The Geology of Denison-Potacan's New Brunswick Potash Deposit

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ABSTRACT

The Mississippian age Cassidy Lake potash deposit is located in the Moncton Subbasin of southeastern New Brunswick. Following an extensive surface exploration program Denison Mines Limited began sinking a shaft in September 1979, reaching the Windsor Group evaporites at 745 metres in early 1982. Continued underground exploration over the next year defined an area of approximately 100 hectares in the southeast segment of the Windsorian deposit.

The detailed geologic mapping of underground openings, core logging and radar surveys, in conjunction with the surface geophysical surveys and surface drill data, has delineated an extensive thick, high-grade sylvinite bed. This bed is located in a lens-shaped salt mass that has a maximum thickness of 850 m and can simplistically be divided into two structural regions. These are the generally undulating, tabular flanks and the central "domal" area where salt flow has more than doubled the stratigraphic thickness. Within these structural regions folds of three orders of magnitude have been initially observed with an orientation generally parallel to the regional northeastern structural trend.

INTRODUCTION

Significant salt and potash deposits have been found associated with a thick sequence of Carboniferous sedimentary rock in southern New Brunswick, Canada. Two deposits consisting of thick high-grade sylvinite have been confirmed and are presently under development near the town of Sussex by Potash Company of America and Denison-Potacan Potash Company. A third prospect, located near Lower Millstream, is presently being explored by B. P. Exploration Ltd.

Denison-Potacan Potash Company's Clover Hill deposit was first identified by the New Brunswick Department of Natural Resources with the drilling of the discovery hole, Salt Springs No. 1 in 1973. In 1975 the Government of New Brunswick, sole owner of the salt and potash mineral rights, granted International Minerals and Chemical Corporation Ltd. (IMC) the right to explore and develop the Clover Hill property. IMC conducted an intensive exploration program, including the drilling of twenty-two boreholes, eighteen of which encountered sylvinite that defined an estimated 200 million tonnes of potash, grading 28% K_2O.

In April 1979, Denison Mines Limited purchased the Clover Hill property and began sinking a shaft in September that year. The Potash Company of Canada, owned jointly by Entreprise Miniere et Chimique and Kali Und Salz Aktiengesellschaft, joined with Denison Mines Limited in 1980 to form the Denison-Potacan Potash Company to explore and subsequently develop the Clover Hill deposit.

The sinking of the 4.9-m-diameter, concrete-lined exploration shaft experienced difficult water conditions associated with fracturing and faulting in the lower segment of the overlying sandstone and siltstone strata. Below the water-bearing formations the shaft encountered the watertight caprock from 730 m to 745 m, which was followed by 34 m of halite and 53 m of basal anhydrite before bottoming at 832 m.

An extensive underground exploration began in May 1982 from the 794-m shaft level and was completed in January 1983, following the excavation of over 3000 m of headings and in excess of 8000 m of diamond drilling.

UNDERGROUND EXPLORATION

The intent of the underground exploration program was to delineate the configuration, grade and mineralogy of the main sylvinite bed as well as to define 5 years of mining reserves and observe any characteristics that could affect the mineability of the deposit.

An exploration crosscut was excavated from the 794-m shaft level in a northwest direction across the deposit to 1874 m (Figure 1). At 680 m along the crosscut two drifts

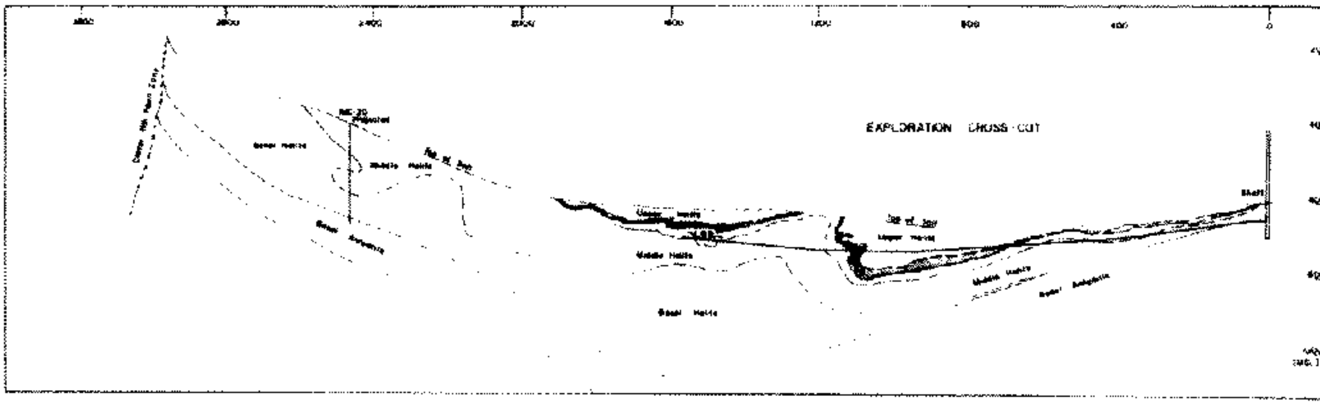

Figure 1. Profile of Exploration Crosscut

were turned off and excavated in an east and west direction along the strike direction of the deposit. These east and west drifts were driven 600 m along the lower and upper contact of the sylvinite bed respectively (Figures 2 & 3).

An extensive drilling program was undertaken along the crosscut and laterals resulting in a total of 8000 m of coring. The holes were of two types: short definition holes of less than 100 m, drilled in profile above or below the drift to intersect the sylvinite bed; and long investigation holes up to 1000 m, drilled radially from the crosscut at near horizontal angles (0 to 15 degrees).

The drilling was done using two Canadian Mine Services' superdrills, employing a counterflush technique for all long holes. This system involved reverse circulating the drilling brine down the annulus and up the drill pipe, which carried the core (52 mm) back to the collar where it was collected in a discharge trough. This method enabled very high penetration rates and excellent core recovery.

In conjunction with and an integral part of the underground exploration program was the use of Kali Und Salz AG's underground "radar" equipment, as described by Thierbach and Mayrhofer (1979). The radar surveys permitted the detailed mapping of the top of salt which was essential for the positioning of mine openings and drill holes to prevent intersection of the caprock. Surveys also enabled definition of internal reflective layers of the sylvinite and overlying halite intervals and facilitated the structural mapping of the crosscut and drifts.

GEOLOGIC SETTING

The potassium-bearing evaporites of Atlantic Canada form part of a thick sequence of Carboniferous age sediments deposited in a complex rift-valley system commonly referred to as the Fundy Basin (Kelly, 1967; Schenk, 1969). This basin consisted of a series of well defined linear depositional troughs or subbasins with intervening uplifted areas, extending from southern Nova Scotia to western Newfoundland (Figure 4).

The New Brunswick segment of the Fundy Basin is in

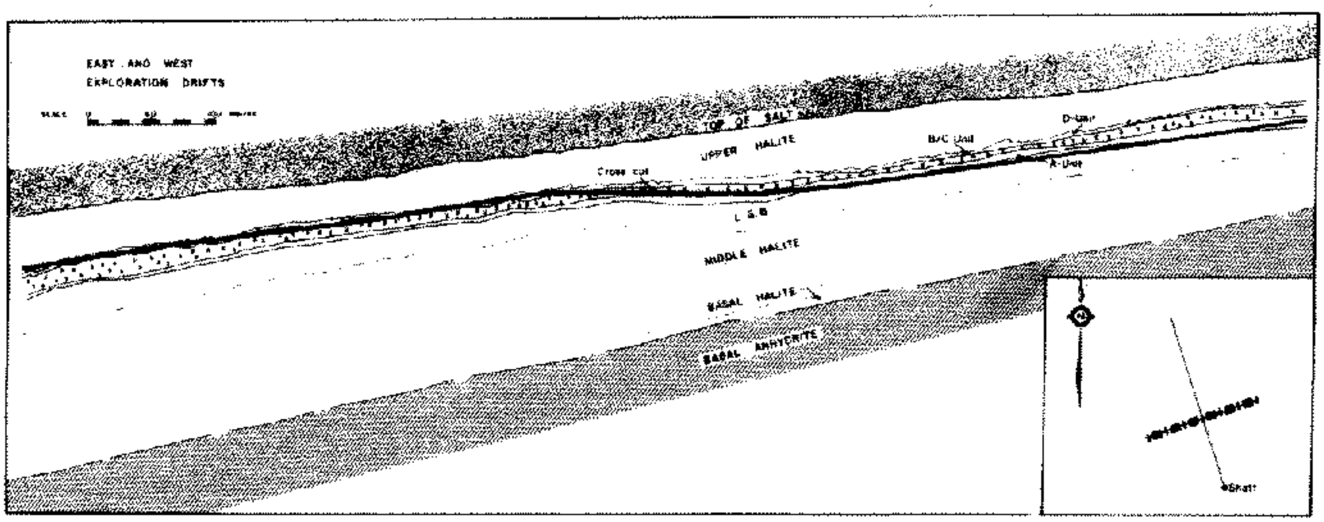

Figure 2. Profile of East and West Drifts

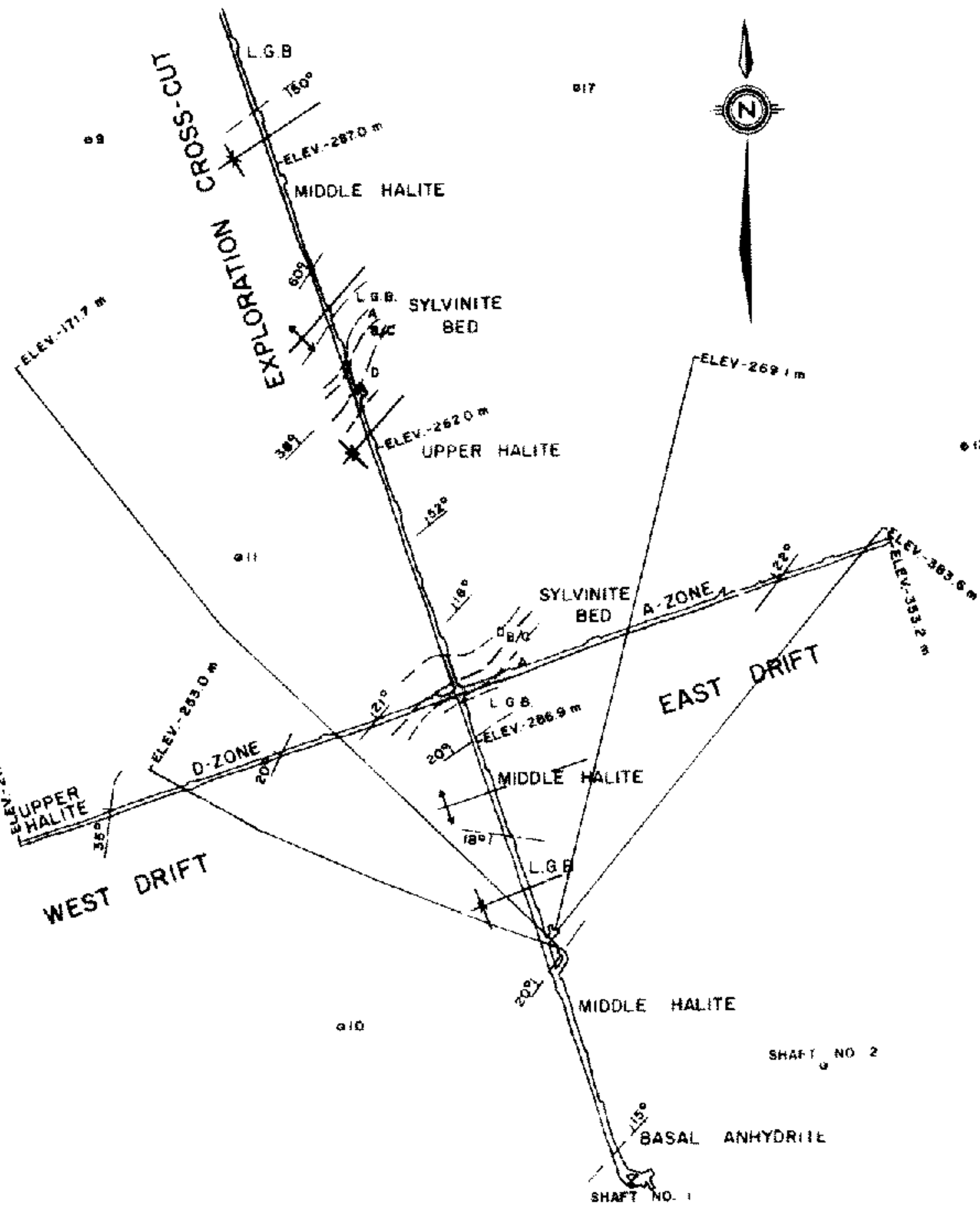

Figure 3. Plan of Underground Exploration

part represented by the Moncton depositional trough or subbasin. It is bordered by the Kingston uplift to the north, the Calendonia uplift to the south and the buried Westmorland uplift to the northeast, defining an area in excess of 5,500 km^2.

The Clover Hill potash deposit is confined to Marchbank syncline, the most southerly major structural feature of the Moncton subbasin (Figure 5). This structure is bound to the south by the Caledonian precarboniferous complex and to the north by the Clover Hill Fault zone and can be followed for 38 km along a northeast-southwest strike, and has a maximum width of 7 km.

The Marchbank syncline is filled with a maximum thickness of 1800 m of Carboniferous age sediments, as postu-

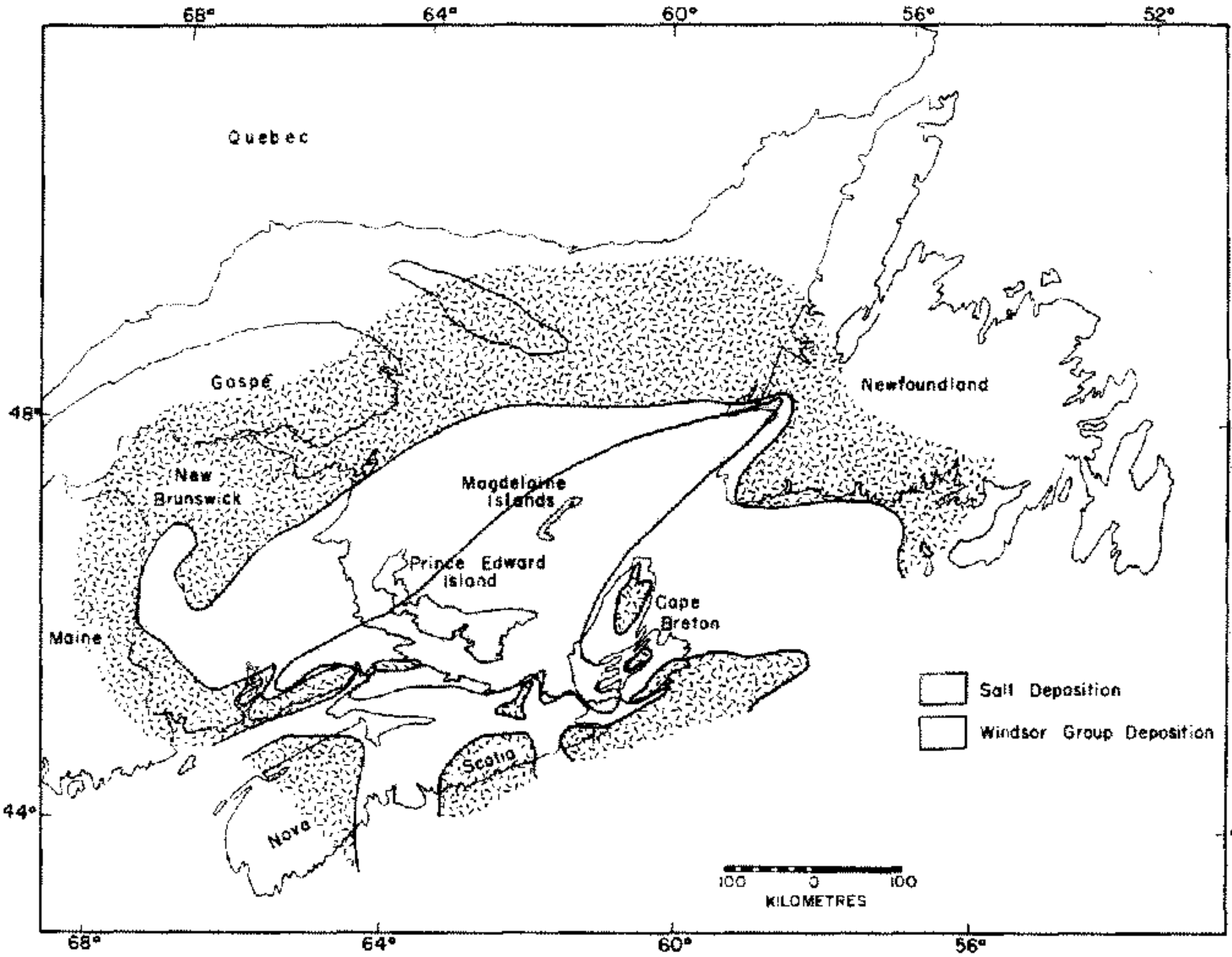

Figure 4. Location of Carboniferous, Windsor Group Evaporites in Atlantic Canada (after R. D. Howie, 1979)

lated from available drilling and geophysical surveys. This strata can be divided into four major stratigraphic units, which are from oldest to youngest; the Horton, Windsor, Hopewell and Riversdale Groups (Figure 6). Information collected and interpreted from the surface and underground exploration program has permitted the further subdivision of the Windsor and Hopewell Groups (Figure 7).

General Stratigraphy of the Marchbank Syncline

Carboniferous sedimentary rocks of the Marchbank syncline are underlain by basement complex of metasediments, volcanics and granites of Precambrian through Devonian age. The oldest Carboniferous lithologies that overlie the basement complex are those of the Horton Group, which has been subdivided into the Albert Formation and Moncton Group. These rocks consist of sandstones, conglomerates and siltstones and are exposed along the south margin of the syncline and to the north of the Clover Hill Fault.

Above the Horton Group in paraconformable contact lie the evaporite formations of the Windsor Group. The Windsor Group has been subdivided into three stratigraphic segments, which are from oldest to youngest: Upham, Cassidy Lake and Plumsweep Formations (Roulston and Waugh, 1983).

The Upham Formation consists of massive to bedded limestone of the Devine Corner member (Macumber member; McCutcheon, 1981) which has been observed only in surface exposures along the southern margin of the syncline and is overlain by the basal anhydrite of the Upperton member. The anhydrite observed in the exploration shaft and in the majority of surface exploration boreholes varies from massive to interbedded with anhydritic claystone. The boron mineral, danburite, is commonly observed in the anhydrite as white nodules 1 to 5 mm in diameter, and in the shaft area as 1-to-2-cm-thick beds near the upper contact.

Above the Upham Formation in a conformable contact (except for local decollement flows) lie the halite and syl-

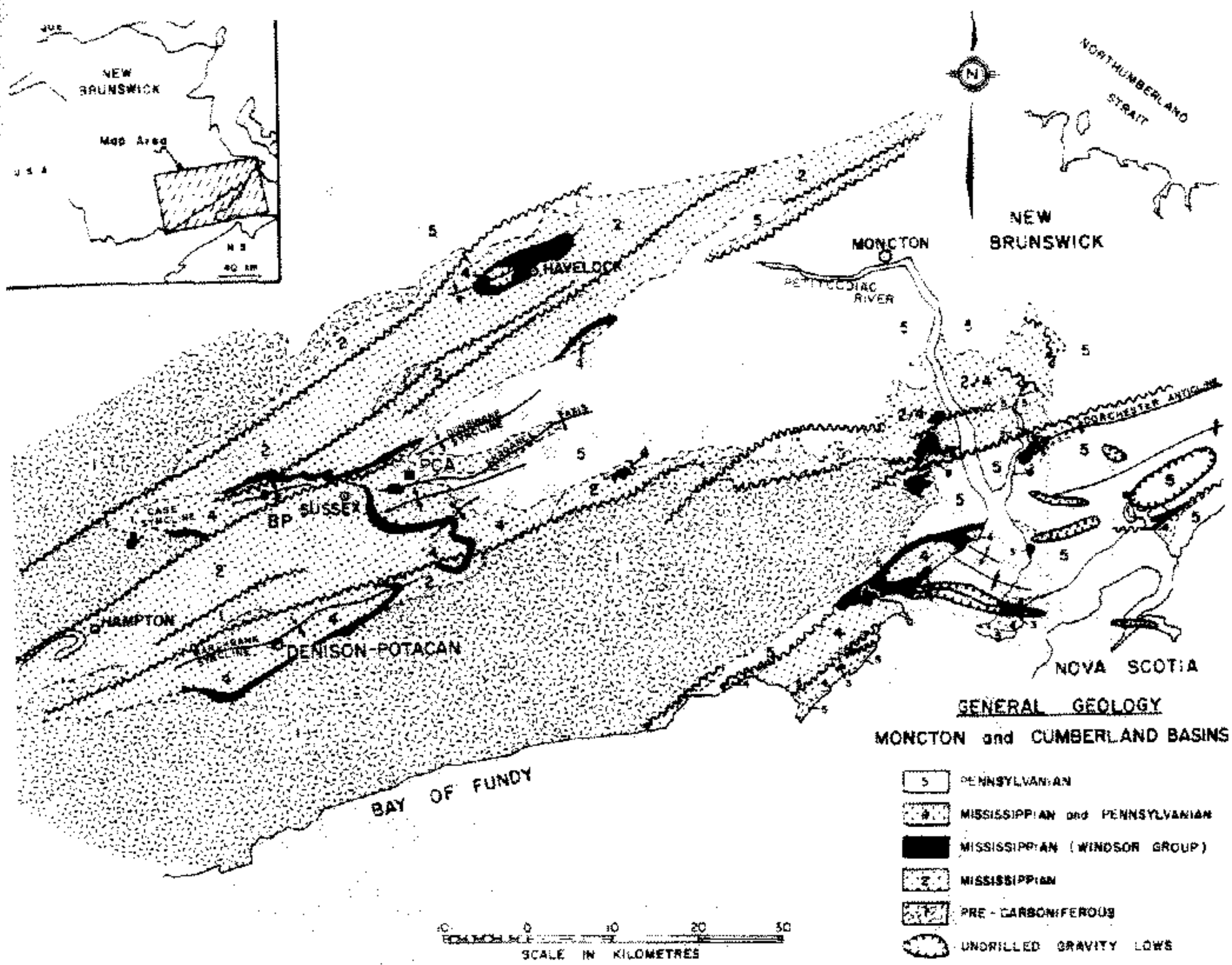

Figure 5. Geology of the Moncton Subbasin in New Brunswick (after Dr. R. Potter, 1981)

vinite beds of the Cassidy Lake Formation and the "capping" Plumweseep anhydrite/claystone Formation. These formations, which were the object of detailed investigation during the exploration program, will be described in a following section.

Windsor Group evaporites are gradationally overlain by the Hopewell Group redbeds. Although the Hopewell Group had not been successfully divided in the Moncton subbasin, it was possible in the Marchbank syncline area to designate several new formations and members. These formations were earlier documented by Anderle *et al.* (1979) and are here partly revised from observation during the mapping of the exploration shaft. These are from oldest to youngest: the Poodiac, Campbell Settlement and Wanamaker Formations (Figure 6 & 7), and due to their importance to the overall geologic setting and integrity of the deposit are briefly described below.

The Poodiac Formation's lower contact is placed at the last green-grey claystone bed of the Plumweseep Formation and ranges to a maximum thickness of 350 m. It is divided into three distinct, informally designated members which are: a collapse breccia-siltstone/sandstone member, a sandstone/siltstone member and an upper siltstone member. The collapse breccia is a secondary feature of the siltstone/sandstone member; therefore, it varies significantly in thickness, depending on the amount of suberosion of the underlying evaporites (118 m in Shaft No. 1 to 68 m in Shaft No. 2). The silt matrix in this impermeable weak member has acted as an effective sealant of the evaporites from the overlying water zones.

The sandstone/siltstone member is interbedded grey to grey-brown competent quartzose sandstone and siltstone which is commonly faulted and fractured over the 500 to 600 m segment of both shafts. This faulted area is frequently unstable and water-bearing. The overlying upper siltstone member consists of a homogeneous interval of

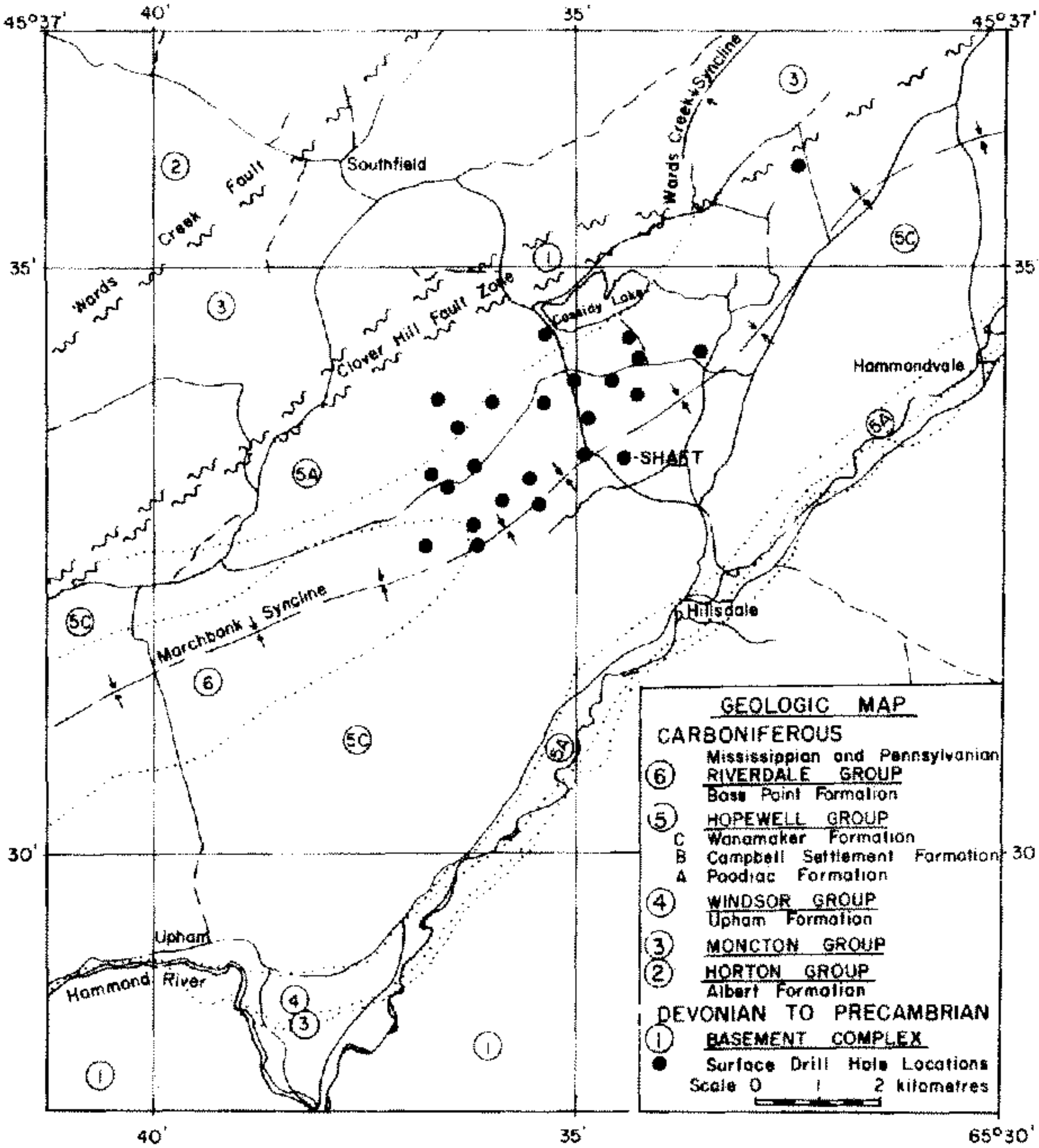

Figure 6. Surface Geology of the Marchbank Syncline

grey red siltstone that is in gradational contact with the Campbell Settlement Formation.

The Campbell Settlement Formation, which is up to 40 m thick, is essentially comprised of weak vesicular, silty, very fine-grained sandstone with a low permeability ranging from 1.16×10^{-6} to 8.4×10^{-8} cm/sec. The contact with the overlying Wanamaker Formation is very distinct, probably representing an unconformity between the fine sediments below and the coarser sediments above.

The Wanamaker Formation consists of red-brown sandstones, conglomerates and siltstones in contrast to the grey brown finer clastics of the Poodiac Formation. This formation can also be divided into three intervals: the homogeneous very fine-grained sandstones of the Scoodic Brook member, the chaotic conglomerates and sandstones of the DeForest Lake member and the upper very fine-grained to fine-grained sandstones with numerous limestone nodules and lenses of the Fowler Brook member. The Wanamaker Formation ranges up to 450 m thick in this area.

The youngest lithology in the Marchbank syncline is the

MARCHBANK SYNCLINE - STRATIGRAPHIC COLUMN					
GROUP	FORMATION	MEMBER	BED		GENERAL LITHOLOGIES
HOPEWELL	Wanamaker	Fowler Brook			Gry rd ss and sltst num gry limestone nod
		DeForest Lake			Gry rd to gry brn congl and ss.
		Scoodic Brook			Gry rd ss and sltst
					unconformity
	Campbell Settlement				Pale rd vuggy sltst / ss.
	Poodiac				Gry brn sltst
					Gry to gry brn ss / sltst.
					Gry brn sltst and ss.
					Variable collapse breccia.
WINDSOR	Plumweseep (Clover Hill)	Grey Clay			Grn gry claystone.
		Upper Salt			Not present in Marchbank Syncline.
		Upper Anhydrite			Gry to bluish gry anhy.
	Cassidy Lake	Upper Halite			F to med gr org to brn halite interbedded with num org and rd syl beds and borate min.
		Potash	Sylvinite Bed		Brick rd v f to f gr sylvinite
			L G B		Lt org halite with syl clusters
		Middle Halite			Lt brn med gr halite with irregular bands of dk brn to dk gry org halite.
		Basal Halite			V lt gry to clear med to c gr halite with irregular dk brn blk org halite bands.
	Upham	Upperton			Gry anhydrite
		Devine Corner			Lt gry to buff limestone

Figure 7. Stratigraphic Column—Marchbank Syncline

distinctive green-grey and buff, commonly quartzose sandstones and conglomerates of the Riversdale Group—Boss Point Formation. It is restricted to the axis of the Marchbank syncline where the thickness is postulated as up to 25 m.

DETAILED EVAPORITE GEOLOGY

Stratigraphy of the Cassidy Lake Formation

The Cassidy Lake Formation represents the halite/potash strata of the Windsor Group in the Moncton subbasin. It has been observed only in the subsurface from over 14,000 m of drill cores and 3000 m of underground excavation in the Marchbank syncline area. This evaporite interval has been subdivided into four members: Basal Halite, Middle Halite, Potash and Upper Halite (Figure 7).

The Basal Halite member consists of light grey to clear, medium- to coarse-grained halite. It is interbedded with dirty argillaceous dark brown to dark grey halite bands which become more numerous upsection. These dirty bands consist of disseminated, interstitial grey-green anhydritic clays, varying from 0.1 to 1.0 m thick with diffused boundaries between the interlayered clean halite bands. Danburite nodules 2 to 5 mm in diameter have been observed near the lower contact with the basal anhydrite of the Upperton member. The Basal Halite member varies from 1.0 thick on the south flank of the deposit to over 150 m thick in the center of the structure where salt flowage has resulted in a thickness greater than 500 m.

The Middle Halite member consists of light brown to orange medium- to fine-grained halite. Its lower segment is represented by interbanded clean and argillaceous halite becoming entirely argillaceous in the upper interval. The argillaceous halite bands are composed of disseminated interstitial green-grey and brown clays with a variable thickness of 10 to 60 cm. The clay is occasionally observed in subangular fragments to a maximum of 10 cm in size. Distinct continuous clay laminations have not been observed; however, sporadic, irregular anhydrite wisps and erratic patches of red to purple interstitial hematite plates are apparent. The Middle Halite member varies from an observed minimum thickness of 24 m to greater than 75 m and forms a gradational contact with the underlying Basal Halite.

The Middle Halite intersected in the exploration shaft had numerous, near-vertical hairline stripes 1 to 10 mm in width of very fine, clear halite with grey-green clay fragments up to 5 m long cutting across bedding. No evidence of slickensides or schistosity was observed to indicate movement. The bedding planes were only slightly disrupted (slumped) through these zones (Figure 8). Similar features were also observed in the exploration crosscut close to the shaft in the Middle Halite. These were irregular lens-shaped features, consisting of dirty halite or clay stripes, cutting across the general bedding direction. At this time the significance and distribution of these subvertical features is not fully understood, although there appears to be some similarity with the vertical structures, described by G. Richter-Bernburg (1979), which he suggested may in part be the result of diagenetic redissolution.

The Potash Member, which represents the only major potassium salt deposition in the Marchbank syncline, has been observed in surface boreholes over the majority of the deposit and has been examined in detail in the area of the underground exploration. From these observations it has been possible to divide the Potash Member into several distinct stratigraphic units that are generally characteristic of the member throughout the deposit. These consist of two main subdivisions: the Lower Gradational Bed and the Sylvinite Bed.

The Lower Gradational Bed is characterized by light brown to orange medium- to fine-grained halite as the Middle Halite below, except for the occurrence of sylvite clusters. These clusters are randomly disturbed, elongated lenses or circular in shape, 1 to 10 cm in size, and consist of red to red-rimmed, clear fine- to medium-grained sylvite. Occasionally blue halite crystals are disseminated through the clusters. The clusters increase in abundance from bottom to top, although sporadically there are barren intervals within the mineralized segment. The Lower Gradational Bed ranges from less than 5% to 10% K_2O, and varies in thickness between 1 and 25 m.

The overlying Sylvinite Bed is a homogeneous interval composed almost entirely of sylvite and halite with minor disseminated clays. Although the Sylvinite is bedded, it has a "massive" appearance in comparison with the Plumweseep deposits' Sylvinite Bed, which is distinctly layered. Distinct layering is in part the result of enhancement of the bedding by the presence of 2% to 5% disseminated clay, whereas the Clover Hill Sylvinite averages only approximately 1% clay content.

Sylvite crystals range between 2 and 5 mm in size and show varying textural alignment with the bedding, from a common "massive" texture to a highly "schistose" texture. In areas of "schistose," or strongly aligned sylvinite crystals it is common to observe disseminated blue halite crystals 1 to 2 mm in size and slickensided bedding planes.

The Sylvinite Bed can be further subdivided into five generally distinct units, which are designated from bottom to top as the A, B, C, D and E zone, or unit (Figure 9).

Zone A lies between the Lower Gradational Bed and the overlying B/C main ore beds. This interval varies between sylvite, barren light brown, fine-grained halite and high-grade, light reddish brown, fine-grained sylvinite. It is generally distinctly bedded and has a fine-grained texture that distinguishes it from the medium-grained, Lower Gradational Bed; however, when it is highly mineralized it is difficult to discern the A zone from the overlying B zone. The mineralized interval consists of clear to light red fine-

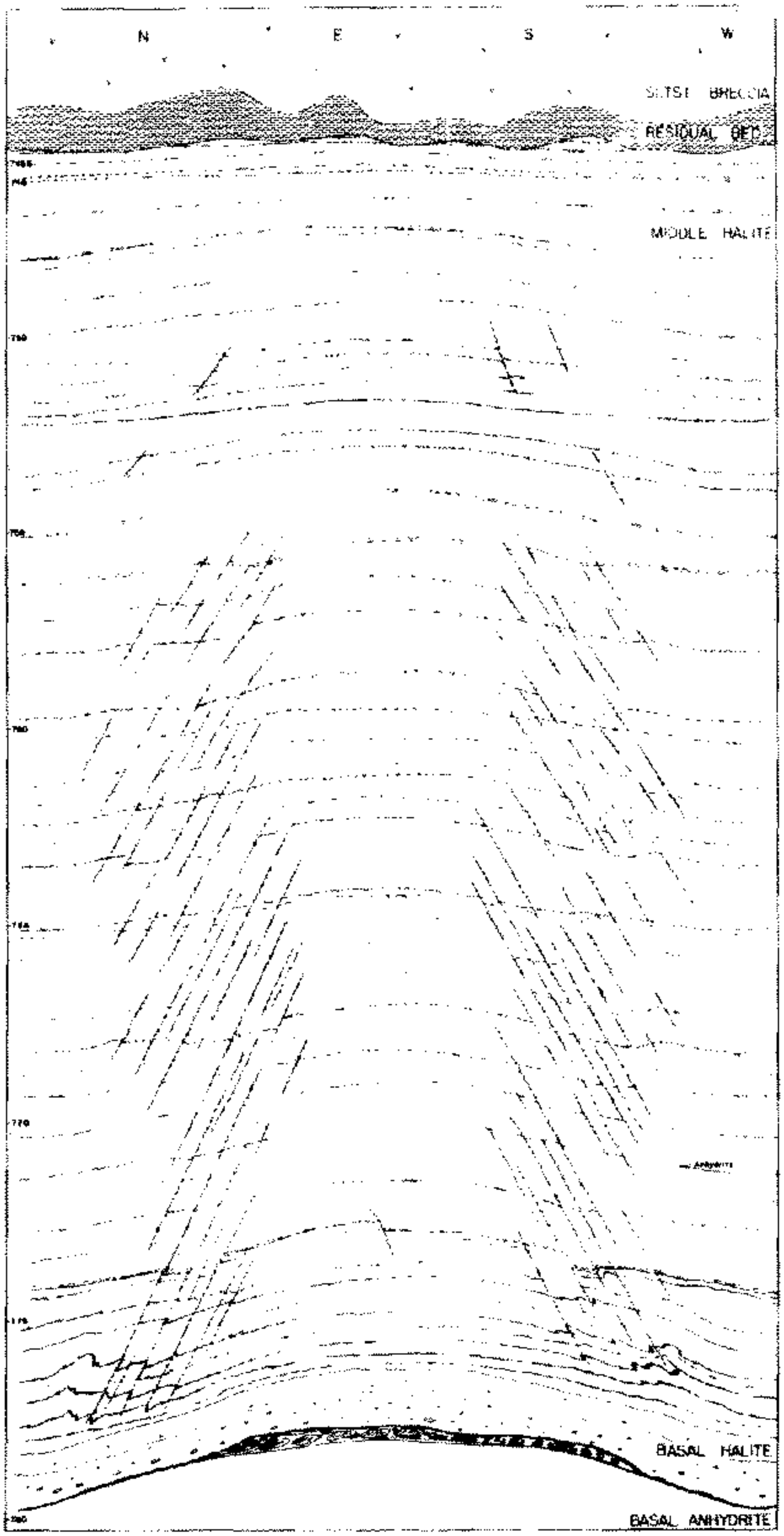

Figure 8. Shaft No. 1—Circumference View of the Salt Section Showing Near Vertical Structures and Caprock/Salt Unconformity.

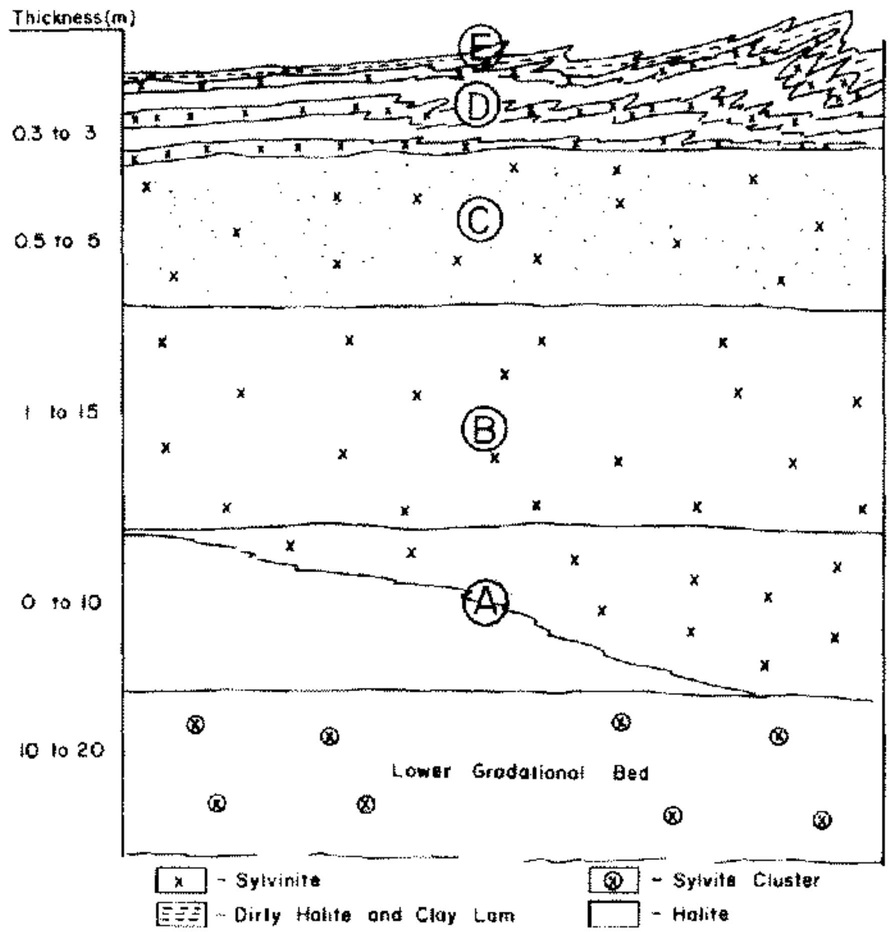

Figure 9. Schematic of Sylvinite Bed Showing A, B, C, D & E Zones

grained sylvite and very light brown fine-grained halite with less than 1% insolubles.

Zone A ranges from 0% to 38% K_2O over a thickness varying between less than 1 m and 10 m. Mineralization gradually changes laterally over hundreds of metres, as observed in the east drift. The A zone, which begins as a barren interval at the crosscut intersection, was 10% K_2O at 100m, 25% K_2O at 200 m and 33% K_2O from 400 to 600 m (Figure 2). Local mineralization variations have been observed but of a small scale and of short extent.

The main ore bed is composed of the B and C zones, which may or may not be readily apparent (Figure 9). The B zone contains brick-red to grey-red, fine-grained sylvinite consisting of fine-grained red to clear sylvite and light brown, fine-grained halite. Generally, there is less than 1% disseminated green-grey clay and as a result the interval has a clean appearance. This zone frequently is higher grade than the overlying C zone and varies from 1 to 15 m thick.

C zone is mainly composed of brick-red to bloodred, fine-grained sylvinite with infrequent thin, 5- to 10-cm, discontinuous barren halite beds. The sylvinite is comprised of red fine-grained sylvite and light brown fine-grained halite that is generally dark, brown or grey due to greater than 1% disseminated green-grey clay. The sylvite is on average 1% to 2% K_2O lower than the B zone and ranges from 0.5 to 10 m thick.

D zone forms the upper gradational contact of the Sylvinite Bed. It consists of interbedded sylvite barren, fine- to medium-grained halite, and brick-red fine-grained sylvinite. Where observed in the west exploration drift, the D zone consists of two halite beds and three sylvinite beds; however, it is generally difficult to observe the characteristics of this interval because of extensive internal folding.

Capping the Sylvinite Bed is the E bed, which consists of fine- to medium-grained, dirty halite with several distinct green-grey claystone laminations with the notable absence of any potassium mineralization. This bed varies from 10 to 30 cm thick and is generally present.

Overlying the Sylvinite Bed is a very distinctive Upper Halite member. Unlike the generally homogeneous Middle and Basal Halite members, the Upper Halite is a heterogeneous unit. It is characterized by orange and brown fine- to medium-grained halite with interbedded argillaceous halite beds, red sylvinite beds and laminae, claystone and anhydrite laminae and a distinctive borate mineral assemblage which is unique to that interval. These consist of boracite, hydroboracite, szaibelylite, hilgardite, ulexite, colemanite, danburite and priceite, of which several are restricted only to the Upper Halite member (Roulston and Waugh, 1981).

During the underground exploration, an Upper Halite marker bed was observed approximately 5 m above the Potash Member, consisting of argillaceous halite with several green-grey claystone laminae, 0.3 to 1 m thick. This bed served as a useful tool for structural mapping along the crosscut and in the boreholes. With the exception of the ore bed, this is the only specific marker bed identified to date within the Cassidy Lake Formation.

The thickness of the Upper Halite is very difficult to estimate because of the complex internal folding that was identified in mapping the exploration crosscut, and the apparent dissolution along the upper contact by suberosion. It is estimated to have a maximum thickness of 60 m which thins toward the south flank.

The Upper Halite and the overlying Upper Anhydrite contact is variable from conformable to a marked angular unconformity, depending on the extent of flowage and folding of the salt. The contact is a dissolution structure, in all areas observed, marked by a 0.5-to-1.5-m-thick, minutely laminated bed of brown to red-brown anhydritic claystone, designated the Residual Bed. In the exploration shaft the Residual Bed varied from 0.5 to 1.3 m thick and was slightly undulating, visibly truncating the underlying salt beds (Figure 8).

Analyses of the Residual Bed indicate the presence of halite, sylvite and insolubles such as borate minerals, clay and anhydrite. The insolubles are similar to those found in the Upper Halite member, and it is therefore considered to be the residue resulting from the suberosion of the salt beds at the contact.

Overlying the Cassidy Lake Formation is the Plumweseep Formation, which has been divided into three units (Roulston and Waugh, 1983), of which only two are present in the Marchbank syncline. These are the Upper Anhydrite and Grey Claystone members that are frequently observed as a collapse breccia. In the exploration shaft the Cassidy Lake Formation is "capped" by 13.7 m of siltstone, claystone and anhydrite breccias with a similar sequence (18.5 m) indicated in Shaft No. 2 pilot hole. Elsewhere over the deposit the Upper Anhydrite and Green-Grey Claystone members have been observed to be undisturbed and up to 7.5 and 13.5 m thick, respectively.

The Plumweseep Formation's Green-Grey Claystone member is in conformable gradational contact with the overlying Poodiac Formation of the Hopewell Group, marking the end of the Windsor Group deposition.

Structure of the Cassidy Lake Formation Salt Beds

The Marchbank Syncline and Clover Hill Fault are northeast-trending structural features associated with the regional tectonic setting of the Fundy Basin. The Marchbank Syncline, which is the major local structural feature affecting the Windsor Group evaporites, plunges approximately 3 degrees to the southwest and is asymmetrical in shape.

Within the Marchbank Syncline, the Clover Hill evaporite body, as delineated by surface and underground drilling and geophysical surveys, is greater than 10 km in a northeast-southwest direction and a maximum width of 3.5 km. It varies greatly in thickness from less than 30 m to 850 m (Figure 10). It is truncated to the north by the Clover Hill Fault, pinches out to the northeast and south and is undefined to the southwest. The evaporite body can be divided into two segments based on thickness and related complexity of salt flowage. These segments are: the thinner flanks and the thick, slightly domed central area. Thus the mass forms an elongated lens, or pillow-like, shape in marked contrast to the domal, or diaperic, shape of the evaporite deposits located near the more central portion of the Moncton subbasin. This difference is possibly explained by the deeper burial of the centre basin salt beds (Plumweseep deposit) as opposed to the thinner sedimentary burial along the basin margin (Clover Hill deposit).

The Denison-Potacan Potash Company mine enters the salt body along the extreme south flank, and crosses the deposit in a northwestern direction (Figure 3). Observations from the exploration crosscut, drifts and boreholes have identified three fold categories within the Marchbank Syncline. These are in declining order of magnitude, beginning with the first order Marchbank Syncline; the second order, 10 to 150 m amplitude folds; the third order, 1 to 5 m amplitude folds; and the fourth order, less than 1 m amplitude folds.

Second order folds of 10 to 150 m amplitude have been observed in all members of the salt strata from surface drill core and underground exploration. The wavelength of these folds varies greatly from 50 to over 500 m with a general northeast trend, plunging to the southwest, as observed in the exploration crosscut (Figure 1). It is apparent from surface boreholes that the larger amplitude folds of this category will be more typical of the thicker salt center "dome" area where the greatest degree of flowage is anticipated. However, large amplitude folds have also been recognized to a lesser degree in the generally gently undulating, tabular strata of the south flank. These anomolous structures, as observed along the exploration crosscut at 1200 m (Figure 1), may be associated with faulting in the underlying basal anhydrite of the Upperton member.

Third order folds of 1 to 10 m amplitudes have been commonly observed in the Potash member and in the Upper

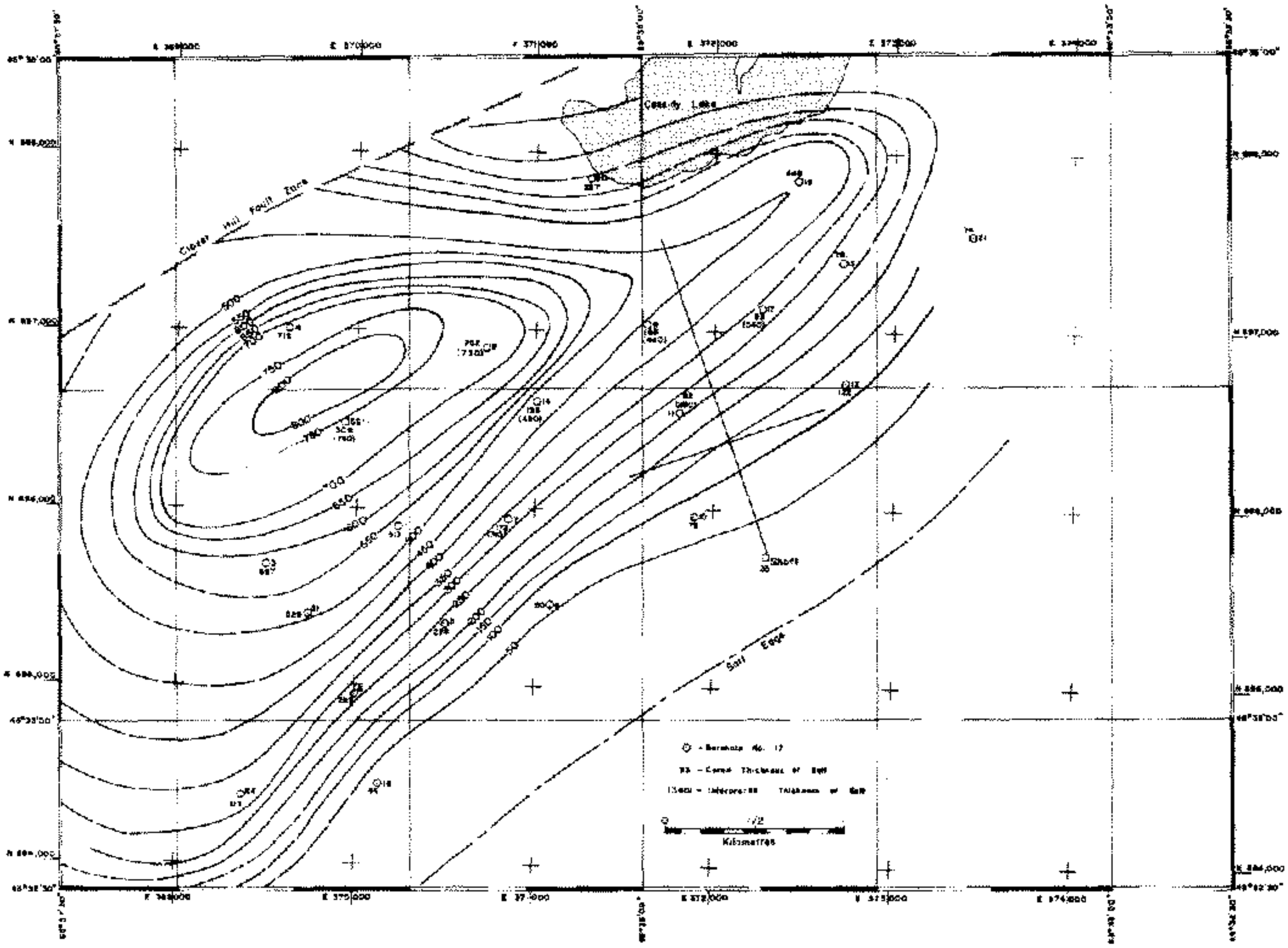

Figure 10. Salt Thickness Isopach of Clover Hill Deposit

Halite member and appears to be largely confined to those strata; although, this type has been observed at the contact with the basal anhydrite. The folds in the Upper Halite member have wavelengths of 5 to 10 m and are asymmetric to frequently overturned to the northwest.

The third order folding in the Potash member is almost entirely in the Sylvinite Bed D zone. This unit is frequently intensely folded with amplitudes of less than 1 m to 10 m, generally overturned to recumbent to the northwest, generally striking northeast (Figure 11). This folding is in part attributed to drag folding due to differential flow rates of the interbedded barren halite and high-grade sylvinite beds characteristic of the D zone.

The fourth order folds are generally enterolithic features from 1 cm to 1 m in amplitudes with similar scale wavelengths. These folds are generally northeast trending, overturned and associated with second and third order folds. They have been observed in all the stratigraphic units of the salt in the underground excavations and surface boreholes.

SUMMARY

The Clover Hill deposit has been delineated by 24 surface boreholes, a 4.9-metre shaft, over 3000 metres of underground excavation and 8000 metres of underground drilling. The widely spaced surface holes have defined the basic shape of the salt body and permitted a preliminary understanding of the internal structures of the halite/sylvinite sequences. This has been augmented by the detailed underground exploration of approximately 100 hectares of the southwest segment of the deposit. Within the limits of current observations and studies, several conclusions can be made:

1. A homogeneous, thick, high-grade, finely-crystalline sylvinite layer occurs in a classic evaporite cycle (Anderle *et al*, 1979; Roulston and Waugh, 1983). The Sylvinite Bed is entirely composed of fine-grained sylvite and halite with minor disseminated interstitial clays and only sporadic traces of carnallite. This Sylvinite Bed is only locally interrupted by barren

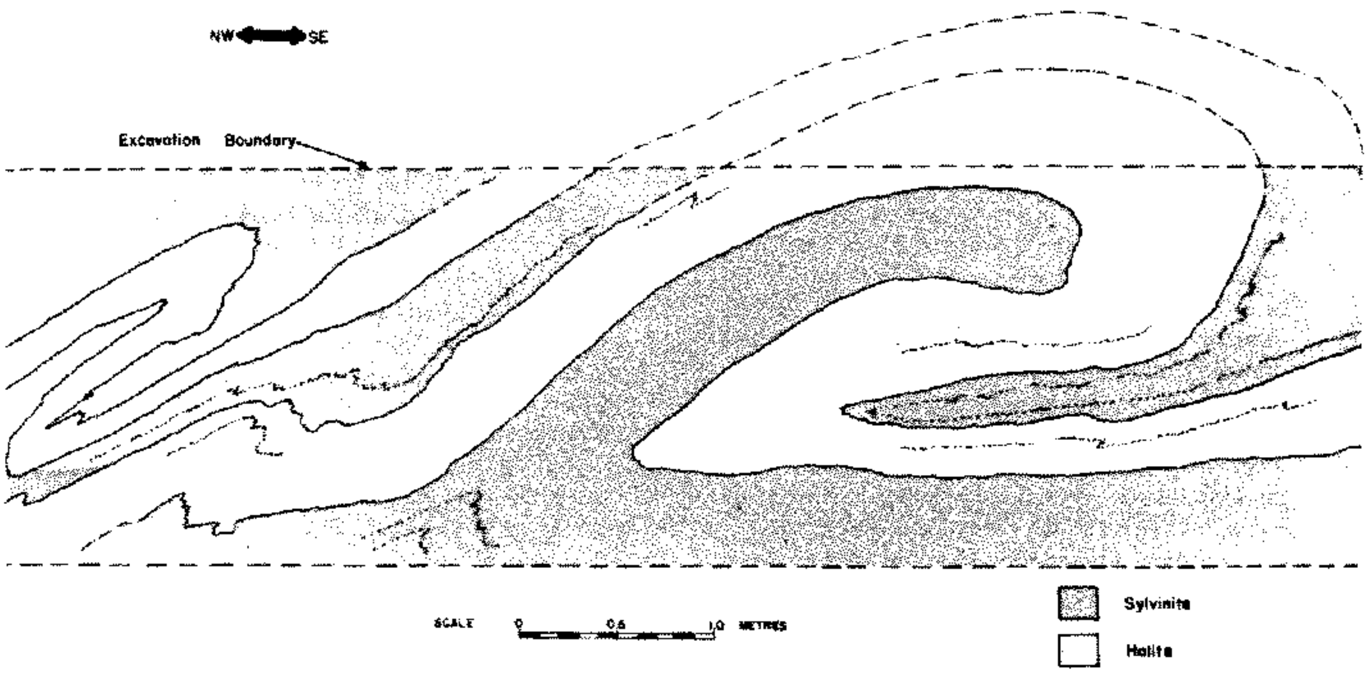

Figure 11. Third Order Overfolding of the Sylvinite Bed—D Zone Along the Exploration Crosscut (traced from photographs)

halite beds with lateral grade variations between 24% and 35% K_2O, averaging 28% K_2O. The thickness varies from 1 to 25 metres. This variation is locally due to thinning and thickening in association with structural features. It may, however, also be representative, in a more regional sense, of primary depositional variation, although this has not been substantiated.

2. The Sylvinite Bed has been divided into five zones based on mineralization, percent insolubles and colour. These have been designated from oldest to youngest; the A, B, C, D and E zones. The A zone consists of clear to red fine-grained sylvite, which varies laterally from barren to high-grade K_2O. The B and C zones, which represent the "main ore bed," are subtle divisions that are not always apparent. These consist of the lighter coloured, higher grade, cleaner B zone and the deeper red, slightly dirtier C zone. The upper gradational D zone consists of interbedded halite and sylvinite representing the end of the main potassium event. This interval is capped by a thin, dirty halite bed with several clay laminae, called the E zone, which may represent a short dissolution interval or hiatus at the end of the Potash member deposition.

Simplistically, the potassium salt deposition began slowly. In the Marchbank area it began as irregular laminae or lenses in the Lower Gradational Bed and progressed to the concentrated deposition in the A zone. Alteration during diagenetic stages may have accounted for the present occurrence of sylvinite clusters and stringers in the Lower Gradational Bed and resulted in lateral mineralized facies in the A zone. The main potassium deposition continued apparently undisturbed during the B and C zones until the upper gradational D zone. It is postulated that the ever-present dirty bed at the top of the Potash member is a chronastratigraphic unit which represents the aberrant termination (perhaps erosional hiatus or redissolution) of the potassium salt depositional event.

3. The salt body can simplistically be divided into two structural regions: the flanks and the central "domal" area. The structurally gentle, undulating flanks, as observed in the underground exploration, is in marked contrasts to the strongly folded central area, as interpreted from surface boreholes. The central area has experienced salt flowage and thickening to reach an approximate thickness of 850 metres; estimated as more than double the true stratigraphic thickness observed in the flanks.

The folds observed in the underground and interpreted from boreholes have tentatively been assigned order of magnitudes. The Marchbank Syncline is recognized as the 1st order fold. The 2nd, 3rd and 4th order folds were observed only in the Cassidy Lake salt horizon and are indigenous features of this unit. These fold orders vary from less than 1 metre to over

150 metres in amplitude with proportional wavelengths and are generally asymmetrical to overturned to the northwest, trending northeasterly.

4. The structures observed in the Cassidy Lake Formation parallel the northeast-trending regional structural features of the Moncton subbasin. Locally, in the Clover Hill area, these features are the Marchbank Syncline and the Clover Hill Fault zone. This fault is interpreted as being a thrust fault with an apparent vertical displacement of over 1000 metres (Anderle *et al*, 1979). The Clover Hill evaporites were subjected to renewed activity along the Clover Hill Fault zone in the mid-Pennsylvanian (Gussow, 1953), as the fault is covered by late Pennsylvanian strata. This movement pushed up the north limb of the Marchbank Syncline and mobilized the buried evaporites. This and later tectonic pulses resulted in the consistent northeasterly trending folds observed in the evaporites. The associated compression, and shortening of the slightly northwest dipping sedimentary strata, as referred to by Evans and Linn (1969) after DeSitter (1958), is postulated as the controlling mechanism for the consistent asymmetrical to overturned, northwest orientation of the folds.

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