Progress Report on the Stratigraphy and Structure of the Kingsville Salt Deposit (NTS 11F/14), Inverness County, Cape Breton Island, Nova Scotia[1]

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Introduction

This work and progress report are part of the Nova Scotia Department of Natural Resources contribution to the federal-provincial Targeted Geoscience Initiative (TGI) project. The Cape Breton Island TGI project is a joint project of Natural Resources Canada (Geological Survey of Canada) and the Province of Nova Scotia (Department of Natural Resources) and operates between 2000 and 2003.

The Kingsville salt deposit is located near Kingsville in the southwestern end of the River Denys lowland, approximately 20 km north of the Port Hawkesbury-Point Tupper industrial area on the Strait of Canso (Figs. 1, 2 and 3). The Cape Breton area was investigated for its salt and potash potential by Hayes (1931). Although no salt springs or indications of salt were found in the Kingsville area, many were described in the River Denys Valley near the Whycocomagh, St. Patricks Channel, Orangedale, and Bucklaw areas, and near Dundee-West Bay. Deep exploration drilling for salt was initiated in the Kingsville area between 1968 and 1971 by Domtar Limited (1968, 1969, 1971) on the significant Bouguer gravity anomalies in the area (Domtar, 1968).

Domtar Inc. (1978) also considered the deposit for possible development of an underground salt cavern for petroleum storage. The Kingsville deposit is attractive because of the potentially large salt resource present and it is located approximately 20 km north of ice free, deep water port facilities on the Strait of Canso. The complex geology of the deposit, especially the stratigraphy and structure, was not well defined within individual drillhole sections or between adjacent sections. Further exploration and development work on the deposit by Domtar ceased in 1978. Currently, there is renewed interest in use of the Kingsville deposit for underground storage, as well as other similar deposits in the region.

Based on a preliminary review of the Domtar Inc. (1978) report describing the geology of the deposit, including drill logs, maps and cross-section plots, indications of fold repetition were recognized. These included the symmetrical (inverted) repetition of interstratified anhydrite, carbonate and red to green siliciclastic units identified within several of the salt-dominated drillholes. A selection of the drillholes, including DK-3, -4, -5, -9. -10, -11 and -12, was examined in the summer 2001. These were used to investigate the carbonate and anhydrite strata that serve as the key markers to document internal stratigraphy, structure and correlation of the deposit (Boehner, 2001). A progress report on the results of this study is presented here.

Geology

The geology in the Kingsville area (Fig. 3) was described in geological maps and reports by Kelley (1967) and Lynch and Brisson (1996). The two highland ridges that border the area are the Creignish Hills to the northwest and North Mountain to the southeast (Raeside and Barr, 1990). The Creignish Hills comprise late Proterozoic to early Paleozoic metamorphic and intrusive rocks and represent the basement rocks to the overstepping Carboniferous basin strata. The

[1]Contribution to the Targeted Geoscience Initiative project: Geological Mapping for Mineral Development in South-central Cape Breton Island. Funded by Natural Resources Canada and the Nova Scotia Department of Natural Resources.

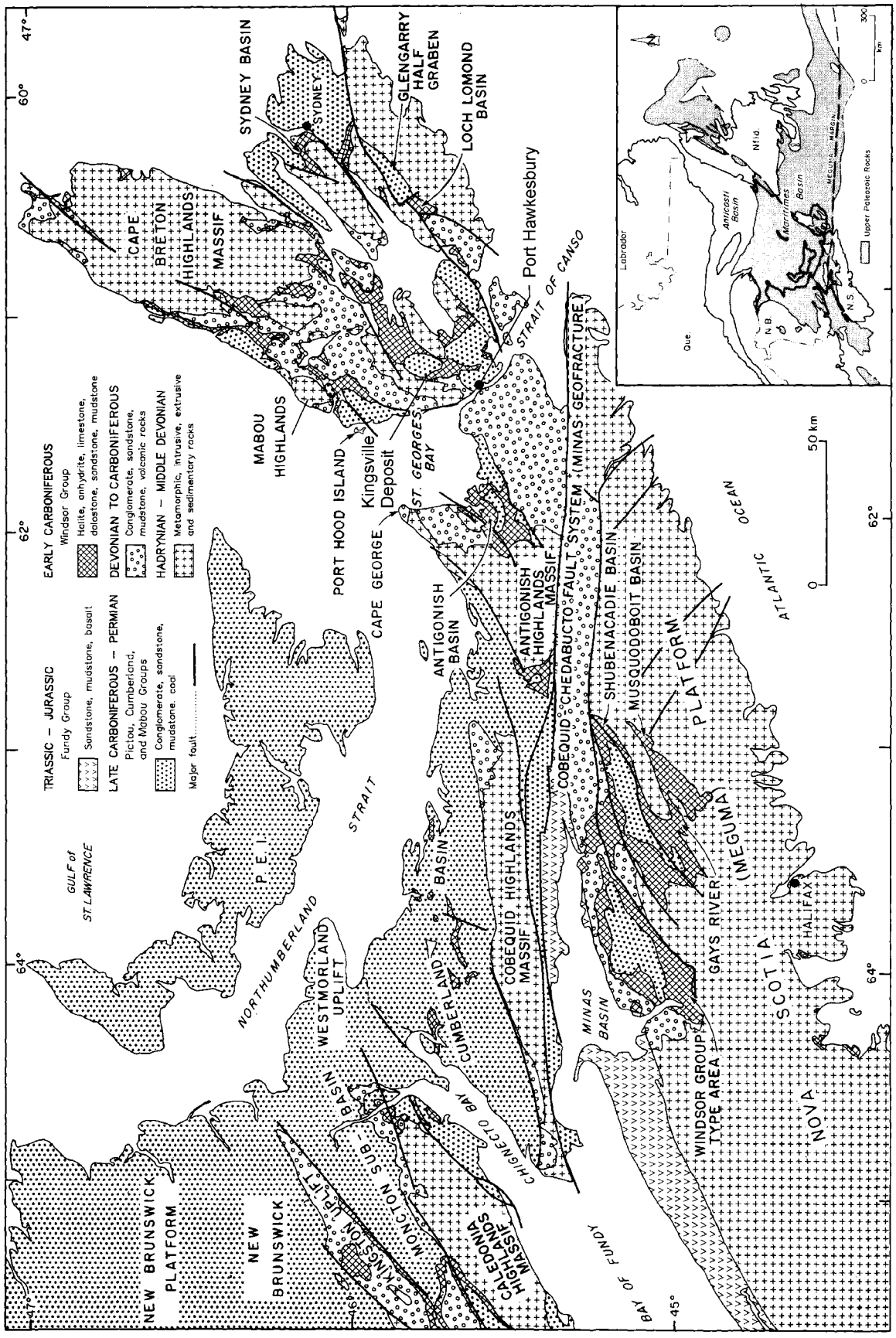

Figure 1. Regional geology and location map, Nova Scotia.

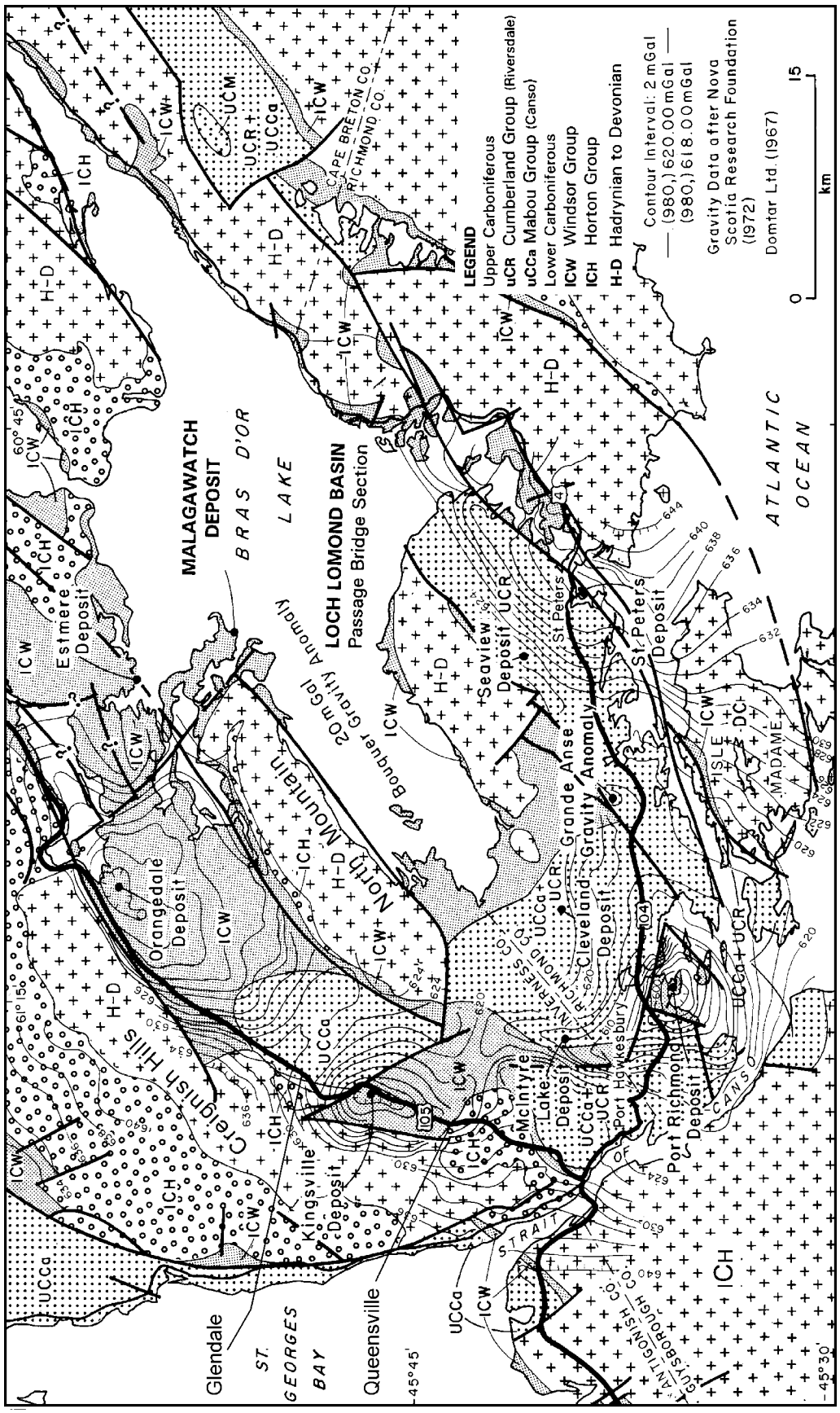

Figure 2. General geology and Bouguer gravity anomaly map, south-central Cape Breton Island.

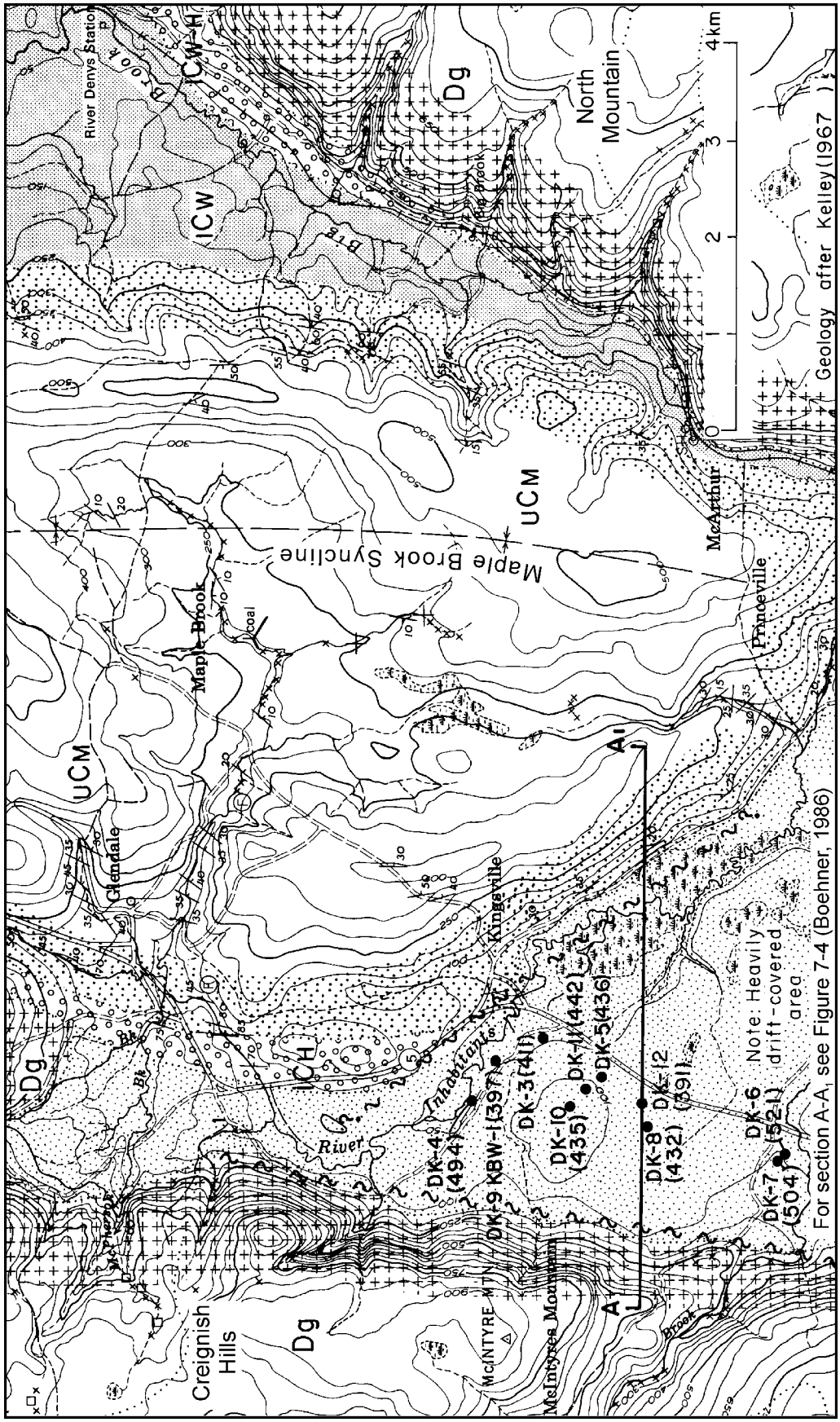

Figure 3. Geology in the vicinity of the Kingsville Deposit, Inverness County.

complex of metamorphic rocks in the Creignish highlands have been mapped as the George River Group or Blues Brook Formation of Raeside and Barr (1990). These include quartzo-feldspathic and micaceous quartz schist, quartz gneiss, limestone, quartzite, minor volcanic rocks and greywacke of late Proterozoic age (Hadrynian) age. These rocks have been intruded by Ordovician dioritic and granitic rocks. In addition, there are small areas of late Proterozoic gneiss (Bras d'Or metamorphic suite) that occur in association with the George River Group.

The Lower Carboniferous Horton Group, Strathlorne-Ainslie Formation, onlaps the older rocks of the highlands and occurs in a narrow outcrop band to the north near Glendale where the geology is obscured by thick drift cover. To the north of Kingsville, the Windsor Group is in fault contact with Mabou Group strata along the northwest border of the Maple Brook Syncline. Upper Carboniferous strata in the Maple Brook Syncline define a broad syncline in the central lowland area. These relatively resistant rocks of the Mabou and Cumberland groups form prominent hills with elevations of up to 200 m that separate the River Denys and River Inhabitants areas.

Windsor Group rocks outcrop both north and south of the Maple Brook Syncline. North Mountain, like the Creignish Hills, comprises Ordovician dioritic and granitic intrusives, Proterozoic gneiss (Bras d'Or metamorphic suite), and George River Group (Malagawatch Formation of Raeside and Barr, 1990) metasedimentary and volcanic rocks of late Proterozoic age (Hadrynian). These older rocks are overlain by a stratified section of sandstone, conglomerate and siltstone which Kelley (1967) mapped as marginal facies of the Horton Group and/or Windsor Group. This unit occurs in a narrow outcrop band between Big Brook and River Denys Station. This section is overlain with uncertain relationship by Windsor Group strata, which occur in a southerly narrowing outcrop band beneath the Mabou Formation in the Maple Brook Syncline. The area is included on a recent geological map of Whycocomagh (11F/14) by Lynch and Brisson (1996).

The deep salt exploration drilling by Domtar Limited at Kingsville (Figs. 3 and 4) indicates the present geological maps of NTS areas 11F/11 and 11F/14 require revision and re-interpretation, especially in the area of the map sheet borders. A new map of NTS area 11F/11 is currently in preparation by Giles *et al.* (2001). Previously unmapped faults may explain this discrepancy. The contact between the Windsor Group (salt section) and the pre-Carboniferous to the west is interpreted as a major fault that brings the very thick section of saline Windsor Group (drilled depths exceeding 1200 m) in contact with Hadrynian to Devonian granitoid and metamorphic rocks that comprise the Creignish Hills (Figs. 3 and 4). This contact zone is a dramatic north-south topographic break where the crystalline basement rocks of the highlands rise abruptly to elevations approximately 250 m above the lowlands. The lowlands are underlain primarily by the evaporitic Windsor Group and thick surficial valley fill (presently the River Inhabitants system), where elevations are approximately 30 m with little local relief. Lynch and Brisson (1996) identified a north-south fault at the northern end of the inferred west border fault to the Kingsville deposit.

The northern and southern boundaries of the Kingsville deposit are complicated by inferred fault blocks of Horton Group strata (southwest of Glendale and north of Queensville). The Horton Group outcrop pattern in the Glendale area (Fig. 3) is conspicuously narrow, indicating a thin onlap configuration or, alternatively, a fault contact with the underlying basement rocks of the Creignish Hills. The contact area is further complicated by the fault contact juxtaposing Mabou Group rocks of the Maple Brook Syncline with the thin basal Windsor Group and Horton Group strata outcropping in the narrow zone between Glendale and Melford. The Horton Group in the Queensville area, in contrast, has a wide (several km) outcrop pattern and variations in bedding orientations indicate some folding and local faulting. A block of Horton Group and overlying Macumber Formation and basal anhydrite of the Windsor Group has been mapped in the area northeast of Queensville (NTS 11F/11) by Giles *et al.* (2001). This block strikes north-northeast into the southern end of the Kingsville salt deposit (near drillholes DK-6 and DK-7, Figs. 3 and 4). Similar to the relationship at Glendale, a fault is inferred to be present to

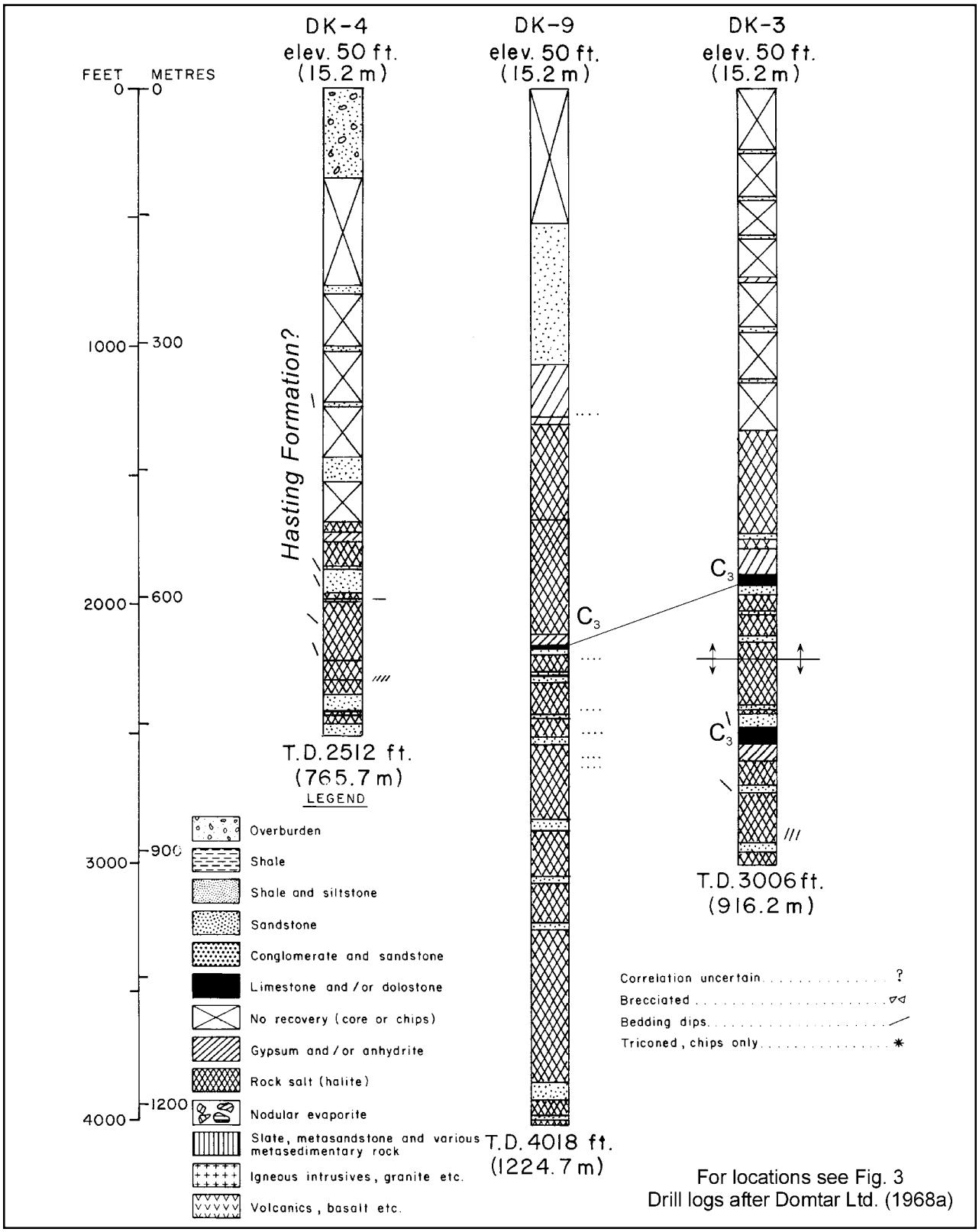

Figure 4. Drillhole profiles, Kingsville deposit, Inverness County.

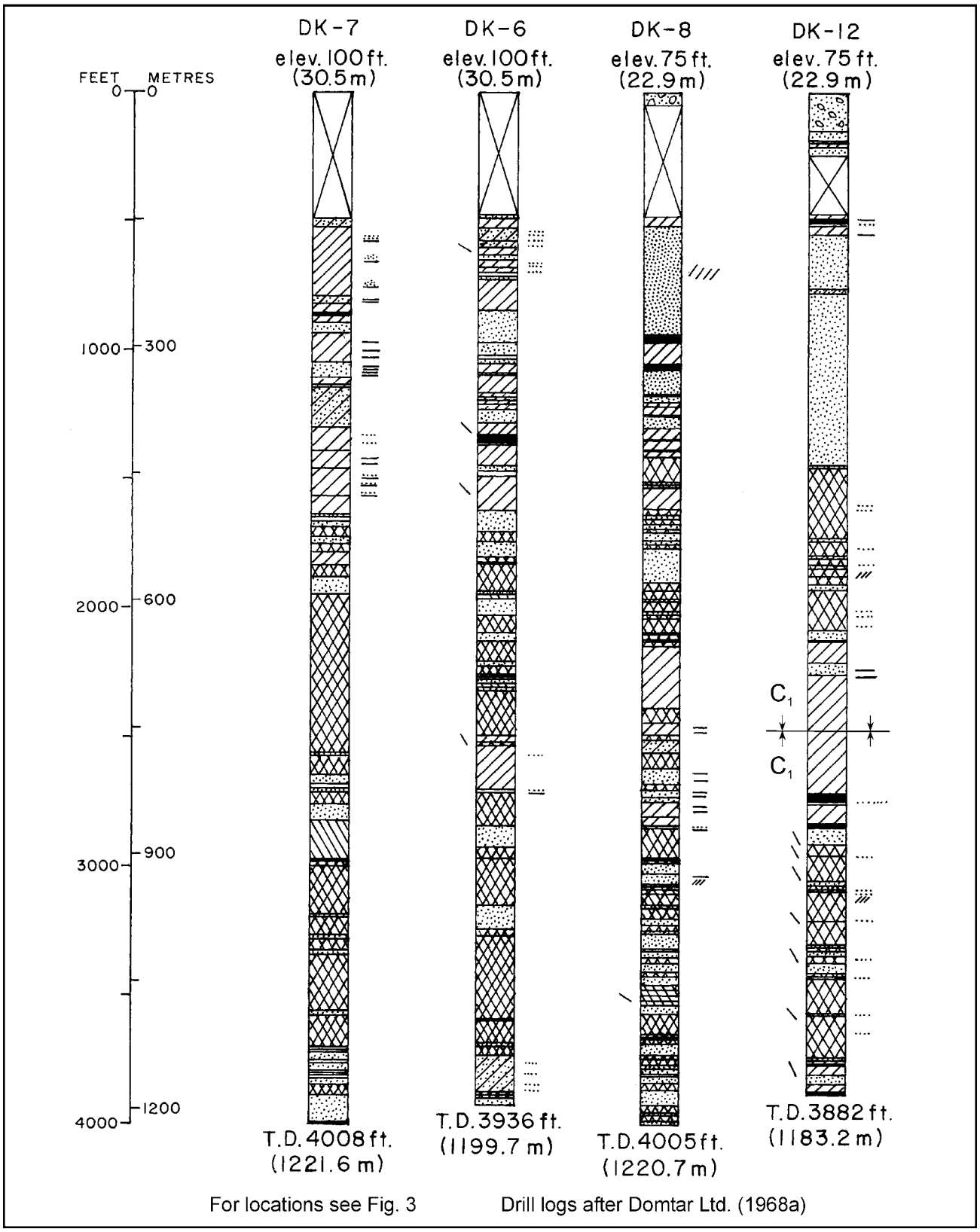

Figure 4. (Continued).

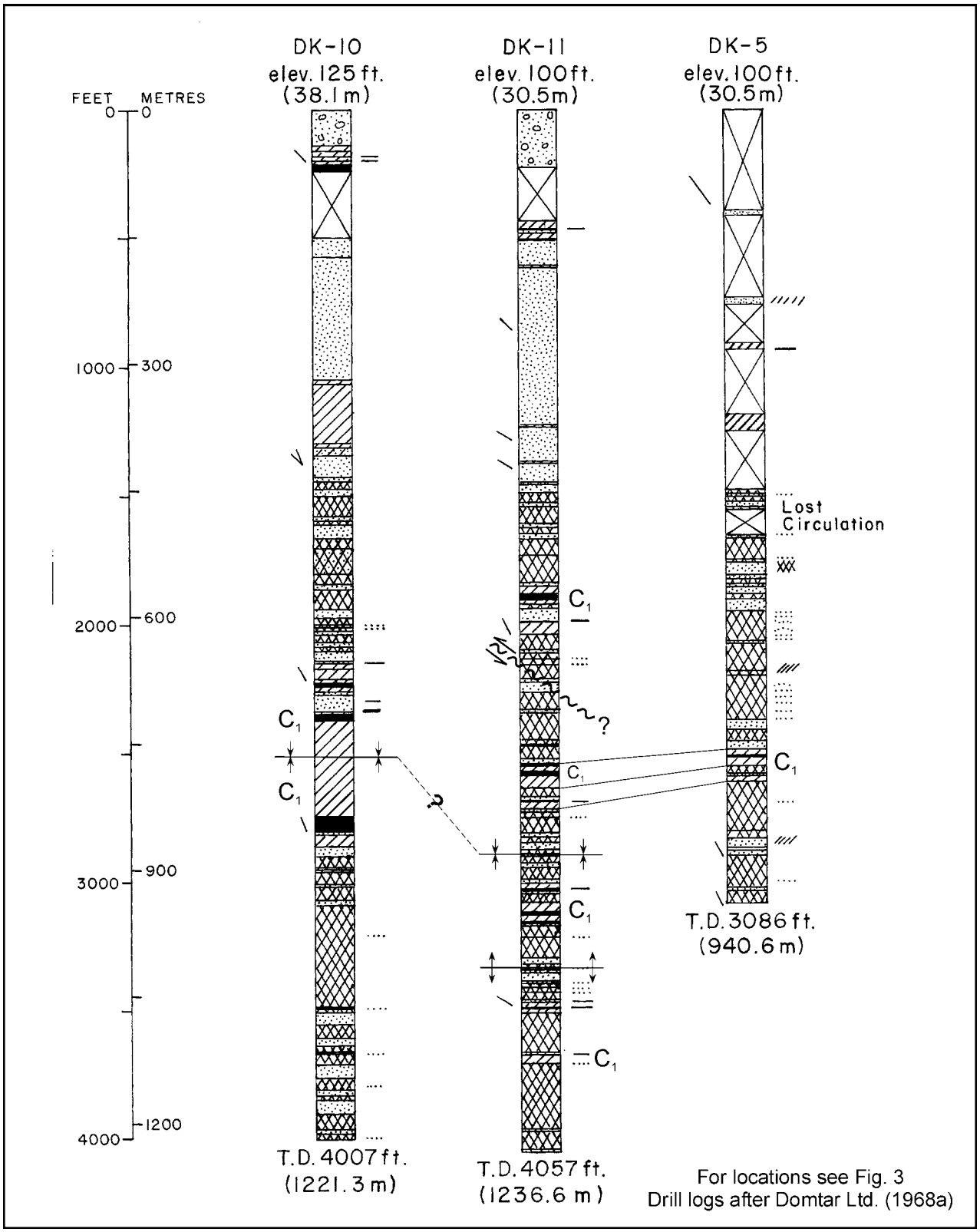

Figure 4. (Continued).

separate the extremely thick, saline Windsor Group at Kingsville from the Horton Group rocks that outcrop in Lamey Brook located approximately 1.5 km south of Domtar drillholes DK-6 and -7.

A major lineament paralleling River Inhabitants along the western limb of the Maple Brook Syncline may reflect the possible position of a major fault bounding the northeastern side of the salt mass. The only Horton/Windsor and Mabou rocks that outcrop in the immediate area of the Kingsville deposit occur near Highway 105 along River Inhabitants to the north of the Domtar drillholes. Kelley (1967) and Lynch (1996) indicate steeply dipping Horton Group and basal carbonate (Macumber Formation) of the Windsor Group juxtaposed with Mabou rocks of the Maple Brook Syncline. This relationship is typical of the Ainslie Detachment that occurs as a low-angle fault in the region. The relationship may also be produced by a high-angle fault with normal or reverse relative movement.

The area in the vicinity of the Kingsville salt deposit is included on Nova Scotia Research Foundation Bouguer gravity anomaly map of Whycocomagh (Domtar, 1968) at a scale of two inches equals one mile (Figs. 3 and 5). The presence of salt, indicated by the large, high amplitude (16 mGal) Bouguer gravity low, has been confirmed in diamond-drill holes. The Bouguer gravity anomaly coincident with the salt is oriented approximately north-south and parallels the western border fault (Figs. 2, 3 and 5). Although the precise structural configuration of the salt mass is not clear, abnormal thickening, very steep dips and fold repetition are apparent in this complexly folded structure (Fig. 4). A structural setting similar to that described by Giles (1981a and 2001) in the McIntyre Lake deposit area may be present in the Kingsville deposit. Further comparison will require additional detailed examination of drill core from the Kingsville deposit.

The Kingsville salt deposit was briefly described by Boehner (1986) and more detailed descriptions and data are provided by Domtar Inc. (1978), who completed much of the exploration work on the property in the late 1960s to early 1970s. Domtar Limited (1968) made a preliminary review of potential Maritime salt deposits and selected Kingsville, St. Peters and Seaview for diamond-drill testing the following year. The first hole drilled at Kingsville (Kingsville No. 3, Figs. 3 and 4) intersected salt at 376 m (1235 ft.) and was terminated in salt at 916 m (3006 ft.). Because all the Kingsville exploration holes were drilled using feet as depth measurements, both SI and Imperial measurements are used for reference. Encouraged by the success of this hole an additional nine holes (nos. 4 to 12) were completed at Kingsville to depths of approximately 1220 m (4000 ft.) in 1968-1970. Based on the exploration drilling data, a solution mining test well (KBW No. 1) was drilled in 1971 near Kingsville No. 9 in a nearly vertical-dipping section of high-grade salt at the northern end of the Kingsville deposit. This hole, completed at approximately 1220 m (4000 ft.), was fitted with a large diameter production casing for the brining test that was begun near the bottom of the well. The test indicated that brining was a satisfactory method to extract salt from the Kingsville deposit.

The Kingsville deposit is geologically complex and the full limits have not been defined by drilling. The exploration holes were drilled as a series of four northwest-southeast transects along a north-northeast-trending strike line. Spacing between the transects is approximately 600 m to 1200 m. Domtar geologists interpreted the structure as a diapiric antiform with a long, arcuate, anticlinal fold axis through these four drill panels. The fold axis was indicated to strike northeast-southwest to near north-south, with steep fold limbs and a plunge to the south. Approximately eight salt sections were recognized and utilized in correlation and definition of resource blocks for potential solution mining for salt or development of underground storage cavities. Domtar Inc. (1978) reported salt reserves of 1.152 billion tons in the drilled area of approximately 2400 m (8000 ft.) long by 900 m (3000 ft.) wide to a depth of 1220 m (4000 ft.). Depth to the top of first salt ranges from approximately 400 m to 500, with the greater depth in the south end of the deposit area.

Domtar Inc. (1978) indicated that blocks of salt appropriate for potential brine production cavities were outlined in every drillhole except DK-4,

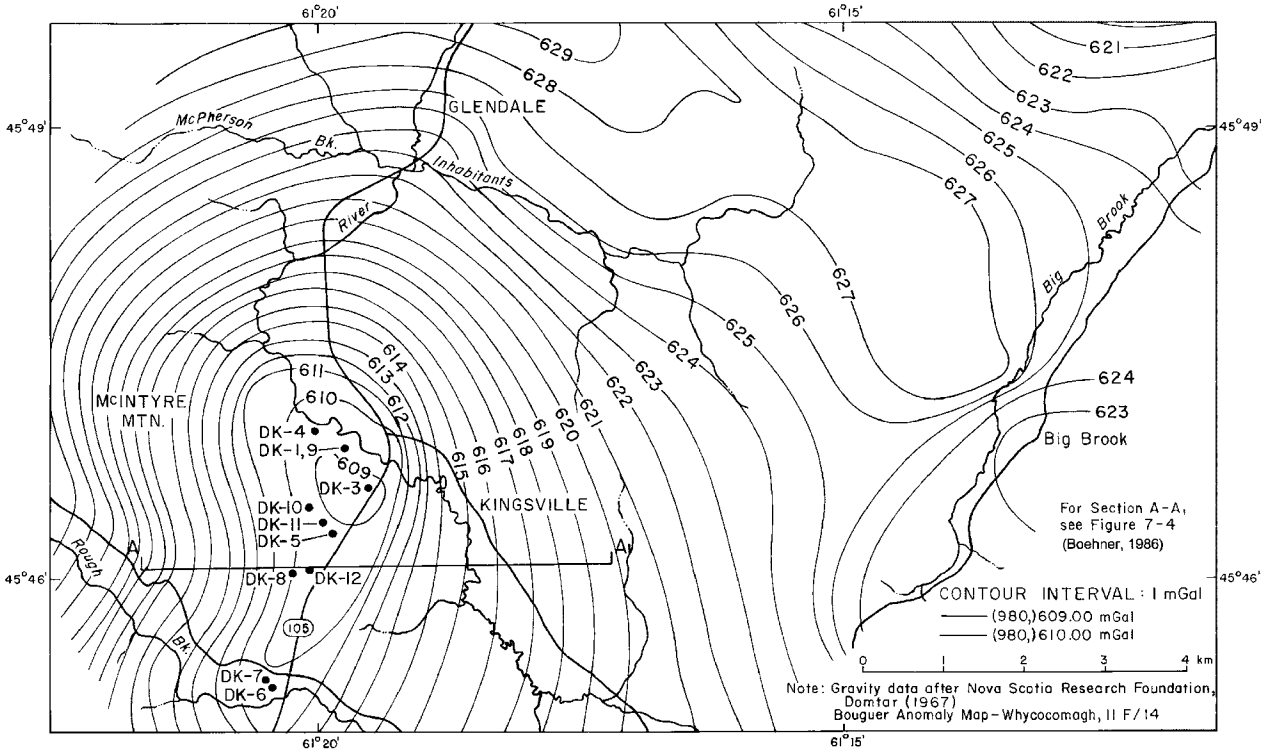

Figure 5. Bouguer gravity anomaly map, Kingsville deposit, Inverness County.

which was a shallow hole of 765.7 m (2512 ft.). Drillholes DK-6, 7 and 9 were considered to offer the best potential for developing large cavities. Reserves of over 10 million tons of approximately 90% NaCl were identified in DK-6 and -7, with 5 million tons of approximately 90% NaCl identified in DK-9.

A preliminary review of the drill logs, maps and plots in the Domtar Inc. (1978) report indicated the probable presence of fold repetition of interstratified anhydrite, carbonate and red to green siliciclastic units within the salt-dominated stratigraphy. This interstratified succession is typical of Major Cycles 2 to 5 of the Windsor Group. Sections of salt strata typical of the lowermost Windsor Group Major Cycle 1 are not apparent in the available information. In the summer of 2001, the drill core available from drillholes DK-3, -4, -5, -9. -10, -11 and -12 was examined to identify the major stratigraphy and structure of the deposit (Boehner, 2001). Inverted and normal minicycle sequences of the strata typical of Major Cycles 2-5 are indicative of folds with suspected repetition over drill core intervals of less than 500 feet to over 1000 feet (e.g. DK-10, -11, -12). The identification of this type of folding, which is well documented at nearby deposits near Malagawatch and Orangedale, will require further investigation through detailed core logging and analysis.

Boehner (2001) described a very distinctive section of anhydrite with limestone and dolomite beds occurring at depths of approximately 600-900 m in drillholes DK-10 and DK-12. The sequence of green siltstone, carbonate, then anhydrite in a normal, upright minor cycle forms a major synform succession. Examination of the core from these drillholes confirms these are major synforms and probably are the upper Windsor Group, C1 Limestone. Dips are steep (65-75°) and the true stratigraphic thickness is approximately 75 m. Stratigraphically correlative units are represented in the adjacent drillholes (e.g. DK-11 and DK-8, with multiple fold repeats probable). Drillhole DK-11 has an overturned section of three carbonate/anhydrite/salt minor cycles, inferred to be the C1 Limestone. Synform/antiform folds repeat part of the stratigraphic section 3 times with

a synform at 2860 feet (872 m) and an antiform at 3340 feet (1018 m).

A similar succession with the C3 Limestone occurs in the transect that includes the KBW No. 1 brine well. Here, DK-3 has a major antiform sequence and lithology typical of the C3 Limestone at a depth of 1800-2620 feet (550-800 m). The fold axis is inferred at a depth of approximately 2250 feet (686 m) and two mirror image intersections of the C3 Limestone occur upright at 1820-1960 feet (555-597 m) and overturned at 2420-2620 feet (738-800 m). An upright section through the C3 Limestone occurs in DK-9 at 2120-2180 feet (646-665 m). Although the drill core is not available, a lithologically similar section occurs in KBW No. 1 at 2470-2560 feet (753-780 m) in an upright orientation. KBW No. 1 and DK-9 are only 38 m apart, although the 70° dips produce an intersection depth difference of approximately 100 m. The dips are very steep (70-85°) and thus the >1200 m deep drillholes may contain as little as a 300-500 m (or less if fold repeated) of stratigraphic section, and consequently only a hundred metres (stratigraphic thickness) of salt. The lithology in DK-4 is very similar to the lower part of the Mabou Group, with saline evaporite facies and fine-grained mudrocks (marine carbonates absent) immediately above the Windsor Group. DK-4 is dominated by grey with minor red lacustrine mudrocks typical of the Hastings Formation. DK-4 and nearby drillhole DK-3 were sampled and submitted for palynological dating to Dr. John Utting, Geological Survey of Canada, Calgary, to confirm age, and identify thermal maturity and stratigraphic correlation. All samples were determined by Utting, in a preliminary report, to have a high level of thermal maturity with Thermal Alteration Index of 3+ to 4, equivalent to vitrinite reflectance of Ro 1.7 to 2.6%. Age determinations based upon the identifiable taxa were consequently limited and indicate the sections sampled were not older than the Lower Windsor Group (Utting, written communication, 2001).

In general, the Domtar drilling appears to represent the upper Windsor Group (Major Cycles 3 to 5; Giles, 1981) to lower Mabou Group (Hastings Formation), but may not reach the sections of Major Cycle 2 (B subzone) or Major Cycle 1 (A subzone of the Lower Windsor). The complete composite stratigraphic section of correlative Major Cycles 2 to 5 in the Malagawatch and McIntyre Lake areas (Giles 2001) is approximately 470 m thick and comprises 36% salt. Major Cycles 1 and 2, with stratigraphic thickness of 400 m and 530 m, are generally the most saline of the Windsor Group in the area, with 40% and 55% salt and minor potash. These may be prospective units at deeper levels at Kingsville or elsewhere in the area. The depth to the bottom of the saline Windsor Group may be considerable based on extrapolation from the existing drilled stratigraphy and structure. It may be interrupted, however, by a major structural break and consequent section truncation (e.g. the Ainslie Detachment at the top of the basal anhydrite, possible decollement/thrust). Stratigraphic and structural comparisons with the McIntyre Lake and Port Richmond salt deposits, as well as the Orangedale and Malagawatch salt and potash deposits (Giles, 2001), will be investigated.

Salt Geochemistry

Although salt springs have not been reported from the Kingsville area, several were reported by Hayes (1931) to occur near Whycocomagh, 20 km to the north, and West Bay, 12 km to the east. The presence of these salt springs indicates that salt probably underlies a large part of the River Denys lowland valley area. Domtar Inc. (1978) reported four main categories of salt grade: (1) very high grade, greater than 95% NaCl; (2) high grade, 90-95% NaCl; (3) medium grade, 75-90% NaCl; and (4) low grade, 60-75% NaCl. Potash salts are not reported in significant amounts in any of the drillhole logs or analyses. Domtar Inc. (1978) described notable intersections of very high and high grade salt in drillholes DK-5, DK-6, DK-7 and DK-9 (Table 1).

The salt analytical database on approximately 10,000 salt samples provided by Domtar Inc. (1978) is the largest available for any salt deposit in the province. The Domtar Inc. (1978) analytical data are included in a digital compilation by Boehner (2002). The success of the brining test (KBW No. 1), and the deposit description by Domtar Inc. (1978), indicates that salt grades and

Table 1. Very high-grade salt intersections, Kingsville deposit. Note all depths and intervals are in feet (after Domtar Inc., 1978).

Hole No.	Intervals	Apparent Thickness	NaCl Grade %
DK-5	2620-2687	67	95.55
DK-5	3024-3086	62	97.39
DK-6	2325.1-2497.5	172.4	96.4
DK-6	2721.7-2847.6	125.9	95.17
DK-6	2976-3169.1	193.1	95.82
DK-6	3278-3600.3	322.3	96.22
DK-7	1968-2293	325	97.64
DK-7	2342-2569.7	227.7	97.54
DK-7	3008.3-3198.5	190.2	97.13
DK-7	3410-3552	142	96.82
DK-7	3588-3648	60.7	96
DK-9	1302-1598	296	97

tonnages would be sufficient for economic extraction.

Economic Considerations

The Kingsville deposit comprises halite with no significant intersections of potash reported. It is defined by 11 drillholes and coincides with a high amplitude Bouguer gravity low extending over a length of more than 4000 m. Domtar Ltd. (1968) reported proven salt reserves, based on the drilling data, of approximately 28.6 million t (31.5 million tons). Domtar Inc. (1978) estimated probable reserves adjacent to the drilled area of approximately 1.04 billion t (1.15 billion tons), based on a 40% salt extraction ratio. Domtar Inc. (1978) has also considered the deposit for possible development of an underground salt cavern for petroleum storage. The Kingsville deposit is well suited for this use because it is situated approximately 20 km north of the ice free, deep water port facilities on the Strait of Canso. Currently, there is renewed interest in part of the deposit for underground storage use.

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