CHAPTER 1. INTRODUCTION

Nova Scotia is strategically located in southeastern Canada on the Atlantic Ocean with easy access to the Great Circle Route. Numerous deep water harbours provide shipping opportunities to markets in the Eastern Seaboard of the United States, the Caribbean, Europe, Africa and via the Panama Canal to Pacific Rim destinations. Gypsum has been produced in the Province and exported to a variety of markets, predominantly in North America, for over 200 years.

Nationwide, in 1988 the value of metals production was approximately six times the value of nonmetals production (Vagt, 1989). Nova Scotia, on the other hand, produced $388.6 million worth of minerals in 1986 (with production primarily in nonmetallic minerals, especially coal), 25.4% of which was industrial minerals and only 5.4% metals (Nova Scotia Department of Mines and Energy, 1987). This trend is a long standing one in the Province as is the fact that the production of gypsum and anhydrite have greatly contributed to the economy of certain areas of the Province.

According to Statistics Canada, 6.27 Mt of gypsum and anhydrite were produced in Nova Scotia in 1987 which is 69% of Canada's total production. That year gypsum producers directly employed 485 people and spent $26.8 million in the Province on wages, materials, supplies, fuels and electricity. They also employed three dedicated unit trains, many highway trucks and company owned and chartered vessels to get their products to market. Statistical information published by Roskill Information Services Ltd. (1987) shows that Nova Scotia is the most productive gypsum mining area in the world.

Gypsum or hydrous calcium sulphate ($CaSO_4 \cdot 2H_2O$) and anhydrite ($CaSO_4$) are ubiquitous minerals which are found in virtually every country in the world. Roskill Information Services Ltd. (1987) listed 38 nations in which gypsum, anhydrite or both were produced and reported in 1985, however Davis (1988) listed 77 producing nations including those producing byproduct gypsum. Natural supplies of gypsum and anhydrite worldwide are described by many authors as inexhaustible and ever increasing amounts of byproduct gypsum now exceeds current demand.

Gypsum usage goes back as far as recorded history having been carved by the early Chinese, Assyrians and Greeks. According to Schroeder (1970) it was used as a mortar in the Egyptian pyramids in 3000 B.C. and Pressler (1985) indicated that the burning or calcining of gypsum was described by the early Greeks. The development of gypsum plasters is difficult to trace; however, by the late 1800s, a commercial process had been developed to slow the setting time thereby allowing widespread use of finishing plasters. In 1918 a development occurred in the United States which would later revolutionize the North American construction industry, prefabricated wallboard. Ten years later large scale production was achieved and gypsum wallboard was on its way to becoming the major end use of gypsum processed in North America (Schroeder, 1970; Pressler, 1985). Today this is a multibillion dollar industry.

Worldwide gypsum is used in prefabricated board products, building blocks, plasters, as a set retarder for cement, in agriculture to condition soil or as a fertilizer and as a filler in a multitude of products. Roskill Information Services Ltd. (1987) reported world production in 1985 at 80.9 Mt. The United States is the world's largest producer at 13.4 Mt in 1985 or 16.5% of the gypsum produced in the world. It is also the largest importer, buying 9.0 Mt from sources outside the United States in 1985. Canada ranks second at 8.4 Mt (10.4%) produced in 1985 and is the largest exporter of crude gypsum and gypsum products, most of which goes to the United States. The Province of Nova Scotia dominates gypsum production in Canada averaging 70% of the crude gypsum mined in the nation each year. Virtually all of this material is exported to foreign and domestic destinations.

Widespread, large, readily extractable reserves of gypsum around the world result in the fact that gypsum and anhydrite are low value, high bulk commodities that are subject to minor fluctuations in both local and global economies. All major gypsum fabrication companies are vertically integrated enabling them to ensure long term stability to survive the cyclical nature of an industry that is so intimately associated with the construction industry. Large scale, low cost production facilities at both the mining and fabrication stages are necessary to ensure long term survival. Gypsum does trade on the world market as is seen by the increase in imports of Spanish gypsum by the United States during the 1980s, but such arrangements are highly susceptible to fluctuations in currency exchange rates and the availability of low cost shipping.

Generally, most sources believe that natural supplies of gypsum and anhydrite are adequate to supply the world's needs for the foreseeable future. Recent technological and environmental developments have increased the acceptability of using byproduct gypsum in the marketplace. Gypsum and anhydrite are produced as byproducts of any chemical process which requires the neutralizing of waste acids using calcium carbonate, as well as those techniques used to remove sulphur from the flue gases of coal fired engines (see Byproduct Gypsum). At current levels the generation of byproduct gypsum is greater than total crude gypsum production and greater than total world demand. Although currently small, consumption of byproduct gypsum is slowly increasing and will gradually make inroads into the crude gypsum markets unless technological advances change present trends.

Demand projections for gypsum for various uses have been made (Pressler, 1985). It estimates an overall growth rate of 2.6% domestically and a world wide rate of 2.4% to the year 2000. These figures reflect total demand and cannot distinguish between crude and byproduct gypsum, an unknown which could possibly affect crude gypsum dramatically in the near future.

PREVIOUS WORK

Due to the extensive history of gypsum and anhydrite production in the Province, these commodities have long been the subject of study by those interested in developing the industry. References to gypsum abundance and production for export appear as early as 1828 (Jackson and Alger, 1828a, b), 1829 (Haliburton, 1829) and 1836 (Gesner, 1836). Dawson (1855) briefly mentioned gypsum and anhydrite and How (1869) went into somewhat more detail on the production of gypsum and anhydrite in the Province and included some statistics on production and exports.

Gilpin (1881) wrote a brief account of gypsum in Nova Scotia and Jennison (1911) included extensive observations from this Province in his report to the Canada Department of Mines. This major work included descriptions and analyses from all of the gypsum producing areas of the day, as well as technical data on all of the latest plaster manufacturing technology. Cole (1913) gave a brief description of most of the gypsum quarries in the Province in addition to including Jennison's (1911) report as an appendix in his publication.

More recent studies on gypsum in the Province include Cole's (1951) report on the competitive advantages of gypsum mining operations in Nova Scotia and possibilities for secondary processing, Goodman (1952) who described the geology and origin of gypsum and anhydrite deposits and Wright (1974) who reviewed a limited number of gypsum occurrences. With the exception of Goodman (1952) and Bell (1929), very little attention has been given to the geology and genesis of gypsum and anhydrite deposits in the Province.

SCOPE AND PURPOSE OF THIS INVESTIGATION

The Gypsum/Anhydrite Project was initiated in June 1985 through the Canada-Nova Scotia Mineral Development Agreement to develop an inventory of gypsum and anhydrite resources in the Province. Three objectives were established for the project. The first was to develop a comprehensive inventory of the Province's gypsum and anhydrite resources; the second was to establish a working rapport between the Nova Scotia Department of Mines and Energy (NSDME) and the Province's current producers; and the third was to initiate and encourage development of more diverse ways to utilize Nova Scotia's gypsum and anhydrite resources.

Preliminary research included computer searches using the Department's computerized drillhole database as well as the Geological Survey of Canada's (GSC) coordinated GEOSCAN bibliographic geoscience literature database. At that time the drillhole database included only drillholes from assessment reports and did not contain government drillholes. Even so, in excess of 1400 drillholes were selected by the search as containing gypsum, anhydrite or both. GEOSCAN provided a list of over 700 entries from maps, theses, assessment reports, NSDME annual reports and miscellaneous reports which contained references to gypsum, anhydrite or both.

Using the National Topographic System (NTS) all the data were divided into blocks falling within the confines of 1:50 000 topographic maps. Once this was accomplished, the task of tracking down and obtaining the materials selected by the computer searches began. By early 1986 all of this information was gathered and collated by map sheet in preparation for the field investigations of all reported surficial gypsum/anhydrite occurrences.

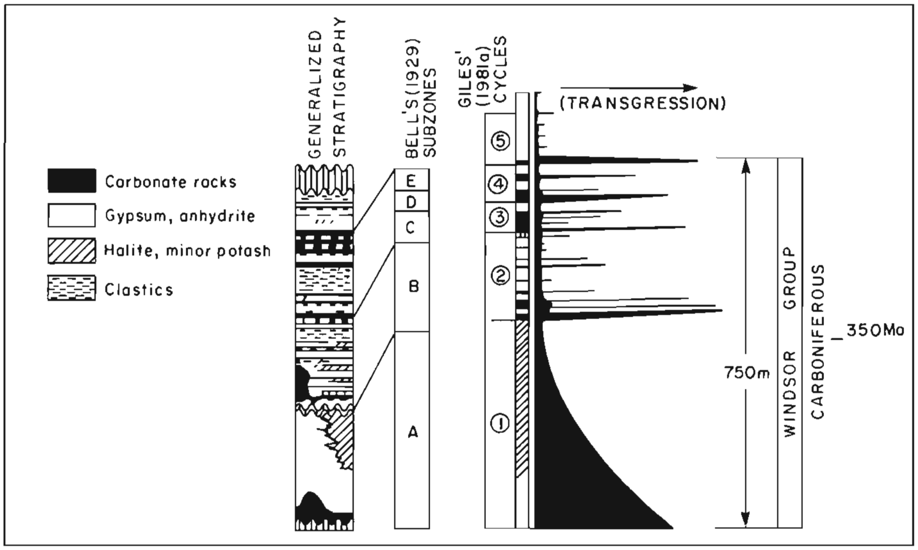
The most comprehensive observations of surface occurrences of gypsum and anhydrite available on a Province-wide basis were contained in Fletcher and Faribault's late 1800s series of geological maps. Occurrences were transferred from these one mile to one inch (1:63 360) scale maps to 1:50 000 topographic maps. This information, typical of these old series maps, later proved to be remarkably accurate and invaluable in the field.

Beginning in 1986, three field seasons were required to carry out site visits on all known or reported occurrences in the Province. All exposures found in the field were measured and sampled and later these data were combined with literature research information to produce the final occurrence writeups which appear in this text. Field samples are shown on the occurrence location maps which appear in the text. Their identifying numbers (e.g. R-201) correspond to analytical data located in Appendix 3.

GENERAL GEOLOGY OF GYPSUM AND ANHYDRITE IN NOVA SCOTIA

All economically significant occurrences of gypsum and anhydrite found in Nova Scotia lie within the Early Carboniferous Windsor Group. In Nova Scotia the Windsor Group consists of interstratified marine and nonmarine sedimentary rocks which were deposited in a large complex intracontinental basin. The basin system developed during the late Paleozoic in the northeastern portion of the Appalachians following the Acadian Orogeny. The basin system was referred to as the Fundy Basin by Bell (1958), but currently the erosional remnant is referred to regionally as the Maritimes Basin (Roliff, 1962). The Windsor Group is usually underlain by the Horton Group, a thick sequence of continental clastic sedimentary rocks which were deposited in the same basin system over older deformed metamorphic and igneous rocks. Continental clastics of the Canso (Mabou) Group overlie the Windsor Group although locally younger Carboniferous strata of the Riversdale, Cumberland and Pictou Groups may overlie it.

Bell (1929) studied the Windsor Group in the Windsor, Hants County, area and subdivided it on the basis of fauna into two major zones (Upper and Lower) consisting of five subzones labelled A through E (stratigraphic base to top). Recent work by Giles (1981a) subdivided the Windsor Group on the basis of major transgressive-regressive cycles (Fig. 1-1) (Giles, 1981a). The five cycles have been defined primarily on lithostratigraphy and coincide closely with the biostratigraphy defined by Bell (1929). The major cycles have been applied to the Windsor Group throughout the Province. The uppermost of these cycles (Cycle 5) extends into the overlying Canso (Mabou) Group.



modified after Bell, 1929; Giles, 1981a

Figure 1-1. Major cycles and subzones of the Windsor Group.

Gypsum and anhydrite can be found in all five major cycles in the Windsor Group as well as extending in the basal part of the Canso (Mabou) Group. Economically significant sections of gypsum and anhydrite are restricted to the two lowermost Cycles, 1 and 2 (Giles, 1981a; Boehner, 1986). Major Cycle 1 comprises 40-90% $CaSO_4$, Major Cycle 2 up to 75% $CaSO_4$, and Major Cycles 3 to 5 are typically <20% $CaSO_4$ (Boehner, personal communication, 1990).

Cycle 1 is roughly correlative with A Subzone (Bell, 1929) and represents a rapid marine transgression into the Maritimes Basin system during the Early Carboniferous. The initial transgression was followed by basin restriction and evaporite deposition in a thick cover 400 m progressive sequence. The earliest marine deposits were thin laminated carbonates within the basins and thicker bank facies on paleotopographic highs (Giles, 1981a). With increasing salinity the marine carbonates were succeeded by the thick massive to moderately stratified basal sulphate up to +300 m thick. The anhydrite is succeeded laterally and vertically by thick halite and locally potash salts. The end of Cycle 1 is represented by karstification, infilling and minor deposition of siliclastics under subaerial conditions (Giles, 1981a).

Cycle 2, in contrast, comprises a number of thinner (typically <30 m) transgressive-regressive cycles of carbonates, evaporites and clastics. Laterally the evaporite component has a wide range (5-85%). Major Cycle 2 typically is 150-200 m thick, but locally may exceed 500 m becoming increasingly clastic-rich towards the top. Economically significant calcium sulphate horizons in Cycle 2 are confined to its lower portion. These horizons vary in thickness due to deformation, but are generally <20 m (Lewis and Holleman, 1983).

Similar to Cycle 2 major Cycles 3, 4 and 5 also comprise numerous small transgressive-regressive cycles (Giles, 1981a).

The proportion of evaporite contained in these upper cycles is less than in Cycles 1 and 2 (30% maximum) and generally of little economic interest. The uppermost marine carbonate found in Cycle 5 defines the top of the Windsor Group even though thin calcium sulphate and halite beds were deposited in the overlying Canso (Mabou) Group during the final stages of marine regression in the Fundy Basin system (Giles, 1981a).

Boehner (1986) suggested that the major change in the depositional sequence between Cycle 1 and Cycles 2-5 is the result of basin infilling by the evaporites deposited during Cycle 1. Deposition went from deep water basins with gradually increasing salinity and decreasing size as well as significant inherited paleotopography during Cycle 1 to a shallow water setting, susceptible with subdued (infilled) topography to widespread transgressive/regressive minor cycles during Cycles 2-5.

GYPSUM AND ANHYDRITE DEPOSIT TYPES

Although evaporites have been the subject of extensive studies elsewhere in the world, the Windsor Group evaporites in Nova Scotia have not been studied in similar detail. Bell (1929) proposed that the thick basal sulphates were deposited in sea lagoons connected to a sea by a restricted channel. Goodman (1952) believed that the Province's calcium sulphate deposits were originally laid down as anhydrite in lagoons "... rhythmically replenished with marine waters ...." Schenk (1969) concluded the evaporites of the Windsor Group represented diagenetic deposition in a coastal sabkha-salina environment (supratidal $CaSO_4$) and halite in a landward salt flat playa environment.

More recent work by Evans (1972) on the evaporites found in the salt mine at Pugwash, Cumberland County, has examined in detail the deposition and diagenesis of calcium sulphates in the mine section. He concluded that the calcium sulphate horizons in the lower part of the Windsor (Cycle 1) were deposited in a restricted sea under water of <150 m depth as gypsum crystals forming within carbonate sedimentary rock. Shortly after deposition the gypsum was replaced by anhydrite. Evans (1972) also suggested, as does Boehner (1986), that the thinner, interbedded calcium sulphate horizons found in Cycles 2-5 of the Windsor Group may have been produced in a different environment, probably the sabkha environment described by Schenk (1969) rather than entirely in restricted sea lagoons. Boehner (1986) concluded that both sabkha displacive nodular evaporite deposition and shallow subaqueous (saline pan) evaporite deposition coexisted during Major Cycles 2-5.

Two different depositional environments and lithological associations for Cycle 1 and Cycle 2 calcium sulphate deposits have led to modern gypsum and anhydrite deposits with distinctly different character. Complex structural deformation (tectonic and solution collapse) of those original deposits has greatly increased the complexity of modern deposits and occurrences. This in turn makes the delineation of economically viable deposits more difficult. Boehner (in press) suggests that the more ductile nature of the evaporite dominated Windsor Group has amplified the effects of tectonism on these strata. Intensity of deformation varies within the Group, as well as within basins depending on basin depth, abundance of salt and tectonic-sediment setting. Boehner (in press) proposes that three mechanisms produced much of the evaporite tectonism observed in the Carboniferous basins " ... (1) decollement: gravity slides and thrusts, (2) compressive-transpressive, and (3) diapiric, tectonic and density contrast driven ..."

The differing depositional environments and resulting lithology in combination with the varied degrees of deformation (tectonic setting) have yielded distinctly different types of gypsum deposits in Nova Scotia. Lewis and Holleman (1983) made the first attempt to stratigraphically locate the Province's major gypsum and anhydrite production sites. Using Bell's (1929) subzones, they placed all active mines within the A and B Subzones (Giles, 1981a, Cycles 1 and 2). Several factors which localized these units include: (1) large component of $CaSO_4$, (2) influence of structure concentrated at this level (decollement-collapse, etc.), (3) enhanced permeability due to structure and paleodrainage (geomorphology).

Although gypsum has been observed in drillcores from today's Windsor Group basins at depths up to 300 m below surface, virtually all gypsum horizons in the Province grade to anhydrite with increasing depth. In contrast to the primary depositional model proposed by Goodman (1952), it is generally accepted by most investigators (i.e. Schenk, 1969) that present day gypsum deposits primarily are the result of rehydration of anhydrite bodies. Whether the anhydrite is primary or secondary after original depositional gypsum in unclear. The spatial relationship and association with near surface environment, fracture-permeability aquifer zones and inferred burial depth below the stability of primary gypsum, as well as abundant replacement textures of gypsum after anhydrite, leave little doubt as to the origin of the gypsum. The time of rehydration varies from area to area and could have occurred at any time between the Carboniferous and the present as is evidenced by multiple episodes of karstification and associated solution infilled materials found in the Cycle 1 and Cycle 2 horizons at various locations in the Province. Giles (1980) suggested that the Lakevale Formation found in the Antigonish Basin was probably deposited in karst features in Cycle 1 evaporites at some time not later than Namurian (Late Carboniferous Canso Group). Similarly Boehner's (1980a) discussion of solution infill material found in the same basal sulphate horizon at Crystal Cliffs, Antigonish County, reported spores of Stephanian (Late Carboniferous Pictou Group) age extracted from infill material.

Much younger Triassic material infills solution features studied by Clifton (1967) in the Windsor Basin. Unconsolidated Cretaceous aged deposits of clay, sand and lignite were reported by Dickie (1987) to be preserved in solution features in Cycle 1 and Cycle 2 at the following areas around the Province: Gays River, Halifax County; West Indian Road, Hants County; McKay Settlement, Hants County; and Diogenes Brook, Inverness County. All deposits of gypsum quarried at present in Nova Scotia have innumerable karst features over their upper surfaces infilled by Pleistocene aged materials and annually cases of sinkholes suddenly opening up on properties around the Province graphically show that dissolution of gypsum and anhydrite continues at present.

Sonnenfeld (1984) stated that "secondary gypsification requires meteoric waters ...." The hydration appears to be enhanced by the presence of porous interbeds adjacent to the anhydrite bodies, faulting of the anhydrite which may have enhanced its permeability, and differing patterns of overlying cover and drainage. Sonnenfeld (1984) also suggested that "the presence of barium, calcium, strontium or trivalent metal ions in the water will accelerate the hydration." It is also known that the presence of other substances such as calcium hydroxide will inhibit hydration.

Theoretically, mole for mole hydration of anhydrite to gypsum results in a 61% volume increase which could, in part, be responsible for some of the structural deformation which is observed within the Windsor Group strata. It is more likely that much of the excess gypsum is removed in solution as part of the throughgoing fluid system during the hydration process. Observations that chloride content of gypsum is usually lower than in the original anhydrite support this idea (removal of $CaSO_4$ and NaCl). Lewis and Holleman (1983) noted that the highest concentration of soluble salts are found in gypsum adjacent to anhydrite often as haloes 2-3 m in width. Sonnenfeld (1984) determined that solutions containing higher concentrations of salt will precipitate anhydrite rather than gypsum. It may be that meteoric water which hydrated anhydrite and flushed salts as they moved downward, gradually became saturated so that they no longer hydrated the anhydrite until additional meteoric water was introduced.

A number of gypsum deposit types have been recognized during the course of this study. Two are seen in the Cycle 1 (A Subzone) and three are observed in Cycle 2 (B Subzone). **Type 1** surface rind/envelope involves the hydration of the massive basal anhydrite from the surface down (Fig. 1-2). Hydration usually extends 10-20 m below the top of the gypsum to an irregular interface with underlying anhydrite. This irregularity may reflect fracture/fault structures cutting the anhydrite, surface groundwater patterns or overburden cover having differing permeability. Interbeds of carbonate and clastics are rare, have limited permeability and thus have little influence as hydration fluid pathways. Examples of this type of deposit are Georgia-Pacific Corporation's Big Brook site at River Denys, Inverness County, and Fundy Gypsum Company Ltd.'s White Quarry at Wentworth, Hants County. Gypsum produced from these Quarries is a white, highly pure product. These deposits are usually of lesser volume than other types.

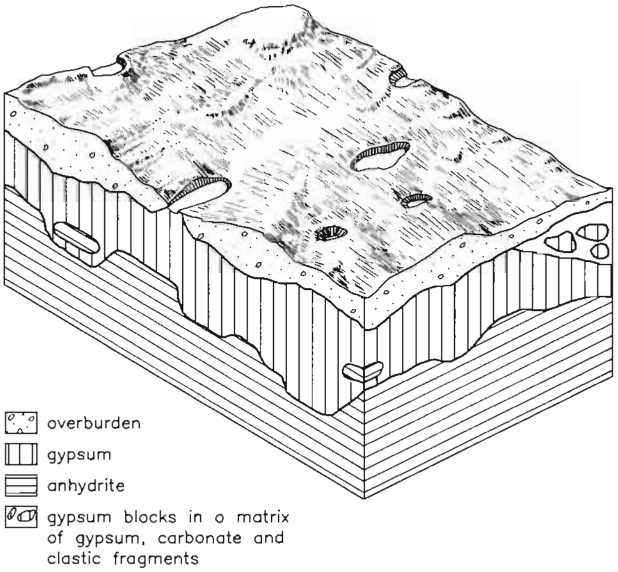


Figure 1-2. Deposit type 1 shows shallow surface hydration of massive basal anhydrite.

Deposit **type 2** of Cycle 1 (A Subzone) is a modification of type 1. In addition to having thin surface hydration over the top of basal anhydrite, these deposits contain a much deeper (+30 m) trough of hydration which roughly conforms to the contact between the basal sulphate and the underlying basement (Fig. 1-3). At

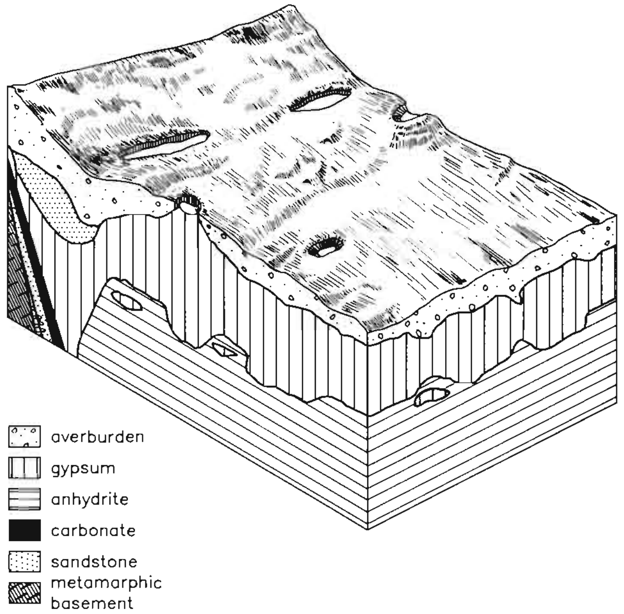


Figure 1-3. Deposit type 2 shows surface hydration and deeper hydration along contact between basal anhydrite and underlying porous units.

many places around the Province there is evidence that these features existed, the gypsum was removed by dissolution and the resultant trench was partially or totally infilled by younger material. Deposits like Domtar Gypsum's McKay Section Quarry in Hants County, Georgia-Pacific Corporation's Sugar Camp Quarry, Inverness County, and the drilled, but undeveloped deposits at Long Hill, Victoria County, held by Republic Gypsum and Domtar Gypsum all are this type. Gypsum from these deposits is a white, highly pure variety equal in quality to the first type; the volume of these deposits depends on how deep hydration extended and how much of this trench material has remained in place. Due to the enhanced hydration thickness from water concentration down the basal contact, they tend to be larger than the first type, but still are smaller than the deposits of Cycle 2.

There are (at least) three separate types of gypsum deposits found in Cycle 2 (B Subzone). Primarily, they differ in the degree and style of deformation of the strata in which they are confined. All three types are confined to the lowermost portion of Cycle 2 where the calcium sulphate interbeds comprise up to 75% of the geological section. Carbonate and clastic interbeds make up the remainder and are considered as waste material to be discarded during the mining process.

Deposit **type 3** consists of gently-dipping interbedded calcium sulphate horizons with interbeds of carbonates and fine grained clastics (Fig. 1-4). These deposits are rare since most of the Cycle 2 sections in most of the subbasins are moderately to highly deformed. Calcium sulphate beds 10-20 m thick, dip gently (8-10°) to the northeast in the Meadows Road area, Cape Breton County. Hydration extends downdip to a point approximately 30 m below surface. A few drillholes have been put down into this section at Meadow Road, however insufficient information is available to comment on the volumes of gypsum which might be extractable. This deposit type would most likely be amenable to underground, room and pillar mining only and as such would be more expensive than any of the other deposit types. Gypsum quality is good here and is generally white to light grey in colour.

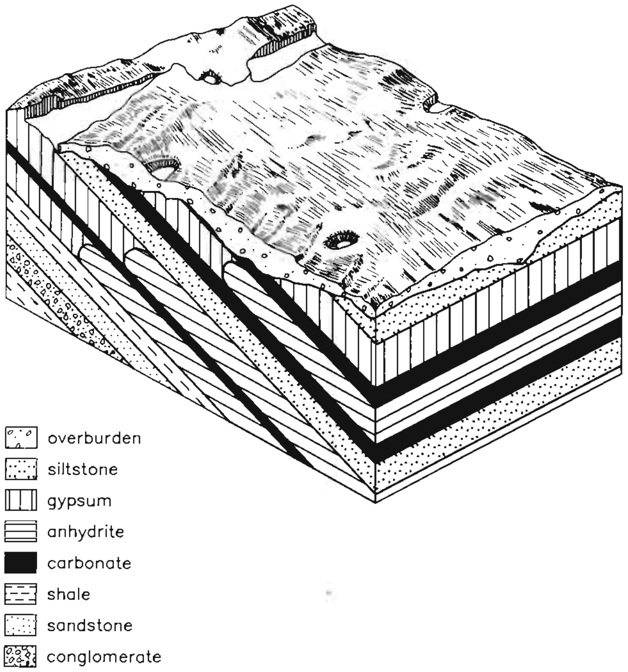


Figure 1-4. Deposit type 3 shows deep hydration of anhydrite between more porous interbeds.

Deposit **type 4** is comprised of type 3 strata structurally deformed to produce a folded and faulted section (Fig. 1-5). Structural mechanisms previously mentioned enhance the permeability of these sections which results in greatly increased depths of hydration in excess of 100 m. Degree of deformation varies from a broad plunging syncline in the Little Narrows Gypsum Company Ltd.'s Magazine Quarry at Little Narrows, Victoria County, to a recumbently folded and faulted section at Fundy Gypsum Company Ltd.'s Miller Creek Quarry. Gypsum taken from this type of deposit is usually light to dark grey in colour and varies from very fine grained to selenitic. Interbeds of carbonate and clastic materials are usually removed from the quarry during the mining operation and some fine grained

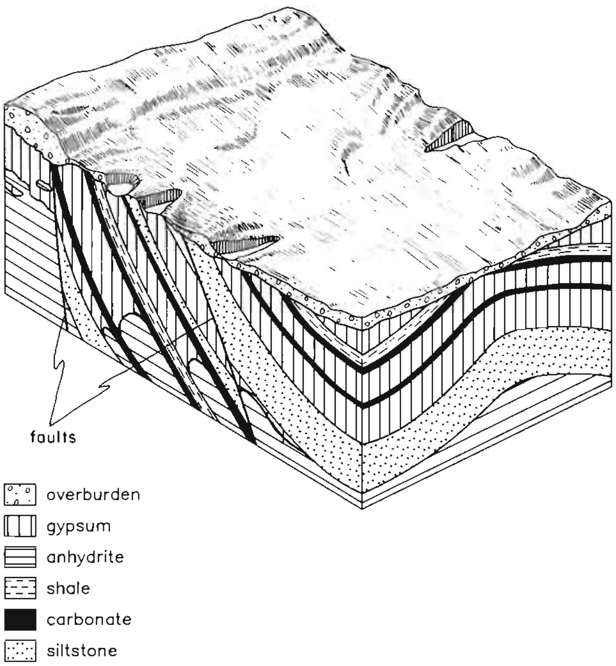


Figure 1-5. Deposit type 4 shows hydration enhanced by structural deformation (folding and faulting).

waste material is screened after crushing has occurred. Final products are dark and less pure than those generated from all previously described deposit types.

Type 5 occurs in the same strata near the base of Cycle 2 (B Subzone) as is seen in types 3 and 4, however the deformation and disruption of the beds is so complete that little remains of the original beds which made up the section (Fig. 1-6). The mechanisms which produced these deposits are still unclear; Boehner (in press) and Moore (1967) proposed faulting, either thrusting or decollement, and Howie (1986) proposed brecciation after the dissolution of halite horizons; perhaps both processes were involved. Whatever the mechanism, these deposits are generally large (+50 Mt thick), with +100 m depths of hydration. They are quite homogeneous in composition and thus are less complicated and more straightforward to mine than any other type. The grade and character of the gypsum is the same as in type 4, however all impurities (carbonates and clastics) must be removed in the crushing and screening process rather than by the selective mining practised in type 4. Occasionally, larger blocks of carbonate can be avoided in mining, but generally everything is removed from the quarry. National Gypsum (Canada) Ltd.'s East Milford Quarry in Halifax County is an example of type 5 and a similar deposit has been outlined nearby at Dutch Settlement, Halifax County, by Fundy Gypsum Company Ltd. Type 5 deposits are also known to exist adjacent to the Big Brook and Sugar Camp Quarries of Georgia-Pacific in Inverness County.

Undoubtedly there are more types of deposits of gypsum and anhydrite present in the variably deformed Windsor basins in the Province. Recognition of these deposit types as well as the stratigraphic and structural parameters and processes which have produced them should aid in extending the reserves of present quarries and help to delineate new ones.

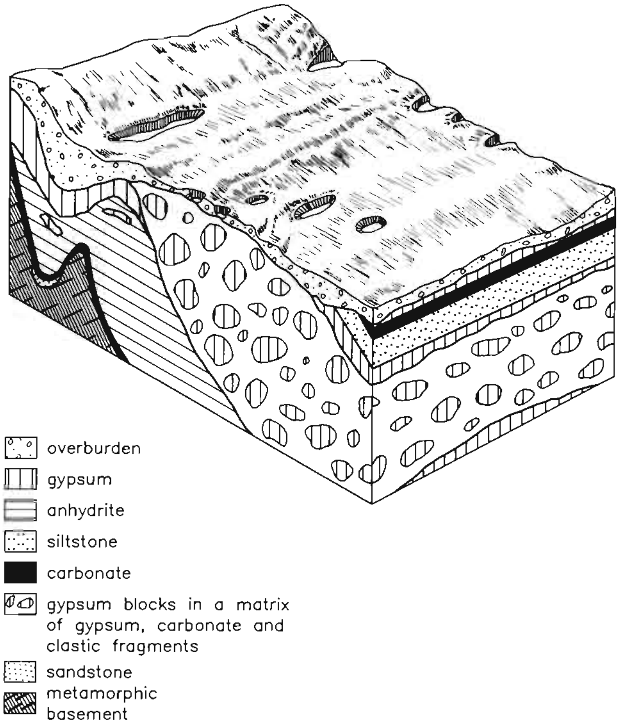


Figure 1-6. Deposit type 5 shows massive disruption of original beds allows hydration in excess of 100 m below present day surface.

HISTORY OF GYPSUM/ANHYDRITE MINING IN NOVA SCOTIA

How (1869) stated that gypsum operations had been active in the area of Windsor, Hants County, for 80-90 years. This puts commencement of the commercial gypsum industry at 1778-1788 and confirms that the gypsum industry has been active in Nova Scotia for over 200 years. In that time, the Province has become the most productive gypsum mining region in the world. Total Nova Scotia gypsum production recorded between 1862 and 1987 was more than 193 Mt with approximately 160 Mt produced between 1950 and 1987.

In the early years, the gypsum industry consisted of farmers who had gypsum/anhydrite exposures on their properties in the Windsor area. They would extract blocks of material and haul it by horse and cart to shipping points near Windsor. There, the soft or hard plaster (gypsum or anhydrite) was sold to local traders and shipped on vessels to various points along the eastern seaboard of the United States where it was commonly used as fertilizer.

During the early 1800s political developments occurred which were to change the face of the gypsum industry in the Province. In 1826 King George IV granted his brother the Duke of York the right to all minerals in Nova Scotia which had not previously been granted. These rights were, in turn, given to a group of his creditors who formed the General Mining Association. Public pressure on the legislative assembly of Nova Scotia in 1856 resulted in the sending of a delegation to petition the Parliament in London to rescind mineral grants given to the Duke of York. The legislative assembly introduced and eventually passed a bill in 1858 which repealed those mineral grants, however it exempted limestone, plaster (gypsum) and other building materials. The results of this were that gypsum has since that time belonged not to the government, but to the owner of the property and in 1858 individuals and companies began to purchase gypsum 'rights' from landowners (King, 1985).

Through the acquisition of quarries and gypsum rights the gypsum industry began to become consolidated into the hands of a small group of companies by the late 1800s. One direct result of this was the development of gypsum operations elsewhere in the Province (i.e. Cape Breton Island) at the end of the nineteenth century. During this period technological advances occurred in the industry which lead to increased productivity in the quarries. In 1882 a locomotive was first used in the Windsor area to haul stone from the quarry to dockside replacing horse drawn carts. In 1885 a commercial process was developed to retard the set of gypsum plaster. The first calcining mill in Nova Scotia for the commercial production of plaster was constructed in Windsor in 1888 by the Windsor Plaster Co. (a plant which is operated today by Domtar Gypsum). The Great Northern Mining Company built the Province's second plaster mill at Chéticamp, Inverness County, in 1907. It operated sporadically until it was finally closed in 1926. Overburden stripping using a steam shovel was first carried out in the Windsor area in 1908. Prior to this, it was blasted down with the stone and sorted in the quarry. A third plaster mill was constructed at Grassy Cove just north of Iona, Victoria County, in 1914. It was operated by the Iona Gypsum Company until its closure in 1933 (King, 1985).

In 1918 a process was developed in the United States to sandwich a layer of plaster between two sheets of paper to form plasterboard (Schroeder, 1970). Large scale production took ten more years but this product revolutionized the construction industry and in doing so, changed the gypsum production industry of Nova Scotia. By the 1930s the vertically integrated, multinational corporations which dominate gypsum production in the Province, began to acquire most of the quarries and gypsum rights that they now hold. Economy of scale prevailed as quarries became larger and more productive; small operations closed. Equipment became larger and more sophisticated as demand for more stone and cheaper stone grew and grew. By the late 1930s most of the companies presently involved in the gypsum business in Nova Scotia had established their positions for the next 50 years or more.

Currently in excess of 7 Mt of gypsum and anhydrite are produced in Nova Scotia annually (Vagt, 1989). Of this material 99.8% is exported to foreign (United States) and domestic markets for secondary processing. Four companies producing from six quarry sites account for 99.3% of total production. Heavy mobile equipment is used to drill, blast, load, haul, crush and move material from the quarry to loadout facilities. Three unit trains and a fleet of trucks transport products from the quarry to company owned shipping facilities from which company owned and chartered vessels take gypsum and anhydrite to market. Gypsum and anhydrite production has evolved into a large scale, capital intensive, highly mechanized business; with little apparent similarities to the original operations run by the farmers of eighteenth century Hants County.

PRESENT DAY OPERATIONS

Six companies were quarrying Nova Scotia's gypsum and anhydrite in 1986 including: National Gypsum (Canada) Ltd., Fundy Gypsum Company Ltd., Georgia-Pacific Corporation, Little Narrows Gypsum Company Ltd., Domtar Gypsum and Nova Construction Company Ltd. (Fig. 1-7). These operations produced 6.5 Mt of gypsum and anhydrite in 1987 and employed 486 people (Nova Scotia Department of Mines and Energy, 1988).

National Gypsum is the largest producer, quarrying in excess of 3.0 Mt in 1987 at the largest producing gypsum quarry in the western world situated at East Milford, Halifax County (Nova Scotia Department of Mines and Energy, 1988). Following crushing and screening at East Milford, the gypsum is transported by Canadian National Railway 42 km to Burnside, Halifax County. On the average three 'unit trains' carrying

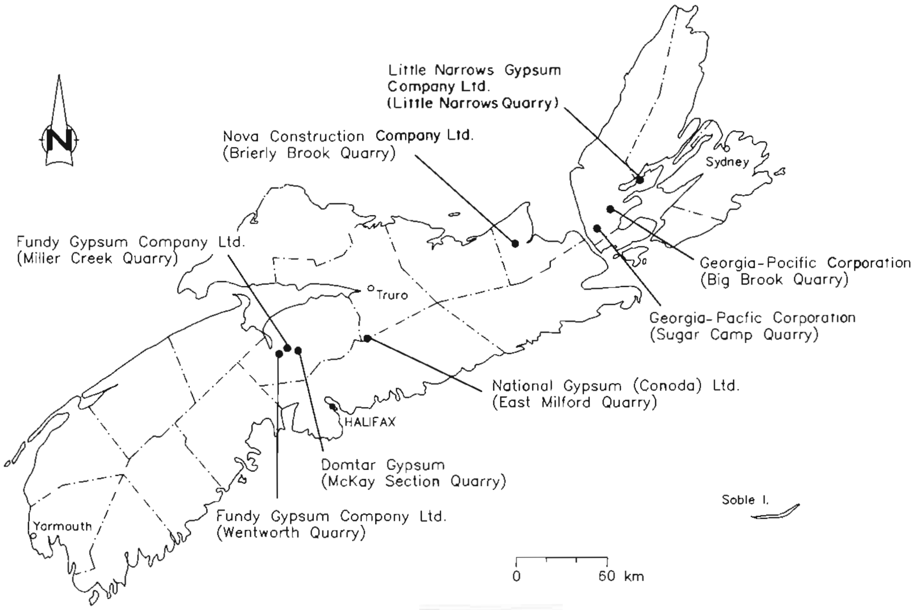


Figure 1-7. Present day gypsum and anhydrite operations.

4500 t each make the trip to National's loading facility at Wrights Cove on the eastern side of the Bedford Basin each day. Upon their arrival at this facility each boxcar is dumped and the gypsum is transferred by a stacker to a large stockpile and in turn it is loaded onto company owned or chartered ships at its loading dock. These ships, generally between 18 000-27 000 t capacity, are loaded from the stockpile by a movable conveyor system which works at up to 4000 t per hour.

Fundy Gypsum runs two separate quarrying operations in the Windsor, Hants County area, which produced a total of 1.6 Mt of gypsum and anhydrite in 1987 (Nova Scotia Department of Mines and Energy, 1988). Production at Wentworth, Hants County, is unique in that both white gypsum and anhydrite are produced using its sink-float (heavy media) beneficiation plant. These products are shipped 16 km along the Dominion Atlantic Railway (Canadian Pacific Railway) to Fundy's shipping terminal at Hantsport. The Miller Creek Quarry at Mantua, Hants County, generates most of Fundy's gypsum production. Its dark gypsum is crushed and screened, then shipped 24 km by rail to the Hantsport facility. The Hantsport loading terminal is unique in that its 11.9 m tidal range permits a maximum of three hours in which to load up to 15 000 t of rock during high tide. Twin conveyor-loaders with movable booms can load ships at a rate of 6500 t per hour, allowing ships to dock, load and depart on the turning tide.

Georgia-Pacific Corporation has its active quarry at Big Brook and is developing a new quarry at Sugar Camp, both in Inverness County. In 1987 it produced 0.86 Mt of gypsum (Nova Scotia Department of Mines and Energy, 1988) which, after crushing and screening, were shipped 32 km by Canadian National Railway to its loading terminal at Point Tupper. Production from its new quarry is hauled by truck instead of rail to Port Hawkesbury. Due to its location on the ice free, deep water Strait of Canso, Georgia-Pacific's loading facility can accommodate ships up to 30 000 t. A fixed discharge conveyor loads its company owned vessels at a rate of 2300 t per hour.

Little Narrows Gypsum also produces both gypsum and anhydrite. The total output for 1987 was 1.2 Mt from its quarry at Little Narrows, Victoria County (Nova Scotia Department of Mines and Energy, 1988). A new quarry, presently under development, is located just to the east of the operating quarry. After crushing and screening, the rock is moved by conveyor to a covered stockpile beside its dock on St. Patricks Channel. Company owned and chartered vessels capable of carrying up to 25 000 t of rock are loaded by a movable conveyor system. Channel restrictions in the Big Bras d'Or Channel limit the size of vessel able to ship out of Little Narrows and winter ice on the Bras d'Or Lakes can also be a problem some years.

Domtar Gypsum of Windsor operates a small quarry in McKay Section, Hants County, with 1987 production amounting to just over 11 000 t of gypsum (Nova Scotia Department of Mines and Energy, 1988). Domtar is the only Nova Scotia operation that undertakes any processing of gypsum. Its small calcining plant produces a variety of plaster finishing products and 'gypcrete'.

The newest production operation in the Province is that of Nova Construction at Brierly Brook, Antigonish County. Its production is aimed at the spot market and therefore is sporadic.

ALTERNATE UTILIZATION

Although Nova Scotia's gypsum/anhydrite industry has been operating for over 200 years, most of the material produced in the first 120 years was used as fertilizer or soil conditioner, a market which, although small, still exists today. The use of gypsum plasters became popular in the late 1800s and that market, again a small one, exists today as is evidenced by one small plaster mill (Domtar Gypsum) in operation as well as white gypsum produced and exported by Fundy Gypsum from its Wentworth Quarries, Hants County. The bulk (+90%) of today's gypsum and anhydrite production in the Province goes to the wallboard and cement industries, 98% of which was exported out of the Province in 1987.

Two motives were behind the efforts to investigate alternate utilization of gypsum and anhydrite as part of this investigation. Primarily, new uses could lead to expanded or new production of these commodities. This in turn could lead to additional secondary processing of gypsum and anhydrite within the Province. At the outset of this project, approximately 0.30% of total production was processed in Nova Scotia to any degree more than coarse crushing, 0.18% was used in cement and 0.12% calcined for plaster products.

The first area investigated was in agricultural applications of gypsum and anhydrite. Information was gathered on scientific research in this field, potential contacts in regional government agricultural agencies and potential markets (Luke, 1986). Provincial Department of Agriculture representatives indicated that with minimal research they could support gypsum/anhydrite use as: (1) a Ca and S source, (2) an additive that would help break up certain types of clay-rich soils, and (3) a product which would help remove salts from dykeland soils or heavily irrigated soils. They believed that an initial market of 20 000 tpa existed for such applications within the Province. The utilization potential has not yet been researched or exploited. As yet no companies have been willing to support the local research required to develop these markets.

Investigations into the use of local anhydrite as a cementitious construction material in underground coal mines have proven far more fruitful. Literature research conducted in early 1986 established that anhydrite had been used in West German coal mines for up to 15 years as a construction material for gateside packs, stoppings and roadway backfill. A project was then proposed jointly by researchers at the Technical University of Nova Scotia (TUNS) and the Nova Scotia Department of Mines and Energy (NSDME) to determine whether indigenous anhydrite could be used in the same way in the coal mines of Cape Breton.

A contract was awarded to TUNS in late 1987, funded by the Canada-Nova Scotia Mineral Development Agreement (MDA) which was administered by the Canada Centre for Mineral and Energy Technology (CANMET). Samples of anhydrite from four sites were tested using information from the limited literature available from West Germany and the United Kingdom. Laboratory testing consisted of uniaxial compressive strength tests on various anhydrite/accelerator/water mixes which were cast in moulds to form blocks to simulate in situ loading conditions in underground coal mines. Since no standards for these materials currently exist in North America the TUNS efforts were greatly assisted by information gained from the West German coal mine research institute, Bergbau-Forschung GmbH.

Results of this research (Jones et al., 1989) showed that, if properly prepared, anhydrite from Little Narrows, Victoria County, could perform as well as, or better than, known European anhydrite products. During the latter stages of work at TUNS interest was shown in the project by Cape Minerals Ltd. of Sydney, Cape Breton County. Cape Minerals Ltd. promoted the idea to the Cape Breton Development Corporation (CBDC) as a means of replacing more expensive imported materials such as hardwood chocks and portland cement-based monolithic packing materials presently being used.

A surface trial of the anhydrite-based gateside pack system was carried out early in June 1989 by Cape Minerals Ltd. Further subsurface trails were undertaken in October and November of 1989 with promising results. If the anhydrite cementitious material proves suitable, it may be instrumental in CBDC's plans to extend the lifespan of the Lingan Colliery by introducing pillarless retreat mining in the near future. Should this transpire >10 000 tpa of anhydrite could be used at Lingan Colliery for gateside packs alone. Additional tonnages might also be used in other construction applications at Lingan and this could easily double if it were used at other CBDC mines.

The success of this research has led to additional research on anhydrite at TUNS. TUNS is currently investigating the possibility of making wallboard products from anhydrite plasters as well as using anhydrite plasters in selflevelling flooring systems (i.e. poured floors). Further studies have already been proposed to investigate the potential use of anhydrite materials in backfill applications in base metal mining where it would replace portland cements at half the cost. Other possibilities include possible replacement of cement in other applications where the material is not exposed to excessive moisture. Potential for marketing anhydrite-based cementitious products, especially to replace, in part, portland cement products, looks very good at this time.

Other possibilities which should be investigated in the near future are the establishment of a mill in Nova Scotia which could utilize the high purity, white gypsum of Cycle 1 (A Subzone) to fabricate plaster and ground gypsum products. New technology in plasters have developed which produce stuccoes having an extended shelf life and therefore can be transported longer distances to markets. Very finely ground, uncalcined white gypsum is finding more and more applications as a filler in plastics, adhesives and paints as well as a coating for papers in pH sensitive processes (Luke, 1990).

In general the prospects for developing additional markets for gypsum and anhydrite look very good. New products developed and fabricated in the Province should help to defray much of the predicted reduction in overall production as byproduct gypsums become more widely accepted in the marketplace.

BYPRODUCT GYPSUM

Slowly but steadily, gypsum produced as a byproduct of the production of phosphoric, hydrofluoric and citric acids, from the desulphurization of flue gases and the treatment of wastes from titanium dioxide and sulphide ore smelting is replacing natural gypsum in the world's marketplaces. At present the greatest source of byproduct gypsum is the phosphate industry which, on the average, generates 4.5 t of phosphogypsum for every 1 t of P_2O_5 or 117 Mt worldwide in 1985 (Roskill Information Services Ltd., 1987). Although not yet of similar magnitude, the production of flue gas desulphurization (FGD) gypsum, spurred on by concern over the reduction of acid rain emissions, will eventually surpass that of phosphogypsum that is currently produced worldwide.

Japan has been at the forefront of byproduct gypsum utilization since the mid 1970s. Limited natural resources there were gradually replaced by phosphogypsum during the early 1970s and eventually all production from natural sources ended in 1977. Japan is still one of the few countries which utilizes phosphogypsum although it produces only 1.6% of the world's total phosphogypsum. Also, during the mid 1970s the Japanese government actively supported research and development work on FGD techniques and FGD gypsum utilization. By 1987 (Hara, 1988) Japan's total supply of gypsum was 7.3 Mt of which phosphogypsum was 29.7%, FGD gypsum 23.6% and imported crude gypsum 23.6%. Gypsum demand, mainly for the cement and rapidly growing wallboard industries, consumed 98.0% of available supplies.

Elsewhere around the world byproduct gypsum utilization has been much slower in developing. By 1983 environmental regulations were emplaced in West Germany to force the reduction of SO_2 and NO_4 emissions in power plant stack gases. Highly dependent on coal fired generating stations, the West Germans will be producing 2.5 Million tpa of FGD gypsum by 1990. Restrictions on dumping of this product in landfills or waterways has forced the utilities to produce gypsum suitable for consumption by the cement and plaster industries. At present small amounts of FGD gypsum are being used, mainly by the cement industry, but Stein (1988) believed that in the long term over 1.4 Million tpa will enter the markets in West Germany chiefly to replace declining natural resources. Little information is available in phosphogypsum production and consumption in this country.

Although moving towards reducing emissions, regulations in this regard were not introduced in the United Kingdom until June 1988. There the Central Electricity Generating Board (CEGB) which produces most of the United Kingdom's electrical power uses mainly coal fired units. Halstead (1988) indicated that by the year 2000 they will have 20 000 MW of FGD plants operating or under construction. These would generate approximately 5.0 Million tpa of FGD gypsum. At present United Kingdom sources produce over 1 Million tpa of phosphogypsum and current consumption of gypsum is in the vicinity of 4 Million tpa. Production from natural sources, of 3.2 Mt in 1985 (Roskill Information Services Ltd., 1987), is supplemented by imports from Ireland, Morocco and Spain. CEGB is presently investigating potential markets for their FGD gypsum as well as researching environmentally acceptable ways to handle the material which cannot be sold.

In the United States phosphogypsum has long been a problem in the phosphate producing areas of the country (Florida, North Carolina, Idaho, Tennessee, Montana and Utah). In 1987, 37 Mt of phosphogypsum were produced by this industry, most of which was added to the existing 300 Mt presently in stockpiles. Reduction of power plant emissions is also on the increase in the United States and although Environmental Protection Agency regulations have not yet been enacted, coal fired utilities are presently moving to reduce their emissions through FGD retrofitting or new FGD equipped installations. Mosher et al. (1988) suggested that by the turn of the Century 100 000 MW of generating capacity in the United States will be equipped with FGD systems having the potential to produce 25 Million tpa of FGD gypsum. This alone would be adequate to supply all of the country's gypsum requirements now supplied by domestic (14.9 Mt) and foreign sources (8.8 Mt) without even considering the available phosphogypsum.

Information is not readily available for byproduct gypsum production and consumption from other nations. However, as with natural gypsum production, every country in the world is at present producing or has the potential to produce, byproduct gypsum. Ever increasing environmental public awareness is forcing governments around the world to establish regulations regarding coal fired generating stations' emissions. Landfills and ocean and river dumping of chemical byproducts are also becoming the subject of regulations.

Under normal market conditions byproduct gypsum would have to compete with natural stone on an even playing field. Most of the gypsum produced in Nova Scotia is shipped to wallboard plants located along the eastern seaboard of the United States and most of the mines and plants are owned by two large multinational companies. Power utilities which produce FGD gypsum must invest substantial amounts of money to produce a gypsum that is acceptable to the wallboard producers which will increase the cost of this gypsum. They must also provide a steady volume and quality of gypsum to the wallboard plants, however variations occurring in the generating patterns and coal supplies can greatly affect these parameters. Finally, shipping FGD to wallboard plants must not increase the cost beyond the point where it can compete with natural gypsum. Much of the electrical generating capacity in the eastern United States is not located close to present wallboard plants.

Rising public awareness with regard to the environment will undoubtedly change governmental regulations and eventually force increased utilization of byproduct gypsum. This, in turn, will negatively affect markets for natural gypsum, especially imported stone. Two factors will greatly influence this scenario and thus the effects on Nova Scotia's gypsum mining industry: changing markets and changing technology. With regard to markets, all companies now faced with generating and disposing of large volumes of byproduct gypsum are researching alternate ways to utilize this product. New gypsum-based products and new processes to utilize gypsum are under investigation with new developments being found constantly.

Public concerns over CO_2 emissions are spurring on further research into clean coal technology. Recent developments in the field of coal gasification have resulted in a number of techniques under the heading of Integrated Gasification Combined Cycle (IGCC). This process is cost comparative with FGD equipped regular coal fired generating plants. It is significantly more efficient in generating power, using less fuel and producing fewer emissions (CO_2, SO_2 and NO_x). Gases are cleaned within the system and so generate less particulate emission. This technology is usually set up to recover elemental sulphur instead of byproduct gypsum which in all normal FGD systems is generated at the expense of producing even more CO_2.

The United States Bureau of Mines forecasts a gradual decline in the United States phosphate industry as environmental concerns and domestic production costs gradually increase while cheap foreign imports increase. The United States phosphate industry representatives do not always agree with United States Bureau of Mines predictions, however these producers of phosphogypsum are also investigating ways to utilize this byproduct.

Accurately predicting the future of byproduct gypsum production and its effects on natural gypsum production is virtually impossible. Technological changes are occurring so rapidly that processes in place today may be outdated in the near future. Public concerns about the environment may force dramatic changes in the industries that are producing byproduct gypsum. Without doubt byproduct gypsum will eventually displace some of the natural gypsum presently being consumed. To what extent this will take place in those North American markets supplied by Nova Scotia's mines is uncertain. The implementation of FGD technology will take time during which new technologies such as IGCC may surpass conventional scrubbing techniques. It is conceivable that gypsum production from Nova Scotia's mines might not suffer any prolonged decline caused by developments in byproduct gypsum.

ORGANIZATION AND CONTENTS OF THIS REPORT

Chapters 2-12 contain descriptions and preliminary evaluations of all those deposits and occurrences of gypsum or anhydrite, or both, which have been investigated during the course of this study. Map 91-1, an overall location map, can be found in a pocket at the back of this report. Without doubt some occurrences do exist that have not been examined. Some areas along the Atlantic Coast in Lunenburg County, underlain by Windsor Group sedimentary rock, purportedly show karst topography and minor gypsum exposures which could not be verified. Several small exposures of gypsum, known to exist along the northern shore of the Minas Basin, east of Parrsboro, Cumberland County, were not investigated. As additional information is gathered from around the Province, the data accumulated in this study will be updated.

The following descriptions have been organized by county with each county's occurrences presented in alphabetical order. Appendix 1 is a list of occurrences ordered by NTS. Each occurrence has been assigned an individual reference number by which it is identified on Map 91-1 found in the back of this volume as well as on each county location map. Appendix 2 is a list of occurrences ordered by reference number. These reference numbers are also used to locate analytical data for hand specimens and drill core samples pertaining to individual occurrences which can be found in Appendix 3. Hand specimens were collected from all exposures visited during field seasons 1986 to 1989 inclusive. Samples were sent to the Minerals Engineering Centre at the Technical University of Nova Scotia for analyses. Samples submitted were air dried, pulverized and tested for moisture, combined water, SO_3 and NaCl. The percentages of gypsum and anhydrite were then calculated. The NaCl content was determined because of its deleterious effects in the gypsum wallboard manufacturing process. Drill logs of previously completed drillholes which were sampled, that pertain to specific occurrences, can be found in Appendix 4.

Each description combines information gathered from surface exposures, assessment reports, drill logs, open file reports and theses accumulated between 1985 and 1989. Also, each writeup includes an appraisal of the resource potential of the occurrence.