PROVINCE OF NOVA SCOTIA

DEPARTMENT OF MINES

Memoir No. 1

GYPSUM AND ANHYDRITE IN NOVA SCOTIA

by

N. R. Goodman

HALIFAX, N. S.
1952

HON. A. H. MCKINNON, Q.C. — MINISTER

J. P. MESSERVEY, BSC., M.E. — DEPUTY MINISTER

PROVINCE OF NOVA SCOTIA

DEPARTMENT OF MINES

Memoir No. 1

GYPSUM AND ANHYDRITE IN NOVA SCOTIA

by

N. R. Goodman

HALIFAX, N. S.
1952

HON. A. H. MCKINNON, Q.C. — MINISTER

J. P. MESSERVEY, BSC., M.E. — DEPUTY MINISTER

Gypsum operations at Dingwall.

TABLE OF CONTENTS

PREFACE

This report comprises a considerable portion of a thesis which was submitted at Oxford University for the degree of Doctor of Philosophy. In the thesis work a study was made of gypsum and anhydrite in the field and at the same time a series of experiments was conducted in the laboratory to support the field investigations. These experiments, which are essentially a study of the stability ranges of the various forms of calcium sulphate, are still being carried on and the results will be published at a later date. The present report covers the field work and the description of the collected specimens.

Individual reports are made on the areas examined. This policy has meant considerable descriptive repetition but it is convenient for persons interested in specific areas and also, it gives an especially accurate picture of the difficulties encountered when investigating these deposits which are amazingly similar. When so many deposits are examined, however, differences are noted and it is a thought from one locality and an idea from some other which, when all put together, yield some sort of picture concerning the origin.

The same general plan has been used in these descriptions. A brief note on the topography is followed by an interpretation of the structure and any other feature of special interest. The gypsum and anhydrite rocks are then described as they appear in hand specimen and also in thin section.

No restrictions were placed on the direction in which the research should progress. The research grant from the Nova Scotia Department of Mines was given without stipulation as to the work to be undertaken and at Oxford the interest is as great in pure as applied science.

ACKNOWLEDGEMENTS

Appreciation is expressed for the research grant from the Department of Mines of Nova Scotia and to Mr. Messervey, the Deputy Minister of Mines, and his staff who at all times were most helpful and co-operative.

All persons connected with the gypsum industry were most kind and went out of their way to be of assistance. It is regretted that it is not practicable to register my thanks to each individually.

Special thanks are extended to Mr. R. Charlick, manager of Victoria Gypsum Company Ltd., who voluntarily contributed a grant to defray expenses and who, on all occasions, offered hospitality and general assistance beyond any reasonable expectation.

Sincere thanks are offered to Mr. R. G. MacLean who was my assistant during the 1948 field season. His untiring efforts contributed greatly to the success of the work.

The author was most fortunate in being able to act as guide to Dr. W. T. Schaller of the U. S. Geological Survey when he visited Nova Scotia to examine the borates in the calcium sulphate beds, and would like to acknowledge the pleasure, stimulation and knowledge gained by this association.

The laboratory work was carried out at Oxford University. I am much indebted to Professor J. A. Douglas and the members of his staff for their co-operation, and to Mr. R. C. Spiller, the University Reader in Mineralogy, who acted as supervisor during this study.

Finally, sincere thanks are due to my friend and former teacher, Professor G. Vibert Douglas for the suggestion which initiated this work and for his interest and co-operation in every way.

INTRODUCTION

Gypsum deposits in Cape Breton Island "will 'ere long, become an article of considerable traffic with our republican neighbors, who know how to appreciate its value." This prophecy by Richard Smith and Richard Brown in the chapter on geology included in Haliburton's (1829) account of Nova Scotia has indeed come true.

Nova Scotia, Canada's southeasterly province, is made up of the Nova Scotia mainland and the Island of Cape Breton. Although one of the smallest of Canada's ten provinces it supplies approximately 80% of the gypsum produced by the Dominion, and almost all is shipped to the United States.

The production is from the extensive deposits found in the Windsor formation, which is Lower Carboniferous in age. The gypsum localities cover an area of approximately 625 square miles (Messervey, 1926) but geologically interpretable outcrops are not numerous. The Nova Scotia gypsum deposits were the first discovered in North America and were known from the time of the earliest settlers. (Cole, 1930). Smith and Brown (Haliburton, 1829) mention gypsum associated with red sandstone occurring as extensive beds and name numerous gypsum localities both on the mainland and Cape Breton Island. They establish also that commercial gypsum was produced from these beds prior to 1829 for they record that quarries at "Plaister Cove" in the Gut of Canso had long been known and "until lately" had exported large quantities of gypsum annually.

Since this early start the gypsum industry has steadily increased its output, with the exception of war years when production was reduced, and in recent years the annual tonnage has been a figure in the millions. Despite this increased production there has been a drop in the number of operating quarries and at the time of writing only five quarries are actively engaged in the production of gypsum. Nova Scotia's geological maps record numerous quarries which are now abandoned, and many are relics of the time when the method of working the gypsum was little more than scratching the surface, and transportation by horse and cart to some sea-port. The quarry operators in many cases were the farmers who happened to have gypsum outcrops on their land, and for this type of production there was little need for large tonnages. Only those outcrops conveniently located to sea transportation were worked. In this century, however, the methods have changed and large scale quarrying has replaced the small producer. These modern methods require extensive deposits of recoverable rock in order to justify their expense.

Although these extensive and valuable deposits have been known and operated for many years, little detailed geological or mineralogical work has ever been done on them and this suggested the need for the present investigation.

The generally accepted view concerning the origin of these beds is that they were laid down as anhydrite from a concentration of marine water in a lagoonal Windsor Sea, and that the anhydrite was subsequently altered to gypsum by the action of surface waters. Little more is ever said about the relationship of gypsum and anhydrite. Originally the writer accepted this view without reservations and the intention was to collect representative samples and concentrate on the minerals associated with the deposits and their paragenesis.

As has been stated, the gypsum-anhydrite deposits have their origin in Lower Carboniferous times. Since then Nova Scotia has been subjected to major mountain building forces which have folded and faulted the rocks of all the major systems represented in the province. If the beds were laid down as anhydrite, and the gypsum formed as a result of hydration, this must be regarded as a continuous process and the quantity of gypsum increasing each day. Indeed, it was several times suggested to the writer that the Pleistocene glaciers must have removed all the soft gypsum, and therefore our present gypsum represents the amount of hydration since that time. The anhydrite beds have been folded by the abovementioned diastrophism and post-deformation alteration to gypsum would be expected to be roughly parallel to the present surface, where the anhydrite could be hydrated by the action of meteoric waters, regardless of the attitude of the beds. At the start of this study the bedded nature of the deposits was constantly evident and the indication that the gypsum-anhydrite contact was not a chance horizon, but a surface having a definite relationship to the structure, suggested that the origin of these beds was more complicated than the accepted view and so the major problem in this investigation became the consideration of the origin of the gypsum and the related processes.

The economic importance of establishing the origin of the deposits is immediately apparent. If hydration of anhydrite has accounted for the entire mass of the gypsum, then the depth of the alteration is a purely chance thing and the economic possibilities of an area can only be ascertained by a comprehensive, and costly, drilling schedule. On the other hand, however, if there is a structural relationship, then normal geological maps could be prepared and have some meaning, and these, plus the information from selected drill holes, would permit the producers to estimate tonnage and conduct a planned operation.

The chief sources of information have been exposures as cliffs along the sea, lakes or rivers; road and rail cuttings; and shallow drill holes. This has been, therefore, essentially a surface study. The need for study of a deep drill hole which penetrates the Windsor beds is obvious and the grindings from the Sun No. 1A hole at Nappan have been made available to the writer and this work will constitute a future report.

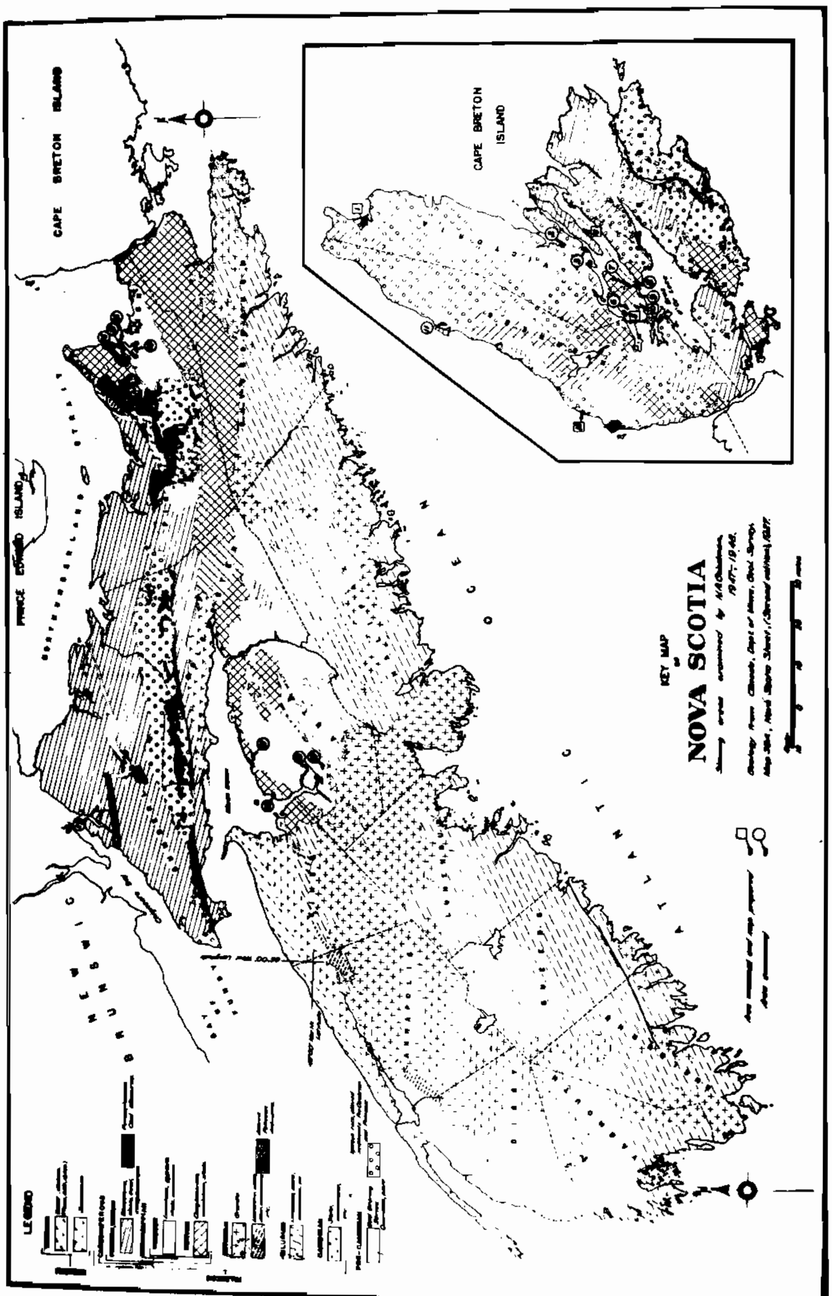
It is perhaps unfortunate that in this study any area where there was a great deal of gypsum without anhydrite was of little interest as a source of information although it might well be of major economic importance. The areas selected are those which were most convenient and lent themselves most readily to examination and some degree of structural interpretation.

PREVIOUS WORK

The first published geological report concerning Nova Scotia was that of Alger (1827). He was primarily interested in the iron ores of Annapolis County but did mention various mineral and rock occurrences. The following year Jackson and Alger (1828) published an account of the geology of Nova Scotia and a map of the province. The map showed a number of gypsum localities and in a publication the next year (Jackson and Alger, 1829) "gypsum of practical worth" was reported at the head of Minas Basin.

Gesner (1836) included a description of the limestone and gypsum of Windsor and Antigonish and recognized their stratigraphic relationship but thought the gypsum and limestone were younger than the Coal Measures. He named the varieties of gypsum as selenite, snowy gypsum, branchy gypsum and alabaster. The deposits are described as "affording an inexhaustible source of commerce . . . The gypsum is largely exported to the United States: and although it affords but a small profit to the carrier at present, the time is advancing when it will become of material importance and open a new source of Provincial wealth."

Lyell (1843) established that the gypsiferous formation was pre-Coal Measures and because of its association with fossiliferous shales carrying **lepidodenda** and **calamites** was Lower Carboniferous. Lyell believed the gypsum was an original and integral part of the stratified series. He mentions abundant proof of contemporaneous trap rock, which led him to the conclusion that the production of gypsum in the Carboniferous sea was connected with volcanic action in the form of heated vapours, hot mineral springs, or other agencies accompanying submarine igneous activity. He appreciated that much of the so-called "gypsum" was the anhydrous calcium sulphate.


CAPE BRETON ISLAND
PRINCE EDWARD ISLAND
KEY MAP
NOVA SCOTIA
LEGEND

Map No. 1

Dawson (1845) gave an account of the "coal formation" and the "gypsiferous formation" and gave their stratigraphical relationship. Two years later he established that the Lower Carboniferous was made up of a gypsiferous formation and an estuarine or lacustrine formation (Dawson, 1847). He postulated an origin similar to that of Lyell and considered that the gypsum was formed by the action of sulphuric acid conveyed by rivers into estuaries which were rich in calcium carbonate from shells. The sulphuric acid was derived from the oxidation of iron pyrites which was abundant in the older formations.

How (1868) in his Mineralogy of Nova Scotia included a chapter which dealt thoroughly with the gypsum industry of the Windsor district and included descriptions of the borate minerals which he had discovered in association with the gypsum and anhydrite. Natroborocalcite (ulexite) and cryptomorphite were first described by How in 1857 and silicoborocalcite in 1868. The last mentioned was appropriately renamed howlite (Dana, 1868). How also reported the presence of glauber salt (mirabilite), common salt (halite) and aragonite in the gypsum beds.

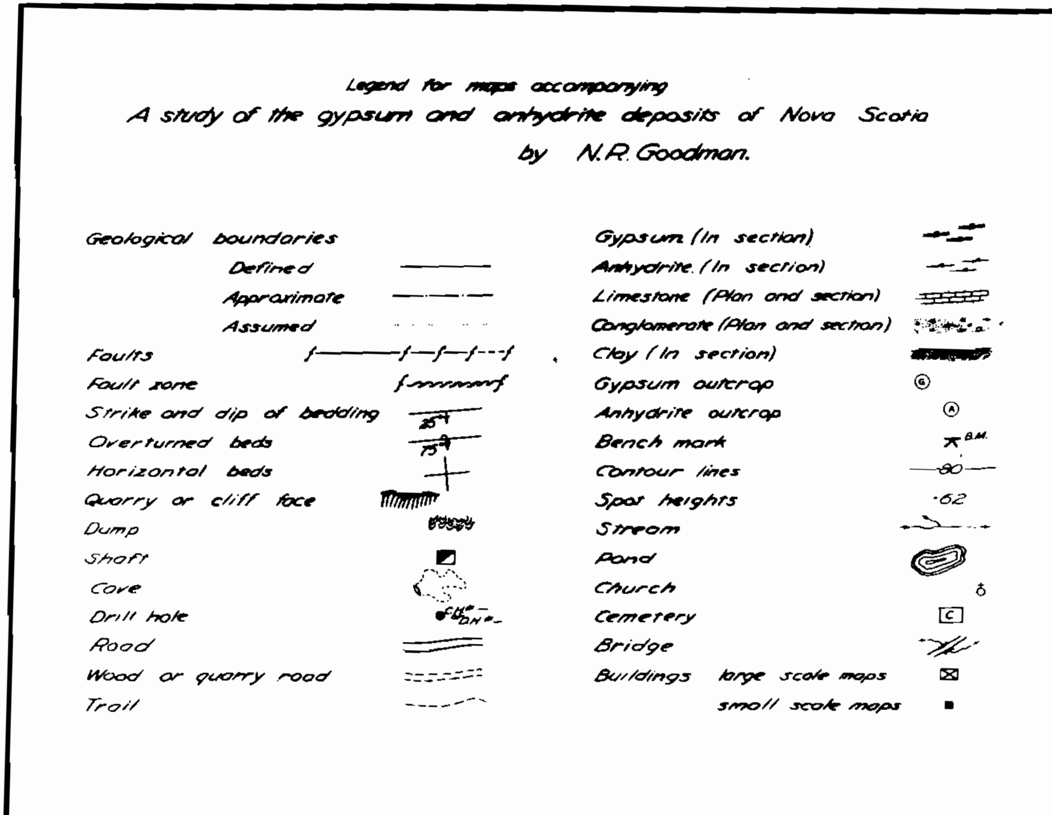
The members of the Canadian Geological Survey have done considerable work in Nova Scotia. Their study of the gypsum deposits, however, has consisted chiefly of general observations concerning various localities and establishing the stratigraphic position of the calcium sulphate beds with little or no detailed work on separate deposits.

Jennison (1911), Messervey (1926) and Cole (1930) have dealt with the general and technical aspects of the gypsum industry.

Wilder (1928) considered that the calcium sulphate was originally deposited as anhydrite and subsequently altered to gypsum along fissures and where exposed to moisture under normal atmospheric conditions. He refers to a hole drilled at Cape North in 1927 which passes through 25 feet of gypsum and then 275 feet of massive anhydrite.

Bell (1929) established the stratigraphical position of the gypsum-anhydrite beds in a detailed study of the Horton-Windsor District. He has considered the origin of the calcium sulphate deposits and states that they were laid down in the Windsor Sea as anhydrite, which was later altered to gypsum.

Bailey (1935) examined the Cheticamp deposits and came to the conclusion that gypsum had been altered to anhydrite as a re-


Legend for maps accompanying
A study of the gypsum and anhydrite deposits of Nova Scotia
by N.R. Goodman.
Geological boundaries
Defined
Approximate
Assumed
Faults
Fault zone
Strike and dip of bedding
25
Overturned beds
75
Horizontal beds
Quarry or cliff face
Dump
Shaft
Cave
Drill hole
Road
Wood or quarry road
Trail
Gypsum (In section)
Anhydrite (In section)
Limestone (Plan and section)
Conglomerate (Plan and section)
Clay (In section)
Gypsum outcrop
Anhydrite outcrop
Bench mark
B.M.
Contour lines
80
Spot heights
·62
Stream
Pond
Church
Cemetery
C
Bridge
Buildings large scale maps
small scale maps

Legend

sult of pressure. (Bailey's evidence is considered in the writer's report on Cheticamp.)

Although relatively little detailed work has been done on the Nova Scotian gypsum and anhydrite deposits there is no scarcity of references to calcium sulphate. Wilder (1928) points out that the Department of Gypsum and Lime of the American Bureau of Standards lists over 5,000 references. The reasons for this large number are threefold: (i) the widespread occurrence of both gypsum and anhydrite, (ii) the numerous technical studies based on the many uses of both sulphate minerals and (iii) the contradictory evidence concerning the properties of the various forms of calcium sulphate. No attempt has been made at a complete analysis of the literature on a world-wide basis but only on the references pertinent to the Nova Scotia deposits.

GYPSUM TOPOGRAPHY

Areas underlain by gypsum but not covered by a heavy mantle of overburden are pitted by depressions variously referred to as "plaster pits", "pot holes", "kettle holes" or "sink holes". These holes occasionally exceed a depth of 40 feet (Photograph 1). They are usually filled with clay or other debris and the skeletons of trapped animals, unable to climb the steep sides of the pit into which they had fallen, have been reported. The cavities are so numerous that in most cases the rim of one hole is tangential with those of its neighbors.

The origin of this type of topography would seem quite obviously to be due to solution effects by surface waters, perhaps assisted by the action of frost and ice. On several occasions, however, it was suggested to the writer that these features are true "pot holes", ground out of the soft gypsum by boulders swirled around in the waters of streams which once flowed over the area. This opinion was based on the fact that there were usually several large stones in the bottom of the holes. There are the following objections to the theory: (i) The pits do not always have boulders and are sometimes completely free of debris. (ii) The pitted areas do not trace out the course of a river but are much more suggestive of a lake than a turbulent stream. (iii) Where streams have been observed flowing over gypsum there has been no tendency to develop "pot holes" in the degree necessary to produce the observed form. (iv) The deep well-like nature of the depressions makes it illogical to suppose that a stream could produce such abrasion thirty feet or more below its bed without breaking down the walls between neighboring holes. (v) The walls were vertically and not horizontally grooved, although it is probable that if horizontal markings were present they would subsequently be removed by solution effects. (vi) Dawson 1868) observed that when "plaster pits" encountered a horizontal or nearly horizontal joint they went no deeper for the joint served to carry off waters from the holes.

It is the opinion of the writer that these pits are the result of solution effects, and should be called sink holes or solution cavities.

The solutions responsible for the sink holes have frequently flowed along joint planes, carrying with them clay and sand and forming clay "veins".

If the country has a deep top-soil or boulder clay cover sink holes do not develop and the area normally has low rolling hills.

DESCRIPTION OF GYPSUM AND ANHYDRITE AREAS

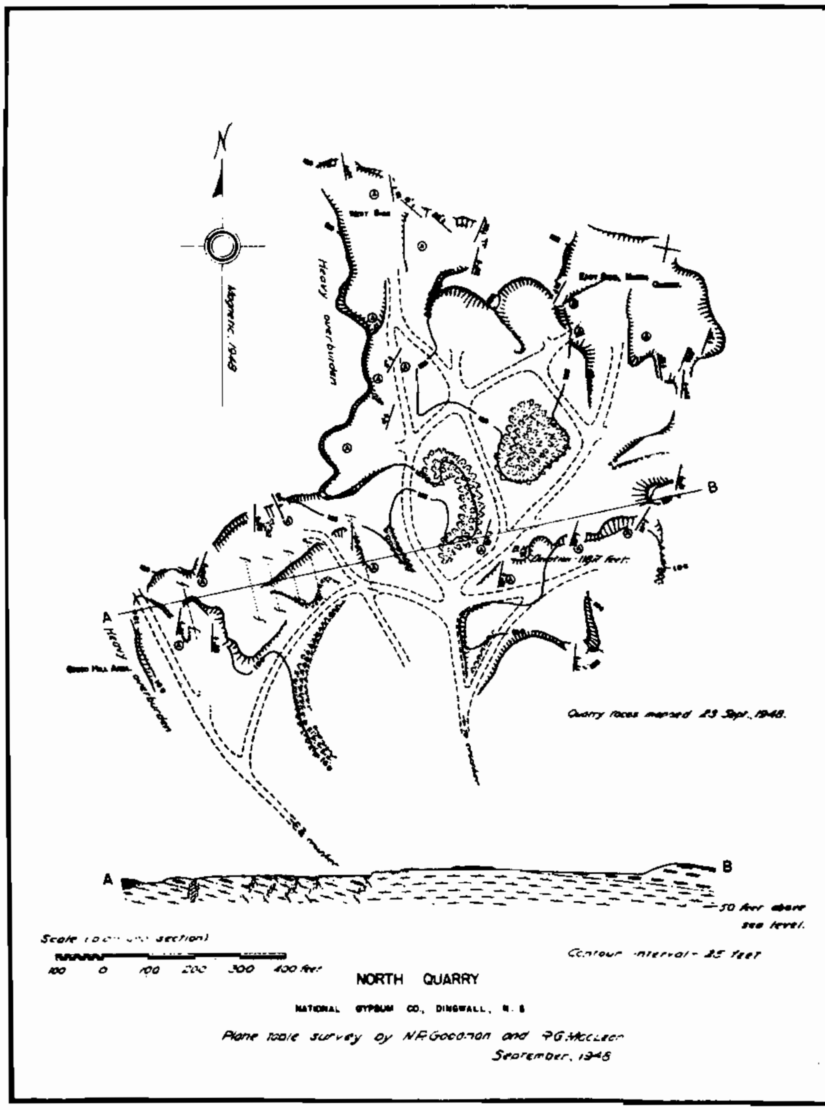
(i) Dingwall, Victoria County

Extensive deposits of gypsum occurring at Dingwall, Victoria County, are operated by the National Gypsum Company. Several large quarries extend over a considerable area but only the North Quarry was mapped in detail (Map No. 2).

The Windsor beds of this area slope gently from the shores of the Atlantic and lie on the flank of the Pre-Cambrian Highlands of Cape Breton (Frontispiece).

Bedding is marked by thin dark limestone members and can be readily observed both in the gypsum and anhydrite (Photograph 2). The anhydrite forms a gentle dome which slopes off in all directions with dips of 5°—10°. In the Green Hill Area the anhydrite has been broken by a number of small faults but the actual number of these is not known. The position of the extreme easterly and westerly ones is definite and that there are others is thought probable because of areas of gypsum on the quarry floor between anhydrite exposures. The faults are confined to the anhydrite, or if they do run into the gypsum they do not penetrate it to any marked degree. In this area it can definitely be observed that the gypsum-anhydrite contact is parallel to the bedding in both members (Photograph 3). The limestone beds in both the gypsum and anhydrite are similar in colour, thickness and degree of contortion.

The gypsum and anhydrite have reacted to deformation as might be expected of two materials of such different relative strengths. Where they have acted as a block the conformability is preserved. In many cases, however, folding and faulting of the re-


A
B
Heavy overburden
Magnetic 1948
Quarry faces mapped 23 Sept., 1948.
50 feet above sea level.
Contour interval 25 feet
100 0 100 200 300 400 feet
NORTH QUARRY
NATIONAL GYPSUM CO., DINGWALL, N. S.
September, 1948

Map No. 2

latively competent anhydrite and sometimes intense folding of the soft gypsum have obscured any original structural relationship (Photograph 4).

Several grey-green beds, averaging three feet in thickness, occur on the east side of the map area. These dark horizons conform to the bedding in the white gypsum and the floor anhydrite. They will prove useful as marker beds in any future mapping in this area. In thin section the rock was found to be a microcrystalline intergrowth of gypsum with numerous minute inclusions of clay material.

On the north face of the West Side of North Quarry, a horizon, approximately three feet thick, contains nodules of yellowish-brown calcite which is replacing white howlite. This is the first time that borates have been noted at Dingwall. The nodules, which are not numerous, vary in diameter from 1 - 6 cms. Only when freshly broken is there any real amount of howlite, which forms the soft core of the nodule. Usually the specimens found on the surface are calcite lined cavities but a few small howlite crystals can be found. Joint planes in this area have irregular patches of shiny, white ulexite. The howlite horizon is parallel to the observed bedding which suggests that it is syngenetic. The ulexite, occurring along the joints, is epigenetic, resulting probably from alteration of the howlite.

The gypsum rock, in thin section, is a colourless intergrowth of anhedral crystals varying in size from .05 - .2mm. This groundmass is crossed by dark bands of limestone but frequently these beds are so contorted and broken that the calcareous material merely forms irregular masses, disseminated through the gypsum. Rhombs of dolomite are often present. Secondary gypsum occurs in two forms: (i) as subhedral to euhedral crystals from .2 - .4 mm. and, (ii) as veins of microcrystalline, colourless gypsum. These veins are irregular in shape and fork or terminate without apparent reason. Although of the same texture as the gypsum of the groundmass, the veins are readily observed for they have a dark margin of fine-grained calcareous material.

The anhydrite, in thin section, is a colourless, granular intergrowth of crystals .03 - .05 mm. in size. There are larger crystals (.4 - .6 mm.) which exhibit cleavages. Irregular bands of dark limestone, which are contorted and frequently broken, traverse the groundmass. Irregular veins of colourless, microcrystalline gypsum, containing many inclusions of anhydrite and limestone, have replaced the anhydrite rock in some sections.

(ii) St. Ann Bay Area, Victoria County

Outcrops of calcium sulphate occur at many points in the St. Ann Bay Area, Victoria County. The exposures along the northwest side of South Gut were convenient for examination and proved to be of considerable interest.

The beds have a northeast-southwest trend and form the low hill parallel to the Cabot Trail for several miles southwest of St. Ann. They are cut into a small scarp by the stream draining into South Gut and form a line of sharp cliffs, 15 - 20 feet in height, on the northwest side of this body of water. These cliffs are made up of a blue-grey anhydrite in which bedding is clearly marked by thin bands of dark limestone (Photograph 5). The strike of the beds is parallel to the shoreline and the dip, which is particularly constant, is 25° northwest.

Only at the headland ½ mile north of the Cabot Trail bridge across South Gut is there gypsum in any quantity. The northwest side of this promontory is made up entirely of white gypsum and on the point itself the gypsum-anhydrite contact can be seen. This contact is parallel to the observed bedding.

The gypsum, in thin section, is a colourless, microcrystalline intergrowth which occasionally has a radiating, fibrous habit. It is traversed by contorted and broken beds of dark limestone or has irregular patches of calcareous material disemminated through it. Anhedral crystals of celestine, varying in size from .2 - .3 mm., are common.

The anhydrite, in thin section, is an intergrowth of anhedral and lath-shaped, radiating crystals of distinct spherulitic habit. The anhedral crystals are colourless and vary in size from .03 mm to larger crystals exhibiting cleavages. The anhydrite groundmass is traversed by distorted bands of dark limestone and is cut by irregular veins of colourless, microcrystalline gypsum. The veins have numerous anhydrite and limestone inclusions.

(iii) Bevis Point, Victoria County

Calcium sulphate forms a spectacular line of scarps at Bevis Point, Victoria County. The outstanding feature of this occurrence is an undulating dark band across the cliff face. Hayes (1930) has used a photograph of Bevis Point to illustrate original bedding planes in gypsum but he is probably using the term "gypsum" as synonomous with calcium sulphate, for these cliffs are almost entirely anhydrite. This bed is a dark, laminated limestone which is slightly folded and has a gentle dip to the south.

The limestone is interbedded with a grey anhydrite. Bedding is not readily observed and the anhydrite is highly contorted and in one horizon, above the limestone, it has a "mashed" appearance. This was apparent on a weathered surface as a peculiar irregular pattern (Photograph 6). On the easterly tip of Bevis Point there is evidence of relative movement between the limestone and overlying anhydrite (Photograph 7). The anhydrite has moved north relative to the limestone but it was not established which was the active side.

In thin section the anhydrite has a marked spherulitic habit with radiating, lath-shaped crystals ranging up to .5 mm. in length. Only in one section did calcareous material suggest a bedded origin. In all others the beds were broken and contorted and in some areas of the sections the appearance of the limestone and anhydrite suggest that the rock has been sheared. Anhedral crystals of celestite were observed in all sections. This mineral occurs as groups of four or five crystals but they were not connected to indicate a bed or vein. The celestite crystals vary in size up to 1 mm. and have grown around lath-shaped anhydrite. The groundmass is cut by irregular veins of microcrystalline gypsum.

At no point was the gypsum-anhydrite contact observed but the topography indicates that gypsum overlies the anhydrite. Small quarries have been operated on the south side of Bevis Point and the district is called Plaster Mines. The gypsum to the south is in accord with the view that the contact is conformable to the gentle south dip observed in the limestone.

Outcrops in the fields of the farm occupying Bevis Point were also examined. These were a light grey anhydrite mottled by irregular patches of dark limestone. This rock is entirely similar, in thin section, to that of the Point. It has distinct spherulitic habit; is traversed by broken and deformed beds of limestone; has large anhedral crystals of celestite which have formed around the anhydrite; and is cut by veins of microcrystalline gypsum.

Approximately 2¼ miles from Ross Ferry there are cliffs, estimated to be 40 - 50 feet in height, on the west side of Bevis Brook. Bedding was not observed but a sample, considered to be representative of the rock, was collected and identified as "gypsum". When examined in thin section the field identification was found to be wrong and the rock was spherulitic anhydrite.

It is interesting to note the similarity between the anhydrite of Bevis Point, Bevis Brook, and South Gut, St. Ann Bay. Lithological evidence suggests a correlation of these beds which would indicate a broad anticlinal structure with a gentle plunge to the west. If this anticlinal structure is correct the gypsum quarries and outcrops occur stratigraphically above the anhydrite.

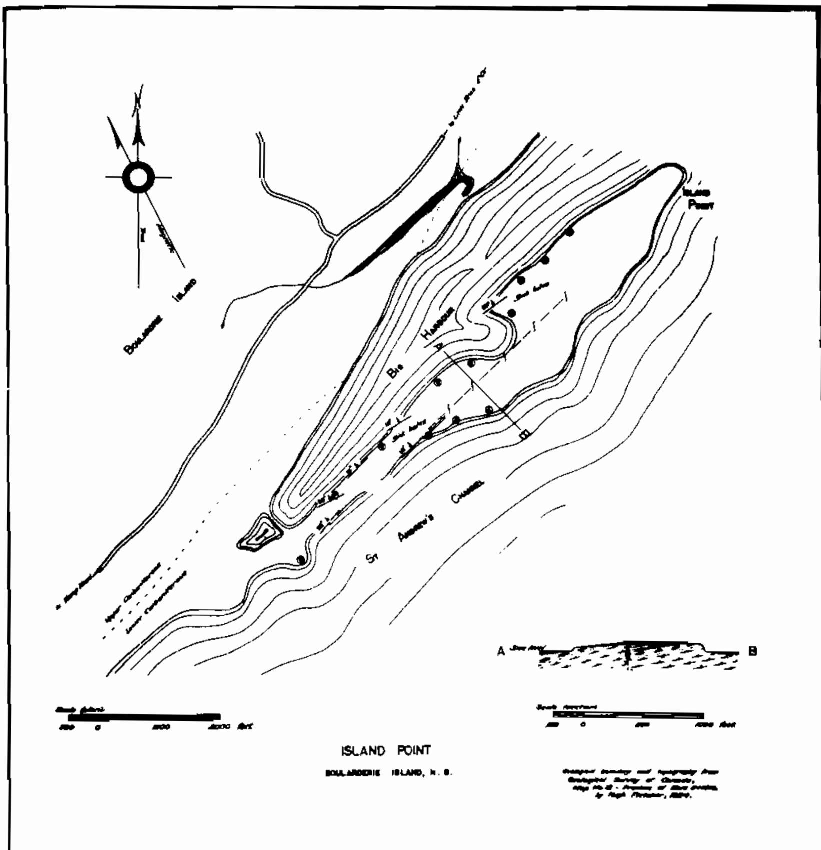
(iv) Island Point, Boulardrie Island, Victoria County

Island Point forms a mile and a half long finger of land jutting into the Bras d' Or Lakes from the southeast side of Boulardrie Island, Victoria County. The point is low and in few places exceeds an elevation of 50 feet above lake level. The area is thickly wooded and the surface pitted by sink holes, some of which are thirty feet or more in depth. The loss of gypsum as a result of these holes represents a considerable loss of quarry rock and will seriously affect tonnage calculations. Cole (1930) estimated 10 million tons of gypsum above sea level but in the writer's opinion this figure is much too high. An estimate of 1 - 2 million tons is a better figure.

Map No. 3 was drawn from the Geological Survey of Canada Map No. 12, Province of Nova Scotia, 1884, and was used as a base map for field observations. The structure, as shown on the section, is idealized. The fault is postulated solely on the evidence of boulders of a coarse, dark limestone breccia. It was unfortunate that the time available did not permit detailed study of this area and so it was not possible to establish the strike and dip of the fault, the movement it represents, or whether it runs the length of the point.

The north side of Island Point is an almost continuous line of white gypsum cliffs. The gypsum at the southwest end of the exposures has a high percentage of interbedded limestone and the bedding is readily observed (Photograph 8). Lower horizons are exposed to the northeast and the percentage of limestone decreases and the gypsum has developed small folds and a nodular appearance suggestive of pressure (Photograph 9). The beds strike northeast - southwest and dip 20° northwest.

The gypsum on the south side of Island Point is similar in character to that on the north and the strike and dip of the beds is the same. Cliffs occur at the southwest end of the area but for approximately a half mile to the northeast there are no outcrops. At one place, however, there are large boulders of limestone breccia. The covered stretch ends with an outcrop of dark fossiliferous limestone overlying a ten foot thick bed or argillaceous material which in turn overlies white gypsum. The gypsum is 50 - 60 feet in thickness and is underlain by blue-grey anhydrite. The beds strike 70° mg. and dip 10° northwest, which is about the same as the observation on the north side. It was not established whether this gypsum is the same as that exposed on the other side of the point. The



Map No. 3

thickness exposed on the north side is considerably greater than that between the clay material and the anhydrite but, when dealing with such plastic material, this evidence would hardly be sufficient to justify the decision that the beds could not be correlated.

Despite the lack of definite evidence concerning the postulated fault and the correlation of the beds, it has been established that the beds dip constantly to the northwest and that only at the stratigraphically lowest point is anhydrite exposed. It has also been established that the gypsum-anhydrite contact is in accord with the general structure. It would be most helpful to establish, by means of a drillhole, the lateral extent of the gypsum overlying the anhydrite and further confirm that the gypsum-anhydrite contact conforms to the observed bedding.

In thin section the gypsum rock is an intergrowth of colourless, anhedral crystals. (.03 - .08mm.) Contorted and broken beds of dark limestone traverse the sections. Dolomite rhombs are disseminated through the gypsum. In the nodular gypsum the microcrystalline core is surrounded by a dark calcareous rim. Numerous subhedral to euhedral porphyroblasts of secondary gypsum were noted. The larger porphyroblasts were frequently zoned, with the zoning marked by dark calcareous inclusions. The margin of the large gypsum crystals is sometimes fringed by tiny ones growing normal to the crystal faces (Photograph 10).

One interesting section showed a gypsum porphyroblast replacing nodular gypsum. The secondary gypsum had inclusions of the calcareous rim and these were perfectly aligned with the material outside the crystal. This suggests that, if the nodules represent deformation, the secondary gypsum was formed after this deformation. It also suggests that there has been little or no deformation since that time for the crystals would either show signs of strain or have moved relative to the groundmass. The gypsum rock is cut by veins of secondary microcrystalline gypsum which also cut the porphyroblasts. The sequence of events in this case would appear to be (i) deformation of gypsum, (ii) formation of secondary gypsum porphyroblasts and (iii) the whole being veined by fine-grained gypsum.

The anhydrite in thin section varies from fine-grained to larger crystals having distinct spherulitic habit. The groundmass is traversed by dark limestone or there are irregular masses of calcareous material disseminated through the rock. The anhydrite has been replaced by both gypsum porphyroblasts and veins of microcrystalline gypsum. The gypsum of both replacement effects contain numerous inclusions of the original anhydrite.

(v) Little Narrows, Victoria County

Gypsum deposits on the south side of St. Patrick's Channel, approximately one mile east of the village of Little Narrows, Victoria County, are operated by the Victoria Gypsum Co. Ltd. These deposits were worked some years ago by the Great Bras d'Or Gypsum Company.

The Windsor rocks in this area slope gently from the shore of St. Patrick's Channel, rising to rounded, heavily wooded hills. The relatively smooth topography is broken by abrupt cliffs of gypsum, 40 - 50 feet in height. Much of the land which is underlain by gypsum is deeply pitted by sink holes.

The Magazine and Thompson Area (Map No. 4)

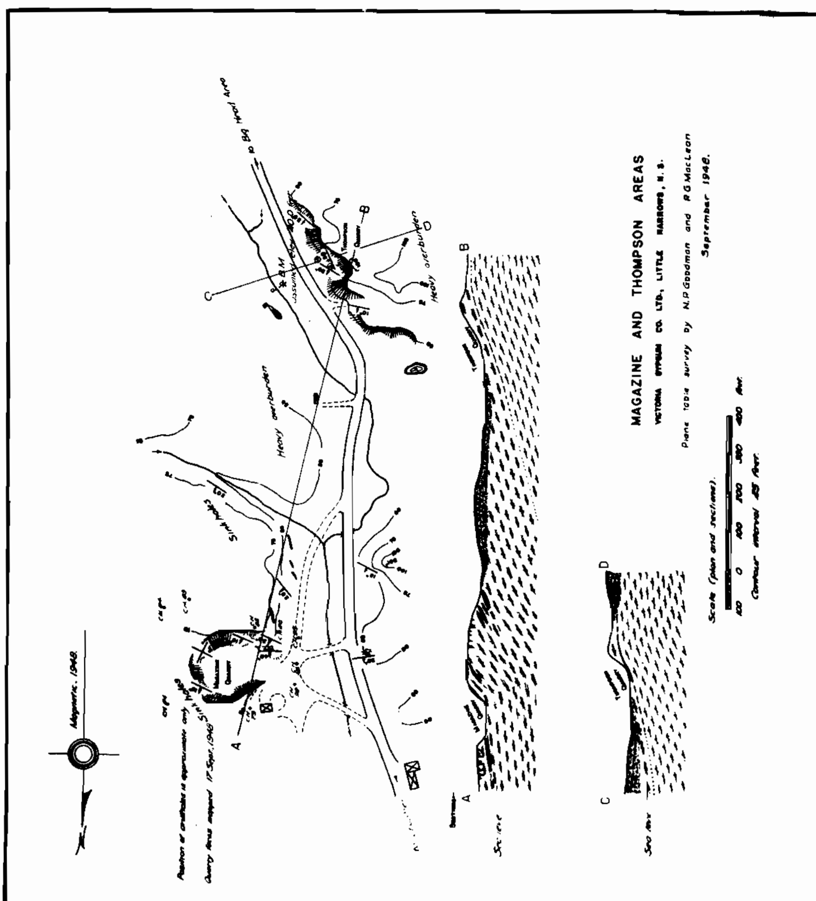
The Magazine and Thompson quarries are approximately 1½ miles from the village of Little Narrows, and are the first quarries to be seen when turning south off the road from the village.

The Thompson Quarry is a 450 foot face, west of the quarry road, ranging up to 65 feet in height. Operations were suspended when blue-grey anhydrite rose sharply from the quarry floor.

The gypsum is a white compact rock with bedding distinctly marked by thin dark limestone beds. The anhydrite also has clearly marked bedding. The bedding planes in the gypsum and anhydrite are parallel to each other and to the gypsum-anhydrite contact.

The beds in the southern end of the quarry strike northwest-southeast and dip 30° northeast, but to the north they have been warped into an isoclinal fold which plunges north and here the strike is east-west and the dip 10° north.

A one foot thick bed of white gypsum occurs 25 feet above the anhydrite at the north end of the quarry (Photograph 12). The gypsum of this bed is similar to that forming the bulk of the quarry. Immediately overlying the white bed there is a brownish member, several inches thick, which in thin section was found to be composed of large anhedral gypsum crystals which were cloudy due to anhydrite and calcareous inclusions. Above the brown member the gypsum was again white and similar to the rest of the quarry. It could not be established whether the brown gypsum represents the alteration of an anhydrite bed, or is a gypsum vein which has preserved original anhydrite and then not been affected when the rest of the anhydrite was altered to gypsum. The latter suggestion, however, seems more unlikely for the brown crystals have a sharp


MAGAZINE AND THOMPSON AREAS
VICTORIA GYPSUM CO. LTD., LITTLE NARROWS, N.S.
Plane table survey by N.P. Goodman and R.G. MacLean
September 1948.
Heavy overburden
Heavy overburden
Magnetic 1948.

Map No. 4

margin against the white gypsum and suggest a vein which formed in the existing rock.

The gypsum is a colourless intergrowth of anhedral crystals (.03 - .15 mm.), traversed by dark contorted beds of limestone or has the calcareous material disseminated through the groundmass.

The anhydrite is a granular intergrowth of anhedral crystals, which vary in size from .05 mm. to 1 mm. The large crystals exhibit the characteristic anhydrite cleavages. Contorted and broken limestone beds traverse the anhydrite intergrowth.

North of the Thompson Quarry is a covered interval of 500 feet but beyond this the structure can be picked up on the exposures east and west of the quarry road. The dips, in general, are to the north but there is evidence of folding and they vary from 40° to horizontal.

The Magazine is a small, horseshoe-shaped quarry with faces 30 - 40 feet high. The ground above the quarry have been cleared of a heavy mixed growth and is deeply pocked by sink holes.

No anhydrite was observed during the current investigation nor has any been reported from the operations in this quarry. The positions of the drill holes shown on the map are approximate only. The logs of these holes, which were very kindly made available by the Victoria Gypsum Company, show some anhydrite and much clay but the anhydrite must be some distance below the quarry floor.

Several dark, fossiliferous limestone beds occur interbedded with the gypsum. The most prominent of these was three feet thick and could be traced for 200 feet along the strike of the bed. The limestone has slicken-sides and is somewhat fractured with the fragments cemented by colourless gypsum. The fossils are small gastropods and lamellibranchs. .

The character of the gypsum in the Magazine Area is completely different to that in the Thompson Quarry. The rock is bedded but in this case the bedding is marked by crystals of clear, dark coloured gypsum which represents alteration of the original rock along the bedding planes. The gypsum varied from fine-grained and brownish to large anhedral crystals. The dark colour is caused by calcareous and argillaceous inclusions.

The Lower Head to Rim-Workings

The Lower Head, Middle Head, Big Head, and Rim Workings form a long continuous quarry face, varying in height from 15 - 50 feet, approximately 3,000 feet south of the Thompson Area.

The gypsum, which is white and mottled by brown limestone, has been quarried to the blue-gray anhydrite which forms the quarry floor. The floor is highest in the Middle Head area and falls off gently to the north and south. Bedding was not readily observed but where noted the gypsum was relatively flat-lying. Lenses of anhydrite occur in the gypsum close to the contact with the underlying rock.

A series of samples was cut at five foot stratigraphic intervals up the face of Big Head. Rectangular solids were cut from these samples and their specific gravities determined to establish whether there was a progressive change, representing varying degrees of alteration, from original anhydrite.

The following are the results of the determinations:

No.	Feet above anhydrite floor	Specific Gravity
1	0 + 40	2.26
2	0 + 35	2.29
3	0 + 30	2.28
4	0 + 25	2.27
5	0 + 20	2.28
6	0 + 15	2.26
7	0 + 10	2.28
8	0 + 05	2.29
9	0 + 00 (Anhydrite)	2.95

The specific gravity of the gypsum rock is practically constant and definitely not a progressive lowering from bottom to top. In view of the limestone, which is invariably present, it is surprising that the determinations were all lower than the 2.32 of pure gypsum. This undoubtedly due to the porosity of the rock.

The gypsum is an intergrowth of anhedral crystals (.03 - .1 mm.). There is some gypsum of fibrous habit with the fibres up to 0.4 mm. in length. The groundmass is traversed by contorted and broken beds of dark limestone or has patches of calcareous material disseminated through it.

The anhydrite is a granular intergrowth of anhedral crystals varying in size from .05 - .2 mm. with larger crystals (1 - 2 mm.) exhibiting the anhydrite cleavages. Patches of limestone occur through the rock. The anhydrite is cut by irregular veins of microcrystalline gypsum.

Western Area

A thick deposit of gypsum, approximately ½ mile west of the Magazine Quarry, makes up the Western Area.

The surface is very rough with the area in the immediate vicinity of the quarry deeply pitted with sink holes. A thirty foot deep valley runs east-west to the north of the quarry face. On the eastern end this feature consists of several deep holes with gypsum bridges, forming barriers across the valley, separating the depressions.

The most interesting physiographical feature was a cave in the gypsum, but this has now been removed by the quarrying. The cave extended 140 feet from the entrance to its farthest extremity. It consisted of three north-south tunnels connected by three which ran east-west. The trace of a joint plane or small fault was visible on the roof along the length of each tunnel. There was water in the bottom of the cave but it was not flowing at any appreciable rate. The origin of the cave is considered to be caused by (i) the joints, (ii) the fractured nature of the gypsum, (iii) the action of frost and ice, and (iv) solution effects.

The gypsum is white and mottled by dark limestone, but it is difficult to observe bedding in the limestone. Only in a few places was it possible to take strike and dip measurements and these were not sufficient to work out the detailed structure. All the observed dips were gentle, the steepest being 25°. The anhydrite floor forms a shallow trough at the entrance to the quarry and rises to the southeast. There are numerous patches of anhydrite in the gypsum close to the contact and this is a considerable nuisance in the quarry operations. Such strike and dip observations as were possible did indicate that there was a definite relationship between the bedding in the gypsum, the bedding in the anhydrite and the contact between these two rocks.

The gypsum is jointed and, in many places, fractured. Strike and dip measurements were taken on the prominent joint planes and there is evidence of regularity, but insufficient observations were available to work out the complexities in this jointing system. It does suggest, however, that in some areas is might be possible to gain valuable information by such observations. The following were some of the measurements:—

North end of quarry	Strike	Dip
Most prominent	75° mg.	85° south
Second	150° mg.	50° west
Third	110° mg.	80° south
South end of quarry		
Most prominent	175° mg.	70° west
Second	70° mg.	85° south
Cave		
Most prominent	160° mg.	85° west
Second	75° mg.	Vertical

The gypsum rock is a colourless, microcrystalline intergrowth of anhedral crystals with patches of dark calcareous material disseminated through the groundmass.

The anhydrite is a granular intergrowth of fine-grained (.05 - .15 mm.) and somewhat larger (1 mm.) anhedral crystals. The rock is cut by microcrystalline gypsum veins and traversed by contorted and broken beds of dark limestone.

Shore outcrop (½ mile southwest of Little Narrows)

A small outcrop on the shore of St. Patrick's Chennel, ½ mile south west of the Little Narrow's fe..y proved to be of particular interest. Bedding is readily apparent in the rock which is made up of thin limestone and gypsum bands. The beds have been highly folded (Photograph 13).

It is considered that the gypsum is primary, or if altered from anhydrite the change occurred prior to the deformation. It is possible, of course, that the gypsum was formed by veining but, if so, the veins must have been pre-folding. The gypsum does not cut across the limestone beds and if it was formed by vein action after the folding there must certainly have been minor fractures across the limestone beds which would have been ready avenues for the vein-forming solutions. The lensing nature of the gypsum also suggests that it was pre-folding, for it is the structure one would expect when such a soft material was subjected to the forces which have been operative in the area.

The rock has been replaced by secondary gypsum porphyroblasts. The largest noted beIng 17 x 13 mm. These crystals are filled with inclusions of calcareous and argillaceous material. They have preserved the structure, for beddIng lines run from the groundmass to the porphyroblast without being disturbed. The porphyroblasts show no evidence of strain and the preservation of the structure Indicates their post-folding formation.

(vi) Washabuck River, Victoria County

High gypsum cliffs form a spectacular series of outcrops extending for approximately four miles along the northwest bank of the Washabuck River. The general bearing of these cliffs is 30° mg.

A brief examination was made of the southwest end of these exposures. At this point the scarp was estimated to exceed 100 feet in height. The gypsum is white and banded by beds of dark limestone. The bedding is undulating but, in general, nearly horizontal. No anhydrite was observed.

The rock, In thin section, is a groundmass of colourless, microcrystalline gypsum traversed by contorted and broken beds of brown limestone. The gypsum in several sections has spherulitic habit. The possibility of thIs representing pseudomorphs of gypsum after spherulitic anhydrite was considered but no evidence was found to suggest that this observed texture was inherited.

The extent of these exposures, their thickness, the apparent absence of anhydrite and the horizontal attitude of the beds indicates that this area represents a large tonnage of workable gypsum.

(vii) Iona, Victoria County

The investigated outcrops extend from a point approximately one mile northeast of the railway bridge at Iona to the abandoned quarry, once operated by the Iona Gypsum Products Company.

Bedding was only observed at one point and therefore it was not possible to map the structure. These beds dip steeply to the northwest. Three samples were cut across this outcrop at stratigraphic intervals of 35 feet. All three samples were cut from the same height above lake level and all three had the same exposure to the weather.

The two stratigraphically lower samples are identical. They are an intergrowth of colourless anhydrite of marked spherulitic habit.

Deformed and broken beds of limestone occur in the groundmass. The anhydrite is cut by veins of microcrystalline gypsum which have numerous inclusions of the replaced material.

The uppermost sample is microcrystalline gypsum with brown limestone. Disseminated through the gypsum are anhedral crystals of celestite varying in size up to 2 mm. The celestite is cut by gypsum veins.

(viii) Shore sections 2 miles southwest of Iona, Victoria County

Calcium sulphate is exposed in a railway cutting and as steep cliffs along the shore of the Bras d'Or Lake approximately two miles southwest of Iona, Victoria County. Of all the occurrences examined during this investigation, this was the most interesting and informative.

These outcrops are almost entirely a dark grey, fine-grained anhydrite, which has irregular patches of dark limestone disseminated through it. Some horizons are characterized by beds or series of beds of limestone. These beds are usually thin but vary in thickness up to several inches. The strike is 20 mg. and the dip vertical.

The vertical dip of the beds made this an ideal location to ascertain if the anhydrite passed into gypsum along the bedding. Two samples were collected along the strike on one horizon. The first was from lake level and the second from the exposure in the rail cutting, approximately 80 feet above the water level. Both samples were anhydrite cut by veins of microcrystalline gypsum but there was no suggestion that the sample from the cutting was altered to any greater degree. The anhydrite is a fine-grained intergrowth of colourless, anhedral crystals. The rock is granular with little suggestion of spherulitic habit.

White gypsum occurs at the western end of the exposure. The attitude of the beds make it possible to establish whether this is stratigraphically above or below the anhydrite.

Coarse, white anhydrite veins cut the limestone, the anhydrite and the gypsum. The age of this veining is not known but it is difficult to think of it as being recent. This anhydrite has been exposed to the weather and has to some extent been altered to gypsum but the alteration is relatively slight. A few millimetres below the surface the anhydrite is practically unaltered. The gypsum formed from the vein anhydrite is quite different in appearance to the gypsum rock. It is much whiter and free from the dark limestone which causes the mottled brown effect invariably present in the rock gypsum.

The most important single specimen collected shows the vein anhydrite cutting gypsum (Photograph 11). It is the writer's considered opinion that the gypsum existed as such prior to the formation of the vein. If the rock was anhydrite at the time of the veining it is impossible to understand why the rock should be altered by hydration at the exposed surface and the vein anhydrite remain unchanged. In thin section the gypsum and anhydrite are both cut by secondary gypsum veins. These pass across the anhydrite - gypsum contact and the order of events must have been: (i) formation of gypsum, (ii) development of anhydrite veins and (iii) the whole cut by gypsum veins.

Danburite, a calcium boron silicate, occurs in some of the anhydrite veins and also as small nodules disseminated through some horizons of the anhydrite rock. This is the first time this relatively rare mineral has been noted in these deposits. Danburite, which is a member of the topaz family, normally occurs in pegmatites and metamorphic rocks and so this occurrence is quite unique. The only known similar danburite is in Bolivia where the danburite occurs in dolomite and gypsum (Ahfeld, 1946). In the Bolivian occurrence, however, some of the danburite is as well developed crystals and it is associated with tourmaline. The danburite in the anhydrite veins is white and resembles unglazed porcelain. It forms botryoidal masses several inches across. Due to its insolubility the danburite nodules stand high on a weathered surface. The analysis on the original specimen indicated that this was a new mineral species but when more and larger nodules were collected a more accurate analysis was possible and this suggested the mineral was danburite. This suggestion has now been confirmed by X-ray powder photograph methods.

(ix) Shore section 4 miles southwest of Iona, Victoria County

Approximately four miles southwest of Iona there are calcium sulphate exposures in a railway cutting and as steep cliffs along the Bras d'Or Lake.

The scarp is made up of light grey anhydrite overlain by white gypsum.

The gypsum varies from granular and microcrystalline (.05 - .1 mm.) to fibrous habit. Irregular and broken beds of dark limestone occur with the gypsum. Secondary gypsum has replaced the rock as euhedral crystals of tabular habit.

The anhydrite varies from granular and fine-grained to distinct spherulitic habit with radiating crystals up to .5 mm. in length. It is interesting to note that this anhydrite is similar to that from the area northeast of Iona, but not to the anhydrite from the shore section two miles northeast, which is granular in habit.

(x) Ottawa Brook Quarry, Victoria County

The Ottawa Brook Quarry, now abandoned, was formerly operated by the Newark Plaster Co., Ltd.

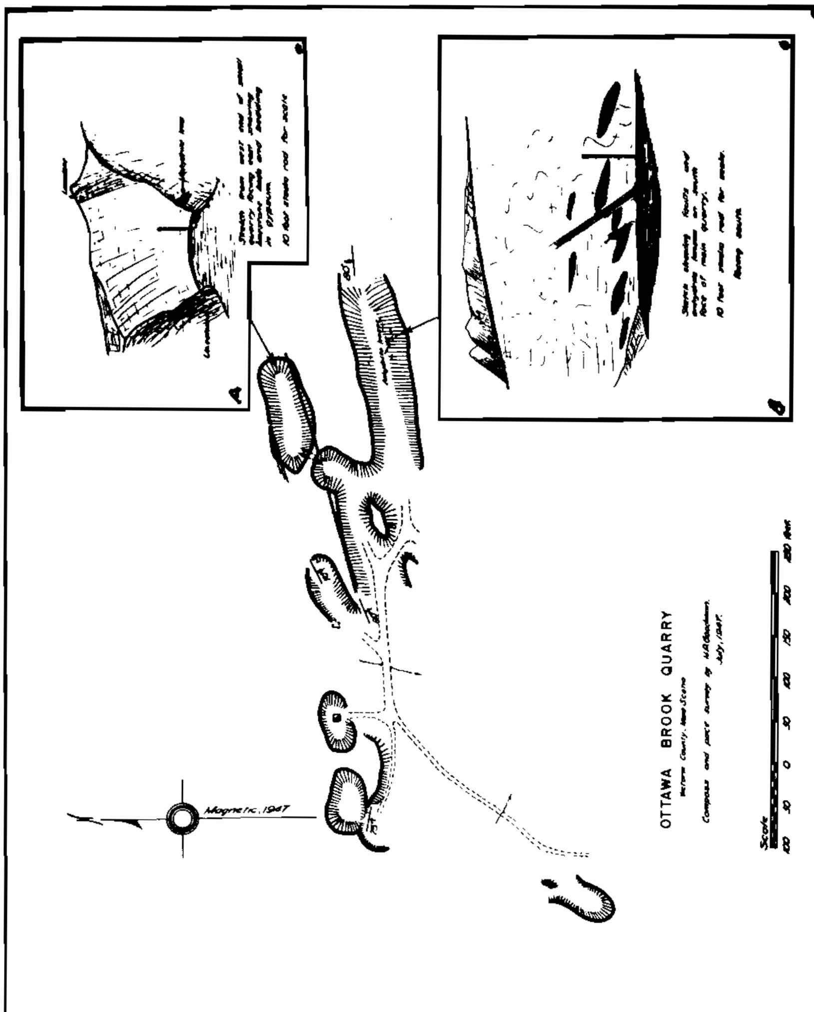
The main quarry consists of several parallel, narrow, trench-lime excavations with the quarry faces having a height of 40 - 50 feet (Map No. 5).

A number of dark broken limestone beds, dipping steeply south, form the north wall of the main quarry. The beds, whose thickness range up to several inches, have a strike parallel to the longitudinal axis of the quarry. Microcrystalline white gypsum occurs between the limestone beds but, although it appears to be interbedded, the possibility of the gypsum being epigenetic, either of vein origin or as an alteration product of anhydrite, could not be completely excluded.

Brown fossiliferous limestone forms the north wall of the small north quarry. Although lithologically similar to the limestone in the main quarry, it is considerably thicker and is not considered to be the same bed, or series of beds, sharply folded.

Insufficient reliable bedding measurements were obtained to work out the detailed structure but the beds have undoubtedly been folded and there has been minor faulting. The observations which were possible suggest either a tightly folded syncline or some of the beds are overturned. The steep attitude of the limestone beds and the method of working the quarry indicates that the gypsum too is a steeply dipping bed. The floor of the quarry is now grass covered and so it is not known whether it is anhydrite or whether the gypsum continues.

Numerous anhydrite lenses, which seem to have a definite orientation, occur in the gypsum. Two explanations are possible for these lenses: (i) that they are relicts of an altered body of anhydrite or (ii) that they have been splintered off the competent underlying anhydrite and driven into the soft gypsum by the deformation forces.



Map No. 5

It is unfortunate that it was not possible to date the faults illustrated in Sketch B, Map No. 5. The small reverse faults are unquestionably post-gypsum. The fault plane is filled with fractured gypsum and there has been little or no alteration of the anhydrite since the faulting.

The gypsum is a microcrystalline intergrowth of colourless, anhedral crystals with patches of dark limestone disseminated through the groundmass.

The anhydrite is an intergrowth of colourless crystals which vary from granular to lath-like, radiating groups of distinct spherulitic habit. The groundmass is traversed by contorted and broken beds of dark limestone. Veins of microcrystalline gypsum replace the anhydrite and contain numerous inclusions. These veins have irregular margins and seem to meander through the rock.

(xi) Cheticamp, Inverness County

The now abandoned quarries at Cheticamp, Inverness County., were formerly operated by the National Gypsum Company.

The upper quarry was flooded at the time of the writer's visit and no anhydrite was observed, so its relationship to the gypsum was not established. The beds are highly deformed and the detailed mapping of this area would make an interesting study.

Bailey (1935) related the structure to quality and suggested the anhydrite was formed from gypsum as a result of pressure. He has worked out the structure as a syncline with dark limestone forming a competent, almost vertical, retaining wall on either flank. Bailey states that where the limestone is bent in towards the centre of the cyncline the anhydrite floor rises, and claims this as proof of anhydrite being formed from gypsum as a result of pressure.

It was not possible to check Bailey's field observations because of the flooded quarry, but on the evidence of other localities, and in view of the contorted nature of the gypsum, it would seem a more reasonable explanation to account for the observed structure by the flow of gypsum between the relatively competent limestone and anhydrite. The folds in the limestone are gentle and it does not seem possible that they would exert an appreciably greater pressure than any other part of the bed. Moreover, accepting that the folds did act as pressure points, there is no foundation for the assumption that pressure can alter gypsum to anhydrite. Wallace (1914) and Bowles and Farnsworth (1925) point out that anhydrite plus water occupies a greater space than an equivalent amount of gypsum and, therefore, at normal low temperatures, gypsum should be the high pressure form.

Although the limestone on either side of the quarry suggests a synclinal structure, it would be necessary to establish that the outcrops are the same bed, and to obviate the possibility of the bed being overturned and therefore an anticline.

The gypsum of the upper quarry is white and fine-grained with an irregular pattern of dark limestone. In thin section the rock is an intergrowth of microcrystalline, turbid, anhedral gypsum. The turbidity is caused by minute inclusions, which are chiefly calcareous. Bands of dark limestone cross the sections and some limestone is present as disseminated irregularly shaped aggregates.

The gypsum of the lower quarry has a sugary appearance. There is evidence of considerable recrystallization. In thin section the secondary crystals have calcareous rhombs and argillaceous material as inclusions, but no anhydrite was identified.

(xii) Mabou Coal Mine Area, Inverness County

The Mabou Coal Mine Area has received geological attention chiefly because of the coal seams which occur in the sediments of the Pictou Group. There are, however, interesting and informative exposures of calcium sulphate at Coal Mine Point to the south, and at Finlay Point on the north side of the broad, open bay which lies below the small village of Mabou Coal Mines.

The low-lying coastal area, composed of Paleozoic sediments, rises gently from a coastline of wave-cut cliffs to the crystalline complex of the Mabou Highlands which, in places, exceeds 1,000 feet in elevation.

A key map showing the general geology after Douglas (1944) is included on Map No. 6.

The geological column for this area is as follows:—

(after Douglas)

Pleistocene			Soil, scree, glacial drift.
	Unconformity		
Upper Carboniferous-Pictou Group			Coals of Mabou Mines, shales and sandstones.
	Unconformity		
Lower Carboniferous	Windsor Group		Gypsum, shale, limestone
		Unconformity	
	Horton Group		Conglomerate, arkose, etc.
	Unconformity		
Basement complex of the Mabou Highlands.			

All contacts between the Pictou Group and Lower Carboniferous sediments in this area are the lines of major faults. At the close of the Carboniferous Period, or sometime thereafter, there has undoubtedly been considerable diastrophism. There is a possibility that the faults are the normal type and represent subsidence of the Pictou beds. Douglas, however, has noted evidence of thrusting forces from a north or northwesterly direction.

Finlay Point

Bedding was not readily apparent but could be observed at several points. Strike measurements range from 50° mg. - 65° mg. with dips of 55° - 70° to the northwest. The strike of the beds is parallel to the crest of a rounded, low-lying, grass covered ridge which runs along the shore and which, on the evidence of sink holes, is underlain by gypsum. These observations indicate a considerable thickness of gypsum, although not necessarily a large tonnage of quarryable rock, above water level.

In thin section the gypsum is a microcrystalline intergrowth of colorless, anhedral crystals. Numerous dolomite rhombs and irregular patches of dark limestone are disseminated through the gypsum. The groundmass is veined by secondary gypsum which is cloudy because of calcareous and argillaceous inclusions.

Coal Mine Point

The structure of the area, as interpreted by the writer, is shown in plan and section on Map No. 6

The Pictou coal measures have been faulted against the calcium sulphate. The strike of the fault is roughly northsouth. Immediately east of the fault plane, which is marked by dark gouge, there is a steep cliff face made up of alternating beds of dark limestone and grey anhydrite. (Photograph 14) The beds average 2 - 4 mm. in thickness. The strike varies from 200° mg. - 210° mg. with dips of 30° - 35° to the west.

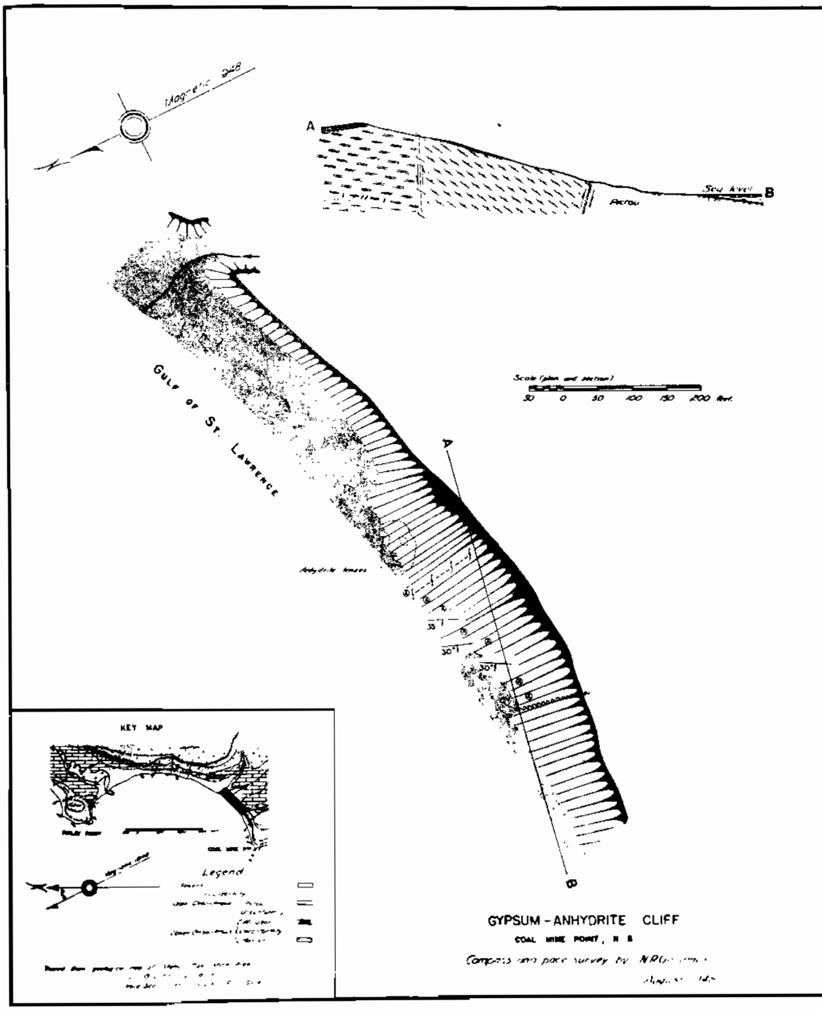
The anhydrite-limestone series pass abruptly, to the east, into a white, mottled gypsum. This abrupt change is the line of a fault. A brown impure limestone shows extreme folding near the line of movement.

There are a number of anhydrite lenses in the gypsum at the base of the cliff, in the proximity of the fault. It is possible that these are relics of unaltered anhydrite but their orientation, general appearance, and proximity to the fault, makes a dynamic explanation equally plausible, that is, they are fragments of the underlying anhydrite driven into the soft gypsum.

If the gypsum has formed as a result of surface alteration, why is there no alteration to any marked degree in the bedded anhydrite, which has had similar exposure to weather and wave? The indication is that the origin of the bulk of the gypsum is predeformation.

The difficulty experienced in differentiating between some of the anhydrite and gypsum is worthy of mention. Several specimens identified in the field as gypsum and later, on further macroscopic examination in the laboratory, thought to be gypsum, were identified under the microscope as anhydrite.

The faulty identification had indicated that the beds graded down through gypsum, across a transition zone, into anhydrite. A series of samples was cut at strategraphic intervals of five feet across the beds and at two foot intervals across the supposed transi-


A
B
Sea level
GULF OF ST. LAWRENCE
KEY MAP
Legend
GYPSUM - ANHYDRITE CLIFF
COAL MINE POINT, N.S.

Map No. 6

tion zone. Rectangular blocks were cut from these samples and the specific gravities determined. The results are shown in Fig 1. The differences in specific gravity are due to variations in the amount of limestone and the degree of gypsum veining.

The gypsum rock is a microcrystalline intergrowth of colourless, anhedral crystals with irregular patches of dark limestone which, although not continuous bands, do ofter suggest bedding. Subhedral to anhedral celestite crystals are disseminated through the gypsum. The largest celestite crystal noted was 1 x 1.5 mm. It was cut by small veins of gypsum and was free of inclusions.

The anhydrite is an intergrowth of granular, colourless crystals

ranging in size from .05 - .10 mm. Larger anhedral crystals, exhibiting the characteristic anhydrite cleavages, occur in almost all thin sections. The groundmass is traversed by bands of dark limestone which are contorted, and often broken, but leave no doubt of a bedded origin. The anhydrite is replaced by gypsum veins and porphyroblasts which contain numerous inclusions of the original material.

Antigonish Harbour, Antigonish County

Antigonish Harbour is surrounded by low-lying Windsor sediments and at a number of places there are gypsum outcrops. There have been several small quarrying operations but at the present time there is no gypsum production from this district.

During the examination of this area the writer observed no anhydrite and as bedding was difficult to observe no work, other than general observations and collection of type specimens, was undertaken.

Some of the deposits constitute a considerable tonnage of economic gypsum.

(xiii) West side, Antigonish Harbour

A cliff of gypsum, 25 - 30 feet in height forms the north bank of North River, Antigonish Harbour. The gypsum is white but mottled by brown limestone. Bedding was not measured with any degree of confidence but seemed to strike southeast-northwest and dip gently northeast.

Approximately half-way between North River and Ogden Pond, on the west side of Antigonish Harbour, 1 3 mile west of the highway, there is an abandoned quarry. Previous operations have done

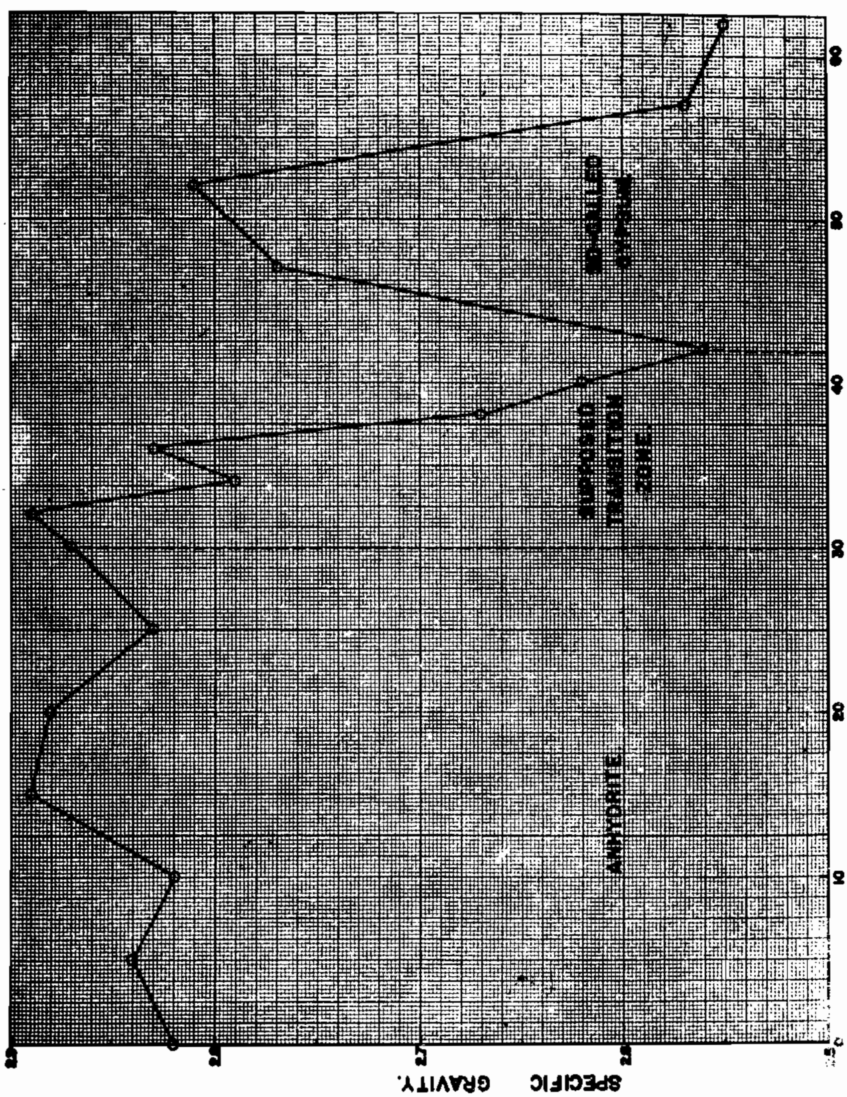


Fig. No. 1

Transition Zone

little but scratch the surface of this deposit. There is a relatively thin mantle of clay and the gypsum is deeply pitted with sink holes. There has been considerable slumping but it was possible to observe that the beds strike northeast-southwest and dip 15° southeast. The gypsum is a fine-grained mosaic of colourless anhedral crystals. Rhombs of dolomite are disseminated through the groundmass. Fragments of limestone indicate a bedded origin although the beds are now contorted and broken.

(xiv) Ogden Pond, Antigonish County

Ogden Pond South

Approximately ½ mile south of Ogden Pond, by the highway, there is a 20 - 30 foot cliff of white gypsum. The beds strike north-south and dip gently east. They did not give the impression of having been highly contorted.

Ogden Pond North

On the coast north of Ogden Pond there are cliffs of dark limestone in contact with a highly contorted gypsum. There has been considerable recrystallization and much of the gypsum is in the form of orange selenite, white fibrous gypsum veins, or as dark gypsum porphyroblasts.

During the field examination no anhydrite was observed. In thin sections the orange selenite was found to have numerous inclusions. Most of these inclusions were calcareous but there were some whose identity was not established and there is a possibility that they were anhydrite.

The limestone underlies the gypsum and dips 20° east. There has been folding and faulting and probable movement along the limestone-gypsum contact. Argillaceous material has been squeezed into gypsum forming pseudo-veins or dykes, and large fragments of foreign material are included by the gypsum.

(xv) Monk Head, Antigonish County

At Monk Head there are cliffs of contorted gypsum. They vary from white compact beds to dark grey horizons which have veins of white fibrous gypsum.

The beds have a general southeast-northwest strike with steep northeast dips.

The dark beds were found to be filled with inclusions. These were chiefly calcareous but some were argillaceous material. This discolouration, due to inclusions, was similar to that noted at Dingwall.

(xvi) South River, Antigonish County

Some quarrying has been carried out on the west side of South River. The gypsum forms a cliff 40 - 50 feet in height. The bedding is difficult to observe but it was possible to establish that the strike is east-west and the dip 10° south.

The gypsum is white, mottled by brown limestone. The rock, in thin section, is a colourless, microcrystalline intergrowth of gypsum with disseminated brown limestone fragments which suggest a bedded origin.

(xvii) Nappan, Cumberland County

The gently rolling agricultural district of Nappan, Cumberland County, is underlain by an inlier of Windsor sediments surrounded by the overlying Pennsylvanian measures. It is on the crest of the Minudie anticline, a structure which has received considerable geological attention as a possible source of oil. The detailed geology of this structural feature has been worked out by Moore, Roliff, and others (1931). The Windsor beds have been examined as a possible source of potassium by Pohl (1930).

In 1931, after several exploratory holes had been bored, Amherst No. 1 Well was drilled by the Imperial Oil Co. to a depth of 4,134 feet. The hole passed through Windsor beds only. No core was recovered but from the examination of the well cuttings the hole was logged by Roliff (1931). The first anhydrite mentioned in the log is from 1,110 - 1,120 feet. Above this the samples are identified as gypsum of varying colour and crystal size, limestone, comglomerate, arenaceous and argillaceous material, and at 920 feet the first salt was observed. Below 1,120 feet the calcium sulphate is usually anhydrite but gypsum is mentioned from a depth of 3,660 - 3,670 feet, and a sample below this is identified as white crystalline gypsum or anhydrite. The bulk of the lower part of the hole was salt with, besides the gypsum and anhydrite, limestone, dolomite and arenaceous and argillaceous material. It is unfortunate, if understandable, that the Windsor beds were of little interest and indeed must have been regarded as a nuisance by the petroleum geologists. Since some of the samples are logged as "gypsum or anhydrite" it would suggest, in view of the difficulty to distinguish between massive samples of the two minerals, that it would be unwise to place complete confidence in the identification of the calcium sulphate.

Sunoco Hole No. 1 was drilled to a depth of approximately 6,500 feet by the Sun Oil Co. in 1945. Anhydrite first appears in this hole at a depth of 163 feet and below this the calcium sulphate is normally anhydrite. Gypsum, however, is mentioned in several samples down to 627 feet. The salt deposits through which this hole passed are now operated by the brine method.

In 1946, the Sun Oil Co. drilled a second hole to a depth of over 11,000 feet. For approximately 7,000 feet this hole passed through Windsor beds. The writer visited the site of this well in August, 1947, when drilling had been suspended and the equipment was being dismantled. Mr. J. P. Mosier of the Sun Oil Co. very kindly went over the log of this hole and discussed the method of sampling and identification. He pointed out that, in the field examination, only appearance was used to differentiate between anhydrite and gypsum and, as a result, caution should be used in the interpretation of the logging of these beds. The samples from this hole have been made available to the writer and it is hoped that the study of this material will make a valuable contribution to the knowledge concerning these sediments.

The beds are so contorted that correlation was impossible between two drill holes only 1,500 feet apart. Outcrops are few in the area and no information regarding the structure or the gypsum - anhydrite relationship was obtained.

A quarry was operated in this area by the Maritime Gypsum Co. but there is no gypsum production from this district at the present time. A number of drill cores were found near the abandoned quarry but the location of the holes is unknown. The cores are chiefly white crystalline gypsum in which there has been a considerable amount of recrystallization. Red clay and sandstone are associated with the gypsum. Two samples of a blue-grey anhydrite were collected. Although these drill cores must have been exposed to the weather for a number of years there is no marked evidence of alteration to gypsum, and only a thin white coating has developed on the surface of the core. Both the anhydrite and gypsum contain patches of dark limestone but in none of the samples is bedding recognizable.

(xviii) Windsor Area, Hants Co.

The deposits of calcium sulphate in the Windsor district are probably the most extensive in Nova Scotia. They were the first beds from which gypsum was quarried and the countryside is dotted with quarries which are now abandoned. The operations of the Canadian Gypsum Company constitute the current production from this area.

Windsor is a farming district and much of the land underlain by Windsor sediments has been cleared and is a gently rolling terrain without marked solution effects. The gypsum usually lies under a thick clay cover which is a considerable nuisance in the quarrying.

The quarries of the Canadian Gypsum Company are two and a half miles east of the town of Windsor on the south side of the St. Croix River. The two main quarries being operated at the time of the writer's visit were the "White" and the "Dark", so named because of the character of the gypsum. The Dark Quarry lies southwest of the White.

The structure is a broad anticline running northeast-southwest. Both quarries are on the northern limb of this fold. The Dark bed, which overlies the White, is exposed in the railway cutting approaching the White Quarry but here it is only 10 - 20 feet thick. The thickness increases considerably to the west where it is worked.

The beds in the rail cutting dip 20° north and there is definite evidence of movement. A 5 - 8 foot fossiliferous limestone bed has been sharply folded, and there are places in the gypsum where the pattern of the brown limestone indicates intense mashing of the beds. This latter structure is similar to that noted at Bevis Point, Victoria County (Photograph 6).

Anhydrite rises from the floor of the White Quarry and forms most of the south face. The contact of the gypsum and anhydrite is irregular, but that this contact conforms to the general structural picture of an anticline is nevertheless evident. Several anhydrite tongues, which are parallel to the bedding, jut into the gypsum in the middle of the south face of the Dark Quarry. It was not established whether these are anhydrite relics or if the gypsum has flowed under pressure and levered these tongues from the main anhydrite body.

The gypsum of the White Quarry is a microcrystalline intergrowth of anhedral, colourless crystals. The groundmass is cut by contorted bands of dark limestone.

The gypsum of the Dark Quarry is a mosiac of relatively large, anhedral crystals, which exhibit the characteristic gypsum cleavages. The crystals are turbid due to numerous organic, calcareous and argillaceous inclusions. Dolomite occurs as euhedral rhombs. In hand-specimen the dark gypsum often has spherulitic habit but in thin section a radiating habit is not apparent and it is merely a nodular group of anhedral crystals.

Veins of white and pink fibrous gypsum, sometimes exceeding a thickness of one foot, are common in the Dark Quarry and also in a clay-like material in the cutting leading to the White Quarry. Clear, colourless, transparent plates of gypsum (var. selenite) over a foot in diameter were found in the Dark Quarry.

The blue-grey, compact anhydrite rock is a colourless aggregate of anhedral and radiating, lath-shaped crystals of distinct spherulitic habit. There is dark limestone disseminated through the groundmass but, due to the degree of deformation, in none of the sections is a bedded origin recognizable. The anhydrite is cut by veins of microcrystalline gypsum.

The writer was fortunate in being able to accompany Dr. W. T. Schaller of the United States Geological Survey on an intensive search of the quarries in this district for the several rare boron minerals discovered by How (1868). During this search only howlite and ulexite were found. The howlite occurred as white, glistening nodules, up to two inches in diameter, in the anhydrite on the west face of the Fraser Quarry, which lies south of the Dark Quarry. The howlite nodules are not numerous and seemed to occur in a definite flat-lying horizon but, unfortunately, it was not possible to observe bedding in the anhydrite and so the relationship of this horizon to the bedding is not known. Ulexite was found in several of the quarries as white, lens-shaped fillings along joint planes.

(xix) St. Croix River Escarpment, Hants County

An impressive calcium sulphate scarp, estimated to be 60 - 80 feet high, forms the east bank of the St. Croix River approximately a mile north of Newport, Hants County.

The St. Croix is a tributary of the Avon River. It is subject to the extreme tides of the Bay of Fundy and at one moment may be a relatively large river, 100 feet or more in width, and a few hours later be little more than a trickle of water at the bottom of a deep red, muddy trough. The steep nature of the cliffs, the muddiness of the river, and the hazards added by the tides made it impracticable to thoroughly investigate these outcrops without the aid of special equipment. It must be pointed out, therefore, that the following observations are not supported by the all-important evidence resulting from the rocks being subjected to a geologist's hammer.

Bedding can be observed in the rock of the scarp and it is assumed that this is due to the presence of dark limestone beds. The beds dip gently north. Collected specimens indicate this scarp is anhydrite.

The southern end of the cliff is accessible and here the rock is a light-grey anhydrite mottled by dark limestone. The anhydrite has spherulitic habit. An interesting specimen of stalactitic gypsum was collected. This was found to be made up of anhedral crystals which were cloudy due to anhydrite inclusions, which were so numerous that the spherulitic habit was still easily recognizable. The centre of the specimen had a deep red colour due to iron staining but outside this core the gypsum was colourless. The gypsum crystals did not have any definite orientation, but interruptions in their growth was marked by dark lines of dust-like inclusions which run from one crystal to the next in a continuous line. The growth lines are usually curved but in some cases mark the position of once-developed crystal faces (Photograph 15). The present surface is microcrystalline, colourless gypsum, which is also found filling crystal interstices throughout the specimen.

Three quarters of a mile north of the St. Croix River Escarpment gypsum beds are exposed in a cutting on the main highway between Sweet's Corner and Brooklyn. The rock at this exposure is distinctly bedded and the beds are almost horizontal. This gypsum is thought to be part of the same series exposed on the St. Croix River and, in view of the general north dip noted there, to be stratigraphically higher.

(xx) White Head, Cheverie, Hants County

Cliffs of gypsum and anhydrite are exposed on the south snore of Minas Basin at White Head, Cheverie, Hants County. This gypsum and anhydrite has been placed by Wright (1930) as the central part of the Cheverie Basin and he mentions the presence of folding and faulting in the area. The highly contorted character of the interbedded anhydrite and limestone, which can be examined on the interesting pavements exposed at low tide, is testimony to the effects of the diastrophism on these beds.

The structure of the area is complex but was not worked out in detail. The limestone beds are contorted and dip steeply northwest.

The limestone is dark grey to black in colour. The beds vary in thickness from a mere film to over a foot. The thicker beds are fossiliferous.

The anhydrite is light grey. In thin section the rock is a colourless, granular, groundmass of anhedral crystals varying in size from .05 - .3 mm. Contorted and broken beds of dark limestone traverse the anhydrite. The rock has been replaced by gypsum in the form of porphyroblasts, averaging on cm. in length, and microcrystalline veins. Both types of secondary gypsum are filled with inclusions of the original anhydrite.

The limestone beds are cut by lenticular calcite-anhydrite veins, varying from ¼ - one inch in thickness. The veins carry a small amount of purple fluorite. Some extend into the anhydrite but others are cut off abruptly, and the anhydrite shows evidence of having flowed under pressure with the flow lines parallel to the limestone-anhydrite contact.

White danburite occurs as nodular aggregates in the anhydrite. The borate is frequently fringed by dark gypsum porphyroblasts. The occurrence suggests that the danburite is secondary.

(xxi) Walton, Hants County

Extensive quarries at Walton, Hants County, formerly operated by the Rock Plaster Corporation are currently producing gypsum for the National Gypsum Company.

The quarries occupy the crest of a line of low, rounded hills which rise gently from the shores of Minas Basin. These hills are somewhat misleadingly called "mountains". Usually the gypsum is not concealed under a heavy mantle of clay but it is deeply pitted by sink holes.

The original operations were in North Quarry, or the North Mountain, but now this is only used to meet occasional demands for anhydrite, when the rock forming the floor is quarried. Quarrying has moved progressively southeast; first to the New Quarry, which lies immediately southeast of North Mountain; next to Phineas Mountain, approximately 3,000 feet southeast of the New Quarry; and then to the Fry's Mountain Area still further southeast. All these quarries lie on a line bearing approximately 120° mag.

It is possible to observe bedding in both the gypsum and anhydrite and to establish that the quarries are on the crest of an anticlinal structure running northwest - southeast. This structure was especially apparent in the New Quarry where the anhydrite can be seen rising from the southwest at an angle of 10° and is then sharply folded. Overturned beds can be seen (Photograph 17).

The gypsum is usually much contorted and it is not possible to observe bedding. Frequently there are irregular masses of arenaceous material and also black, fossiliferous limestone, which exhibits slicken-sides and in many places has been ground into a clay-like material. It is considered that in the development of the anticline the gypsum has flowed under pressure and has increased its thickness on the crest of the fold. It is along this crest that the quarries extend.

The gypsum is, in the main, a white microcrystalline rock mottled by dark limestone but in some horizons the gypsum is grey-green. The rock has been replaced by numerous gypsum porphyroblasts.

The anhydrite is dark grey and banded by thin dark limestone beds. In thin section the anhydrite is a colourless granular aggregate of anhedral crystals varying from .05 - .3 mm. The anhydrite is replaced by gypsum veins and porphyroblasts.

SUMMARY OF OBSERVATIONS ON THE GYPSUM AND ANHYDRITE DEPOSITS OF NOVA SCOTIA

Gypsum Although numerous varieties of gypsum are found and a wide range of colour is exhibited in the Nova Scotia deposits the bulk of the gypsum rock from all localities is surprisingly similar. Selenite, fibrous gypsum, and alabaster form a minute percentage of the deposits.

The rock gypsum is white with interbedded dark limestone, but in many cases this has been contorted and broken giving the rock a mottled appearance due to the irregularly shaped patches of calcareous material. The gypsum is accurately described as microcrystalline (having a grain size of .01 - .2 mm.) and is made up of a groundmass of anhedral crystals. A fibrous, radiating texture was sometimes noted. Beds or irregular patches of limestone are invariably present. Euhedral rhombs of dolomite and anhedral to subhedral crystals of celestite were frequently observed. Organic, argillaceous or calcareous inclusions often cause a discoloration of the gypsum. Howlite and ulexite occur with the gypsum at Dingwall.

The gypsum rock is replaced by secondary gypsum in the following forms: (i) a crust of microcrystalline gypsum on a surface exposed to the weather; (ii) transparent plates of selenite up to a foot or more in diameter; (iii) veins of fibrous gypsum; (iv) veins of microcrystalline gypsum similar in texture to the replaced material; (v) subhedral to euhedral porphyroblasts of colourless to dark selenite disseminated through the rock.

At the shore section 2 miles south west of Iona gypsum rock was cut by white anhydrite veins.

Anhydrite The anhydrite rock of Nova Scotia is compact, fine-grained and varies in colour from white to blue-grey but the latter is more common.

The anhydrite is interbedded with thin, dark limestone members but these are frequently so contorted and broken that they are present only as irregular calcareous patches. The anhydrite has two distinct habits: (i) granular and (ii) spherulitic. The granular rock is a microcrystalline intergrowth with some larger anhedral crystals which exhibit the characteristic pinacoidal cleavages at 90° (Photograph 16). The spherulitic texture has radiating, lath-like crystals up to a millimetre or more in length (Photograph 18). The habit is characteristic of any one bed and would seem to be related in some way to the origin. The lack of euhedral crystals in the anhydrite is in agreement with Dunham's (1948) observations on the anhydrite of the Permian deposits in Northeastern England that if the anhydrite crystals began to form in the brine the process was completed after deposition, or there was recrystallization after deposition, or possibly both processes were in operation. Anhedral crystals of celestite were observed in some sections. Howlite and ulexite both occur with the anhydrite at Windsor.

Veins of white anhydrite cut the rock at the shore section 2 miles southwest of Iona. Danburite occurs in association with these veins. Veins of anhydrite, calcite and fluorite cut the anhydrite rock at Cheverie. Danburite also occurs at Cheverie.

Gypsum replaces the anhydrite in the following ways: (i) a crust of white microcrystalline gypsum on a surface exposed to the weather; (ii) veins of microcrystalline gypsum; (iii) subhedral to euhedral porphyroblasts of colourless to dark selinite disseminated through the rock.

Gypsum porphyroblasts Subhedral to euhedral porphyroblasts of colourless to dark gypsum (var. selenite) occurred at many localities in both gypsum and anhydrite rock. Thin sections were cut through a large number of these crystals.

In all cases where bedding lines are included in a porphyroblast the bedding plane is not disturbed by the crystal and the alignment of the bed is preserved. It is inferred, therefore, that in the observed instances the formation of the porphyroblasts was post-deformation.

All porphyroblasts formed in anhydrite are filled with inclusions of the original material, but those formed in gypsum were free of anhydrite inclusions. The formation of the porphyroblasts is, therefore, considered to be post-gypsum. If anhydrite containing gypsum porphyroblasts was altered to gypsum, the already formed crystal would remain relatively unchanged and would contain inclusions of the original anhydrite. This observation was critically tested in several localities where porphyroblasts occurred in both gypsum and anhydrite within a few feet of the contact.

The porphyroblasts have in many cases been cut by veins of microcrystalline gypsum.

Limestone The thin dark calcareous beds associated with both gypsum and anhydrite are accurately described as limestone. The identity of this material was established in the field by its effervescence in cold, dilute hydrochloric acid and confirmed in the laboratory by establishing the refractive indices by index liquid methods. The limestone beds, although normally thin, sometimes occur as fossiliferous, lenticular beds up to several feet in thickness. Some of the limestones are brecciated, others are folded and all show evidence of being subjected to deforming forces. An odor of bitumen is frequently evident when the limestone is dissolved in hydrochloric acid.

Dolomite Dolomite was observed in some thin sections of gypsum It occurred as dark, euhedral rhombs disseminated through the rock (Photograph 19). The mineral was identified by index liquid methods.

Borates Howlite and ulexite were noted in anhydrite at Windsor and in gypsum at Dingwall. The howlite occurred as nodules disseminated through the rock but it seemed to be in definite horizons, parallel to or almost parallel to the observed bedding, suggesting that the mineral was syngenetic. The ulexite was found along joint planes. Danburite was collected at the shore section 2 miles south west of Iona and at Cheverie.

Celestite The strontium sulphate, celestite, was identified in the thin sections of gypsum and anhydrite from some localities. Its presence in some beds and not others suggests its possible use in stratigraphic correlation. It formed anhedral to subhedral crystals. In some anhydrite it appeared to have sharply defined lath-shaped inclusions indicating it was post-anhydrite but the outline of the inclusions was angular and not corroded suggesting that this was not a replacement process. The celestite in gypsum was cut by veins and had gypsum inclusions but these were not rectangular to indicate they were pseudomorphs after anhydrite.

Structure The bedded nature of the calcium sulphate deposits is sometimes readily apparent and they are seen to be made up of interbedded limestone and gypsum or anhydrite (Photograph 2). In many cases, however, the beds have been so contorted and broken that reliable strike and dip observations cannot be measured. In few of the localities was it possible to work out the detailed structure and in some no structural observations could be made. In every instance, however, where bedding measurements were possible, whether the detailed structure was worked out or not, the gypsum was found to occur stratigraphically above the anhydrite and the contact between these two rocks was parallel to, or approximately parallel to, the observed bedding (Photograph 3).

At Walton the gypsum was found to have increased its thickness along the crest of an anticline. The tendency of gypsum to thicken along the crest of a fold was noted at several places.

All evidence points to the fact that the bulk of the gypsum rock was formed prior to the deformation of the beds. The gypsum and anhydrite have acted as might be expected of two materials with such different relative strengths. Where the gypsum has flowed under pressure the contact is not parallel to bedding, but where there has been no relative movement between the beds the original conformability is preserved.

THE NATURE OF CALCIUM SULPHATE HYDRATION

The term "hydration" has been generally accepted as completely explaining the mechanism by which gypsum has formed from anhydrite. Before "hydration" is used to explain the origin of the bulk of Nova Scotia's gypsum, however, it would help to have a picture of how this process operates.

"Hydration" means the union of water with a substance to form a different compound, which is called a "hydrate". The change of anhydrite to gypsum does indeed fit this definition. There can be no contradiction that the mechanism of hydration is operating and has been in operation. A gypsum crust, gypsum veins and porphyroblasts in anhydrite are all proof of alteration and hence "hydration". Secondary gypsum crusts, gypsum veins and porphyroblasts also occur in gypsum rock, however, and this is not "hydration" although the process is obviously identical.

All the observations by the writer both in the field and in laboratory experiments are in complete agreement with the mechanics of calcium sulphate hydration stated by Newland (1921), "It is not a question of a simple absorption of the proportion of water necessary but there is an actual solution of the anhydrite, molecule by molecule, and the reprecipitate of the calcium sulphate in the hydrated condition."

The thin crust of gypsum often observed on anhydrate is evidence that the hydration process is at work but the following field observations suggest that the anhydrite, in its present form, is not very susceptible to alteration:

(i) Cliffs of unaltered anhydrite in a position where they are subjected to wave and weather.

(ii) When a sink hole reaches anhydrite it goes no deeper. It would be expected that there would be considerable alteration at the base of these holes for there must have been a supply of surface water.

(iii) Irregular masses of anhydrite are frequently observed in gypsum cliffs, but these have not been altered to any marked degree although exposed to the weather.

(iv) Anhydrite boulders on quarry floors and masses of anhydrite in the quarry faces, exposed to the weather for twenty years or more, show little evidence of alteration.

(v) An anhydrite vein was observed cutting gypsum rock. Although exposed on a cliff face the vein was readily identified in the field as anhydrite and this identification was later confirmed in the laboratory. If the gypsum rock represented alteration of anhydrite at the surface why did the vein remain unaltered?

The condition which would favour rapid alteration of anhydrite as indicated by experiments are (i) fine-grain, (ii) permeability, and (iii) solutions which were saturated with respect to calcium sulphate.

CONSIDERATION OF THE VOLUME CHANGE WHEN ANHYDRITE ALTERS TO GYPSUM

The volume change accompanying the alteration of anhydrite to gypsum can be calculated to be approximately 44%. This increase in volume is frequently credited with folding the country rock as well as the gypsum itself.

All the writer's observations indicate that the bulk of Nova Scotia's gypsum was formed prior to deformation and it is considered that diastrophism has been responsible. It is necessary, however, to consider the possibility that the volume change was the cause and the gypsum contorted as it formed from the anhydrite.

Schaller (1932) observed that anhydrite in the New Jersey zeolite region changed to white opaque gypsum with little or no increase in volume. He shows an illustration of an anhydrite crystal which has partly altered to gypsum. The secondary gypsum occupies the same space as the original mineral. When the white opaque gypsum was recrystallized to selenite, however, there was a definite increase in size. This was attributed to "the accretion of additional material from passing solutions during the recrystallization".

Rettger (1935) shows an illustration of complex folding of gypsum and anhydrite from Hillsborough, New Brunswick, which is attributed to recrystallization. The illustration shows a series of small, tight folds where, assuming the thickness to have remained constant, some beds have increased in length by as much as 300%. A block of anhydrite could achieve the necessary 44% expansion by a relatively small increase in all three dimensions or, if confined in a horizontal plane, by an increase in thickness alone. The effect of the folding at Hillsborough, where the beds are assumed to have been confined laterally, is that the overlying beds have been lifted and in the illustrated case this has been considerably more than the calculated 44%. It is possible, however, that the expansion has been passed along to some point of weakness, and that the structure represents the expansion of an amount considerably greater than the length the folded beds now cover.

It is interesting to note the similarity between Rettger's illustration and that of Stoces and White (1935) of an anhydrite vein from Bochnia, Poland, showing the plasticity of rocks under gradually applied pressure. The structures are almost identical.

The porosity of gypsum and anhydrite rock was determined and the gypsum was found to be the more porous. It is possible there has been a loss of gypsum by solution, which would cause the observed porosity. This is certainly evidence against the pressure this expansion can exert. An anhydrite body altering to gypsum would do little folding of itself, or other rocks, before it had compacted its grains.

The calculated expansion presumes a number of conditions which are not achieved in Nature. It supposes that the rock is entirely anhydrite; completely non-porous; entirely altered to gypsum; and that there is no loss of material in the process. The mechanics of the change from anhydrite to gypsum is one of solution and re-deposition, and must therefore infer some loss of calcium sulphate. Thus the actual volume change is less than 44%. In the writer's opinion the expansion is not sufficient to explain the observed structures and he feels they are almost entirely due to diastrophism.

ORIGIN OF THE NOVA SCOTIAN GYPSUM AND ANHYDRITE DEPOSITS

(i) Nature of the precipitating solution

Bell (1929) gives a comprehensive classification of gypsum deposits and has considered each class in detail. He reaches the conclusion that the bulk of the Nova Scotian gypsum is due to the evaporation of sea water and favours a lagoonal sea as the body of water from which it was deposited. He considers that the calcium sulphate was laid down as anhydrite and was subsequently altered to gypsum by hydration.

Gypsum veins must, of course, be placed in Bell's Class C (Vein deposits) and porphyroblasts and other replacement effects in his Class D (Products of alteration or replacement). These, however, form a small percentage of the gypsum deposits.

The interbedded nature of the calcium sulphate with limestones, in which marine fossils have been noted, leaves no doubt in the writer's opinion that, as Bell states, it is the result of a concentration of sea water.

(ii) Form of calcium sulphate deposited

Calcium sulphate can be deposited from sea water as gypsum, anhydrite, the hemihydrate or possibly a number of other forms whimh have not yet been recognized. The existing physical and chemical conditions will determine which form is laid down. Deposited calcium sulphate in any form might alter to any other depending on the existing conditions.

The hemihydrate has been reported by Popov and Vorobiev (1947) forming thin layers in oil sands at several arid, hot places in Turkmenia and Fergana. Some pseudomorphs of hemihydrate after gypsum were noted. This is an unusual alteration for under normal surface conditions the hemihydrate would alter to gypsum in exactly the way Plaster of Paris does when it sets.

Stewart (1949) observed pseudomorphs of anhydrite after gypsum in the Eskdale No. 2 boring in east Yorkshire, and considers the anhydrite in some zones has resulted from the alteration of original gypsum. Although the change of gypsum to anhydrite is undoubtedly possible, no evidence was found to justify postulating this origin for the vast amount of anhydrite found in Nova Scotia.

Some gypsum beds suggest primary deposition but these constitute a small part of the deposits.

From the evidence available during this essentially surface investigation the writer feels he must agree with Bell that the bulk of the calcium sulphate was originally deposited as anhydrite. There is every possibility, however, that as further evidence is available this view will have to be altered.

(iii) Existing conditions at the time of deposition

Bowles and Farnsworth (1925) and others have established that pressure is not a dominating factor in deciding which form of calcium sulphate is deposited, but temperature is most important. The salinity, too, is a highly important factor.

Posnjak (1938) states that above 42°C anhydrite is the stable form regardless of the sea water concentration. The author's experiments have indicated that gypsum is stable under temperatures somewhat above this figure.

Temperatures above 40°C are a reasonable assumption. Kaleczinzky (cited by Grabau, 1920) observed in the salt lakes of Hungary that, although the temperature of the surface layer was 21°C, the layer below was 56°C, and deeper lying brines had temperatures as high as 70°C. These high temperatures are due to absorption of solar heat and the lower specific heat of the more saline layers, which were at greater depths due to density layering. This phenomenon is only possible when a zone of comparatively fresh water is resting on more concentrated solutions. This layer is probably unconcentrated sea water, for the absence of clastic sediments indicates the existence of arid conditions and presents the difficulty of accounting for a supply of fresh water to cover the surface. The high temperature can only be maintained under these special conditions. The removal of the saline solutions would mean a return to normal surface temperatures.

The variation of temperature and salinity with depth will undoubtedly have a corresponding influence on the form of calcium sulphate deposited.

The alternating limestone - calcium sulphate beds indicate a rhythmic deposition. The laminations represent rhythmic replenishment of sea water. Calcium carbonate is deposited with each fresh influx of sea water. Calcium carbonate is deposited with each fresh calcium sulphate. The sulphate deposition is interrupted by a further influx of marine waters.

The laminated character of the Nova Scotian deposits indicates their similarity to the beds of the Permian Castile Formation in Texas investigated by Udden (1924). Udden considered the period of the rhythm as a year but did feel this was rather too long. The period might be much shorter if the influx of water is due to spring tides. The rhythm in Nova Scotia was not as constant as the Texas deposits and the interbedded members vary considerably in thickness. This suggests the possibility that the replenishment of sea water was a result of storms.

The Bar Theory of Ochsenius (1887) and the later modification by Branson (1915) gives a reasonable picture of the origin of thick evaporite deposits. It is felt the Nova Scotian beds were deposited in some form of lagoon. It is not known, however, whether the deposition occurred in one or more lagoons. Reflux of the concentrated sea water through a permeable barrier, or along the bottom of the connecting channel, is a convenient, if experimentally unsupported, method of accounting for the absence of sodium chloride. (King, 1947).

(iv) Dating the alteration of anhydrite to gypsum

The evaporite deposits were laid down in Windsor Seas and soon after their deposition were subjected to deforming forces. There is ample evidence of instability of the crust with warping and tilting movements in Nova Scotia throughout Carboniferous times. Field evidence has established that the bulk of the gypsum was formed prior to folding. To explain these deposits it is necessary to have a process by which anhydrite is altered to gypsum relatively soon after its deposition. Experimentally, two explanations were indicated:

(1) The stability range of hemihydrate shows that this compound would be deposited at high temperatures and high salinity or the upper horizon of already deposited anhydrite could be altered to the hemihydrate. The removal of lagoonal waters would mean the return to normal surface conditions and the hemihydrate would rapidly alter to gypsum, which is the stable low temperature form.
This process gives a deposit of gypsum over anhydrite.

(2) It was established that the conditions which favour the alteration of anhydrite to gypsum are:
(i) Fine grained, but permeable, anhydrite.
(ii) A solution saturated with respect to calcium sulphate.

These conditions are satisfied when the anhydrite is first deposited. The small crystals of anhydrite settle to the bottom of the lagoon and trap with them waters of the lagoon, which must be saturated with calcium sulphate. These waters would rapidly alter the fine-grained anhydrite whenever the physico-chemical conditions were such that the anhydrite became unstable.

Information is lacking on the porosity of recently formed anhydrite but Walther (cited by Grabau, 1920) found that a recent limestone had a pore space exceeding 35%. It seems reasonable to suppose that calcium sulphate would also have a considerable pore space. It is thought that the connate waters would migrate upward as the rock became compacted as a result of recrystallization, or possibly direct pressure.

The thickness of the top horizon in which the connate waters were concentrated would depend on such variables as : (i) The originay porosity. (ii) The thickness of the calcium sulphate beds. (iii) The thickness of the overlying sediments. (iv) The porosity of of the overlying sediments.

The maintenance of a high temperature during the expulsion of the connate waters would account for anhydrite deposits without any alteration.

This theory accounts for the reported deposits of anhydrite, at considerable depth, with the top horizon altered to gypsum when there has been no ready supply of surface waters. It explains a gypsum - anhydrite contact which is approximately parallel to the bedding and also relics of unaltered anhydrite in the gypsum.

The explanation of the uneven thickness of gypsum is not that there has been a varying depth of hydration, but that different amounts of gypsum have been removed by the factors of erosion.

(v) Summary

Briefly the writer's opinion concerning the origin of the Nova Scotian calcium sulphate deposits is that they were laid down from a concentration of sea water in lagoons which were rhythmically replenished with marine waters. This cycle deposited alternating limestone and calcium sulphate. The temperature of the water in the lagoons, or at the bottom of the lagoon, was sufficiently high for anhydrite to be the stable form. With the removal of the lagoonal waters the high temperatures could not be maintained and the upper horizon was rapidly altered to gypsum by the action of the connate waters trapped by the deposited anhydrite crystals. Subsequently the deposits were subjected to, and deformed by, the several periods of diastrophism which were operative in Nova Scotia since the deposition of the Windsor evaporite beds.

This origin does not refer to the small amount of gypsum in veins, porphyroblasts, and other replacement effects, or to the few thin beds which suggest primary deposition of gypsum.

REFERENCES

AHFELD, F., 1946 Danburita de Bolivia
Comunic. Museo Min. Geol. Fac. Cienc. Univer. Cordoba, no 1.

ALGER, F. 1827. Notes on the mineralogy of Nova Scotia
Amer. Jour. Sci. and Arts, vol. XII, pp. 227-232.

BAILEY, H B., 1935. Relationship of structure to quality in the gypsum deposits of northern Cape Breton.
Can. Min. Met. Bull., no. 278, pp. 288-294.

BELL, W. A., 1929. Horton-Windsor district, Nova Scotia.
Canada Geol. Surv. Mem., no. 155.

BOWLES, O. and FARNSWORTH, M., 1925 Physical chemistry of the calcium sulphates, and gypsum reserves.
Econ. Geol., vol XX, pp. 738-745.

BRANSON, E. B., 1915. Origin of thick gypsum and salt deposits.
Bull. Geol. Soc. Amer., vol. 26, pp. 231-242.

COLE, L. H., 1930. The gypsum industry of Canada.
Canada Dept. Mines Pub., no. 714.
1930. The story of gypsum in Canada.
Can. Min. Met. Bull., no. 221., pp. 1206-1229.

DANA, J. D., 1868. A system of mineralogy. 5th Ed.
London.

DAWSON, SIR WILLIAM, 1945. On the lower Carboniferous rocks or gypsiferous formation of Nova Scotia.
Quart. Jour. Geol. Soc. London, vol. 1, pp. 26-35.

1847. An untitled communication.
Proc. Acad. Nat. Sci. Phil., vol. 111, pp. 271-274.

1868. Acadian geology. 2nd Ed.
London.

DOUGLAS, G. V., 1944 Mabou Coal Area.
Nova Scotia Dept. Mines, Ann. Rpt., pp. 124-131.

DUNHAM, K. C., 1948 A contribution to the petrology of the Permian evaporite deposits of north-eastern England.
Proc. Yorks. Geol. Soc., vol XXVII, pt. 111, pp. 217-227.

GESNER, A., 1836. Remarks on the geology and mineralogy of Nova Scotia. Halifax.

GRABAU, A. W., 1920. Geology of the non-metallic mineral deposits. vol. 1. Principles of salt deposition.

McGraw-Hill, New York and London.

HALIBURTON, T. C., 1829. An historical and statistical account of Nova Scotia. Halifax.

HAYES, A. O. and others, 1930. Report on the potash possibilities of Nova Scotia.
Nova Scotia Dept. Mines, Ann. Rpt., pt. 2.

HOW, H., 1857. On the occurrence of natroborocalcite with glauber-salt in the gypsum of Nova Scotia.
Amer. Jour. Sci. and Arts, 2nd ser., vol. XXIV, pp. 230-235.

1868. Contributions to the mineralogy of Nova Scotia. 111. Borates and other minerals in anhydrite and gypsum.
Phil. Mag., vol. 35, pp. 32-41.

1868. The mineralogy of Nova Scotia, a report to the Provincial Government. Halifax.

JACKSON, C. F., and ALGER, F., 1928. A description of the mineralogy and geology of a part of Nova Scotia.
Amer. Jour. Sci. and Arts, vol. XIV, pp. 305-330.

1829. Continuation of 'A description of the mineralogy and geology of a part of Nova Scotia'.
Amer. Jour. Sci. and Arts, vol. XV, pp. 132-160; pp. 201-217.

JENNISON, W. F., 1911. Report on the gypsum deposits of the Maritime Provinces..
Canada Dept. Mines Pub., no. 84.

KING, R. H., 1947. Sedimentation in Permian Castile Sea.
Bull. Amer. Assoc. Petr. Geol., vol 31, pp. 470-477.

LYELL, Sir CHARLES, 1843. Travels in North America in the years 1841-42. 1st Ed., London.

MESSERVEY, J. P., 1926. Gypsum in Nova Scotia.
Nova Scotia Dept. Mines, Monograph Pamphlet no. 13.

MOORE, P. D., 1931. The Minudie Anticline.
Nova Scotia Dept. Mines, Ann. Rpt., pt. 2, pp. 5-13.

OCHSENIUS, C., 1887. Bildung von Steinsalzlagern.
Chem. Ztg., vol 2.

POHL, E. R., 1930. Potassium possibilities in Cumberland County, West of Malagash.
Nova Scotia Dept. Mines, Ann. Rpt., pt. 2, pp. 55-76.

POPOV, V. I. and VOROBIEV, A. L., 1947. Polyhydrate (hemihydrate) in continental desert deposits of central Asia.
Mem. Soc. Russe Min., ser. 2, vol. 76, pp. 268-270.

POSNJAK, E., 1938. The system, CaSO4 -H_20.
Amer. Jour. Sci., ser. 5, vol. 35-A, pp. 247-272.

RETTGER, R. E., 1935. Experiments in soft-rock deformation.
Bull. Amer. Assoc. Petr. Geol., vol 19, pp. 271-292.

ROLIFF, W. A. 1931. Development work in Nova Scotia.
Nova Scotia Dept. Mines Ann. Rpt., pt. 2, pp. 43-90.

SCHALLER, W. T., 1932. The crystal cavities of the New Jersey zeolite region.
U. S. Geol. Surv. Bull. no 832.

STEWART, F. H., 1949. The petrology of the evaporites of the lower evaporite bed.
Min. Mag., vol. XXVIII, pp. 621-675.

STOCES, B and WHITE, C. H., 1935. Structural geology.
MacMillan, London.

UDDEN, J. A., 1924. Laminated anhydrite in Texas.
Geol. Soc. Amer. Bull., vol. 35, pp. 347-354.

WALLACE, R. C., 1914. Gypsum and anhydrite in genetic relationship.
Geol. Mag., vol. 1, pp. 271-276.

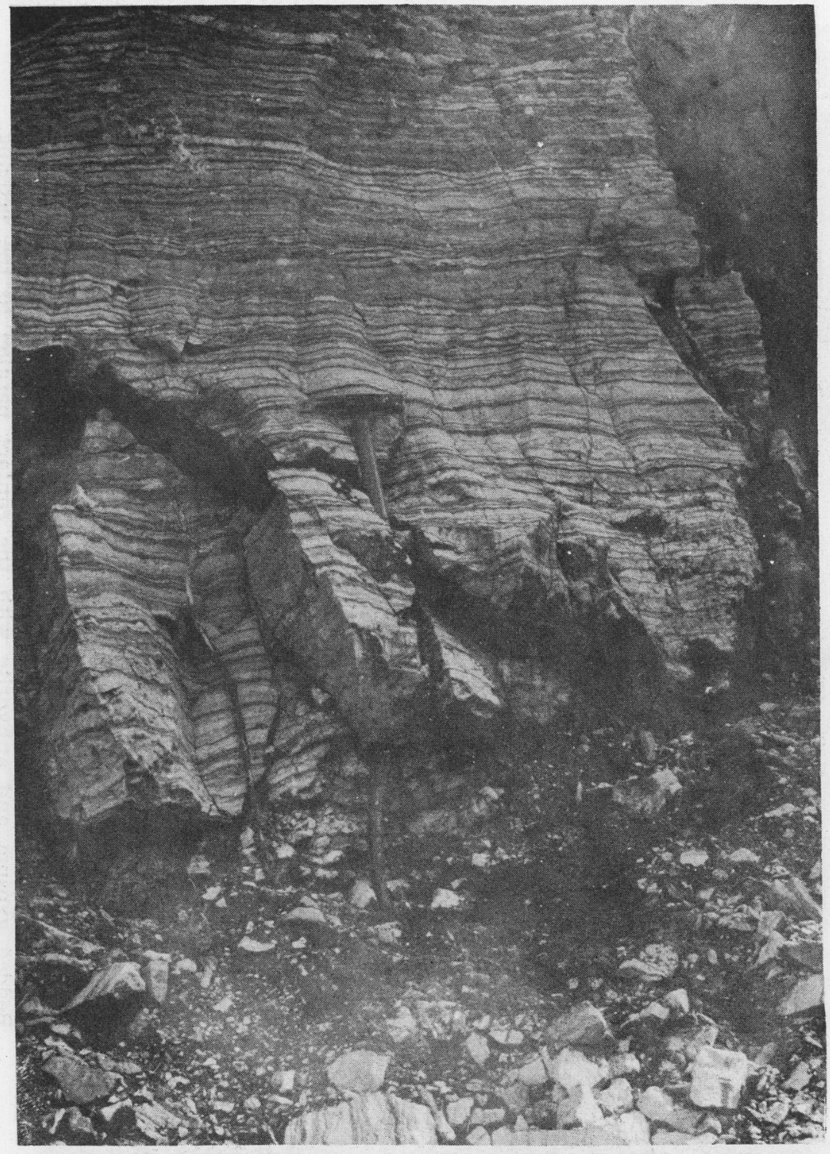
WILDER, F. A., 1928. Gypsum and anhydrite.
Amer. Min., vil. 13, pp. 476-480.

WRIGHT, W. J., 1930. Report on Cheverie, Windsor and Shubenacadie Basins.
Nova Scotia Dept. Mines Ann. Rpt., pt. 2, pp. 117-142.

Photograph No. 1

Quarry face showing depth of sink holes now filled with clay. Half Mile Face, Dingwall.

Photograph No. 2

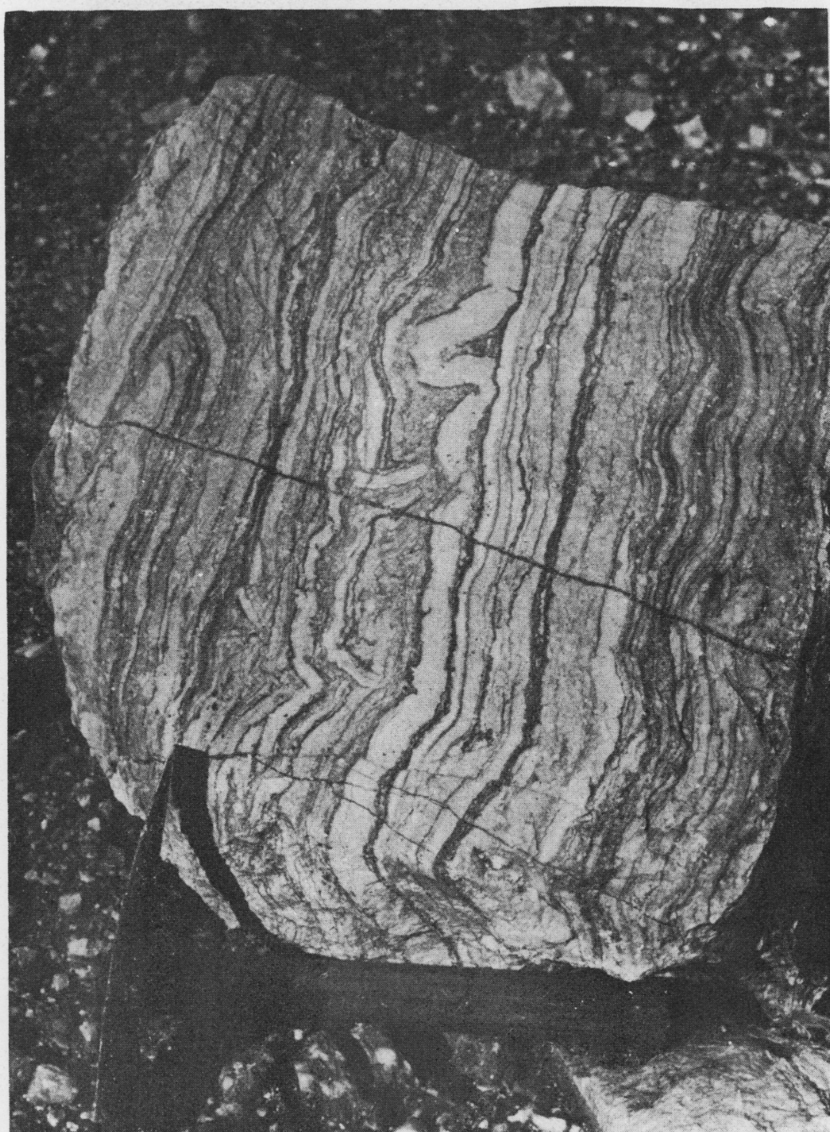


Bedded gypsum. The bedding is marked by thin limestone beds. North Quarry, Dingwall.

Photograph No. 3

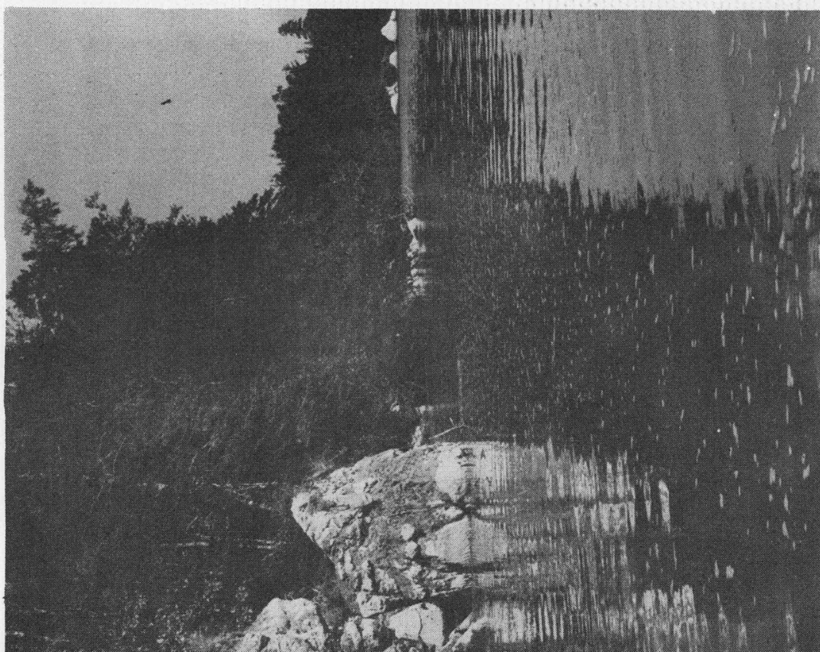
Bedded gypsum and anhydrite with the contact parallel to the bedding. (The hammer is on the contact of gypsum with the underlying anhydrite). North Quarry, Dingwall.

Photograph No. 4



Contorted beds of gypsum and dark limestone. North Quarry, Dingwall.

Photograph No. 5

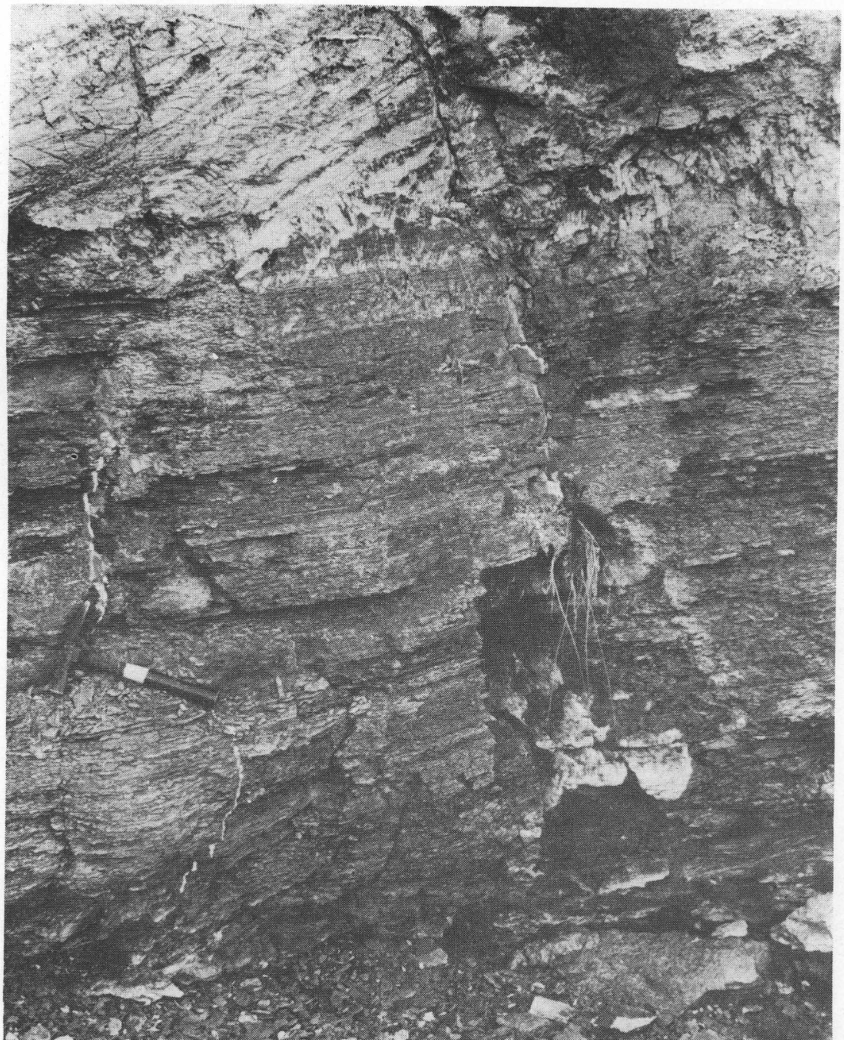


Bedded anhydrite. North side, South Gut

Photograph No. 6

Highly deformed beds of anhydrite and dark limestone. This "mashed" appearance is especially marked on a weathered surface. Bevis Point.

Photograph No. 7



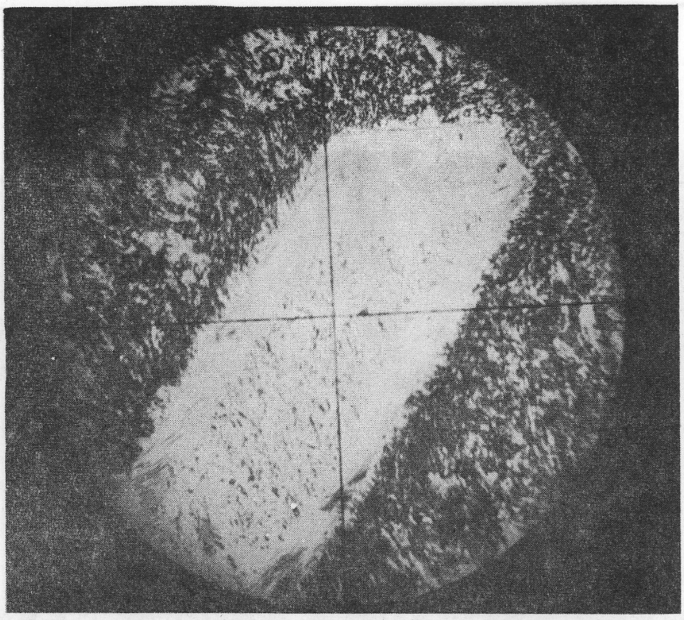
Dark laminated limestone overlain by anhydrite. The limestone-anhydrite contact is irregular as a result of movement. The limestone is cut by veins of fibrous gypsum. Bevis Point.

Photograph No. 8

Bedded gypsum. North side, Island Point.

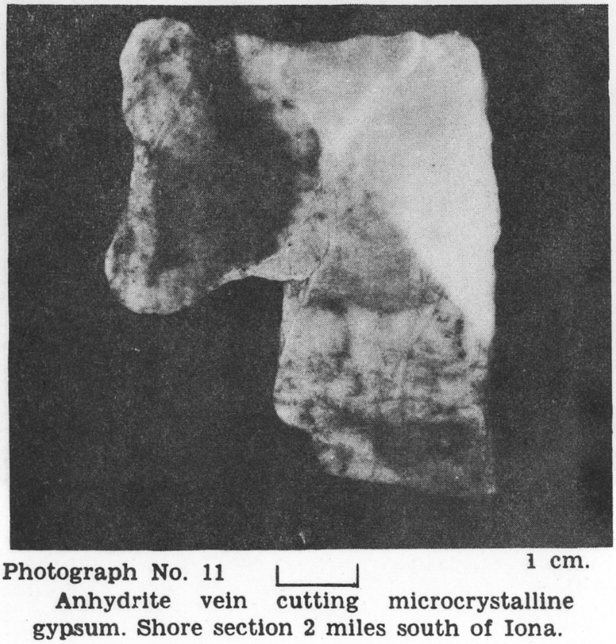
Photograph No. 9

Contorted gypsum. The beds are sometimes broken and formed into rounded masses of white microcrystalline gypsum surrounded by dark limestone. North side, Island Point.



Photograph No. 10 1 mm.

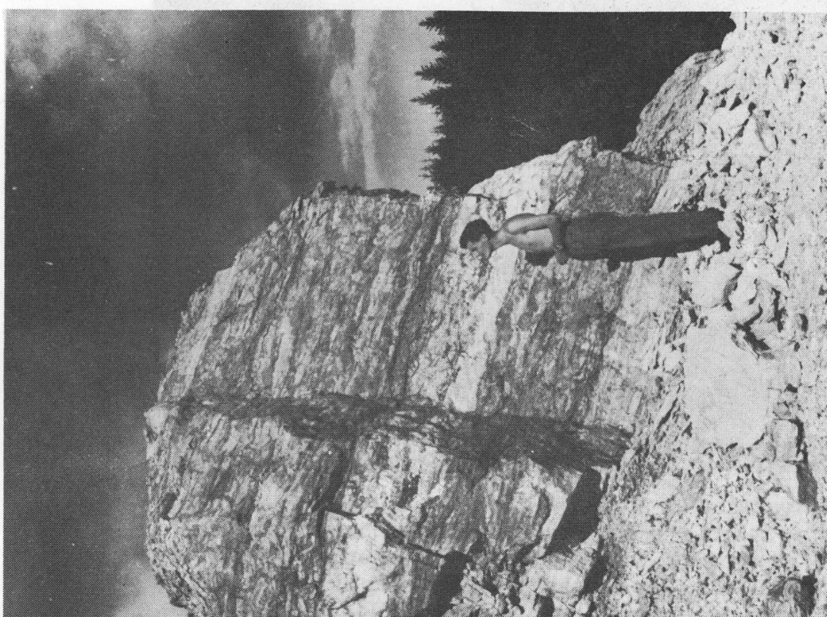
Zoned gypsum porphyroblast in microcrystalline gypsum (crossed nicols). The inclusions are calcareous. Note the concavity of the faces and the small crystals normal to the faces of the large one.



Photograph No. 11 1 cm.

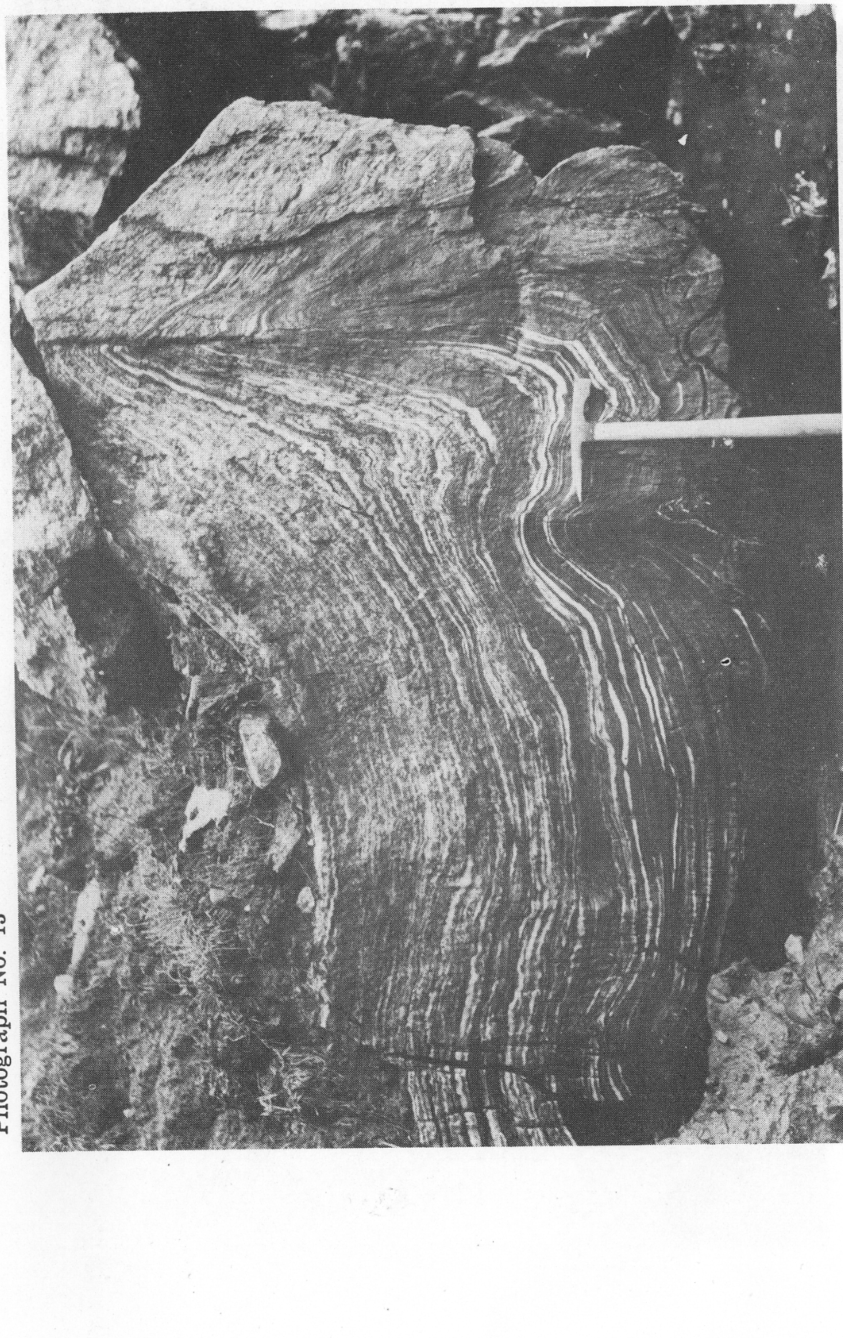
Anhydrite vein cutting microcrystalline gypsum. Shore section 2 miles south of Iona.

Photograph No. 12



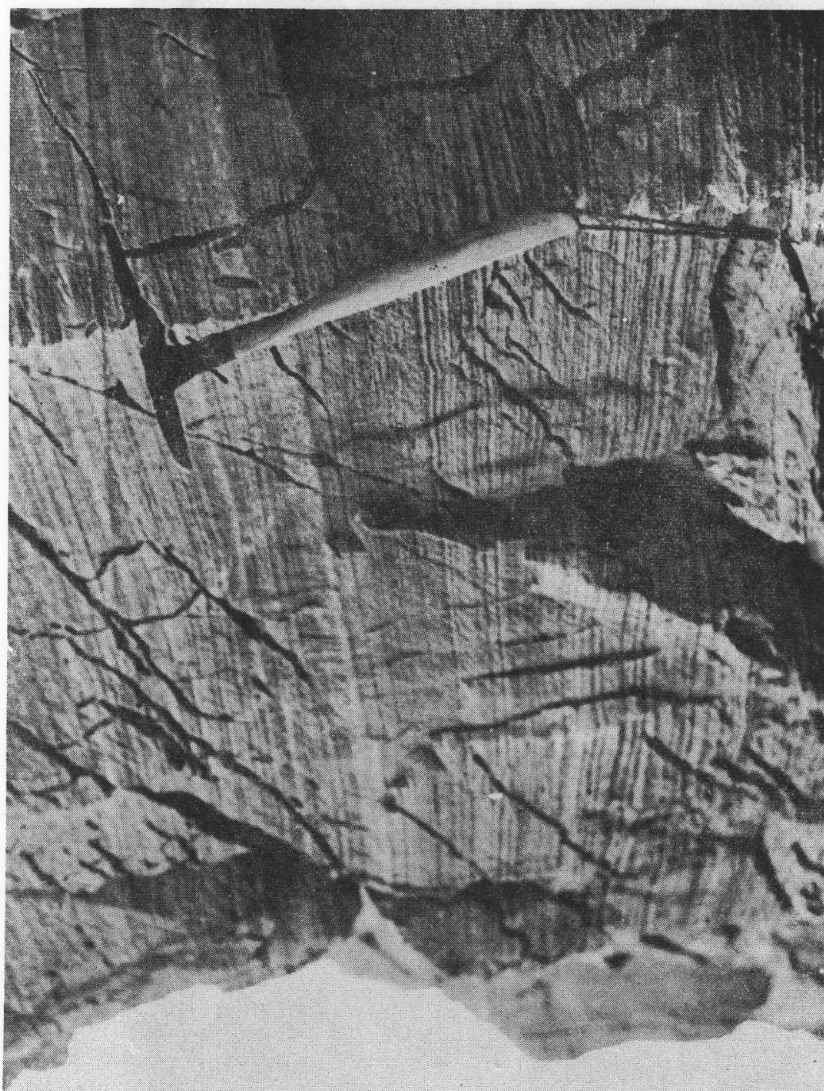
Bedded gypsum. Thompson Quarry, Little Narrows.

Photograph No. 13

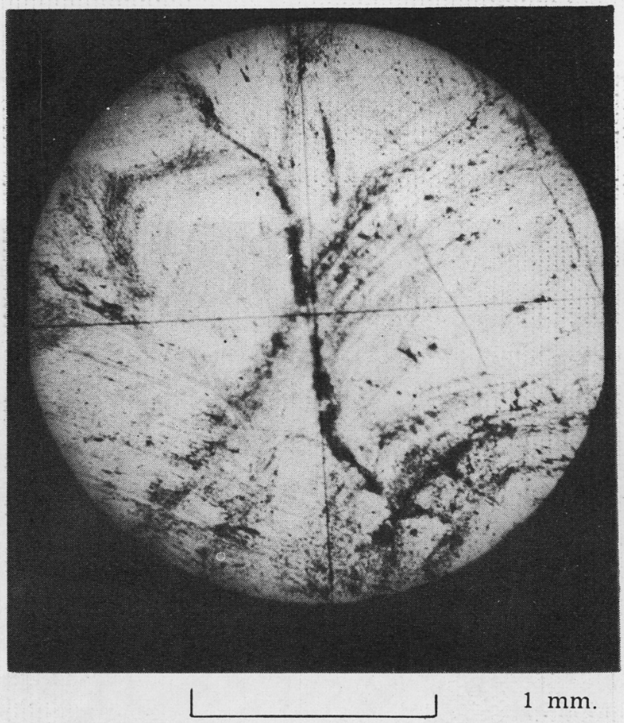


Highly folded beds of gypsum and dark limestone. Shore section one-half mile southwest of Little Narrows.

Photograph No. 14

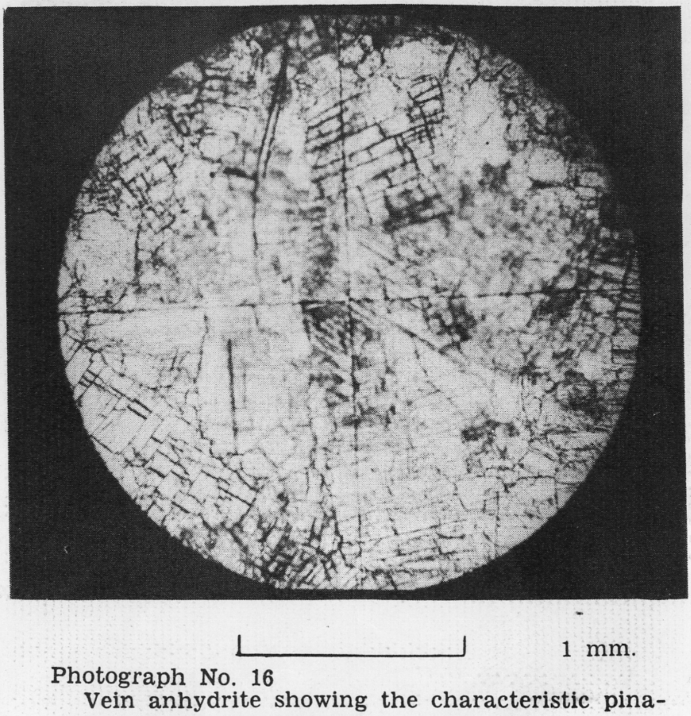


Bedded anhydrite. The bedding is marked by thin beds of dark limestone which stand high on a weathered surface. Coal Mine Point.



1 mm.

Photograph No. 15
Zoned stalactitic gypsum. The growth lines are marked by minute inclusions.

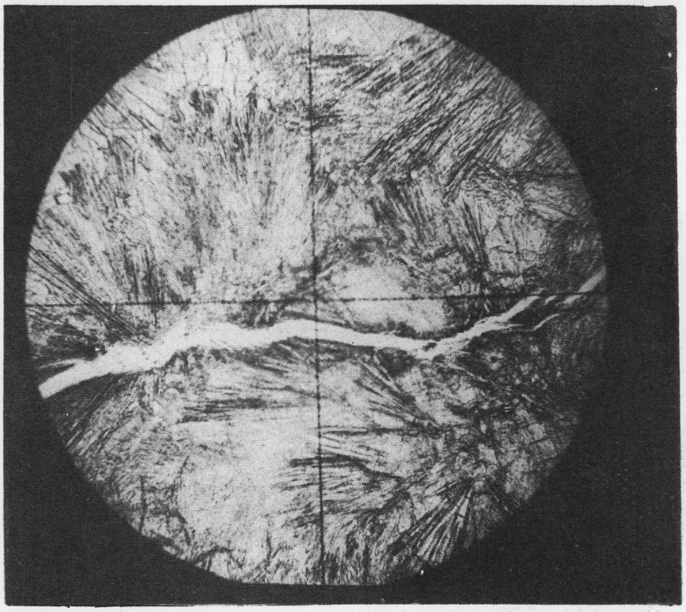


1 mm.

Photograph No. 16
Vein anhydrite showing the characteristic pinacoidal cleavages at 90°.

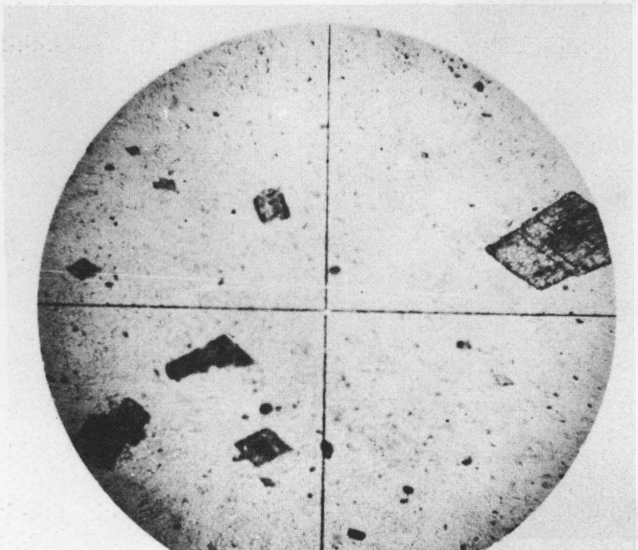
Photograph No. 17

Overturned beds of anhydrite on the crest of an asymmetrical anticline. New Quarry, Walton.



Photograph No. 18 1 mm.

Spherulitic anhydrite cut by vein of microcrystalline gypsum. The vein has anhydrite and calcareous inclusions.



1 mm.

Photograph No. 19

Dolomite rhombs in gypsum.