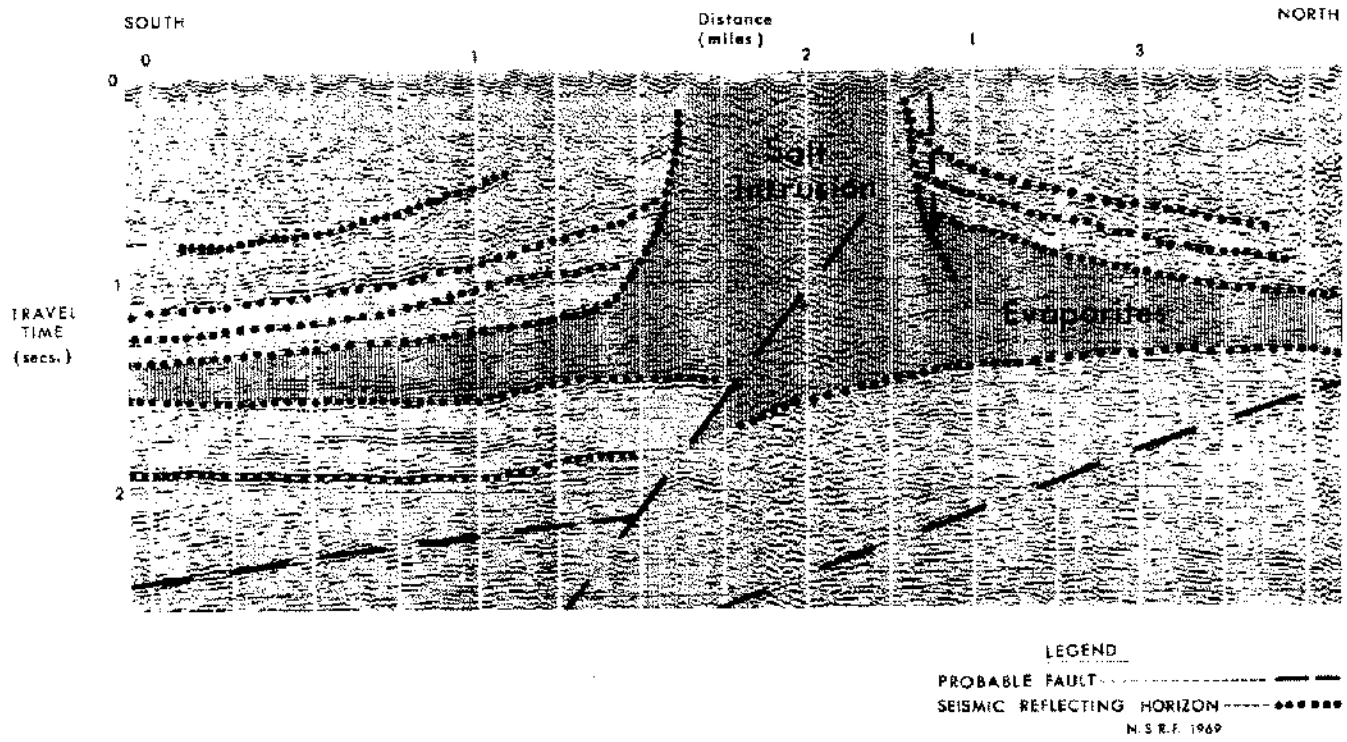

Figure 7. Seismic reflection profile Wallace and interpretation.

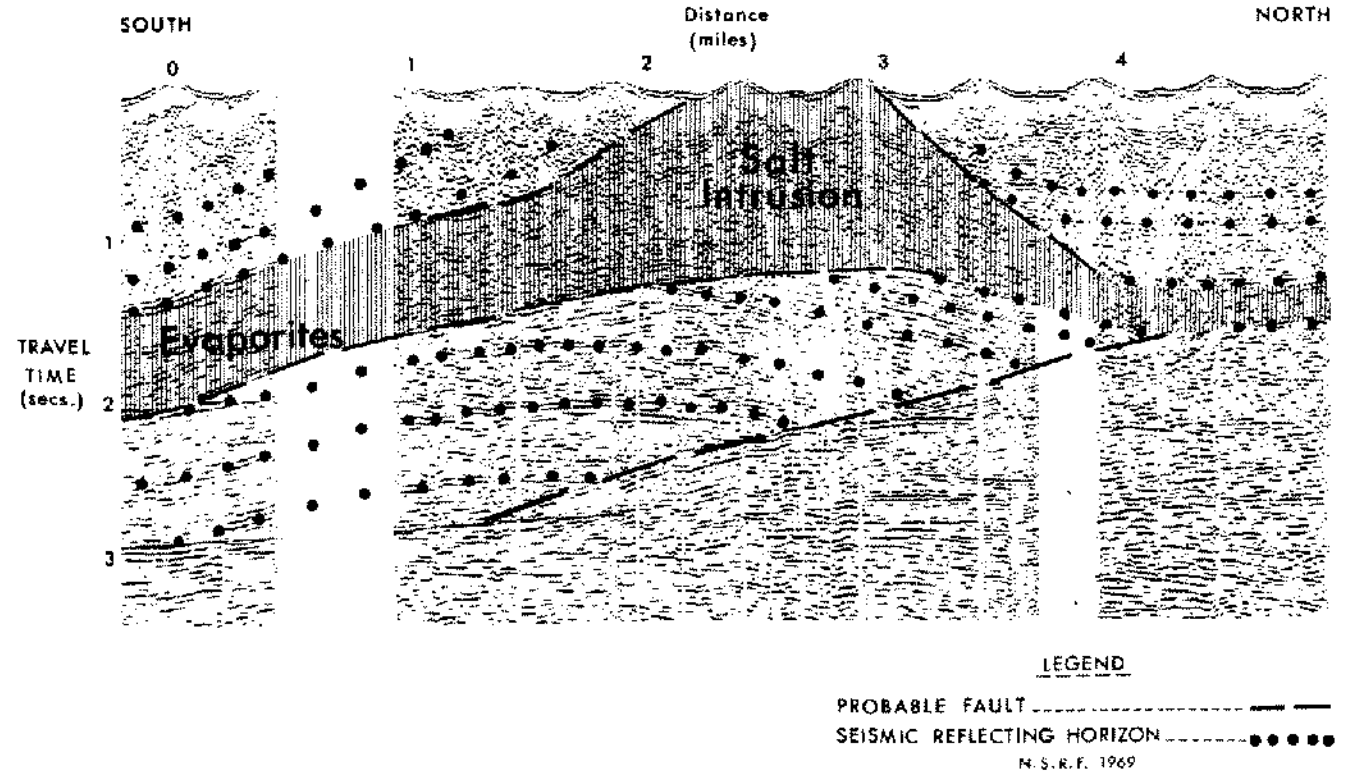

Figure 8. Seismic reflection profile and interpretation, Pugwash.

rocks lie at depths of 7000 to 8000 feet in the area between Roslin and Wallace, and have a southward dip. Salt intrusion forms large east-west oriented elongate structures which may be fault controlled, and smaller isolated structures of regular shape. The larger, elongate salt structures have the form of salt cored anticlines in which the uprising salt has pushed aside the overlying rocks which now dip steeply away from the salt structure. The smaller salt structures are more diapiric in nature and appear to develop where there is a reduced thickness of overlying rock.

The seismic sections and simple model calculations of the amount of salt necessary to produce the larger salt structures indicate that the source rocks which supplied this material must have had aggregate thicknesses of several thousand feet.

The southern or Clairmont anticline which is well defined in outcrop and by gravity, can be traced from Springhill to Malagash. The northern anticline is prominent at Nappan and can be traced discontinuously through to the area south of Pugwash. Salt structures on the Pugwash end of this northern anticline are relatively small and lack elongation. The relationship between these two larger structures is not clear, but the concentration of smaller salt intrusions in the area between Oxford and Roslin may be related to a weakened zone caused by faulting. Roliff (1962) has indicated a fault associated with salt movement in this location.

The Nappan structure has its continuation in New Brunswick near Rockport on the peninsula which separates the Shepody Bay from the Cumberland Basin at the head of the Bay of Fundy. Another salt structure to the south of Sackville (Gussow, 1953) has a northeasterly trend, the edge of which is responsible for the strong gravity gradients to the north of Amherst (Fig. 3). The relationship of these Cumberland County salt structures to more distant areas is conjectural.

Roliff has described bore hole data indicating Windsor age saline rocks in north-eastern New Brunswick and Prince Edward Island. In Nova Scotia a major salt structure has been located by gravity and drilling about ten miles southwest of Truro, and other smaller salt intrusions are known in other parts of Hants County. Small inliers of Windsor in the vicinity of Truro, and a number of negative gravity anomalies close to the Chedabucto fault are probably due to salt structures. To the northeast, major salt structures in the Antigonish area have been investigated by gravity surveys and more recently by drilling.

In Cape Breton, salt structures are known to occur in Inverness County close to the Bras d'Or Lakes, and saline beds have been intersected by deep drilling on the coast near Mabou. Recently, salt structures have been found in southern Cape Breton near the Atlantic end of the Canso Strait. These structures are north of the Chedabucto fault and may be related to the evaporites which are thought to cause the large negative gravity features of the Orpheus anomaly (Loncarevik *et al.* 1966) located in the Atlantic about eighty miles off the coast of Cape Breton.

Photolinear studies by W.F. Take of the Nova Scotia Research Foundation of a part of southern Cape Breton have revealed that several of the salt structures have characteristic photolinear patterns surrounding them. These patterns appear to reflect the long continued movement of the salt, for some of these features are geologically recent and thus indicates that the salt is still mobile.

These salt structures have economic value for salt production, and, in addition, may offer the possibility of underground storage for oil, gas or radioactive waste. Small amounts of potash, sulphur and hydrocarbons in a number of test holes indicate other economic possibilities which have yet to be investigated in any detail. The intensification of the search for oil and natural gas in the Atlantic offshore area could result in a renewed interest in onshore prospects. However, diapiric salt bodies in an already complex geological environment make the search for economic minerals more difficult; and while gravity measurements and limited drilling can find salt structures, it will require a major seismic program together with extensive deep drilling to give a better understanding of the Windsor evaporites in Nova Scotia. For this work to be fully effective it is necessary to establish a satisfactory stratigraphy, particularly within the salt.

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