STRUCTURE AND PETROLOGY

OF

THE GYPSUMVILLE GYPSUM DEPOSIT

A Thesis

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by

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ABSTRACT

The Gypsumville sulphate deposit is approximately 130 feet thick and overlies a sequence of red and grey shales. The upper 40 or 50 feet is composed mainly of well-stratified gypsum, which is underlain by anhydrite. Fusuline foraminifera indicate a Permian or younger age for the deposit.

The gypsum has been deformed. Two sets of ridge-forming anticlinal folds are recognized and are interpreted as having resulted from ice-dragging during Pleistocene glaciation. This interpretation is based on a correlation between fold geometry and inferred directions of ice-movement.

Minor intrastratal convolutions also occur and are regarded as the product of slumping which occurred not long after deposition.

Petrographic observations indicate that the gypsum of the outcrop is a product of the hydration of anhydrite and that no increase in volume accompanied this replacement. The development of gypsum crystals from anhydrite occurred in three stages: a) the growth of large, coarse gypsum crystals at the expense of the anhydrite (G-1 stage); b) recrystallization of coarse gypsum crystals and formation of fine grained gypsum (G-2 stage); and c) growth of euhedral or lath-shaped crystals at the expense of fine grained gypsum (G-3 stage).

It is likely that the anhydrite formed after an earlier generation of gypsum but there is no petrographic evidence to substantiate this conclusion.

ACKNOWLEDGEMENTS

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INTRODUCTION

The purpose of the study is to describe and interpret the structure and petrology of the Gypsumville gypsum deposit. The deposit is located north-west of Lake St. Martin, between Lakes Winnipeg and Manitoba (Fig. 1). There are three major areas of gypsum outcrop; at Gypsumville, at Elephant Hill and at Whippoorwill Hill (Figs. 1 and 2). The Gypsumville outcrops extend for three miles north of Gypsumville and two quarries, the New Quarry and the Recent Working (Fig. 1), are in current operation. The original quarry, termed Old Quarry in the present paper, was opened in 1901 half a mile north of Gypsumville. The Elephant Hill outcrops are located about 4 miles north-east of Gypsumville and the Whippoorwill Hill quarry is located 3 miles north-east of Gypsumville.

The quarries at Gypsumville are accessible by road, but swampy ground occurs around the Elephant Hill and the Whippoorwill Hill outcrops. The quarries at Gypsumville are described in greater detail than those at the other adjacent locations.

The deposit was referred to by J. B. Tyrrel (1887, p. 74A), and since that time only three reports of note have been produced; Wallace (1914), Brownell (1931) and Bannatyne (1959). These reports describe the general geology of the area.

Although the Gypsumville deposit is situated within the outcrop belt of the Silurian Interlake Group (Fig. 2), there is a lack of evidence to indicate the age of the deposit. The discovery, during this investigation, of fusuline foraminifera in the shale below the gypsum, throws new light on the age of the deposit.

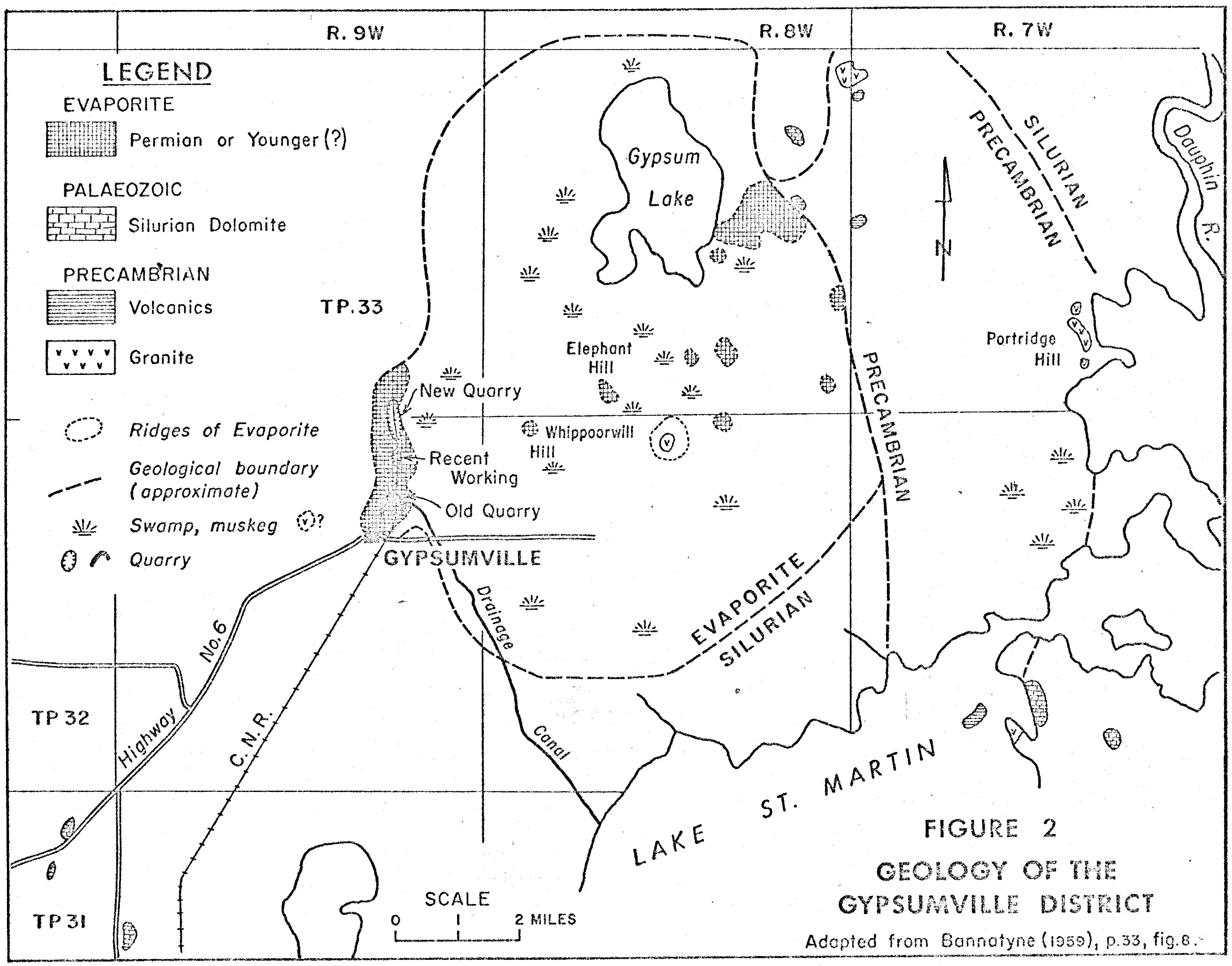


FIGURE 2

GEOLOGY OF THE GYPSUMVILLE DISTRICT

Adapted from Bannatyne (1959), p.33, fig.8.

The gypsum deposit occurs in the form of isolated, low lying ridges, which rise above the surrounding swampy plains. Several of these ridges are anticlinal folds with intrastratal convolutions. These folds and convolutions have been interpreted by previous workers as expansion structures formed during the hydration of anhydrite to gypsum (Wallace, 1914, p. 275; Brownell, 1931, p. 12 and Bannatyne, 1959, p. 31). The hydration theory is not accepted here and the anticlinal folds have been interpreted to be the result of ice-dragging during glaciation. This interpretation is based on an analysis of fold geometry and inferred directions of ice-movement.

A petrographic study was undertaken as an aid in interpreting the relationship between the various types of anhydrite and gypsum occurring in the Gypsumville area.

TOPOGRAPHY.

North-south and east-west trending ridges dominate the topography of the Gypsumville gypsum deposit. Maximum relief in the area is not over 40 feet, and the average relief is approximately 15 feet. The largest ridge in the area extends for three miles from Gypsumville and trends north-south. Similar ridges of anhydrite and gypsum occur scattered over an oval shaped area covering approximately 90 square miles (Fig. 2). While the bed rock in the area is covered by a thin sheet of glacial till, possibly wave eroded, the muskeg and open marshland that surround the gypsum deposit are composed of glacial lake sediments (Fig. 25).

Areas underlain by gypsum, but not covered by a heavy mantle of overburden, are pitted by sinkholes. These sinkholes range in size from a few feet in diameter to 100 to 200 feet in diameter and 20 to 30 feet in depth. Many of the sinkholes are circular in outline and have vertical walls. However, some of the larger ones, particularly those that were formed by the compounding of two or three small sinkholes, are very irregular in shape. The sinkholes are filled with two types of deposits: a) glacial till composed of boulders of granite, dolomite and fragments of gypsum and anhydrite, gravel, sand and silty clay. The occurrence of rotten tree trunks and leaves gives the till a black color. b) white insoluble residues capped by dark organic rich till.

Origin of Topography

The Gypsumville area was affected by Pleistocene glaciation and it might be expected that the relatively soft gypsum deposit would have been planed during ice-movement. The fact that the gypsum occurs as a topographically elevated prominence has been explained by Brownell (1931, p. 13) and Bannatyne (1959, p. 31) on the basis that the ridges were formed post-glacially by the hydration of anhydrite to gypsum, with consequent expansion and folding. This explanation is not completely satisfactory since a hill of nodular anhydrite occurs in the Whippoorwill area and rises above the surrounding depressions as prominently as any of the gypsum ridges. In addition, petrographic evidence suggests that replacement of anhydrite by gypsum was volume for volume, and not molecule for molecule. Thus, the interpretation by previous workers that the ridges were formed postglacially by volume expansion is not supported by petrographic observation.

The sinkhole topography presumably resulted from solution by surface waters, and subsequent collapse, but it is not known whether this occurred in pre- or post-Pleistocene time.

Vegetation

Gypsum hills, with a thin veneer of drift, are characterised by taembling aspen, poplar and willows (Fig. 1). Spruce trees occur away from gypsum outcrops or in regions where a relatively thick cover of overburden occurs on gypsum. Pine is common on the surrounding muskeg. A striking change in vegetation can be seen at the northern edge of the New Quarry (Figs. 1 and 26B).

GENERAL GEOLOGY

Regional Geological Setting

There are no contacts visible for gypsum with underlying or overlying rocks and there is some doubt about the geological relations of the Gypsumville deposit to associated sedimentary rocks (Fig. 2). The deposit lies within the outcrop belt of the Silurian Interlake Group. The discovery of fusuline foraminifera in shales underlying gypsum (Fig. 6, D.H.1c and Plate I-A and B) indicates that the gypsum is Permian or younger.

On the north, south-east and west sides of the Gypsumville deposit, Pre-Cambrian rocks outcrop or occur close to the surface (Fig. 2). Massive granite and other Pre-Cambrian rocks form large outcrops at the narrows, and nearby islands, of Lake St. Martin and granite hills rise as much as 100 feet above the surrounding lowlands on the west shore of Lake St. Martin. Brownell (1931, p.11) reported the presence of a massive, grey granite about 1 mile west of the town of Gypsumville, under a drift cover of 15 feet.

Bannatyne (1959, p. 32) suggested that some of the present granite ridges in the region of Lake St. Martin were also topographic features in Paleozoic time. He further suggests ed that local topography may have caused local restrictions which led to the deposition of the Gypsumville deposits.

Quarry Geology

Gypsum overlies anhydrite and, in the quarry exposures, changes from one to the other are abrupt and irregular.

New Quarry: Shallow drill holes reveal that the gypsum-anhydrite deposits are about 100 feet thick and are underlain by a sequence of red and grey shales (Figs. 3 and 4). At a depth of 45-50 feet, gypsum is underlain by anhydrite. The contact between gypsum and anhydrite commonly is sharp (Fig. 4) but may be gradational over a few feet. Lenses of red shale and dolomitic limestone are interstratified with gypsum.

The gypsum at the surface occurs in beds from less than half an inch to 2 feet thick and less commonly as massive beds. Bedding planes are marked by grey or red argillaceous material. Gypsum beds display granular, porphyroblastic (Pettijohn, 1957, p. 92) and fibrous textures.

For convenience, the 3400 feet long N-S trending quarry face (Fig. 3) is described in two portions positions. One portion starts from the northern end of the 6 feet wide drainage ditch and the other starts from the southern end of the drainage ditch and continues to the southern end of the quarry.

The bedding terms used in this section are derived from Pettijohn (1957, p. 159) as shown below:

a) laminated, less than half an inch thick;

b) very thin bed, half an inch to 2 inches thick;

c) thin bed, 2 inches to 2 feet thick;

d) thick bed, 2 feet to 4 feet thick; and

e) massive, more than 4 feet thick.

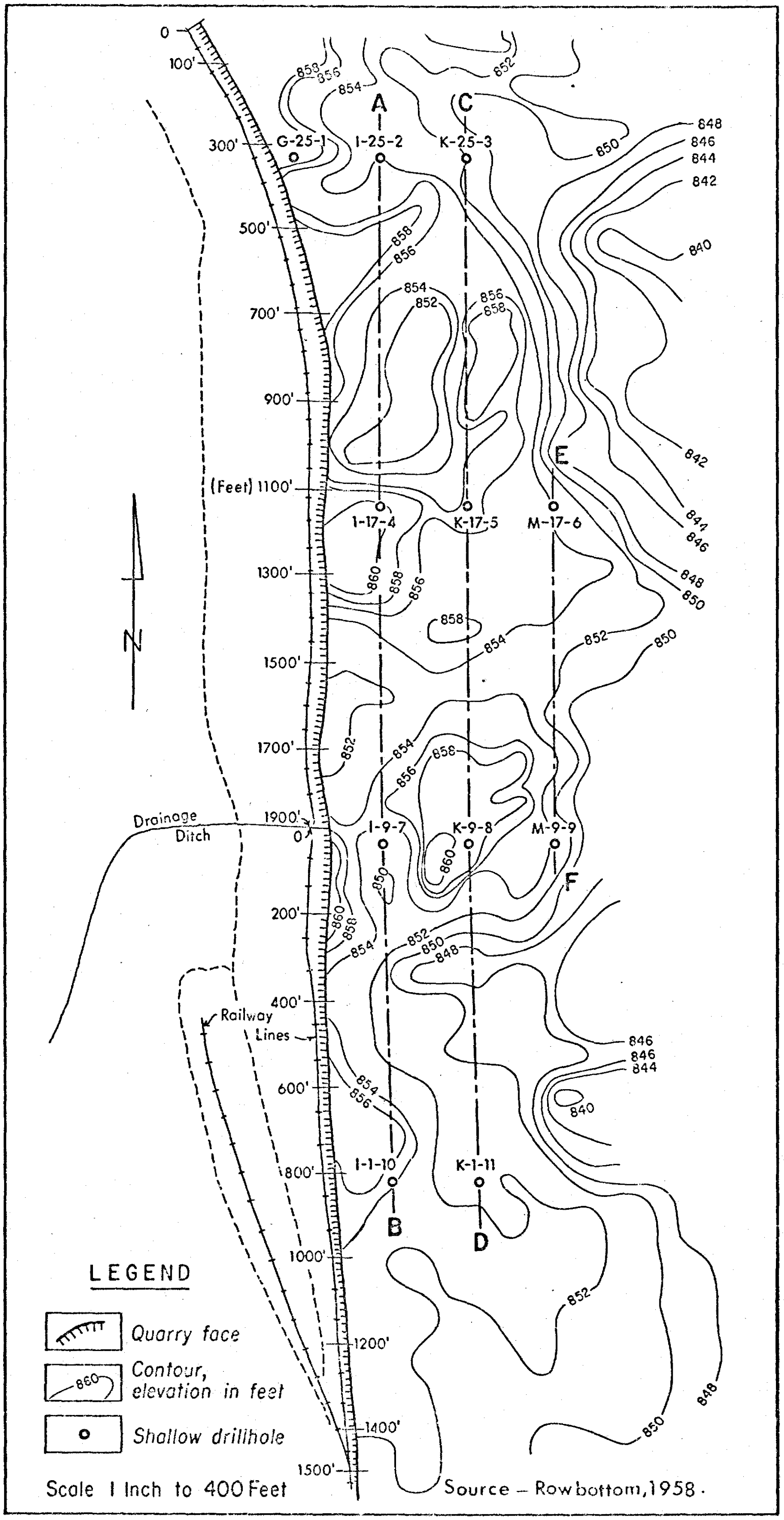


Figure 3 – Location of Boreholes in New Quarry

The gypsum, from the northern end of the quarry to the 350 foot point (Section AB, Fig. 14) is thinly-bedded, greyish-white and fine grained. A section measured at the core of A2 (Fig. 14) southward to the trough of S2 provides the following succession:

SECTION NO. 1

Depth from quarry top in feet	Lithology	Thickness in feet
0 - 12	Very thinly-bedded, fine grained, reddish-brown gypsum; bedding marked by red clay partings.	12
12 - 15	Thinly-bedded, fine grained, greyish-white gypsum; bedding marked by grey calcareous material.	3
15 - 15.25	A three-inch bed of grey to bluish-white anhydrite.	.25
15.25- 16.25	Laminated, fine grained, brownish-stained, white gypsum; lamination marked by clay partings.	1
16.25- 28.25	Thinly-bedded, fine grained, creamish-white to white gypsum; a six-inch thick bed of greyish-blue, coarsely crystalline anhydrite at middle of unit.	12
28.25- 30.25	Thinly-bedded, coarsely crystalline, bluish-white anhydrite at middle of unit.	2
30.25- 32.25	Thinly-bedded, fine grained, white gypsum.	2
32.25- 36.25	Base-rubble covered	4
	Total	36.25

From the 350 foot point to the 500 foot point, the section is characterized by the presence of white, fine-grained spheres of gypsum which weather to greyish and brownish-white, coarse gypsum (for further discussion on spheres see p. 71). The sequence from the 500 foot point to the 900 foot point is characterized by the presence of coarse gypsum crystals associated with fine grained, white gypsum. The section at the 500 foot point (Figs. 3 and 14) is:

SECTION NO. 2

Depth from quarry top in feet	Lithology	Thickness in feet
0 - 8	Very thinly-bedded, fine grained, red stained gypsum; fine grained, white spheres occur with red stained gypsum and coarse gypsum crystals.	8
8 - 8.5	Coarsely crystalline, grey to bluish-white anhydrite; bedding on top and bottom marked by grey calcareous shale.	.5
8.5 - 18.5	Greyish masses of coarse gypsum in thinly-bedded, fine grained, white gypsum.	10
18.5 - 23.5	Thinly-bedded, greyish-masses of coarse gypsum.	5
23.5 - 33.5	Thinly-bedded, fine grained, greyish-white gypsum; middle of unit contains two beds of coarsely crystalline, greyish-blue anhydrite half an inch thick.	10
33.5 - 43.5	Base of face is rubble covered, but exposure 15 feet to the south is thinly-bedded, and consists of partly altered coarse grained anhydrite with large gypsum crystals.	10
	Total	43.5

The quarry face between the 900 foot point and the 1600 foot point is represented by a succession of light-grey, thinly-bedded, fibrous gypsum, white coarse grained gypsum and greyish-white, fine grained gypsum. At the 1150-foot point, a three-foot thick, grey to bluish-white, coarsely crystalline anhydrite bed is exposed and can be traced to the 1600 foot point (Fig. 14). The section measured between the 1100 and 1700 foot points on the quarry face is as follows:

SECTION NO. 3

Depth from quarry top in feet	Lithology	Thickness in feet
0 - 20	Laminated, fine grained, grey gypsum; lamination marked by grey clay; gypsum fibres oriented perpendicular to bedding and growth apparently has displaced clay.	20
20 - 30	Thick bedded, coarse grained, greyish-white gypsum.	10
30 - 33	Massive bed of coarsely-crystalline, greyish-blue to bluish-white anhydrite; marginally weathers to fine grained gypsum.	3
33 - 38	Very thinly-bedded, fine grained, greyish-white gypsum; bedding marked by grey calcareous shale.	5
38 - 41	Thinly-bedded, medium grained, white gypsum.	3
41 - 42	Coarsely-crystalline, bluish-white anhydrite.	1

Depth from quarry top in feet	Lithology	Thickness in feet
42 - 44	Thinly-bedded, fine grained, grey gypsum.	2
44 - 46	Base-rubble covered.	2
	Total	46

Coarse gypsum beds, up to one foot thick, are prominent from the 1600 foot point to the drainage ditch. The gypsum between the 1800 and 1900 foot points, north of the drainage ditch is typified by grey coloured rosettes of gypsum (for further description see p. 74).

Between the 0 foot point and 700 foot point, south of the drainage ditch, the succession consists of greyish to brownish-white, thinly-bedded, fibrous gypsum. A 4 foot thick bed of anhydrite is exposed in the lower part of the section, between the 720 and 760 foot points (Fig. 14). The quarry face between the 760 and 1500 foot points is composed of a sequence of white and greyish-white, fine grained gypsum. White spheres of gypsum are enclosed in greyish-white, thinly-bedded gypsum and grey, coarse gypsum crystals. The upper half of the face, at the southern end of the quarry, is red coloured.

Recent Working: The rock types encountered in the Recent Working are similar to those of the New Quarry (Fig. 14). The eastern face of the working exposes a sequence of fine grained gypsum, white spheres of gypsum and coarse grey gypsum crystals. The upper half of the quarry face is brown coloured with iron oxides.

Old Quarry: About 40 feet of drift overlies an 80 foot section of gypsum, which overlies grey and red shaly beds (Fig. 6). The maximum thickness of sulphates encountered in the northern part of the quarry by a drill hole, is 130 feet, the base of the gypsum lying 40 feet from the surface (Fig. 6). Evaporites were not encountered in any of the shallow wells for water drilled on the southwestern edge of the deposit.

The enclosed map (Fig. 5) shows the gross rock types in the Old Quarry.

Gypsum occurs in beds ranging from one quarter of an inch to about 4 feet with an average of 6 inches. The beds of gypsum are of variable colour from white to grey, pink, red and brown. The beds are separated by thin partings of clay and units of argillaceous limestone. Two varieties of gypsum are common: the thick bedded gypsum, constituting the bulk of the deposit and the fibrous gypsum which forms layers from one quarter of an inch to one inch thick between some of the beds.

At the extreme southeast corner of the west arm of the Old Quarry, reddish-brown gypsum is interbedded with red clay in about equal proportions (Unit 1, Fig. 5). Further to the south and southeast, the deposit appears to grade laterally to red clay.

The unit 2 of Fig. 5 consists of thin to thick bedded, greyish-white gypsum. The bedding planes are marked by thin laminae of argillaceous limestone.

Unit 3 is characterized by dark grey gypsum and fibrous

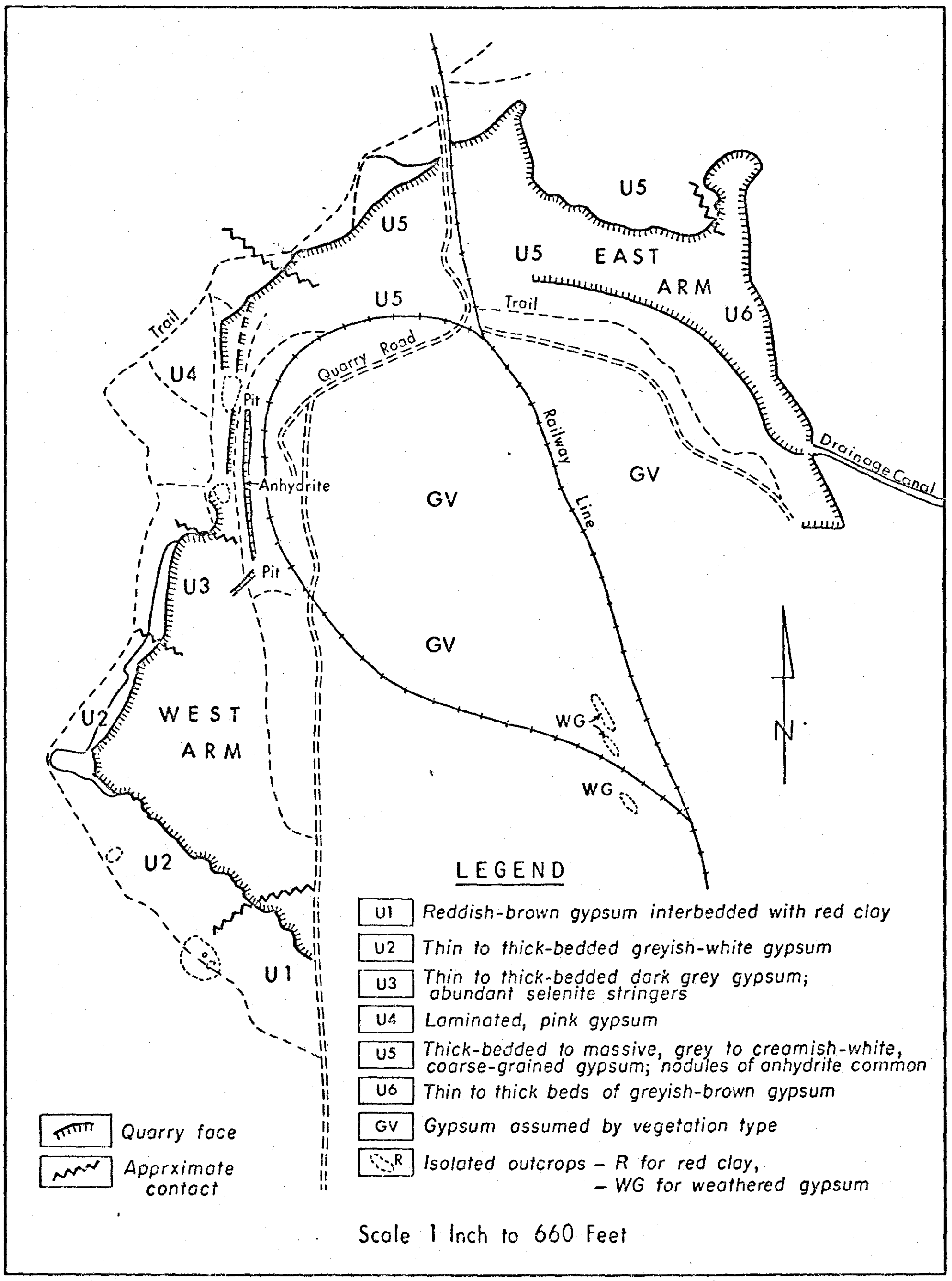


Figure 5 — Rock Types in the Old Quarry

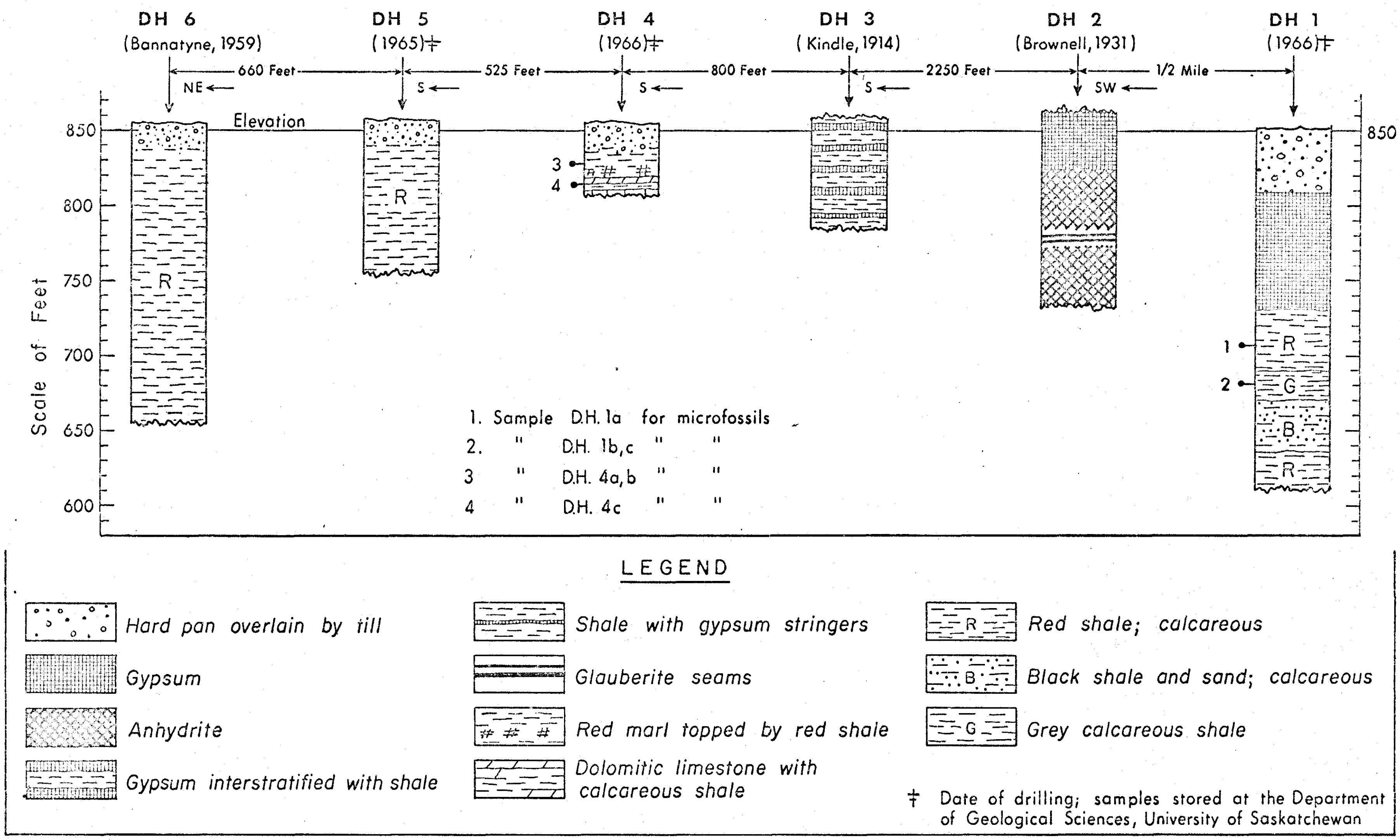


Figure 6 — Cross-section compiled from drillhole data in the Old Quarry
(for location of drillholes see Figure 1)

gypsum stringers are extensively developed. The gypsum beds are thin to thick bedded.

In unit 4, the gypsum is pink banded due to iron oxides associated with contained clay. The gypsum beds, in contrast to unit 4, are well laminated.

Unit 5 consists of dark grey to creamish-white, thick bedded to massive, coarse grained gypsum. Anhydrite occurs at the base of the quarry face as thick beds and nodules. The gypsum contains abundant fibrous stringers.

Thin to thick beds of greyish-brown gypsum comprise unit 6. The lower part of the section contains distinct beds, up to two feet thick, of creamish-white anhydrite. This unit, in the northeastern part of the quarry, is characterized by gypsum beds with red clays.

Whippoorwill Hill Quarry: This quarry is composed almost entirely of greyish-blue to bluish-white, nodular anhydrite. The upper 4 or 5 feet of the deposit is composed of poorly-bedded, creamish to greyish-white gypsum. The nodules of anhydrite are 4 inches to one foot in diameter and marginally weathers to fine grained gypsum. The weathered zones are concentric about the nodules. The thickness of exposed rock in the quarry is about 20 feet.

Elephant Hill: The Elephant Hill deposit (Fig. 1) is developed on the south and southeast sides of the hill as three pits. About 20 feet of gypsum is exposed.

Distinctive lithologic features of the two pits on the south side of the hill include the presence of large plates of gypsum crystals, which occur as pockets and sheets through the fine grained gypsum. Continuous masses of gypsum crystals, sometimes coated with an unidentified dark opaque mineral, have been observed.

Fine grained, white gypsum occurs throughout the pit situated in the southeast part of the hill. The gypsum is thinly-bedded. Thick beds of interstratified anhydrite are greyish-blue.

Summary: The deposit in the Gypsumville and adjacent areas is approximately 130 feet. The upper 40 or 50 feet is mainly gypsum with the notable exception of the Whippoorwill Hill, which is almost entirely composed of nodular anhydrite. In general, the anhydrite content increases with depth.

Age of the Gypsumville Deposit

Historical Review: The age of the Gypsumville deposit has been the subject of considerable debate, since contacts of the gypsum beds with overlying and underlying units are not exposed.

Cole (1913, p. 80) proposed that the Gypsumville deposit might be included within the Devonian Ashern Formation, the red shales of which are superficially similar to the red shales underlying the Gypsumville deposit, although no evaporites are associated with the Ashern.

Wallace (1914, p. 273) and Brownell (1931, p. 11) suggested that the gypsum deposit of the Gypsumville district is of Silurian age, because beds of this age outcrop both to the southeast and southwest of this deposit (Fig. 2). The Silurian age of the deposit cannot, however, be reliably accepted because of the absence of exposed contacts and the absence of fossil evidence of age.

Baillie (1951, p. 35) suggested that the deposit of gypsum and anhydrite at Gypsumville may be related to the middle Jurassic Amaranth gypsum deposit. The suggestion, however, lacks supporting evidence.

Bannatyne (1959, p. 40), although inclined to the opinion that the Gypsumville deposit is of Silurian age, suggested that the evaporites and the underlying dolomitic shale may have been deposited directly on the Pre-Cambrian rocks which are known to occur on the north, southeast and west sides of the deposit. Assuming that the evaporite basin is underlain by Pre-Cambrian rocks, the gypsum deposit could have formed during any of the Paleozoic or Mesozoic Eras, when seas encroached on the southwestern and the central parts of Manitoba.

Present Study: Although the gypsum and anhydrite deposit in the Gypsumville area lacks exposures in contact with the underlying rocks, several cores drilled within, and on the edge of the deposit show that gypsum is underlain by red and grey calcareous or dolomitic shales (Figs. 1, 4 and 6). Core from the drill hole on the eastern edge of the Old Quarry (D.H. 1 in Figs. 1 and 6) consists of 80 feet of gypsum which is underlain by 110 feet of red and grey calcareous shale. In addition to the cores drilled (for location and stratigraphic position of the cores see Figs. 1 and 6) 15 samples of calcareous shale and argillaceous limestone, interbanded with the gypsum beds, were collected for micropaleontological investigation.

Only one of the above samples yielded microfossils. Fusuline foraminiferas were found in D.H.1c, 160 to 180 feet below ground surface. These fossils were studied and identified by Dr. W. K. Braun, of University of Saskatchewan, and are believed to be of Pennsylvanian-Permian age. The spindle shape of the fossils (Plates I-A and B) suggest a Permian age (Braun, 1967, personal communication). From the fossil evidence, it may be concluded that the gypsum is Permian, or younger.

Plate 1-A. Fusuline foraminifera from shales underlying gypsum in the Old Quarry (Sample D.H.1c-Fig. 6). Photographs X25.

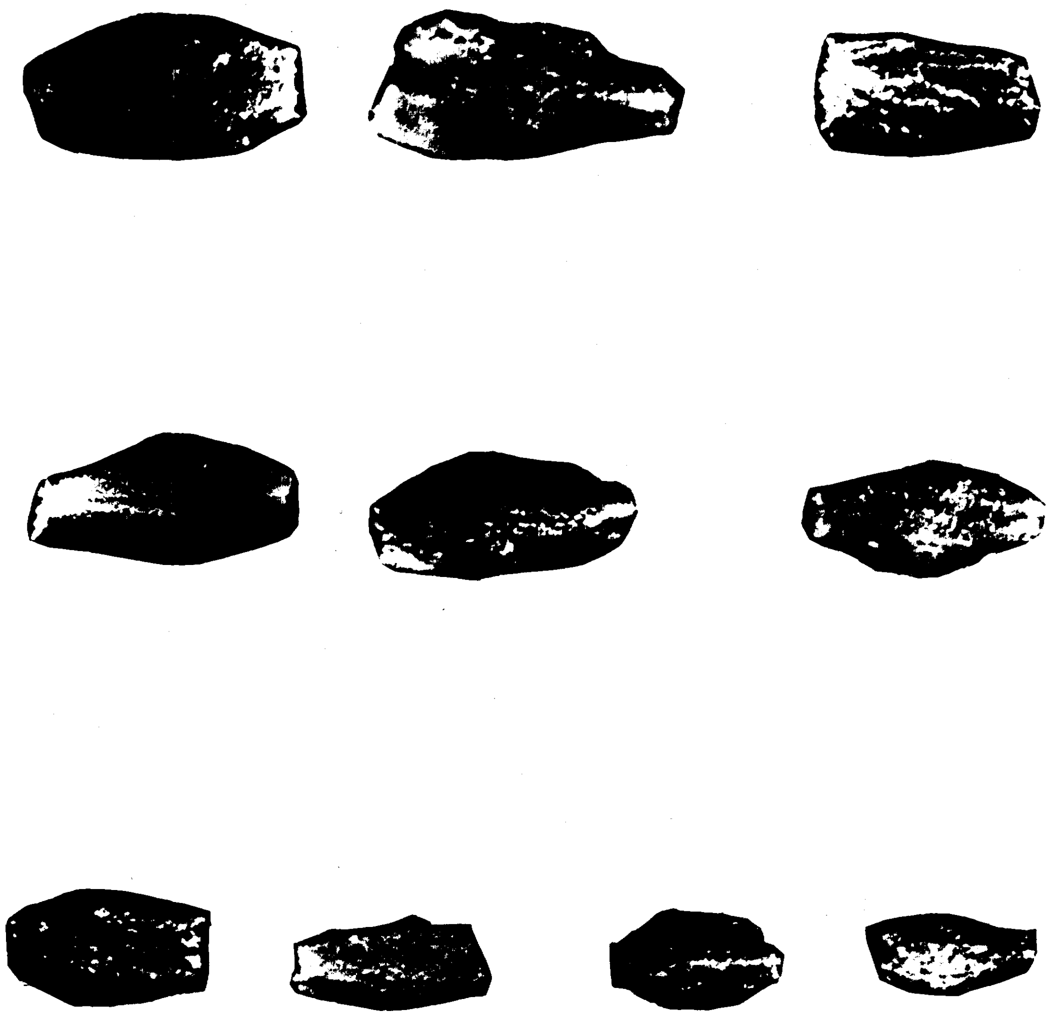


PLATE 1A

Plate 1-B. Fusuline foraminifera from shales underlying gypsum in the Old Quarry (sample D.H. lc-Fig. 6). Drawings X50.

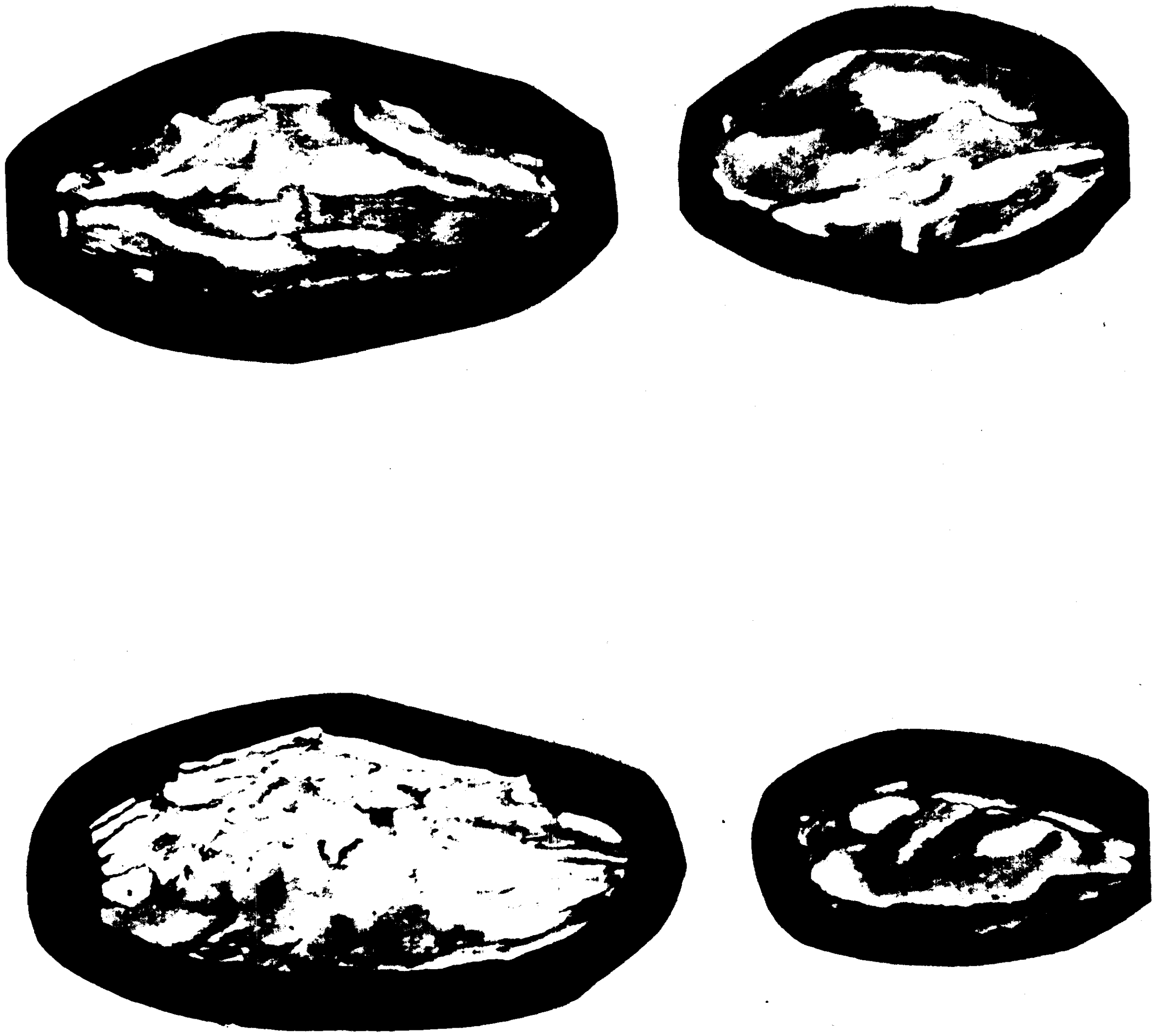


PLATE 1B

STRUCTURE

General

Folds are the main structural feature of the gypsum deposit in the Gypsumville area. These are well exposed on the quarry faces (Fig. 7). In order to study their geometry and origin the orientations of about 200 folds were measured and plotted on Schmidt, lower hemisphere, equal area nets.

Three types of folds are present in the gypsum deposit of the Gypsumville area:

a) a well developed set of N-S trending folds that occur on all scales from a fraction of an inch to a quarter of a mile in wavelength (set 1),

b) an older set of E-W to WNW-ESE trending folds (set 2) that also vary in wavelength from a fraction of an inch to a quarter of a mile, and,

c) a series of intrastratal convolutions not related to either of the previously mentioned fold sets.

Determination of set 1 and set 2 Folds

The orientations of fold hinges and axial planes were plotted and analysed following procedures adopted by Turner and Weiss (1963, p. 49-64 and p. 125-143). Contouring of the points was accomplished by square grid method suggested by Stauffer (1966, p. 475).

The contour diagrams of the fold elements for all the quarries plotted in the nets are presented in Fig. 8, which indicates well-defined point maxima for both axial planes and fold axes. Two groups

Figure 8. Lower hemisphere equal area projection of fold elements of 205 major and minor folds in the Gypsumville quarries. Contours at 1, 3, 5 and 20 percent (stippled area) per 1 percent area.

A. Fold hinges

B. Poles to axial planes

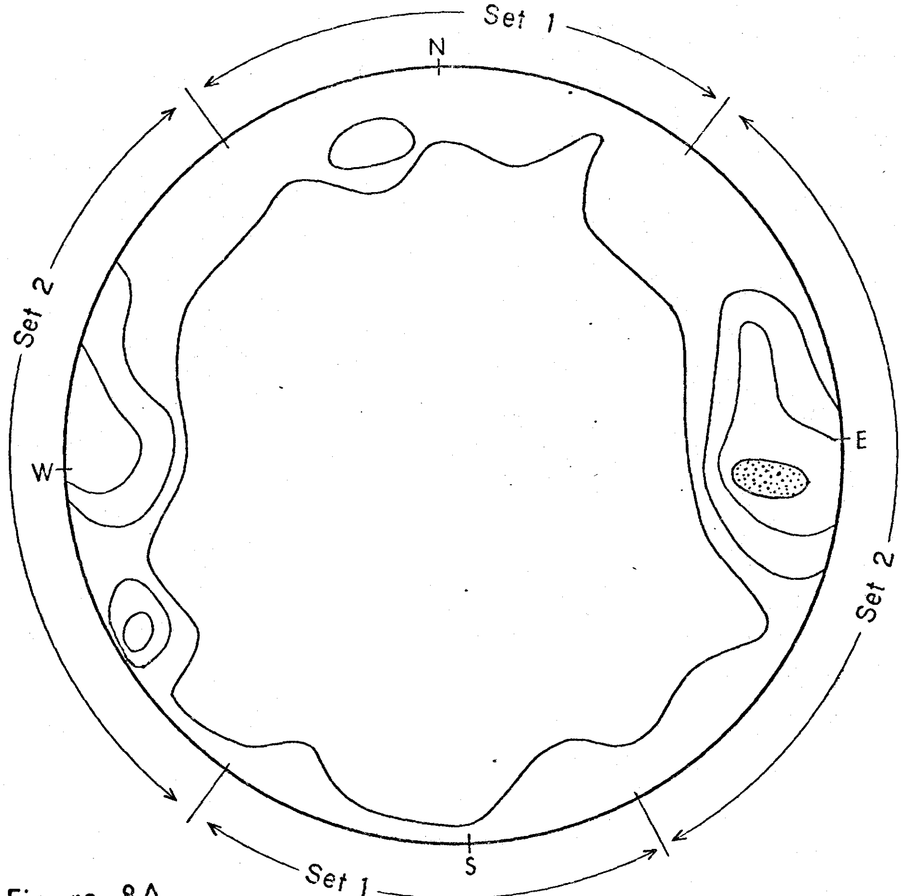


Figure 8A

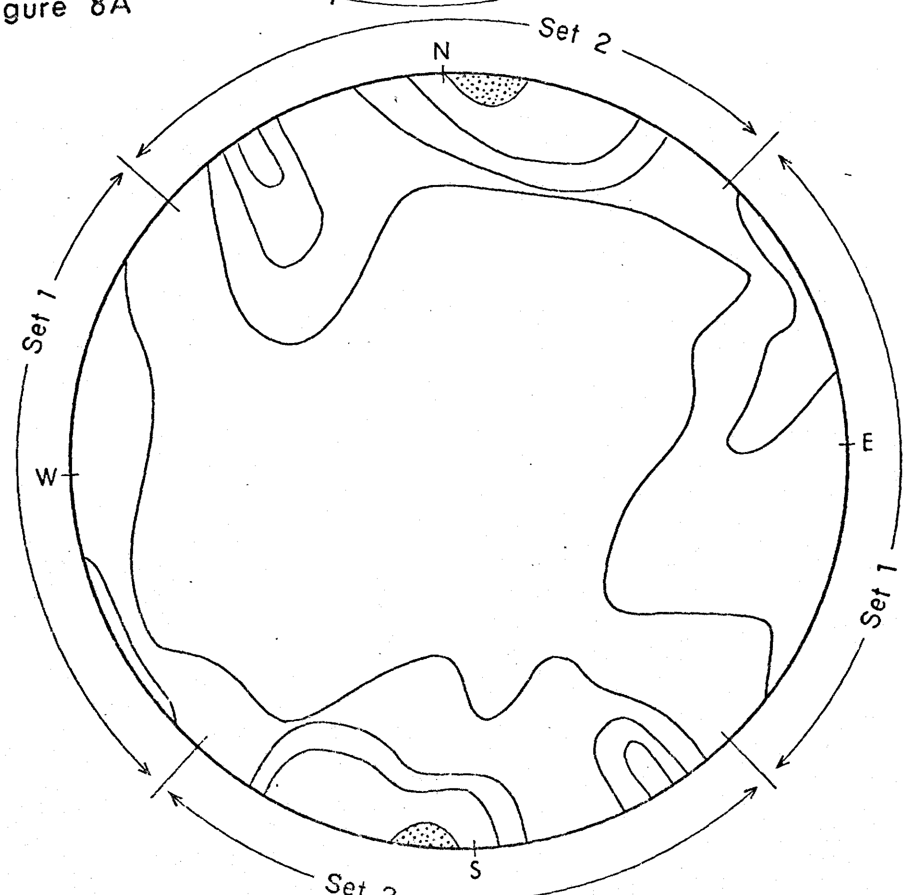


Figure 8B

of fold axes can be seen in Fig. 8A; one well-defined group plunges gently east and west and the other, poorly-defined, plunges gently to the north and south. The diagram of poles to axial planes (Fig. 8B) also shows two well-defined maxima; one tending to lie east-west (set 1) and the other north-south (set 2). Both sets 1 and 2 consist of concentric to kink style folds and range in size from nearly microscopic to $\frac{1}{4}$ mile across and a mile or more long; they differ only in orientation, set 1 trending N-S with nearly vertical axial planes (Fig. 8B) and set 2 trending E-W, also with nearly vertical axial planes (Fig. 8B).

Fold axes in the New Quarry and Recent Working are seen to plunge at low angles to the east (Fig. 9A) with a well-defined maximum at about 20° to the east. Most axial planes dip vertically but some are inclined to the north and to the south (Fig. 9B).

Folds in the Old Quarry also have gently plunging axes (Fig. 10A), but the strikes of their axial planes vary greatly (Fig. 10B). The dips of the axial planes are vertical for most folds (Fig. 10B). The great diversity of strikes and plunges for axial planes may be indicative of superposed folding in the area. Both sets 1 and 2 folds are present in this quarry.

Set 1 Folds

The set 1 folds (with axial planes which strike generally N-S) are well exposed in the quarry faces of the Gypsumville area (Fig. 7). Most of the folds have vertical axial planes and are gently plunging; however, a few are asymmetrical. The folds are

Figure 9. Lower hemisphere equal area projections of fold elements of 100 major and minor folds in the New Quarry and Recent Working of the Gypsumville outcrop.

A. Fold hinges. Contours at 1, 5, 11 and 15 percent (stippled area) per 1 percent area.

B. Poles to axial planes. Contours at 1, 3, 9 and 22 percent (stippled area) per 1 percent area.

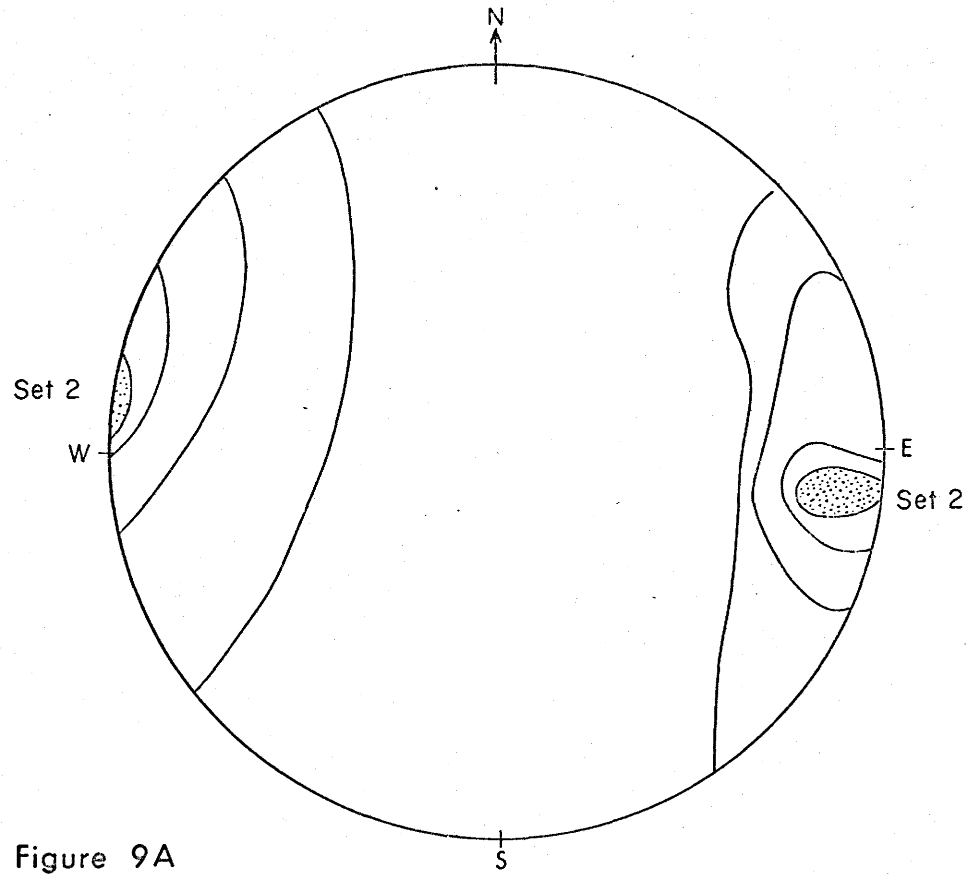


Figure 9A

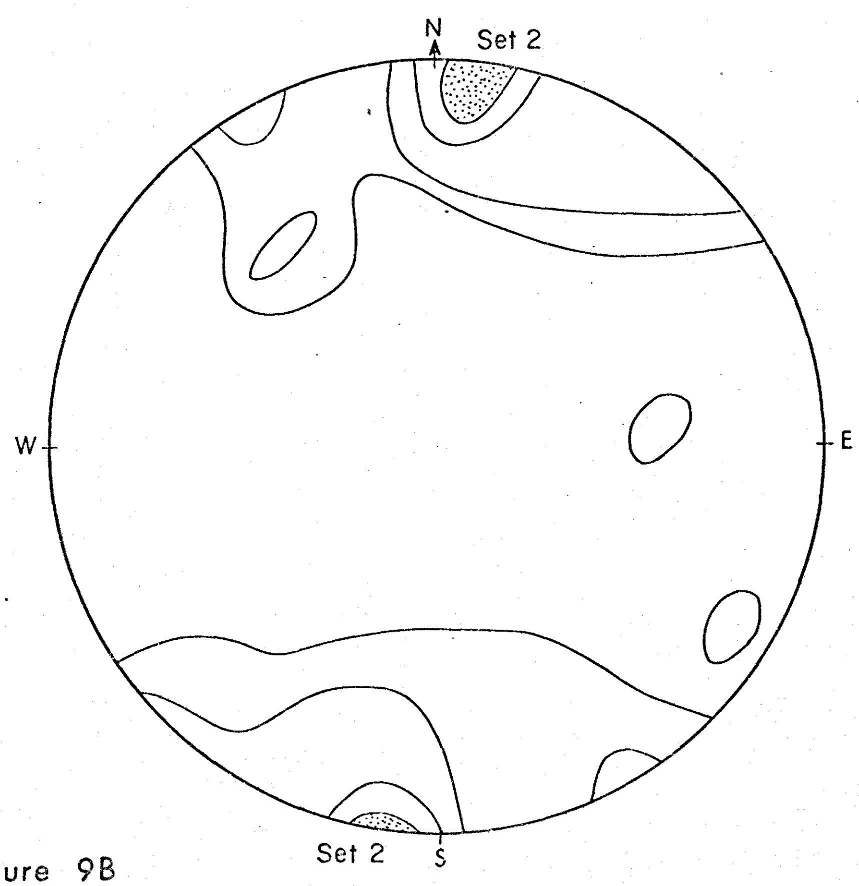


Figure 9B

Figure 10. Lower hemisphere equal area projections of fold elements of 105 major and minor folds in the Old Quarry of the Gypsumville outcrop.

A. Fold hinges. Contours at 1, 3, 5 and 7 percent (stippled area) per 1 percent area.

B. Poles to axial planes. Contours at 1, 3, 5, 7 and 10 percent (stippled area) per 1 percent area.

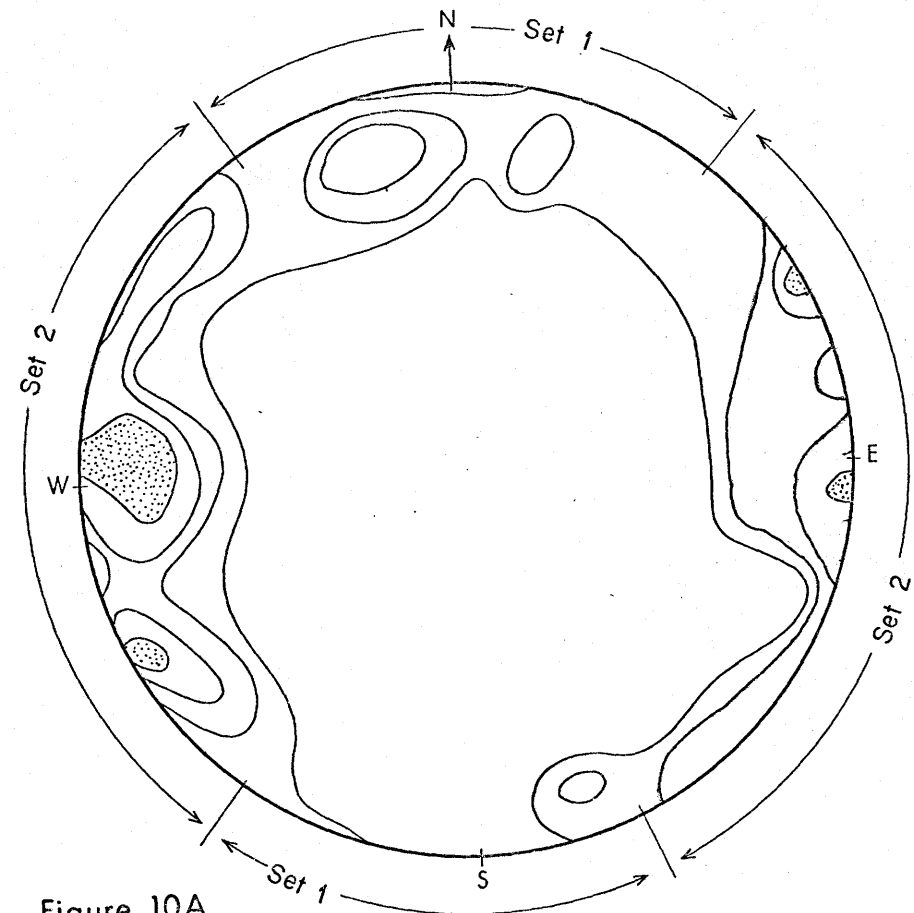


Figure 10A

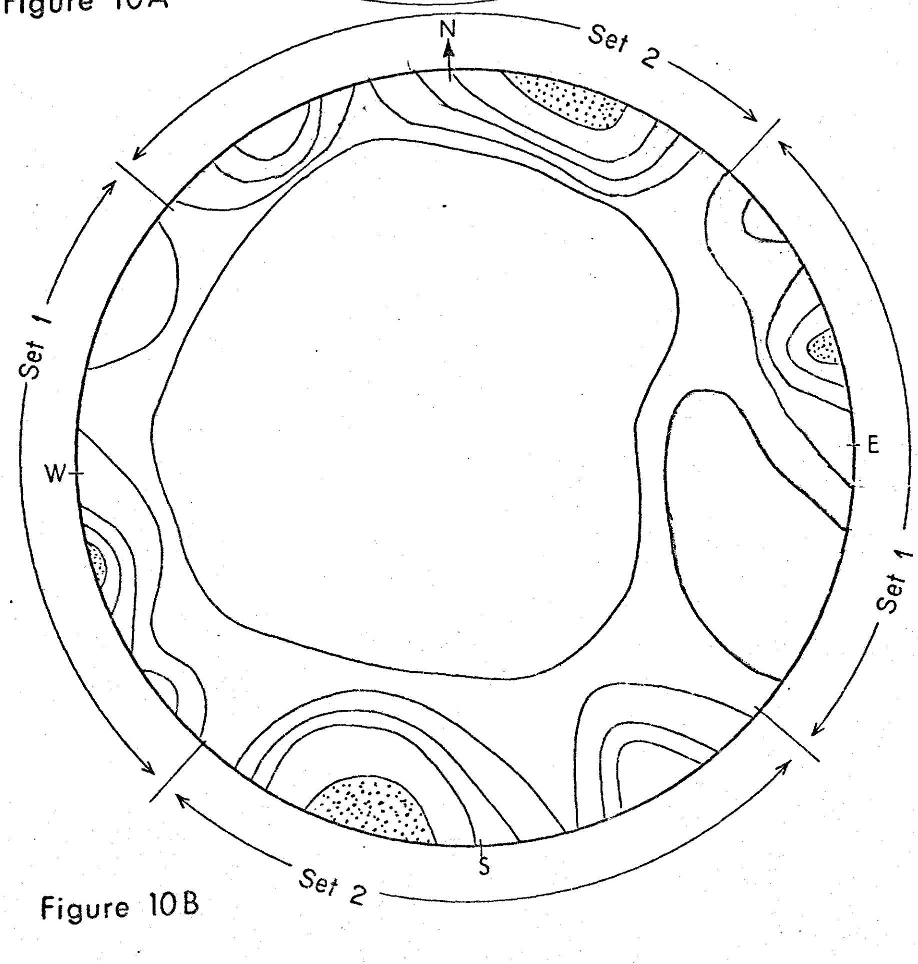


Figure 10B

dominantly concentric in style (Turner and Weiss, 1963, p. 112), but locally may be described as kink folds (Turner and Weiss, 1963, p. 114). Folding of this type is most prevalent in thinly-bedded and well-stratified gypsum with prominent clay layering. As with other concentric folds, the vertical extent probably is limited and the folds are, therefore, superficial in nature.

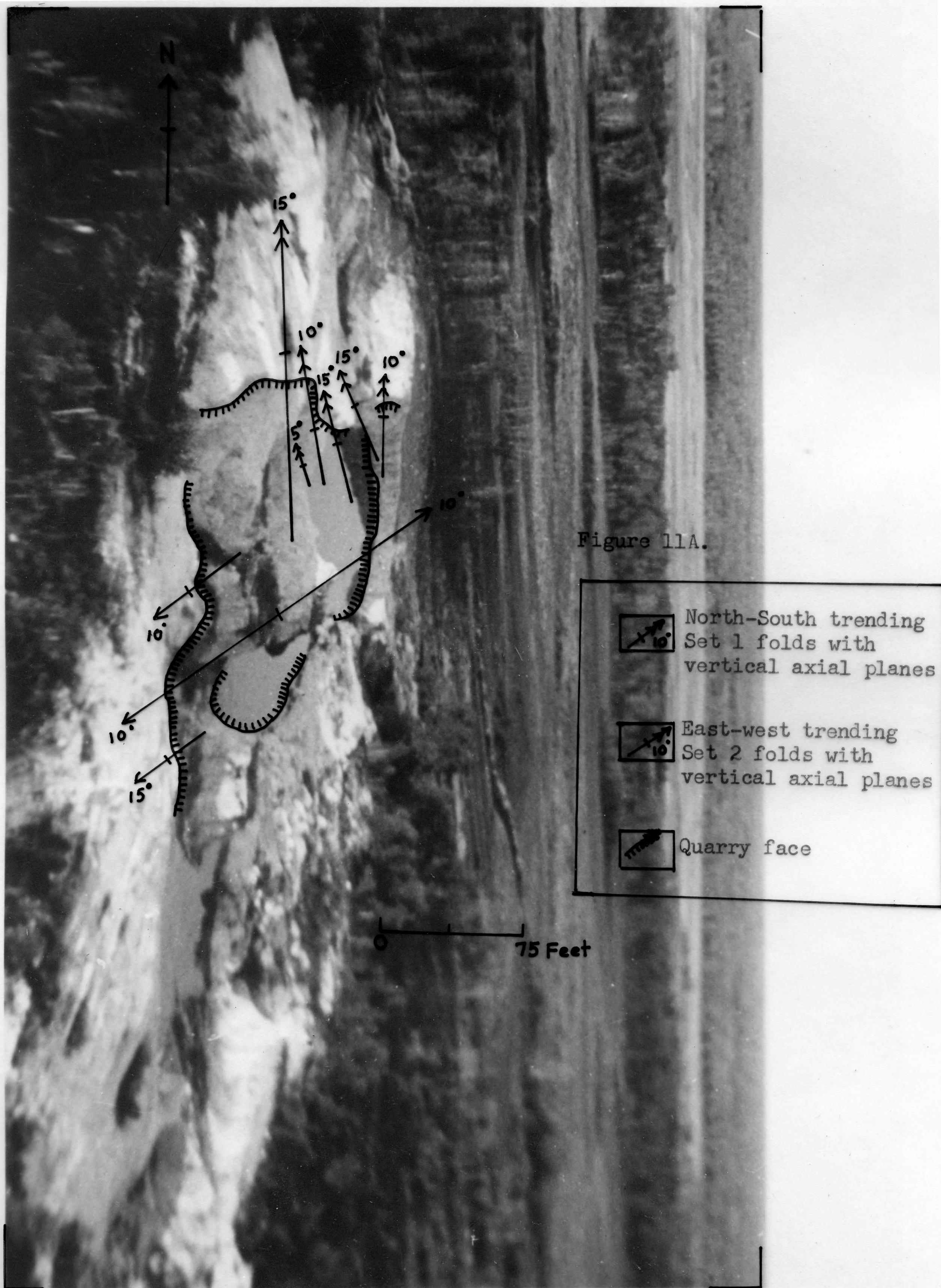
Several prominent set 1 anticlinal folds are particularly well-developed in the east arm, eastern part of the west arm of the Old Quarry, and the northern and southern parts of the New Quarry (Fig. 7). The northwall of the southeastern pit in the Elephant Hill exposes six set 1 folds, which plunge at low angles northward (Fig. 11A and B). The Whippoorwill quarry (Fig. 12) also contains set 1 anticlinal fold.

Associated with the major anticlinal folds (wavelengths from three feet to a quarter of a mile) there are minor folds with wavelengths from a fraction of an inch to two feet or so. These folds occur most commonly on the flanks and hinges of the major set 1 folds (Plate II and Fig. 13). Most of the folds are concentric in nature and only a few show thinning and thickening in the limbs and axial regions.

These minor folds have plunges which are consistent with the plunges of major set 1 folds (Fig. 13). Locally they have either fanning or reverse fanning relationships (Turner and Weiss, 1963, p. 189) with the major folds.

The rocks involved in minor folds include gypsum beds, layered clay and fibrous gypsum stringers. Many of the clay layers have been displaced by seams of fibrous gypsum deposited by solutions

Figure 11A. Structure of the southeastern pit of the Elephant Hill Quarry.



N
15°
10°
15°
10°
15°
5°
10°
10°
10°
15°
0
75 Feet
North-South trending Set 1 folds with vertical axial planes
10°
East-west trending Set 2 folds with vertical axial planes
10°
Quarry face

Figure 11A.

Figure 11B. Lower hemisphere equal area projection of fold axes (dots for set 1 and triangles for set 2 folds) and poles to axial planes (crosses for set 1 and squares for set 2 folds) of folds in the southeastern pit of the Elephant Hill Quarry (see Fig. 11A).

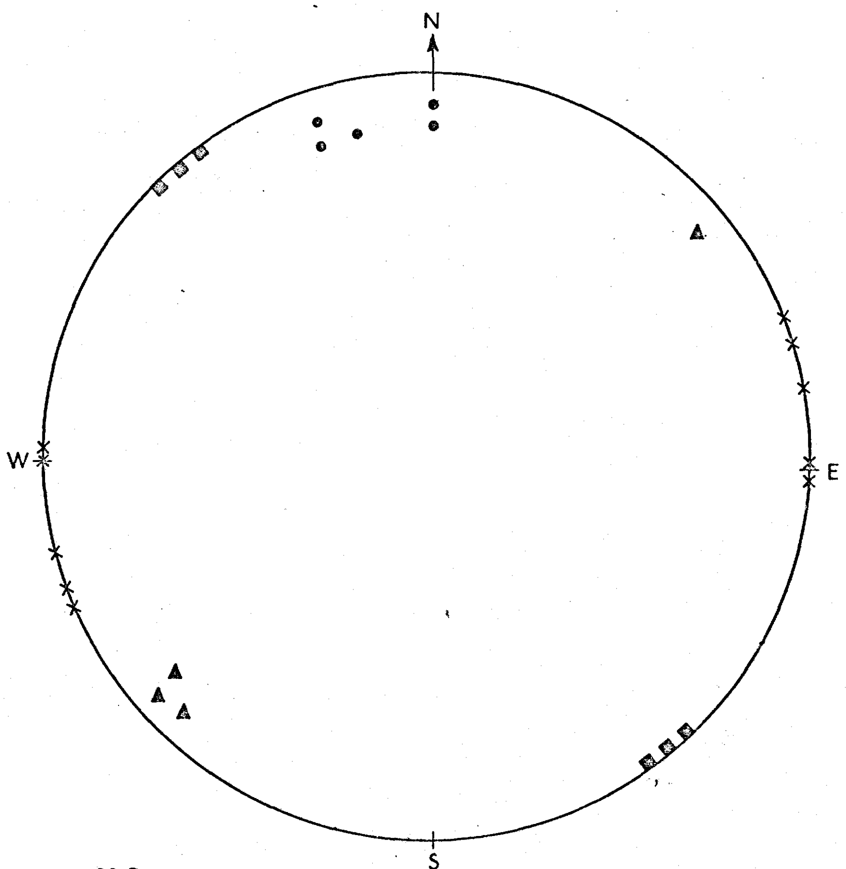


Figure 11B

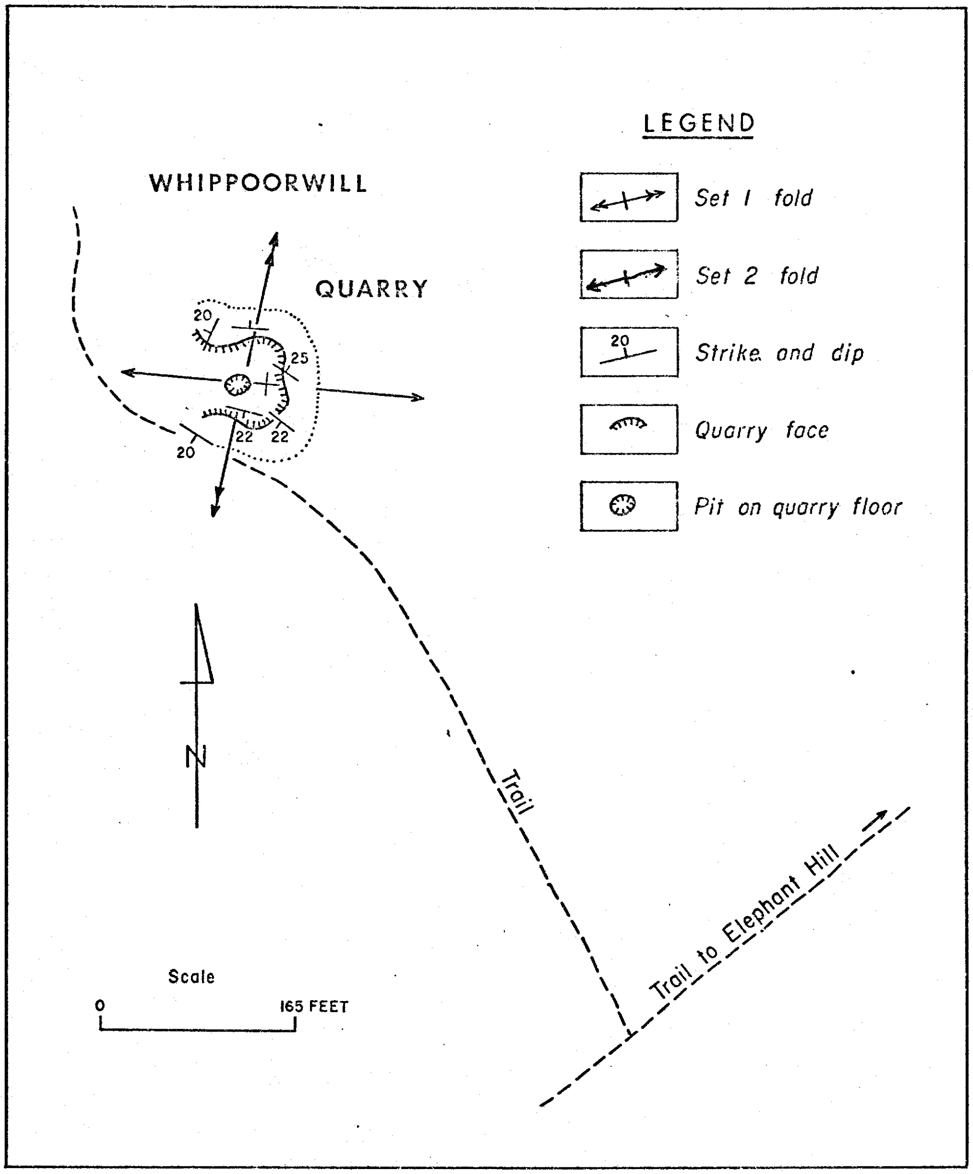


Figure 12 — Folded structure in the Whippoorwill quarry

Figure 13A. Diagramatic section of a major N-S trending set 1 fold at the northern end of the Old Quarry. Note also the associated minor folds.

Figure 13B. Orientation of minor set 1 folds developed on flanks and hinge of major set 1 fold 18A (Fig. 13A); dots and crosses represent plunges of hinges and poles to axial planes, respectively, of minor folds; dot and cross within circle indicate plunge of hinge and pole to axial plane of major fold 18A respectively.

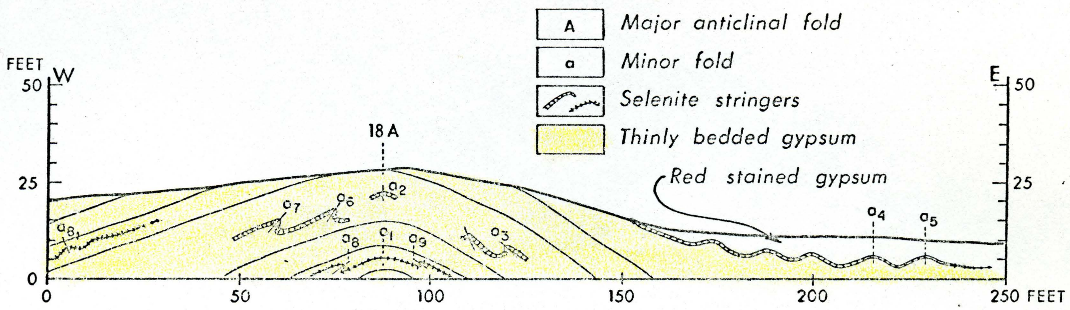


Figure 13A

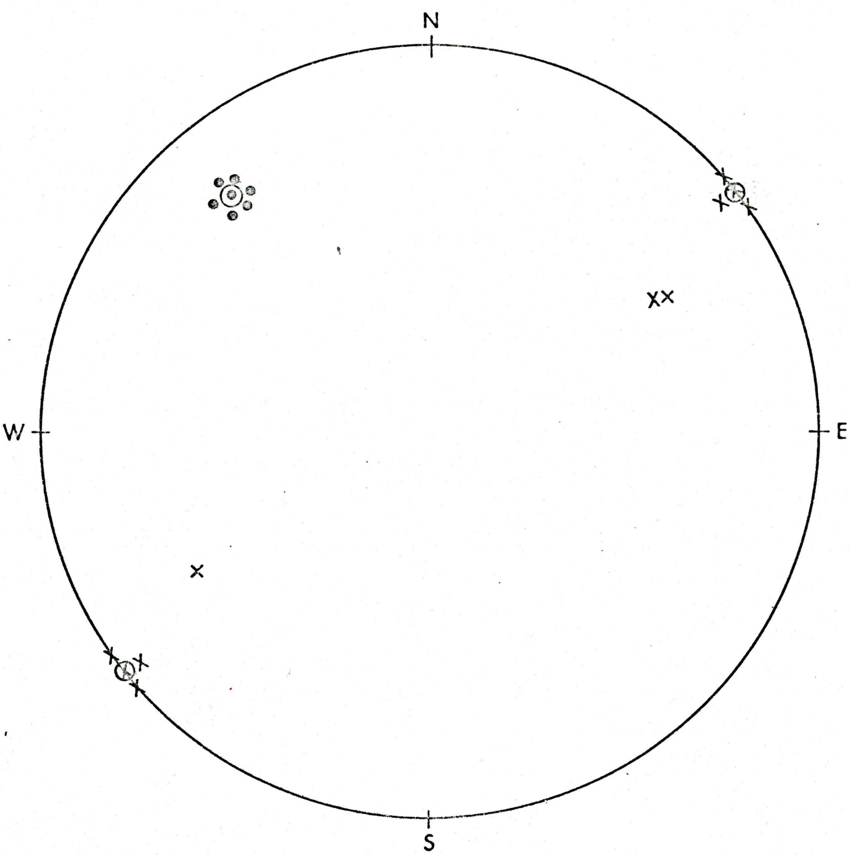
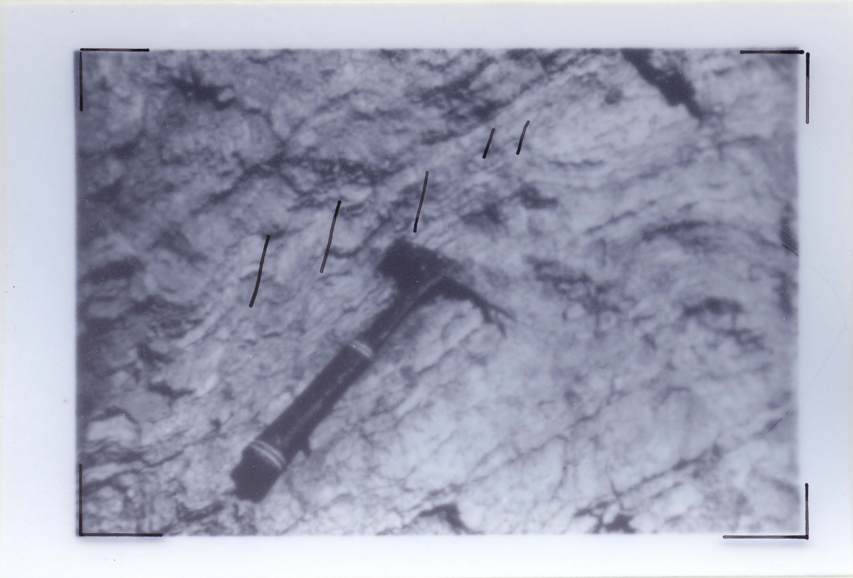


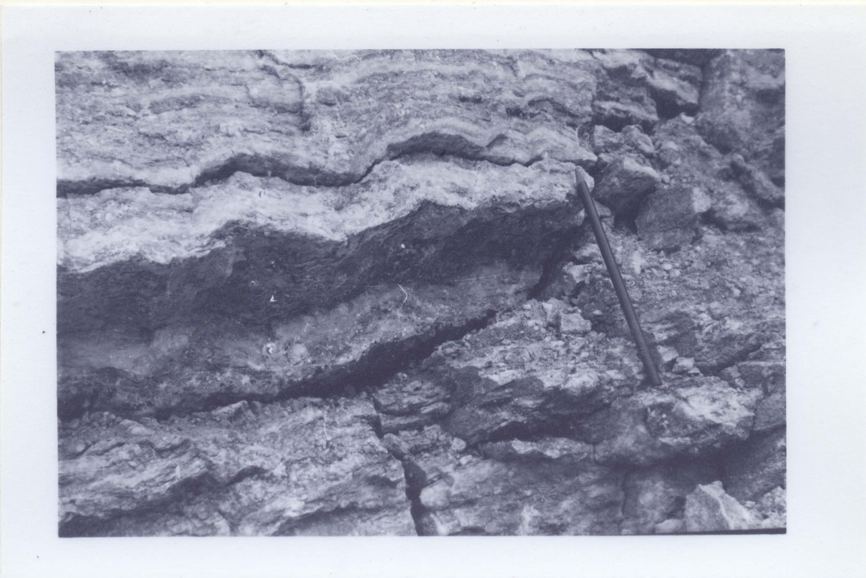
Figure 13B

Plate II-A. Minor folds in the limb of a major set 1 fold. Location, northern end of the east arm of the Old Quarry. Photograph taken facing north.

B. Minor folds on the flank of an anticline of small amplitude (set 1 fold). Location, northern end of the Old Quarry.



A



B

PLATE II

Plate II.

A

B

PLATE II

passing between the beds.

Set 2 Folds

The set 2 folds (with axial planes which strike predominantly E-W) are present in all the quarries of the Gypsumville gypsum deposit (Figs. 7, 11A and 12). As with the set 1 folds, most of these folds have vertical axial planes and are gently plunging. Folds are dominantly of concentric style but locally develop into kink and isoclinal folds, especially, in the cores of large concentric folds.

The set 2 folds are particularly well-developed in the 3400 feet long N-S trending face of the New Quarry (Figs. 7 and 14). The axial planes of the folds dip to the north in the 0-350 foot part of the northern end of the New Quarry (Fig. 7) and along the quarry face (Figs. 7 and 14). The asymmetrical folds have short steep limbs on the southern sides of the anticlines and the longer limbs dip gently to the north (Plate III A and B). Fold asymmetry is most pronounced in the north and decreases to the south; folds become symmetrical at the 350 foot point. Further to the south, the folds are irregularly symmetrical and asymmetrical. At the 500 foot point, the dip of the axial plane of the anticline marked A6, in section AB (Fig. 14), is to the south, whereas the anticline A8 has pronounced asymmetry, with a northerly dipping axial plane. The remainder of the folds of the sections in Fig. 14 are normal (or upright) except at a few localities.

Throughout the entire length of the quarry face, the rock involved in the deformation is thinly-bedded gypsum except at a few localities. The three foot thick bed of anhydrite that crops out at the 1160 foot point, at the base of the quarry face, is found to

Plate III-A. Asymmetrical anticlinal fold (set 2) at northern end of the New Quarry. Horizontal dimension of outcrop is 50 feet. Photograph taken facing east.

B. A series of asymmetrical anticlines and synclines (set 2) at the northern end of the New Quarry. Horizontal dimension of outcrop is 150 feet. Photograph taken facing east.

A

B

PLATE III

Figure 15A. Orientation of minor set 2 folds developed on flanks and hinge of major set 2 fold A15 (Fig. 14); dots and crosses represent plunges of hinges and poles to axial planes, respectively, of minor folds. Dot and cross within circle indicate plunge of hinge and pole to axial plane of major fold A15.

Figure 15B. Orientation of minor set 2 folds developed on flank and hinge of major set 2 fold A2 (Fig. 14); dots and crosses represent plunges of hinges and poles to axial planes, respectively, of minor folds. Dot and cross within circle indicate plunge of hinge and pole to axial plane of major set 2 fold A2.

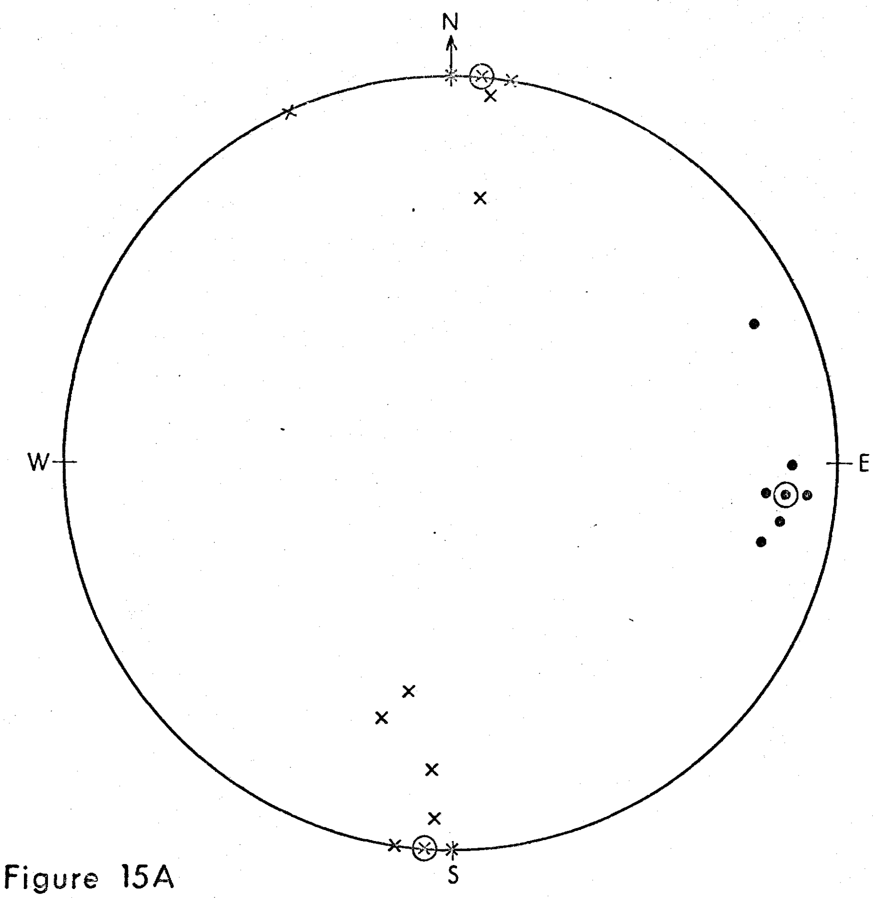


Figure 15A

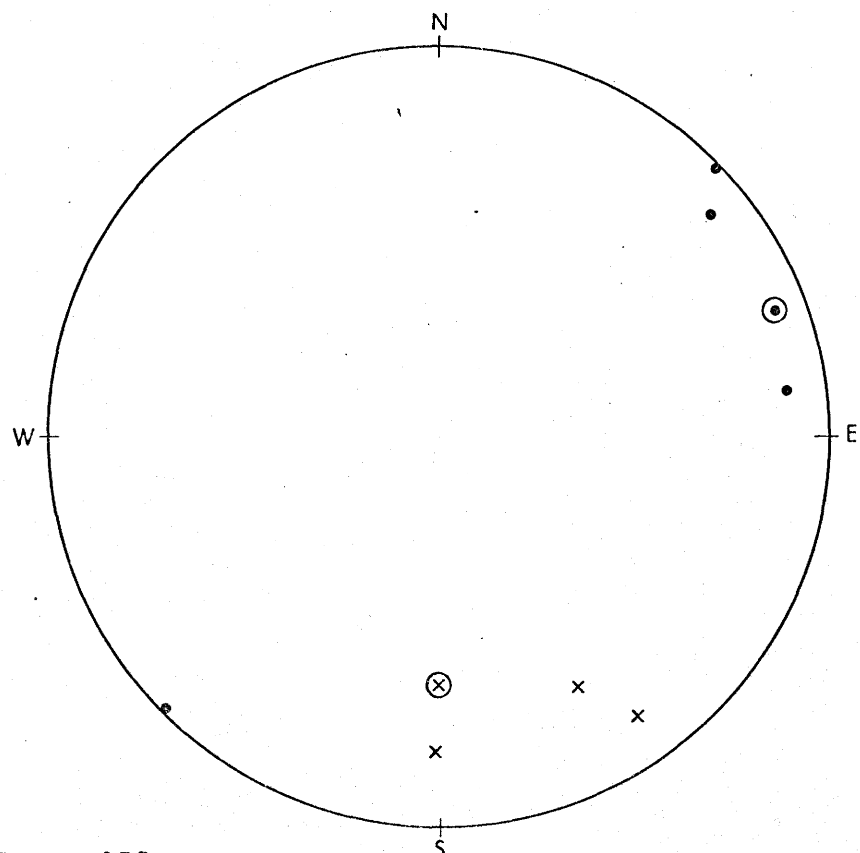


Figure 15B

extend upto the 1600 foot point (Fig. 14) without any appreciable change in thickness. The anhydrite bed is folded into several anticlines and synclines with the same style and orientation as those developed in gypsum beds. Beds of anhydrite exposed at the cores of anticlines A2 and A4 (Fig. 14) are also found to be involved in folding.

In the Old Quarry a series of set 2 folds intersect some prominent set 1 folds. The intersection of folds is well-displayed in the west arm of the quarry. Fold hinges are curved rather than linear in a number of cases, which may be the result of superposed folding (discussed later in this chapter).

The west and east walls of the southeastern part of the Elephant Hill quarry contain three set 2 folds, two of which plunge gently westward and one of which plunges westward at one end and eastward at the other (Fig. 11A and B). An anticline belonging to set 2 is also exposed in the Whippoorwill quarry (Fig. 12).

Many set 2 minor folds occur on the flanks and hinges of major set 2 folds. Since the style and orientation of these minor folds are similar to those of the major folds, they are probably genetically related; the difference being only the scale. Fig. 15 exhibits the relationship between set 2 major fold axes of anticlines A15 and A2 (Fig. 14) in the New Quarry, and their associated minor folds developed on fold limbs and hinges.

Age Relationships

Six N-S trending anticlines (set 1) have minor E-W trending folds (set 2) developed on their limbs (Fig. 7). Evidence of the relative ages of the two sets of folds may be obtained by making a series of orientation diagrams for these folds. To facilitate analyses, the Old and New Quarries are divided into three structural domains (I, II and III, Fig. 7). B1, in the following discussion, represents the axis of the large set 1 folds and B2 represents the average fold axis of the E-W trending set 2 folds.

Domain I: Fold 5A (Fig. 7) is the only structure in this domain which contains E-W trending folds on its limb. Because there is a high angle between B1 and B2 (80°, Fig. 16) and due to the lack of data for the eastern limb of the anticline, interpretation of the relative age of the folds is not possible.

Domain II: The domain contains folds 4A and EA8 and their subsidiary E-W trending folds. Fig. 17 shows the orientation of hinges of both the large fold 4A, and the associated minor folds developed on its limb. In fold 4A, cross folds plunging west (on the west limb of fold 4A) average 78° from the fold hinge (B1) whereas cross folds plunging east (on the east limb of fold 4A) average 68° from the main fold hinge. The average angle between B1 and B2 is, therefore, 73°. In equal area projection, B2 lies in a 73° small circle centred on B1. Therefore, the E-W trending folds are interpreted as being older than the N-S trending folds (Turner and Weiss, 1963, p. 128 - Fig. 4-31).

The orientation of fold hinges of both the larger fold, EA8, and its associated smaller folds, is plotted in Fig. 18. The data in this figure cannot be interpreted because of lack of information on the western limb of EA8.

Figure 16. Orientations of the N-S trending anticlinal fold 5A in domain I and the small set 2 folds on its limbs (lower hemisphere equal area diagram); dot within a circle represents plunge of hinge for fold 5A. Dots indicate plunges of hinges for small folds; cross represents their average. Angular separation between fold 5A and the average of set 2 folds is 80°.

Figure 17. Orientations of the N-S trending anticline 4A in domain II and the small set 2 folds on its limbs (lower hemisphere equal area diagram); triangle within a square represents plunge of hinge for fold 4A. Triangles indicate plunges of hinges for set 2 small folds; cross represents their average. Angular separation between fold 4A and the average of set 2 folds plunging west is 78° and the folds plunging east is 63°.

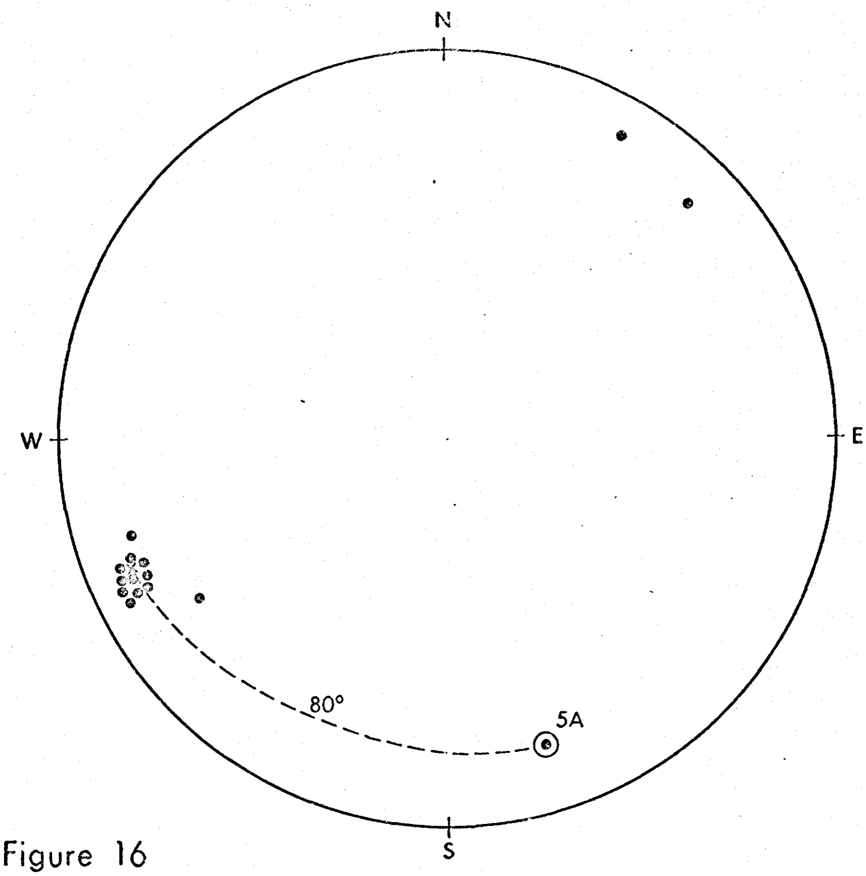


Figure 16

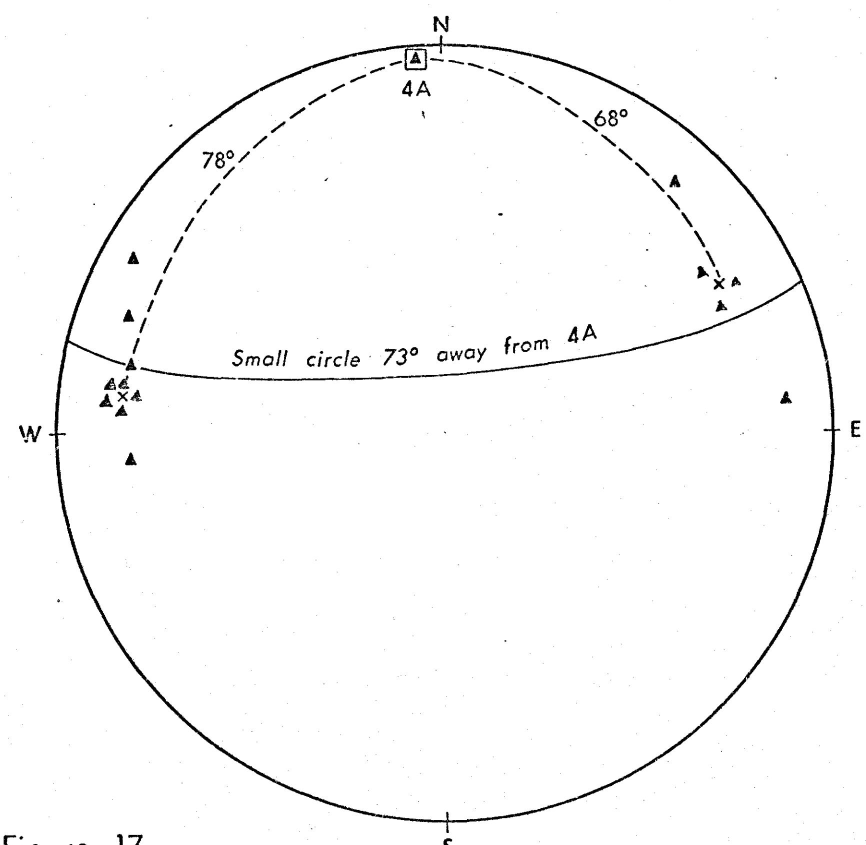


Figure 17

Figure 18. Orientations of the N-S trending anticlinal fold EA8 in domain II and the small set 2 folds on its limb (lower hemisphere equal area diagram); dot within a square indicates plunge of hinge for fold EA8. Squares represent plunges of hinges for small folds; cross indicates their average. Angular separation between fold EA8 and the average of set 2 folds is 70°.

Figure 19. Orientations of set 1 folds 4A and EA8 in domain II and the small set 2 folds on their limbs (lower hemisphere equal area diagram); triangle within a square and dot within a square represent plunges of hinges for folds 4A and EA8 respectively. Triangles and squares indicate plunges of hinges for set 2 small folds associated with set 1 fold 4A and EA8 respectively; cross and cross within a circle show their averages. Angular separation between average set 1 folds and the average of set 2 folds plunging west is 81° and the folds plunging east is 73°.

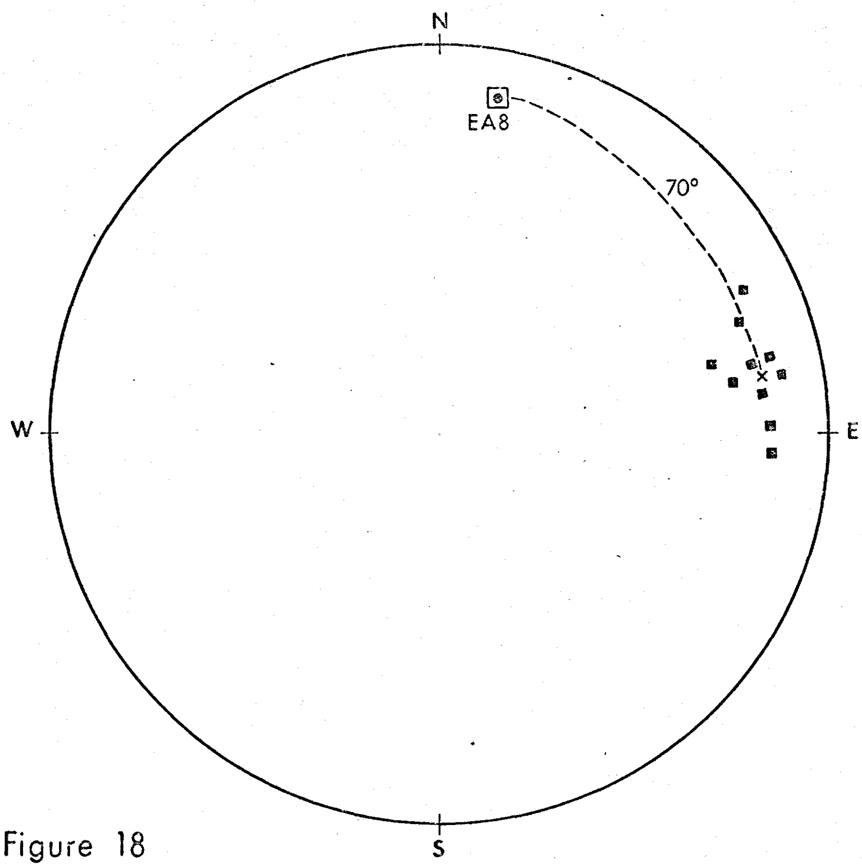


Figure 18

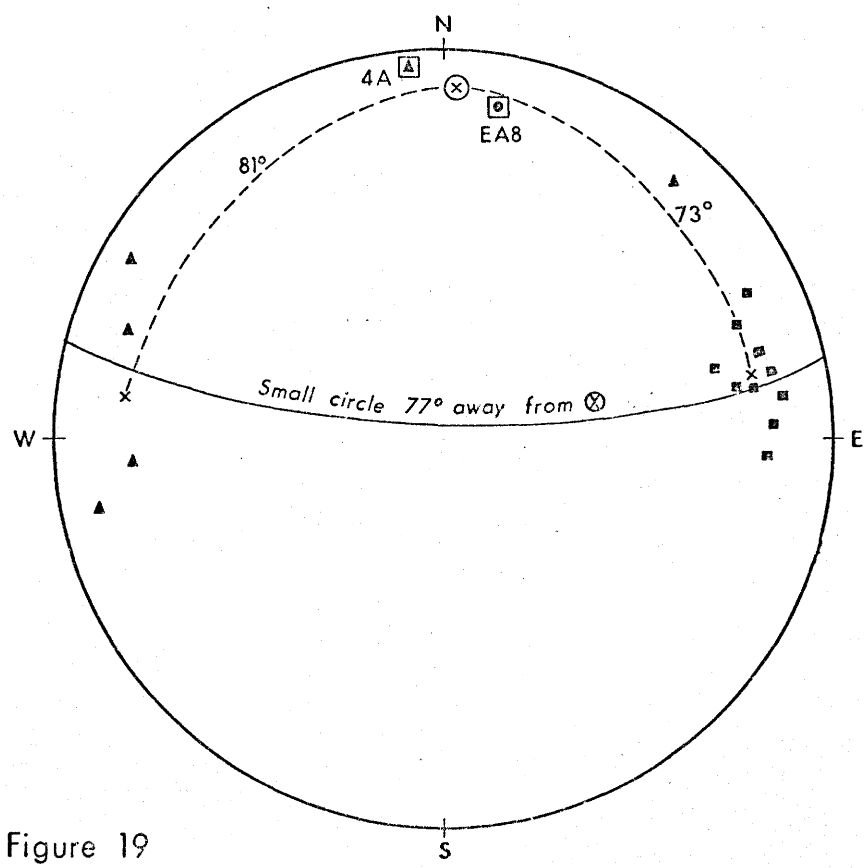


Figure 19

Figure 20. Orientations of set fold RWA in domain III and the small set 2 folds on its limbs (lower hemisphere area diagram); dot within a circle indicates plunge of hinge for fold RWA. Dots represent plunges of hinges for small folds; cross indicates their average. Angular separation between fold RWA and the average of set 2 folds is 90°.

Figure 21. Orientations of set 1 fold A39 in domain III and the small set 2 folds on its limb (lower hemisphere equal area diagram); small circle within a square indicates plunge of hinge for fold A39. Small circles represent plunges of hinges for small folds; cross indicates their average. Angular separation between fold A39 and the average of set 2 folds is 44°.

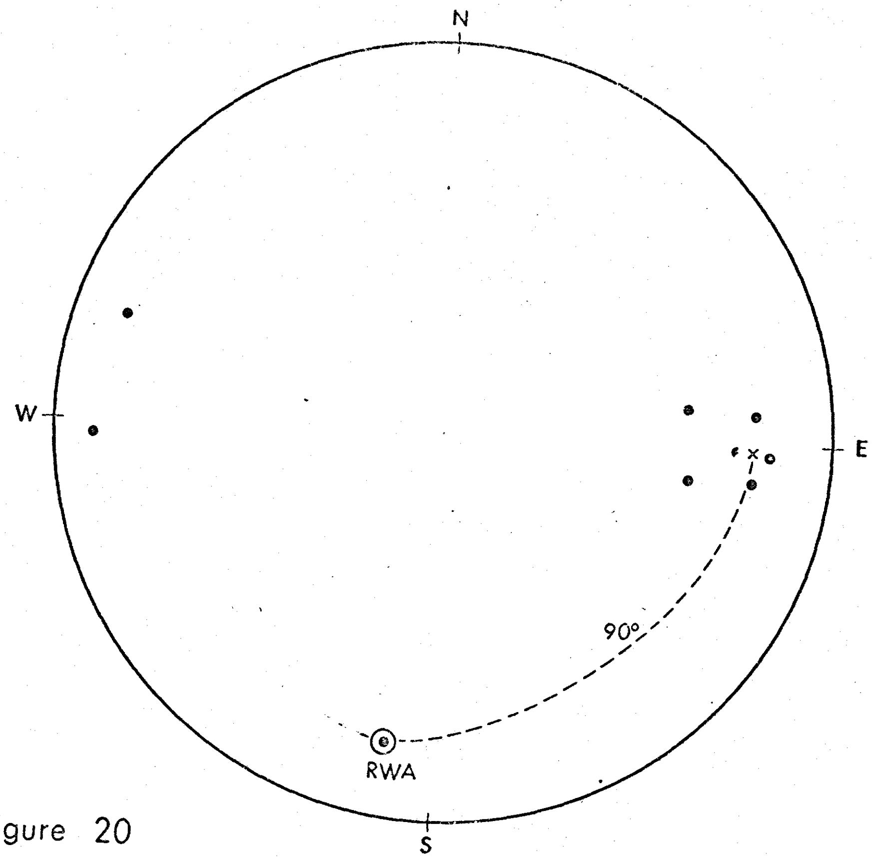


Figure 20

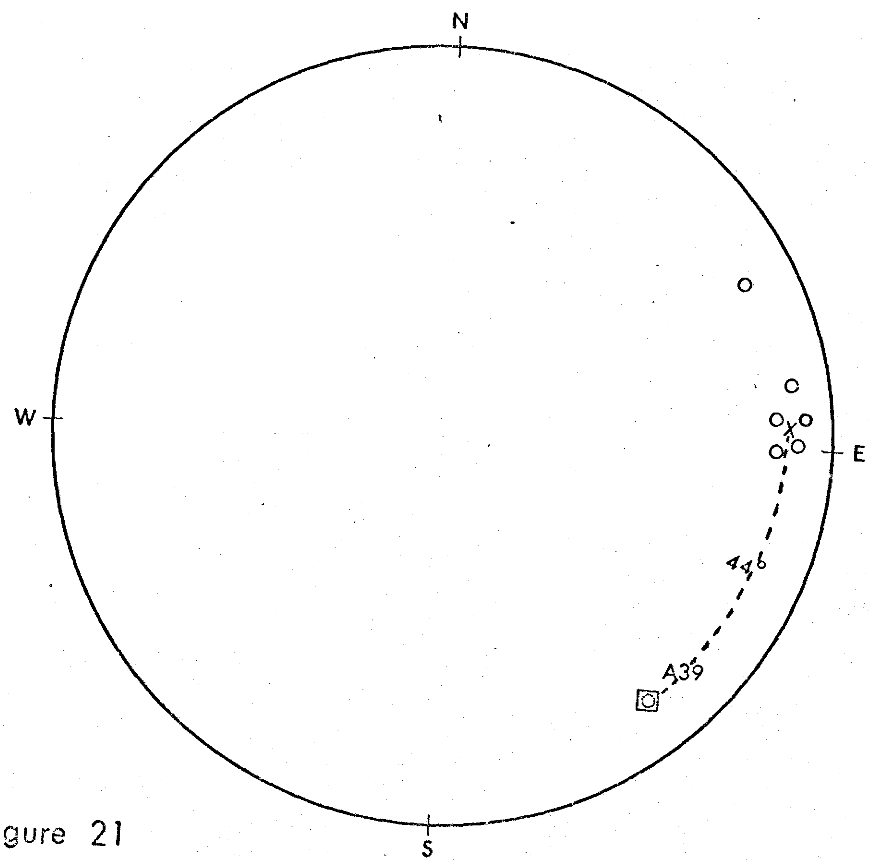


Figure 21

Figure 22. Orientations of the N-S trending anticlinal fold AX1 in domain III and the small set 2 folds on its limb (lower hemisphere equal area diagram); square within a square represents plunge of hinge for fold AX1. Squares indicate plunges of hinges for small folds; cross shows their average. Angular separation between fold AX1 and the average of set 2 folds is 83°.

Figure 23. Synoptic diagram of fold hinges for anticlines RWA, A39 and AX1 in domain III and the small set 2 folds on their limbs (lower hemisphere equal area diagram); dot within a circle, circle within a square and square within a square indicate plunges of hinges for folds RWA, A39 and AX1 respectively. Dots, circles and squares represent plunges of hinges for small folds associated with RWA, A39 and AX1 respectively; crosses show their averages. Angular separation between average set 1 folds and the average set 2 folds is 90°.

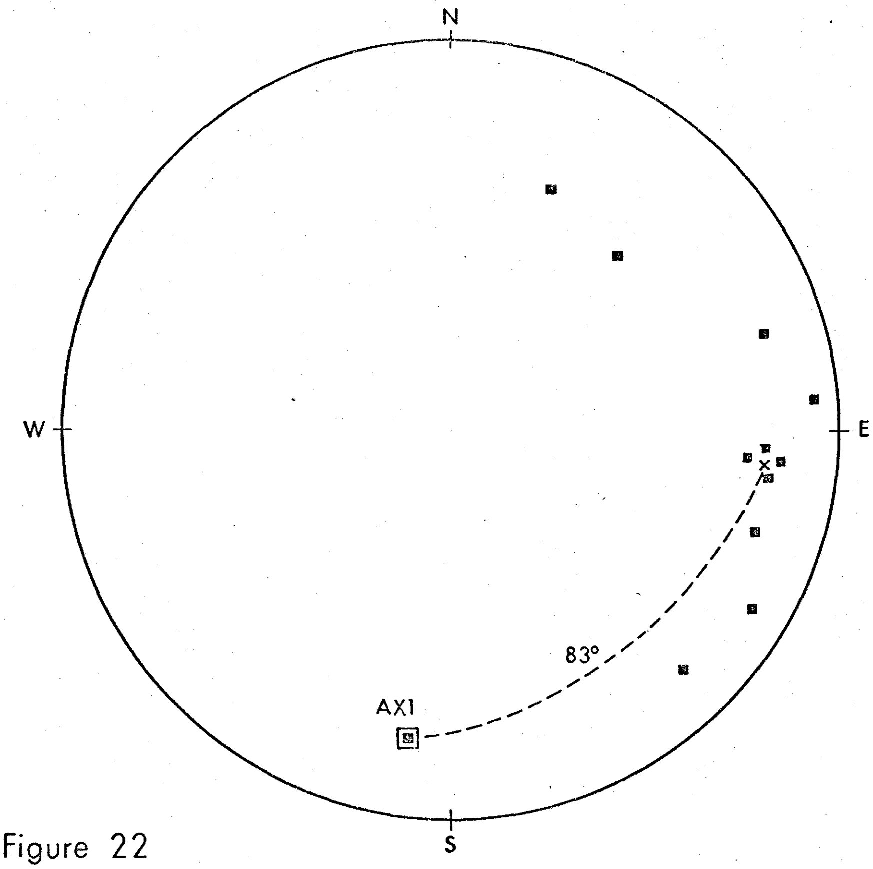


Figure 22

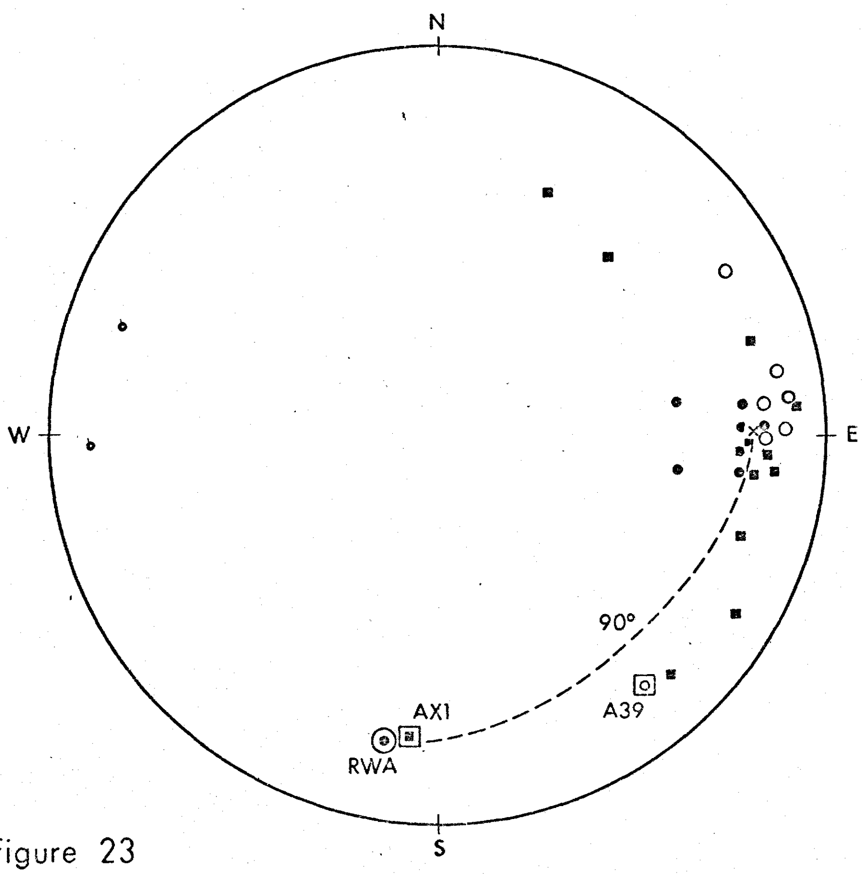


Figure 23

Fig. 19 shows the orientation of hinges of folds EA8 and 4A combined, and their associated cross folds. Since the main E-W folds (B2) tend to lie on a small circle 77° away from the average of B1, it is suggested that they are older than the N-S folds.

Domain III: Unfortunately the orientations of E-W trending folds, in relation to the three large N-S trending folds, R.W.A, A39 and AX1, in domain III (Fig. 7), are too irregular and the data too incomplete to interpret an age relationship (Figs. 20, 21 and 22). Also the combined plotting of data for folds R.W.A, A39 and AX1 (Fig. 23) shows too much scattering of points for the E-W folds and too high an angle between average B1 and average B2 (86.5°).

In summary, it appears likely that large north-south trending folds (set 1) are younger and superimposed on the smaller east-west trending folds (set 2), although the data is not as conclusive one as one would wish.

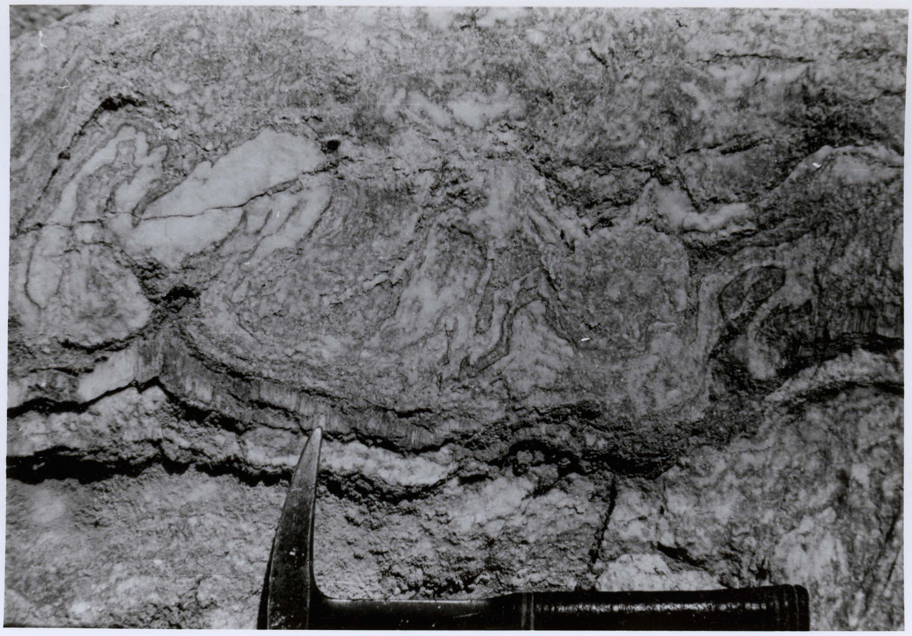
Intrastratal Convolutions

The folds of this category commonly occur as intricate, internal contortions limited to individual gypsum beds, within which folds die out both upwards and downwards. Some of these contortions exhibit considerable, though irregular, thickening and thinning (Plates IV - A and B, and V - A). The contortions are in the form of domal and basinal structures (Plates V - B and VI). In some cases, smaller marginal folds occur on the domes with radially arranged axial planes (Plate VI - A). In profile, the domal structures appear either as steep-sided isoclinal folds (Plate IV), or sharp-crested,

Plate IV-A. Isoclinal folds in cut perpendicular to bedding. Location, northern end of the Old Quarry. Photograph taken facing north.

B. As for Plate IV-A; layers tend to be thicker and thinner on limbs of folds; anticlines are sharp-crested and synclines are box-shaped. Dome-shaped upfolds can also be seen.

A

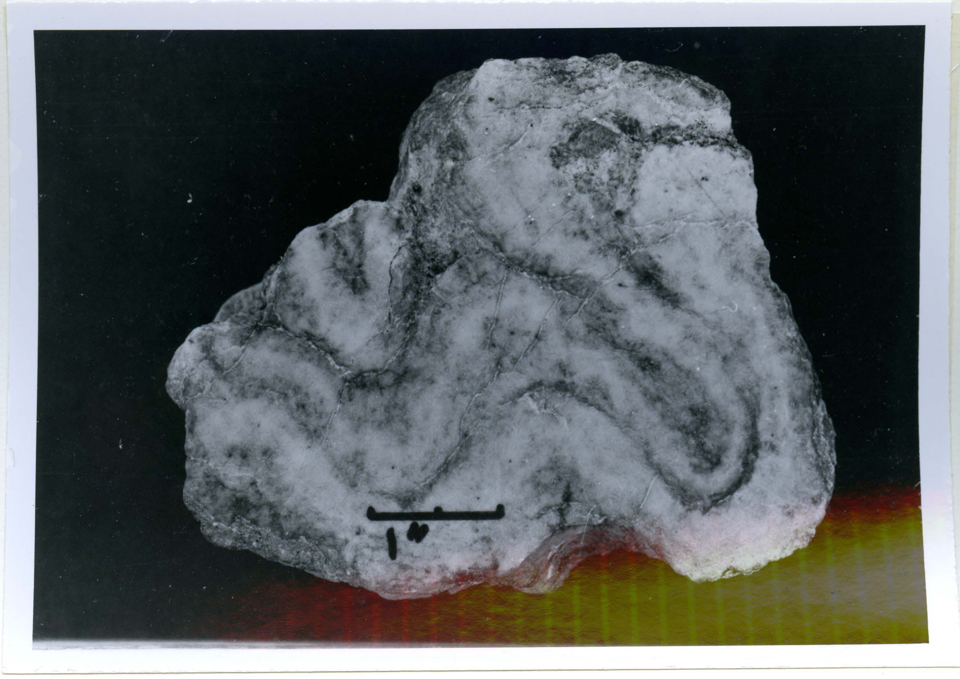


B

PLATE IV

Plate V-A. Marked thinning and thickening of layers in axes and limbs of folds. Such folds probably formed by slumping shortly after deposition. Location, northern end of the east arm of the Old Quarry.

B. Small dome, possibly a product of exfoliation or surface weathering. Location, northern end of the Old Quarry.



A

B

PLATE V

Plate VI-A. Bedding surface with small spiral structures apparent at the centre of the dome. Location, northern end of the Old Quarry.

B. Convolutions associated with small basinal structure. Location, northern end of the Old Quarry.

A

B

LATE VI

Plate VI.

A

B

PLATE VI

steep-sided anticlines and wider, rounded to box-shaped synclines (Plate IV - B). Some of the intrastratal contortions form spiral patterns (Plate VI - A).

Minor folds, with the above characteristics, are not widespread in the Gypsumville quarries and are absent in the Whippoorwill and the Elephant Hill quarries. They occur most abundantly in the north end of the Old Quarry and in the central part of the New Quarry.

Origin of Folds

The folds developed in the gypsum beds of the Gypsumville area must have formed by causes other than tectonism, since there is no evidence of intense orogenic activity in this region of Manitoba. A number of non-tectonic processes could possibly be responsible for the origin of the folds. These are:

1. Expansion due to hydration of anhydrite to form gypsum.
2. Subsurface solution and collapse.
3. Penecontemporaneous slumping.
4. Glacial ice-push.

1. Expansion due to Hydration of Anhydrite to form Gypsum: Anhydrite expands on changing to gypsum. An increase in volume of 60.5 per cent occurs with complete hydration assuming that initial and final porosities are zero. This volume increase could cause folding in gypsum beds and folds formed in this way, described as enterolithic structures (Grabau, 1924, p. 758), have certain characteristics: lack of systematic deformation, lack of slickensiding, tightly closed folds,

irregular thickening of beds and confinement of the structure within individual layers.

Most of the previous workers in the Gypsumville area ascribed the origin of the major folds (sets 1 and 2 here) to hydration of anhydrite to gypsum. Bannatyne (1959, p. 31) assumed that the total thickness of the evaporite sequence is 100 feet and that half of the original anhydrite was transformed to gypsum. The transformation of the upper half of the anhydrite to gypsum, would, according to Bannatyne, be adequate to account for the formation of 30 - 40 foot ridge-forming anticlinal folds. This idea is not accepted here for the following reasons:

a) The style and geometry of all the major and most of the minor (sets 1 and 2) folds in the area are markedly different from those cited for typical enterolithic structure (Grabau, 1924, p. 758).

b) Expansion due to transformation of anhydrite to gypsum can hardly explain the presence of two sets of folds with different trends.

c) Volume expansion due to hydration of anhydrite to gypsum only occurs if the replacement is molecule for molecule. Petrographic evidence indicates that the replacement of anhydrite by gypsum, at Gypsumville, has been volume for volume and not molecule for molecule.

2. Subsurface Solution and Collapse Structure: The deposit is characterized by the presence of abundant sinkholes. The origin of the sinkhole topography has been ascribed to the solution effects of surface waters followed by collapse. If the origin of the folds in

the Gypsumville area is related to the formation of sinkholes, then a definite relationship between the two should exist. However, sinkholes occur randomly within the folds (Plate VII and Fig. 14) and their distribution (as plotted from aerial photographs, Fig. 7) indicates that the formation of these depressions is quite independent of folding.

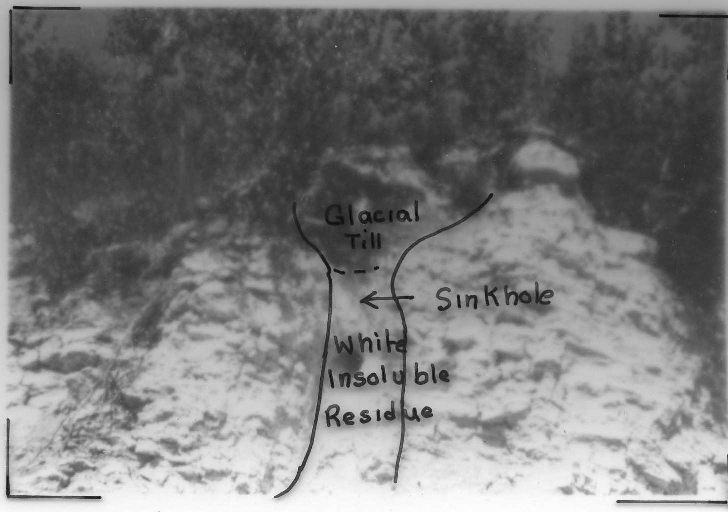
3. Penecontemporaneous Slumping: Although the sets 1 and 2 folds in the area cannot be explained by the slumping of unconsolidated sediments, some of the intrastratal convolutions in gypsum beds show a strong resemblance to examples of slump structures described in the literature (Rettger, 1935; Kuenen, 1948; Carozzi, 1960; and Kelling and Williams, 1966). Carozzi (1960, p. 111-130), while conducting microscopic investigations of limestones and sandstones, encountered spiral structures associated with small scale domes, similar to those at Gypsumville (eg. Plate VI-A). He attributed these structures to slumping, without initial folding of the unconsolidated sediments. Kelling and Williams (1966, p. 927-939), while working on deformation structures of sedimentary origin, observed sharp-crested folds, overturned folds, domical upfolds and box-shaped synclines, all of which were related to penecontemporaneous deformation.

It is quite probable that the minor intrastratal contortions, in the Gypsumville area, have been formed by penecontemporaneous deformation.

4. Glacial Ice-push: The ability of glacier ice to deform consolidated and unconsolidated sediments, on a regional scale,

Plate VII-A. Sinkhole, on crest of an anticlinal fold, is filled with white, insoluble residue and organic rich glacial till. Location, northern end of the west arm of the Old Quarry. Horizontal dimension of outcrop is 20 feet. Photograph taken facing north.

B. A synclinal structure in the southeastern pit of the Elephant Hill. Sinkholes occur in the synclinal trough. Horizontal dimension of outcrop is 40 feet. Photograph taken facing north.



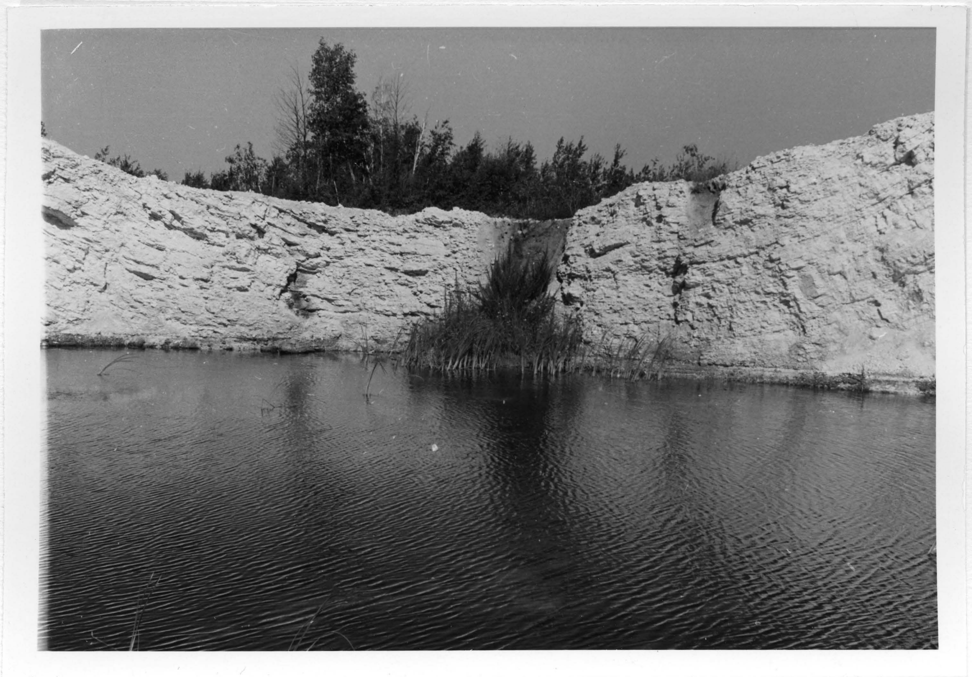
A

B

PLATE VII

Plate VII.

A



B

PLATE VII

was established by Fuller (1914), and Slater (1926). The work of Byers (1959) and Kupsch (1962), on the ice-thrust features in Western Canada, provide excellent examples of rock deformation by glacier ice. The following lines of evidence may indicate that the sets 1 and 2 folds of the Gypsumville area were caused by glacial action:

a) The folds in the Gypsumville area are superficial, which accords with the superficial nature of deformation by glacier ice.

b) The Gypsumville area probably was a topographic high during late pre-Pleistocene and Pleistocene time. The gypsum deposits are covered by a thin sheet of till, possibly wave eroded (Johnson, 1934) (Fig. 25 of the thesis), indicating that the area was glaciated. Large erratics of Silurian dolomite and Pre-Cambrian granite, randomly distributed over the Gypsumville quarries, are conspicuous and provide further evidence of glaciation.

c) The two major inferred directions of ice movement (Fig. 24) are found to be at right angles to the trends of major fold axes in the area.

Direction of Ice-movement -- Structures indicating direction of ice-movement, such as bed-rock striations and various stream-line features, have not been observed in the Gypsumville area. However, several sets of lineaments characterize the area surrounding the gypsum hills and are well developed in the muskeg (Figs. 26A and 26B). These lineaments have been the subject of some controversy and may not be of glacial origin. Due to the prominence of these lineaments,

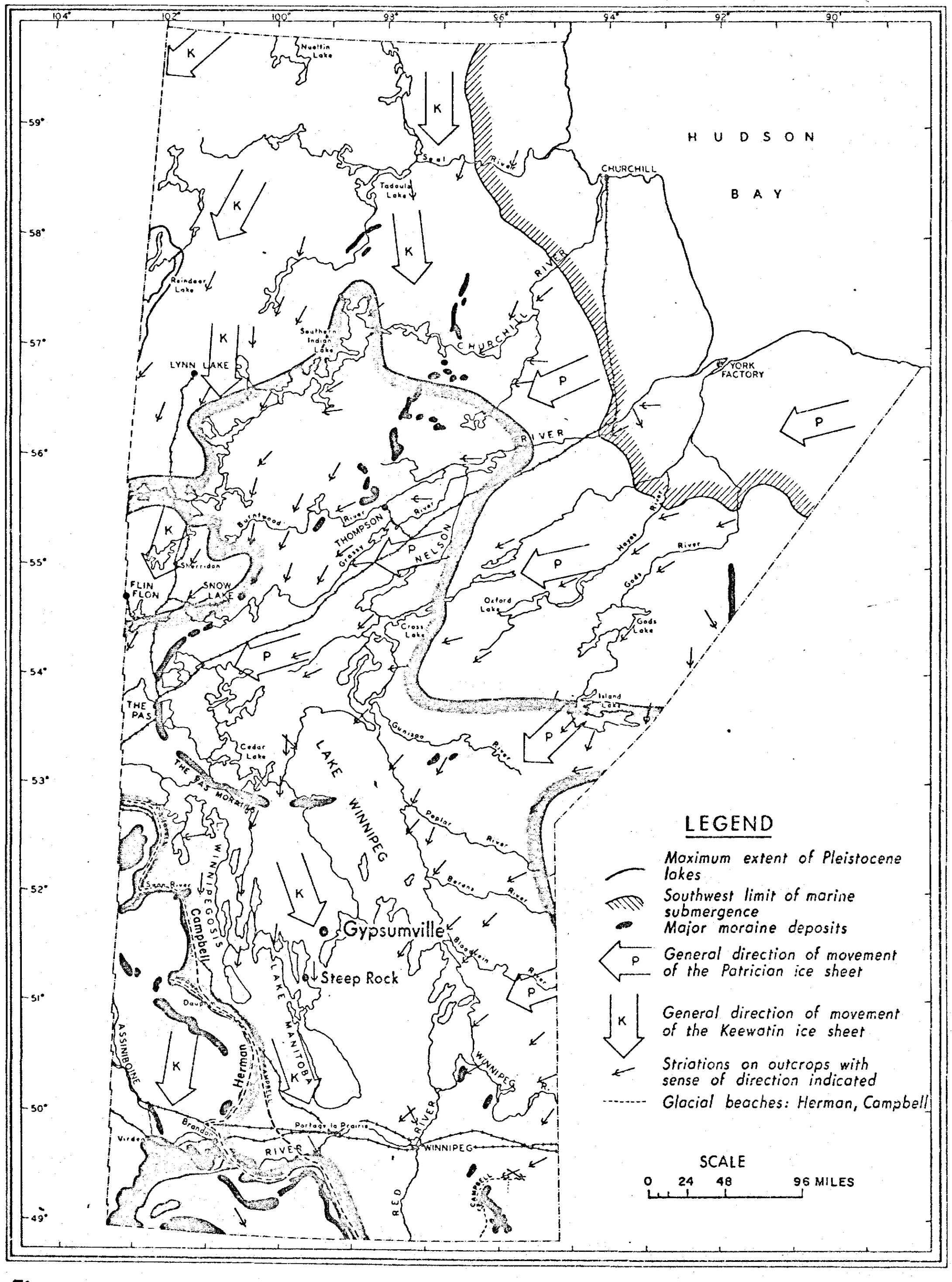


Figure 24— GLACIAL MAP OF MANITOBA
REPRODUCED FROM. DAVIES ET AL (1962, FIG. 35, P. 150)

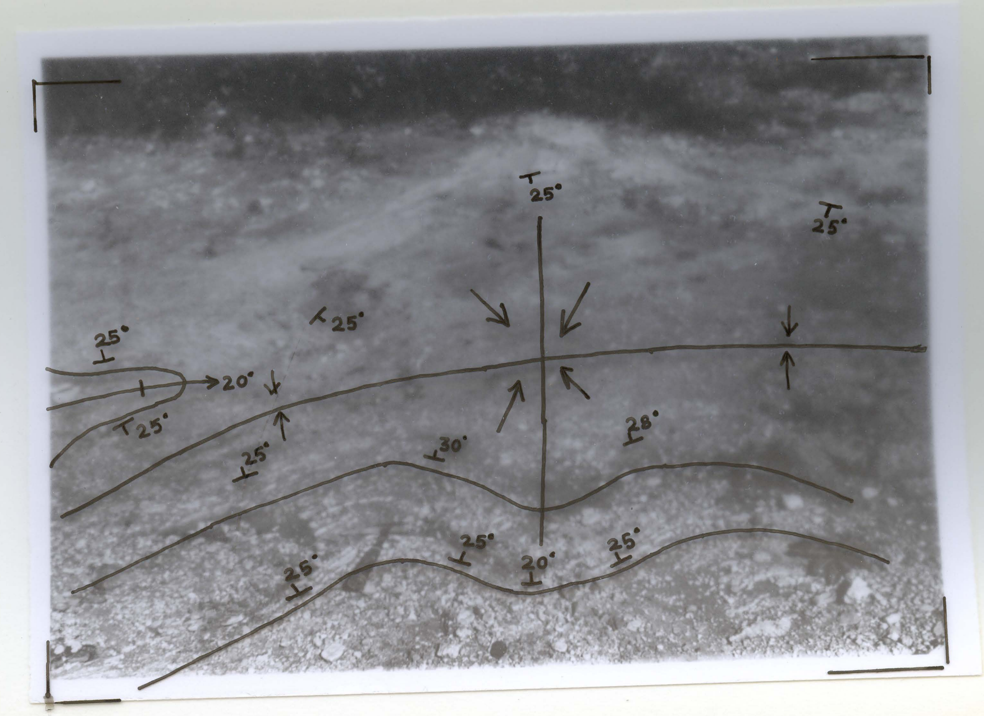
and because of the present controversy concerning the origin of similar lineaments elsewhere in the plains of Glacial Lake Agassiz (Clayton et al, 1965 and Mollard, 1957), they form the subject of a separate chapter (see section on intersecting lineaments).

Although the direction of ice-movement in the Gypsumville area cannot be determined from local features, two probable directions can be estimated from records of bed-rock striae in adjacent areas (Fig. 24). Regional studies of glacial striae, drumlins, eskers and moraines (Davies et al, 1962, p. 151) indicate two centres of accumulation for the ice-sheets which covered Manitoba during the Wisconsin glacial period; the Keewatin centre, in the Northwest Territories west of Hudson Bay, from which the ice flowed south, and the Patrician centre, southwest of James Bay, from which the ice spread to the southwest and west (Fig. 24). The nearest bed-rock striations to Gypsumville are in the Steep Rock area, on the eastern, western and northern shores of Lake Winnipeg, and in the Ceder Lake - Pass Moraine areas; evidence from these areas indicates two directions of ice-movement; one southerly and the other westerly. The relative ages of the two sets of striations, however, are not known.

Ice-movement and Genesis of Structure -- There is a correlation between fold geometry and inferred directions of ice-movement, suggesting that the two may be related. The N-S trending set 1 folds may have been caused by the westerly moving Patrician ice-sheet (Fig. 24) and the E-W trending set 2 folds by the southerly moving Keewatin ice-sheet. Structural evidence suggests that the set 1 folds are younger than the set 2 folds.

Plate VIII-A. Small basinal structure probably formed by the superposition of synclines (sets 1 and 2). Location, southern part of the west arm of the Old Quarry.

B. Axial trace of N-S trending fold (set 1) is marked by the hammer. At the extreme right corner another fold with E-W trend (set 2) can be seen. Location, northern end of the west arm of the Old Quarry.



A

B

PLATE VIII

Plate VIII.

A

B

PLATE VIII

The symmetrical nature of most of the folds in the area can be explained if the ice-push was very weak and gypsum and anhydrite were folded by dragging of the ice over the area. The asymmetric nature of the folds in the northern part of the New Quarry (Fig. 14 and Plate III) could indicate a comparatively stronger push, perhaps induced by the presence of an escarpment along the edge of the gypsum outcrop, similar to the present escarpment.

The two ice-sheets, moving over the area at different times, could explain the superposed nature of the two sets of folds (Fig. 7 and Plate VIII). The minor set 1 and set 2 folds probably formed as a result of interlayer slippage which accompanied progressive flexing of the major folds.

Conclusion: Folds in the gypsum beds of the Gypsumville area probably have two types of nontectonic origin. The folds classified as set 1 and set 2 may have formed as a result of glacial push and drag during Pleistocene glaciation. Small scale, complex and domal convolutions, which occur within and not between beds, may have formed as a result of slumping which occurred not long after deposition.

INTERSECTING LINEAMENTS

General

Several sets of intersecting lineaments occur in the Gypsumville area and are particularly well developed on the muskeg or open marsh-land. The gypsum deposit at Gypsumville is covered by a thin sheet of unsorted drift or boulder till, composed of boulders, gravel, sand, silty clay and enclosing rotten tree trunks. These glacial deposits are regarded by Johnston (1934) (Fig. 25 of the thesis) as having been modified by wave action in Lake Agassiz. The muskeg surrounding the gypsum ridges is underlain by silty, sandy loam and clayey loam of glacio-lacustrine origin.

The present study on the intersecting lineaments is based on examination of airphotos. Several sets, with consistent orientations, occur. The majority of these lineaments are oriented N30W - N45W (Fig. 27).

Five sets of lineament trends are discernable on aerial photographs of the area (Figs. 26A, 26B and 27). Some of these lineaments show "cross-cutting" relationships. Individuals belonging to set no. 5 are found to cut across individuals of set no. 1, in several places (see areas marked X_1, X_2 and X_3 in Figs. 26A and 26B). The evidence suggests that set no. 1 is older than set no. 5. The area marked 'Y' (Figs. 26A and 26B) shows the intersection of 4 sets of lineaments; sets no. 1, 2, 3 and 5, of which set no. 5 cuts linear sets no. 1, 2 and 3; set no. 3 cuts sets no. 2 and 1. It is

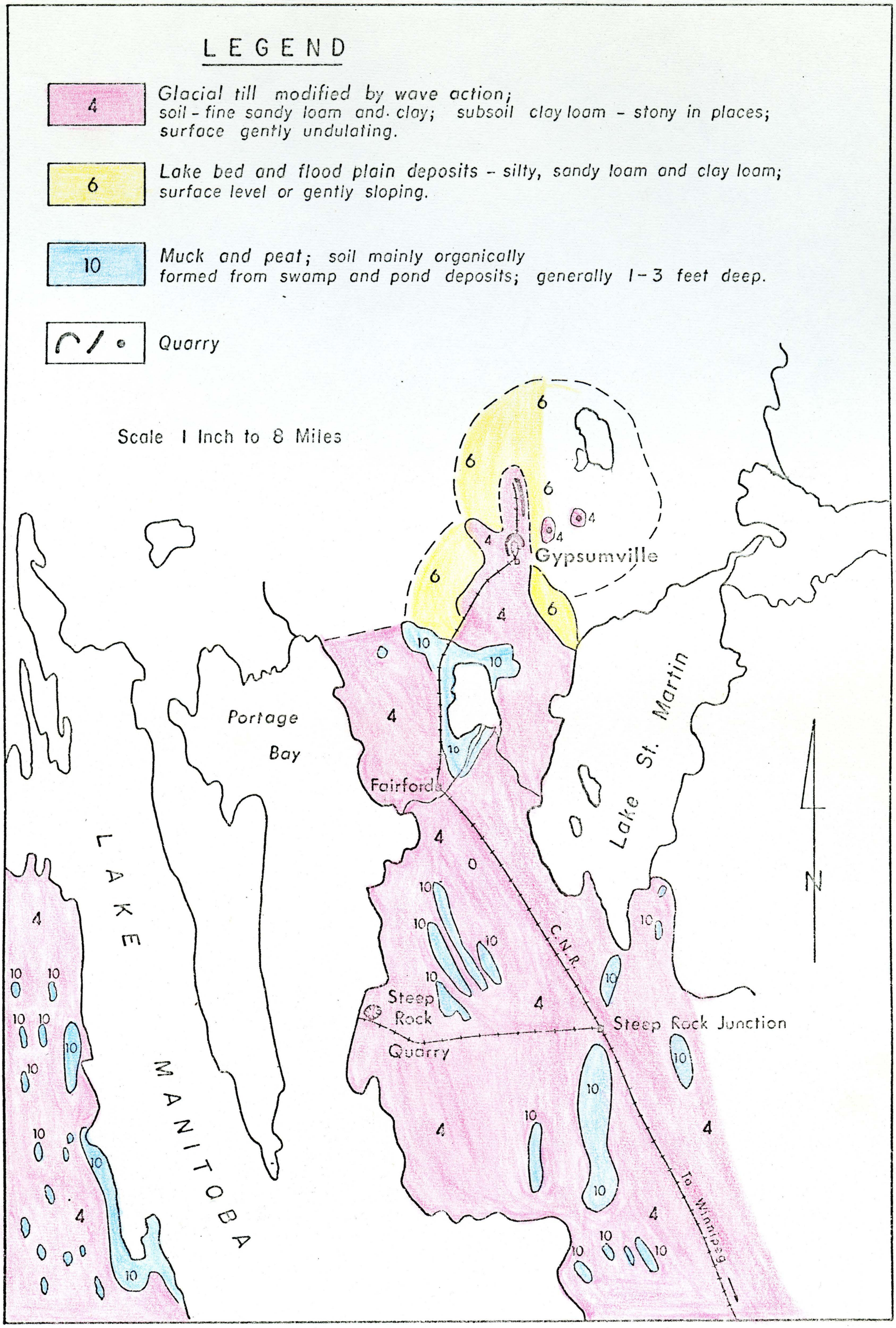


Figure 25 — Surficial Deposits in the Gypsumville—Steep Rock Areas
After W. A. Johnston, 1934

Figure 26A. Lineaments in the Gypsumville area as drawn from airphotos. X_1, X_2 X_3 and Y positions are lineament intersections referred to in text.

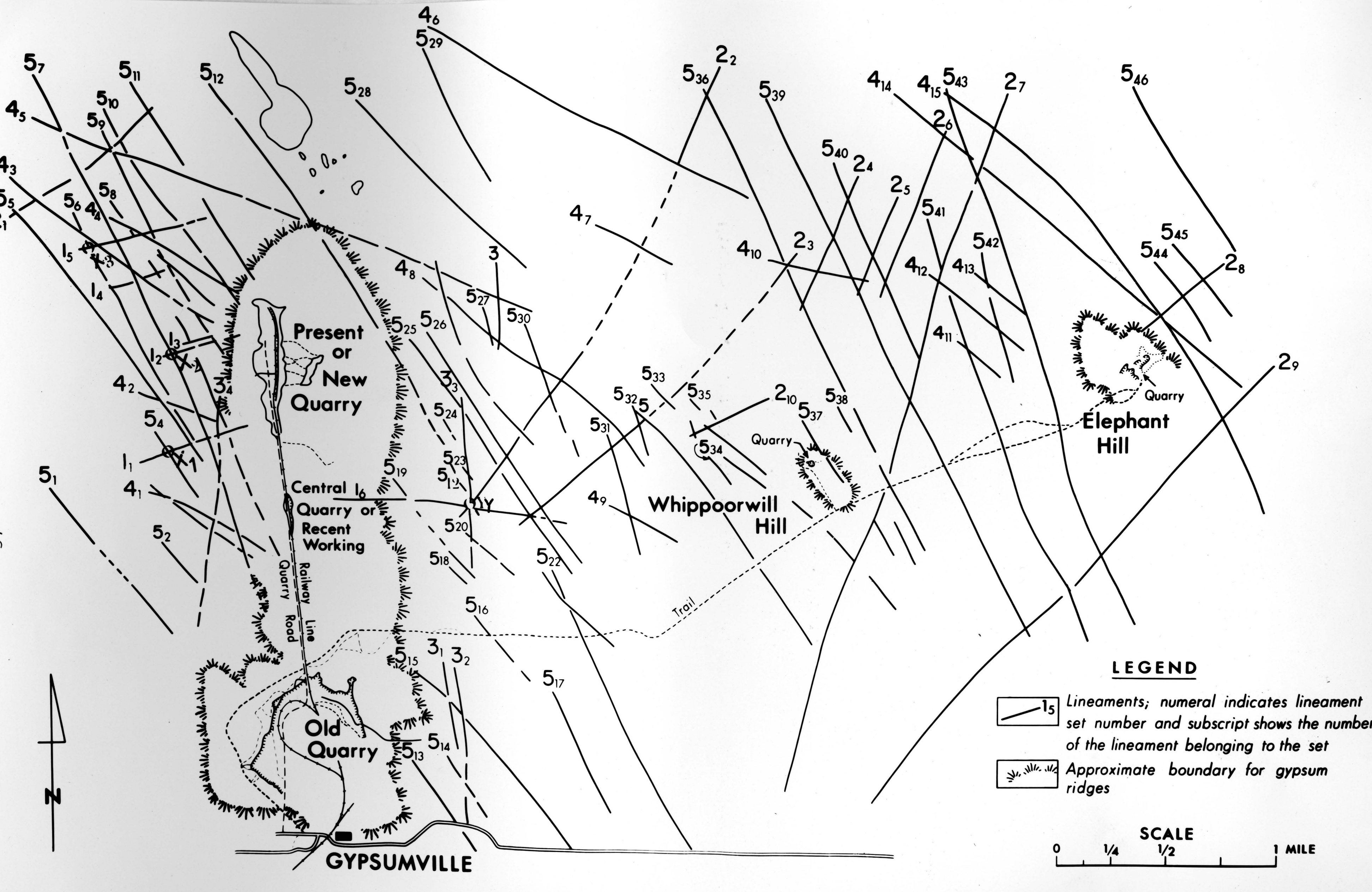
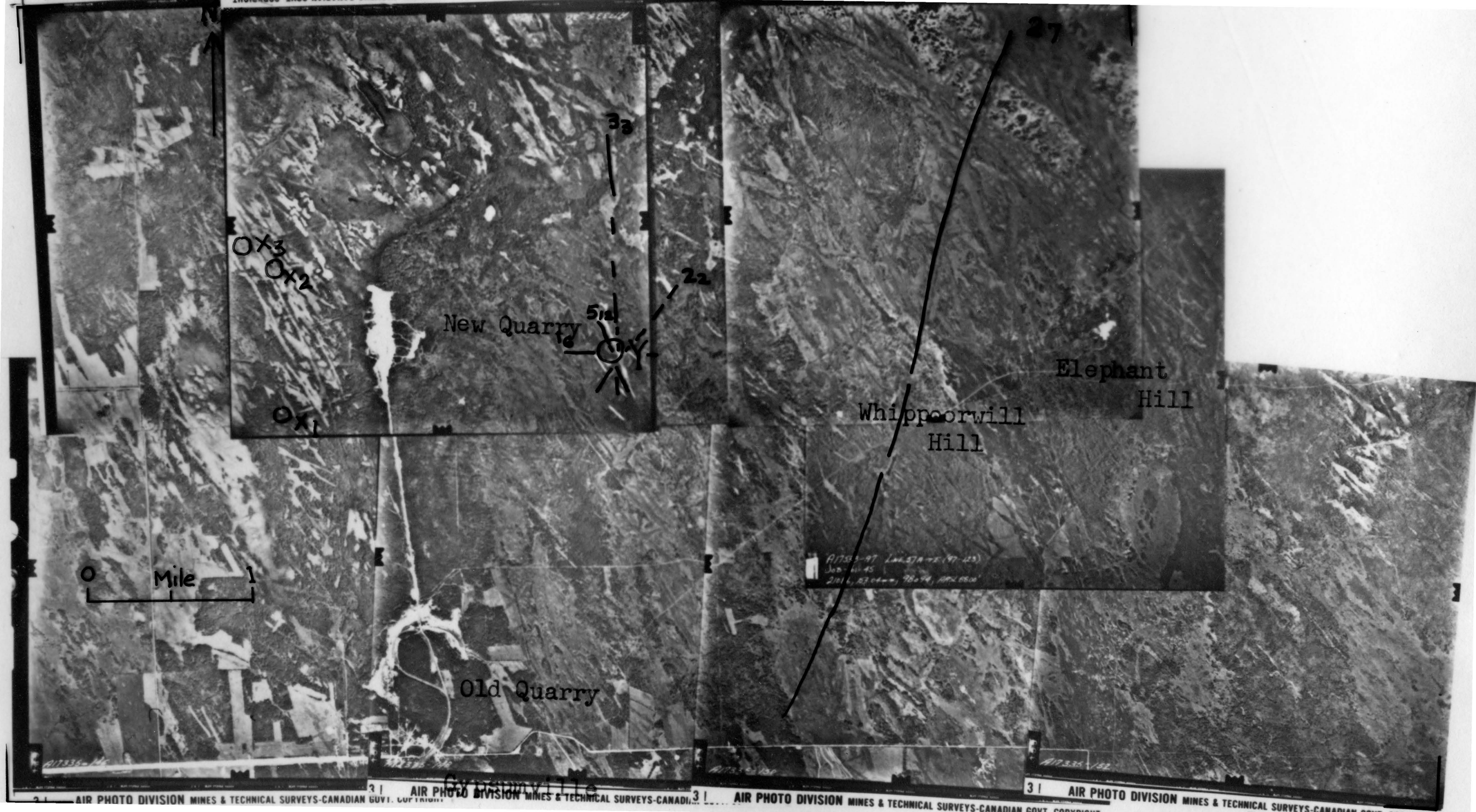


Figure 26A - Lineaments in the Gypsumville area as drawn from air photos

Figure 26B. Airphoto mosaic of the Gypsumville area.

1_6, 2_2, 2_7, 3_5 and 5_{12} labels on lineaments indicate lineaments referred to in text.

X_1, X_2, X_3 and Y positions are lineament intersections referred to in text.



N
OX3
OX2
OX1
New Quarry
33
22
512
16
27
Elephant
Hill
Whippoorwill
Hill
0
Mile
1
Old Quarry
Gypsumville
AIR PHOTO DIVISION MINES & TECHNICAL SURVEYS-CANADIAN GOVT. COPYRIGHT

AIR PHOTO DIVISION MINES & TECHNICAL SURVEYS-CANADIAN GOVT. COPYRIGHT
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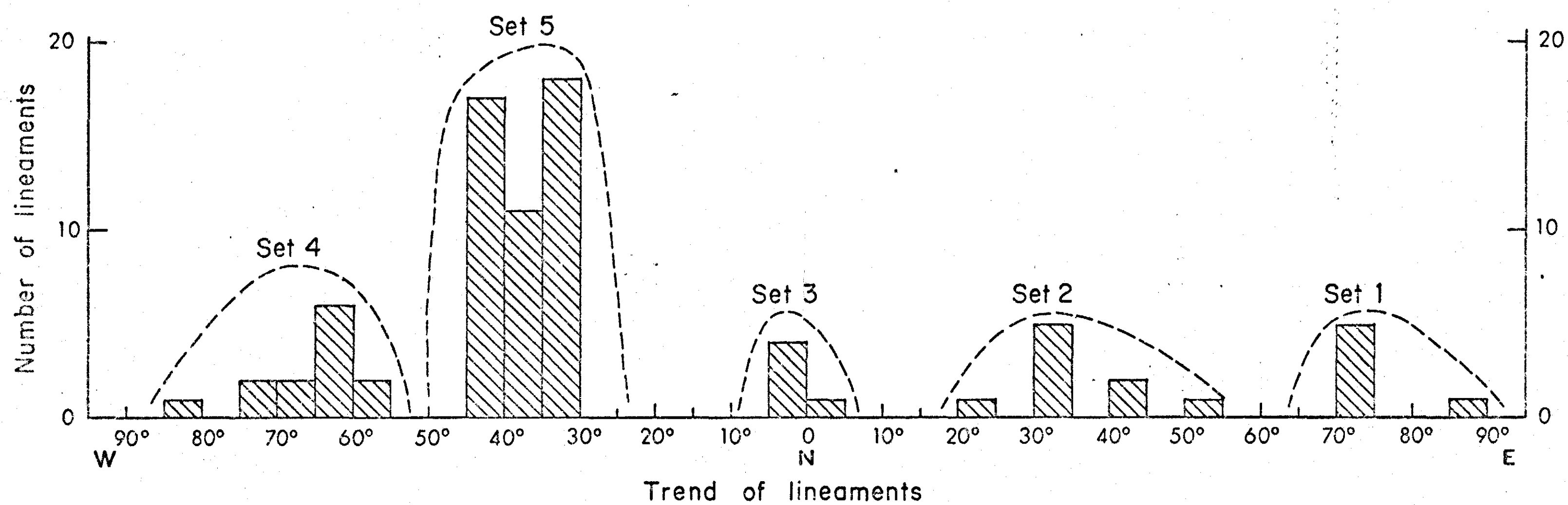


Figure 27 — Histogram showing trend of lineaments in the Gypsumville area

inferred, therefore, that lineament set no. 3 is older than set no. 5 but younger than set no. 1. Set no. 1 appears to be the oldest and no. 5 the youngest. The relative age of sets no. 2 and 4 could not be established.

Some individual lineaments in the Gypsumville area can be traced continuously, or discontinuously, for distances of up to 4 miles (see lineament no. 2_7 in Fig. 26A). The lineaments range in width from 40 to 400 feet. Some are curved slightly towards the east or west.

Origin

Intersecting lineaments on the Lake Agassiz plains, apparently similar to the ones at Gypsumville, were discussed first by Horberg (1951, p. 1-18). Horberg suggested that these lineaments formed in a "periglacial" climate and were relic permafrost features. This theory was severely criticized by Nikiforoff (1952, p. 99-103) who attributed the intersecting linear features to shore line processes.

Mollard (1957, p. 26-50) proposed that systematic intersecting linear depressions, in the region between Lakes Manitoba - Winnipegosis and Lake Winnipeg, were caused largely by leaching of the overburden which was controlled by bed-rock fractures. Mollard pointed out that "the orientation and incidence of these minor linear features of the landscape bear little or no relation to the age, origin, composition or depth of the surficial materials. Geologic processes forming the surface linear elements are thought to have persisted over a great length of time; moreover, the processes are active at present."

In support of his theory that the intersecting lineaments are the surface expression of joint patterns in the underlying bed-rocks, Mollard furnished examples from Saskatchewan and Manitoba. He indicated that surficial lineaments can be traced to fracture patterns developed over locally exposed bed rock.

In the Steep Rock area, about 24 miles southwest of Gypsumville (Figs. 25 and 28), Devonian Elm Point limestones are exposed. From a study of airphoto mosaics, the bed-rock joint pattern has been intepreted (Figs. 28 and 29) and plotted in histogram form (Fig. 30). The maximum concentration of joints is N65E. The presence of two subordinate trends, N45E and N20W, is apparent also in the histogram.

The muskeg to the south and east of the Steep Rock limestone quarry (Fig. 28), covered by a thin sheet of glacial till (Fig. 25), exhibits well developed linear depressions. The lineaments in the Steep Rock area have the following characteristics:

a) The maximum concentration of lineaments lies between N30W - N45W (Fig. 30).

b) Some lineaments are up to half a mile wide (see area marked in parallelogram, about 4 miles east of the quarry).

Figure 30, which is a combined histogram of lineaments and joint sets, indicates that there is, as interpreted from airphotos, no obvious correlation between bed-rock joints and surface lineaments. However, direct measurements of joint trends on outcrop is required to substantiate this preliminary work from airphotos.

Figure 28. Airphoto mosaic of the Steep Rock area showing lineaments and joint trends.


0
1
Mile
Steep Rock
Quarry


A17417-145
A17417-147
A17417-148

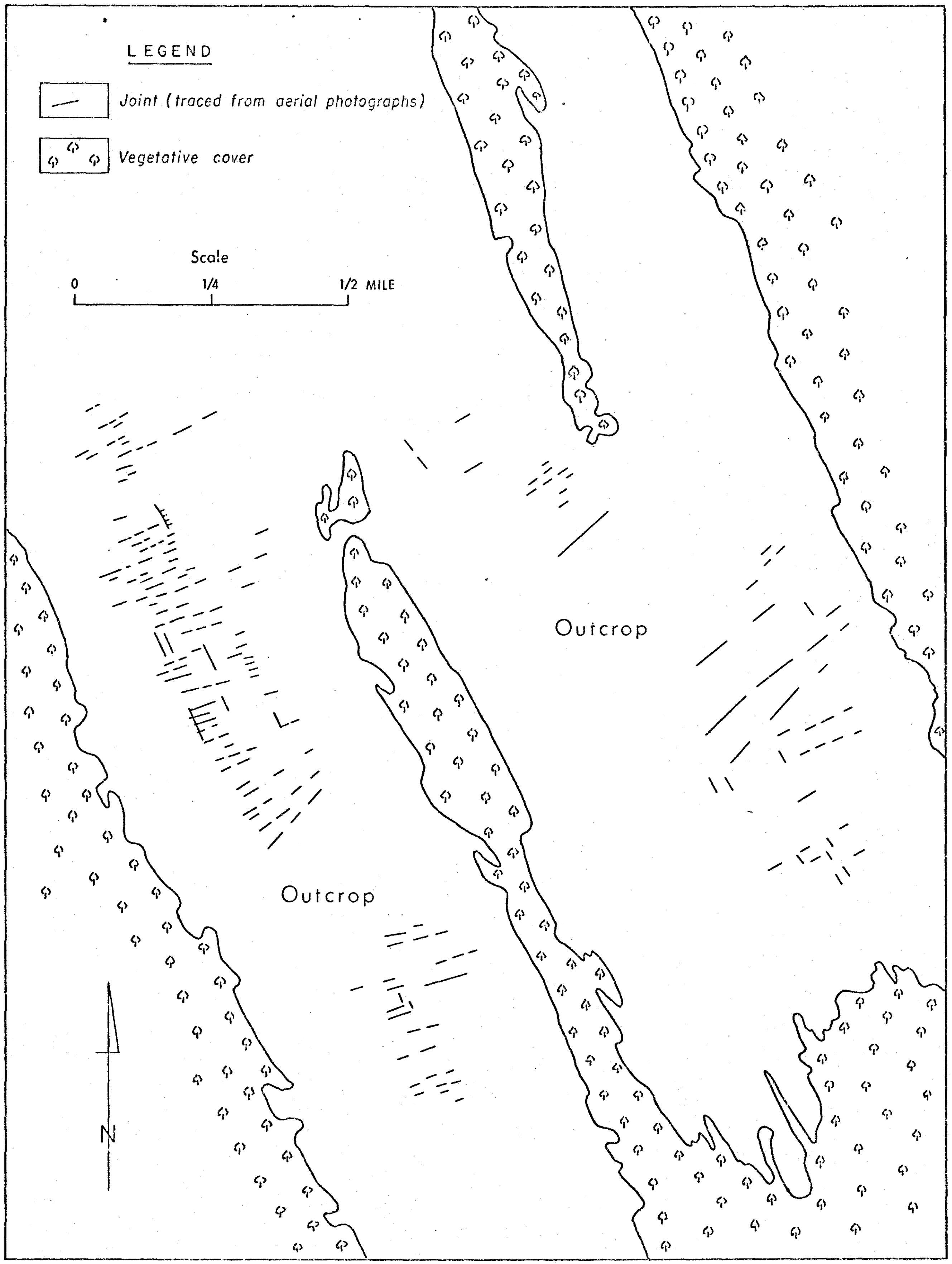


Figure 29 — Joint pattern in outcrop east of the Steep Rock Quarry (see Fig.28)

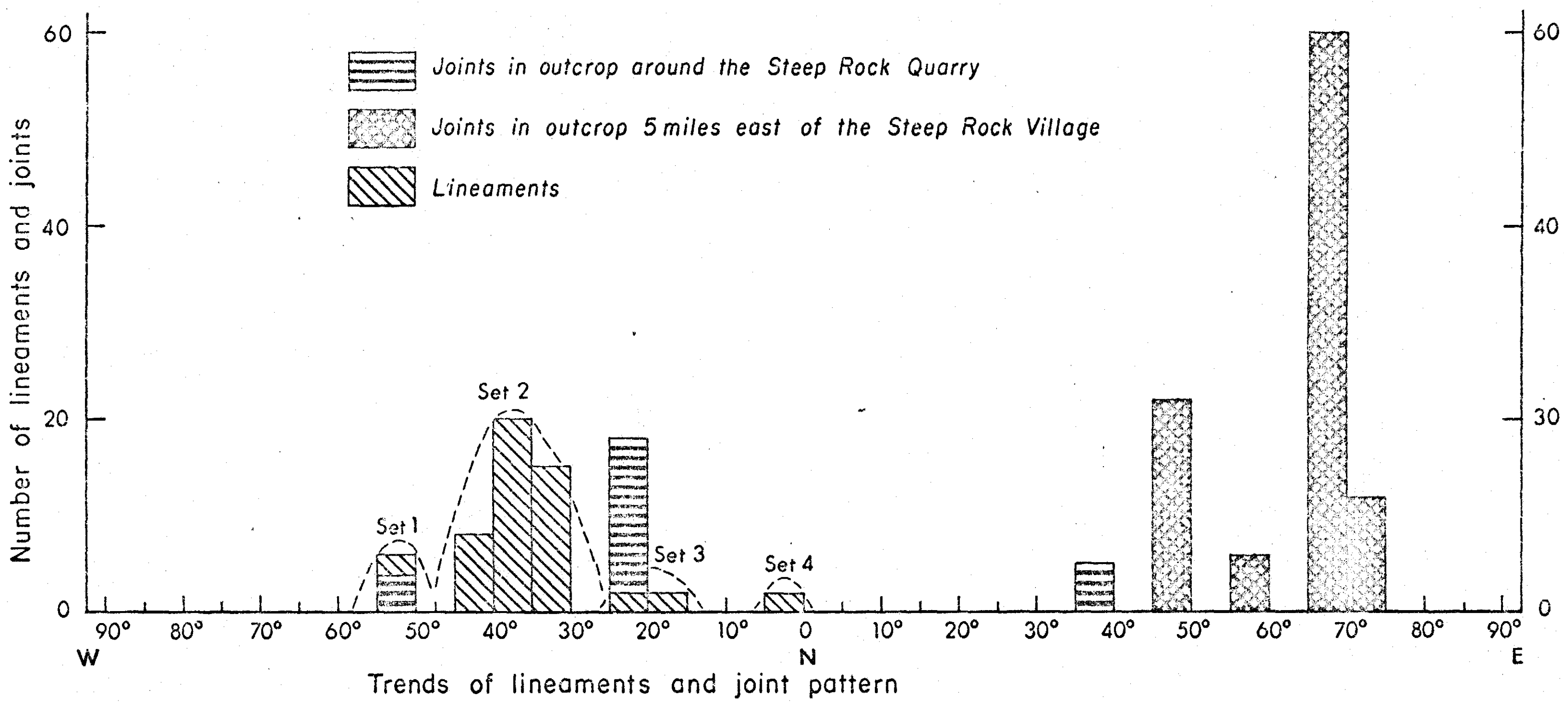


Figure 30 — Histogram illustrating trends of lineaments and joint pattern in the Steep Rock area

Clayton et al. (1965, p. 652-656) noted intersecting lineaments, in the form of grooves and ridges, on the Dakota, Manitoba and Minnesota portions of the Lake Agassiz plains. They likened these lineaments to lineaments which can be observed developing in lake bottom sediments by ice-rafting. Weber (1958, p. 333-341) found identical groovings, up to 108 feet wide, and 15,654 feet long, on the recent lake bottom sediments of Great Slave Lake, Northwest Territories. The N30W to N40W trend of many of the lineaments is explained by these authors on the assumption that the prevailing wind was from northwest and southeast. Under present climatic conditions, these are the prevailing wind directions during spring break up. The curvature of the lineaments is ascribed to change in wind direction as the ice dragged along the lake bottom.

Intersecting Lineaments as Ice-movement Indicators

Ice-movement indicators, such as striations or groovings, have not been observed in the Gypsumville area. Intersecting lineaments, developed on adjacent muskeg, may not be of glacial origin and cannot be used as reliable indicators of direction of ice-movement. In fact, the dominant N30W - N40W trend of the lineaments in the Gypsumville area, and elsewhere in the plains of Lake Agassiz (Mollard, 1959 and Clayton et al, 1965), does not correspond with the bed-rock striations which more surely provide evidence of direction of ice-movement (Ceder Lake - Pass Moraine area (N), eastern shore of the Lake Winnipegosis (N02E), eastern, western and northern shores of the Lake Winnipeg (N45E - N60E) (Fig. 24).

Conclusion

The theory that the lineaments represent ice-floe features (Clayton *et al.*, 1965) is favoured because this theory accounts for the observed curvature of some lineaments and the present study has not revealed any adequate correlation between bed-rock fractures and surface lineaments, which would support the alternative theory of bed-rock control. The glacial origin of these features can be discounted on the grounds that the trends of these lineaments do not agree with directions of ice-movement inferred from bed-rock striae and other features.

PETROLOGY

A petrographic study was undertaken in an attempt to interpret the relationships between the various types of anhydrite and gypsum.

Gypsumville Quarries

The following rock types occur:

i) thin to thick beds of anhydrite;

ii) fine grained, well-stratified gypsum;

iii) white gypsum with medium to coarse granular texture;

iv) spheres of white fine-grained gypsum which weather out on bedding planes of coarse gypsum;

v) large, coarse gypsum crystals;

vi) rosettes of fibrous gypsum;

vii) veins of fibrous gypsum;

i) Thin to thick beds of anhydrite: Anhydrite occurs in outcrop as beds 2 inches to 4 feet thick, which are interlayered with gypsum. The anhydrite is hard and greyish-blue to bluish-white on fresh surfaces. Weathered surfaces consist of fine grained gypsum.

Anhydrite crystals range in size from .05 to .50 millimetre, with less common larger anhedral crystals of up to 3 millimetres length. The crystals are elongate having a sub-parallel or parallel orientation and commonly are bent (Plate IX-A).

Fine grained aggregates of gypsum occur along grain-boundaries and cleavage planes of anhydrite (Plate IX-B). Irregular grains of anhydrite occur in gypsum, but become less common away from the anhydrite-gypsum contact. The anhydrite grains are highly

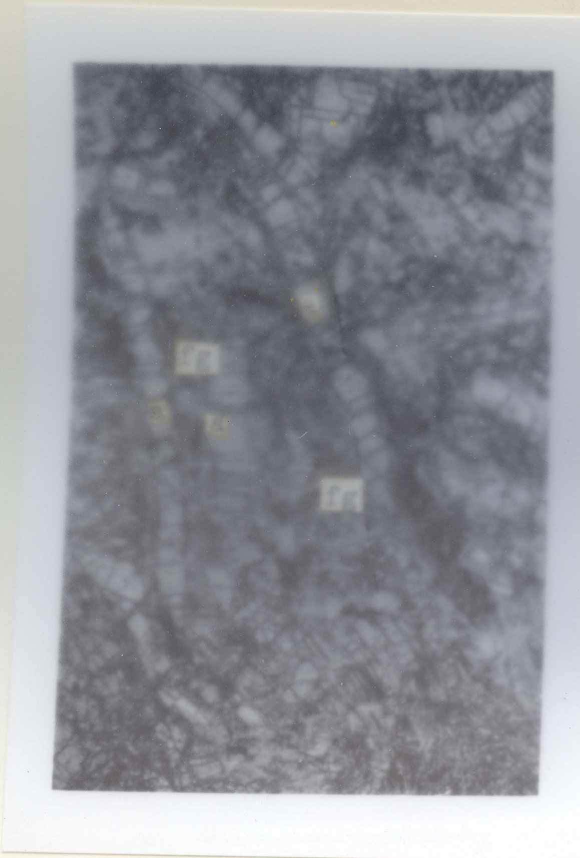
Plate IX. Photomicrographs of sample from a three-foot thick bed of anhydrite. Location, 1100 foot point (Fig. 14) in the New Quarry.

A. Elongate anhydrite grains (a) within fine grained gypsum (fg). Grains are bent. Plane polarized (X 11.5).

B. Same slide as that of Plate IX-A. Fine grained aggregates of gypsum (fg) occur along grain boundaries and cleavage planes of anhydrite (a). Plane polarized (X 11.5).

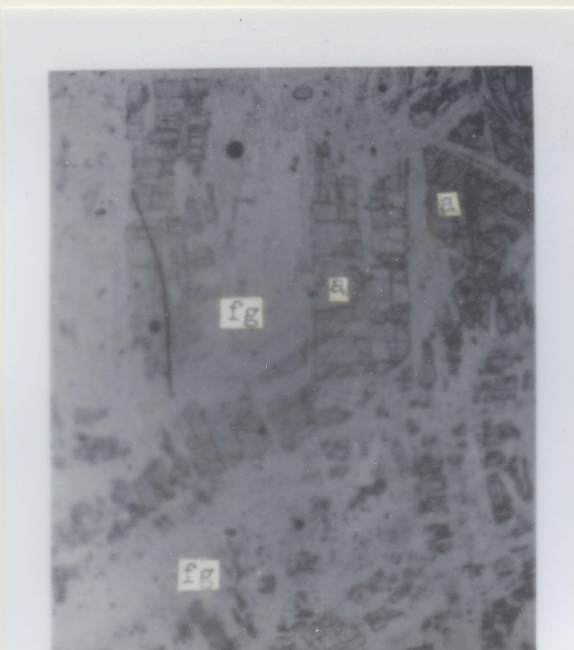
C. Relics of anhydrite grains (a) replaced by fine grained gypsum (fg). Thin section as for Plate IX-A. Plane polarized (X 11.5).

D. Euhedral to subhedral, medium to coarse-textured gypsum (cg) associated with fine grained gypsum (fg) and anhydrite (a). Note planar grain-boundaries of coarse gypsum compared with irregular grain-boundaries of fine grained gypsum. Thin section as for Plate IX-A. Plane polarized (X 11.5).

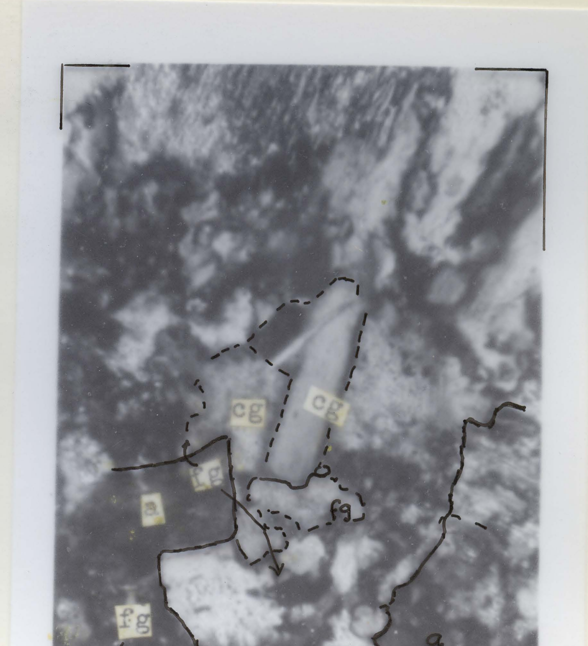


A

B



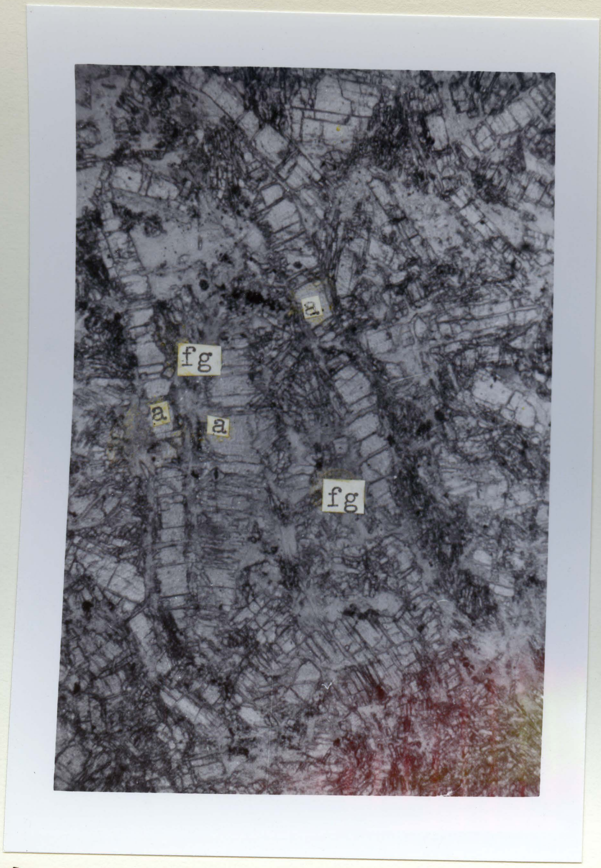
C



D

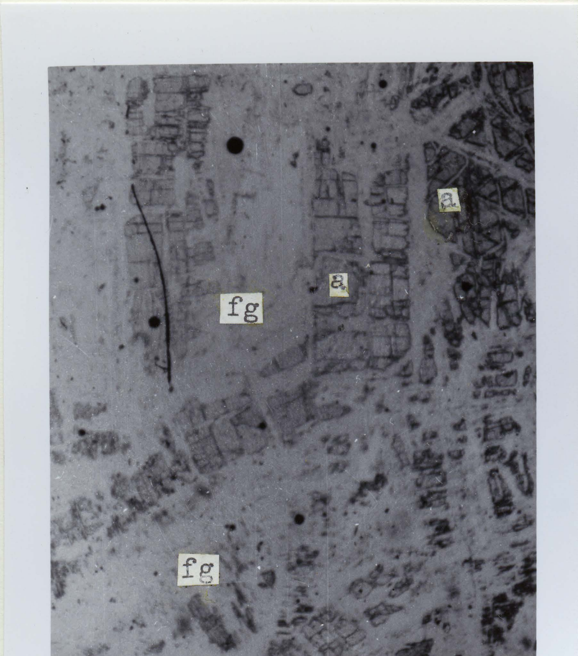
PLATE IX

Plate IX



A

B



C

D

PLATE IX

irregular, with fine grained gypsum occurring preferentially along the cleavage planes and grain-boundaries (Plates IX-B and C). Medium to coarse-textured, euhedral to subhedral gypsum crystals are found to be associated with fine grained, anhedral gypsum and anhydrite grains (Plate IX-D). The fine grained gypsum has irregular grain-boundaries. The large gypsum euhedra contain numerous inclusions of fine grained gypsum. It is suggested that the coarse gypsum crystals have grown in situ at the expense of fine grained gypsum. Such a suggestion is based on planar grain-boundaries of the coarse gypsum as compared with irregular grain-boundaries of fine grained gypsum.

ii) Fine grained, well-stratified gypsum: This is the most abundant variety of gypsum in the Gypsumville quarries. Bedding planes are defined by red and grey argillaceous and calcareous materials.

Gypsum grains are anhedral and range from .01 to .2 millimetre. Medium to coarse grained, euhedral gypsum crystals, with planar boundaries, occur embedded in the fine grained gypsum aggregates which have highly irregular boundaries (Plate X-A). It is inferred that the large gypsum crystals have grown at the expense of the smaller anhedral gypsum grains. There is no evidence here of the smaller grains having replaced the larger.

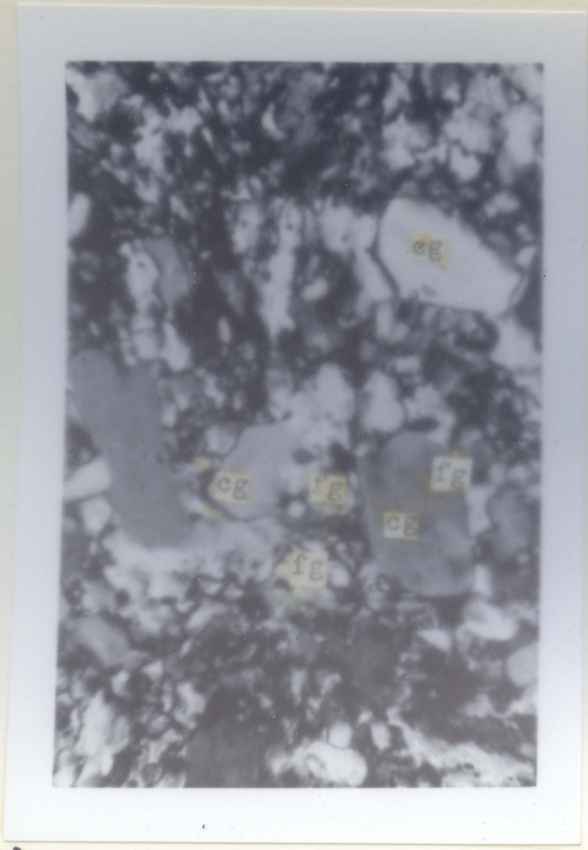
iii) White gypsum with coarse granular texture: Gypsum crystals, ranging in length from .5 to 3 millimetres, occur in a matrix of fine grained gypsum presumably similar to that described above. The coarse gypsum crystals are subhedral to euhedral and have planar boundaries. The fine grained gypsum has irregular grain-boundaries (Plate X-B). The large gypsum plates have a mottled appearance. Individual mottles have a similar size and form to fine gypsum grains in the groundmass and mottles may be ghosts of replaced finer grains.

Plate X-A. Photomicrograph of fine grained, well-stratified gypsum. Location, northern end of the New Quarry. Medium to coarse, euhedral gypsum (cg) occurs in a matrix of fine grained, anhedral gypsum (fg). Note the irregular grain-boundaries of fine grained gypsum. Crossed nicols (X 40).

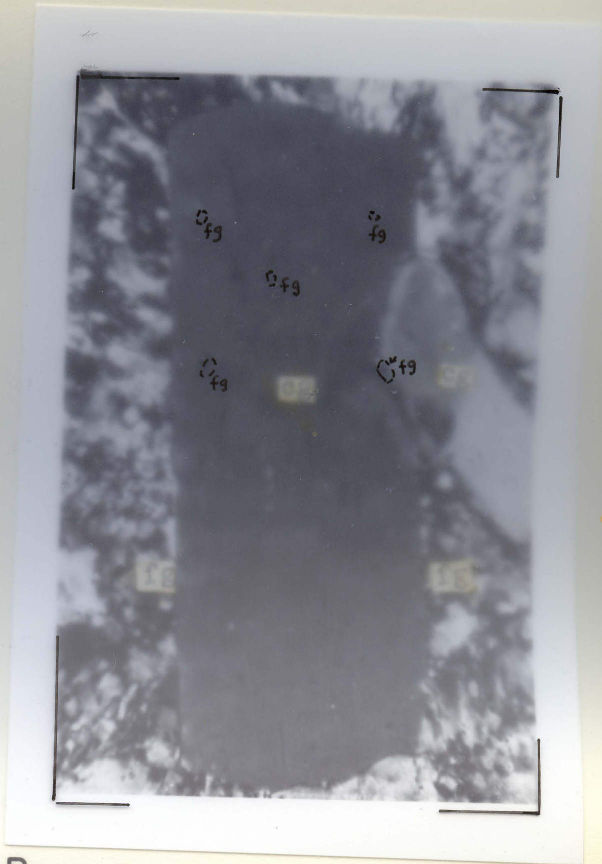
Plate X-B. Photomicrograph of white gypsum with coarse, granular texture. Location, 1600 foot point (Fig. 14) in the New Quarry. Coarse, euhedral gypsum (cg) in a matrix of fine grained, anhedral gypsum (fg). Crossed nicols (X 40).

Plate X-C. Spheres of white, fine grained gypsum (fg) which weather out on bedding planes of coarse gypsum (cg). Location, northern end of the New Quarry.

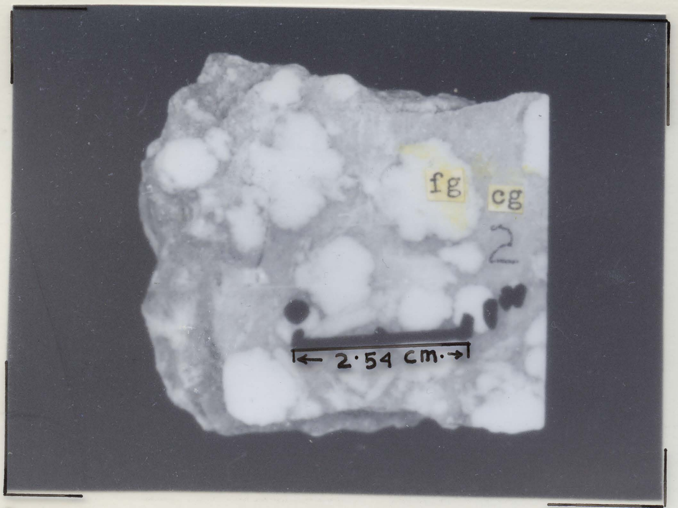
Plate X-D. Photomicrograph of the white spheres. Location, same as for Plate X-C. White spheres are composed of fine-grained, anhedral gypsum (fg) with irregular grain-boundaries; the matrix is composed of coarse gypsum crystals (cg) with planar grain-boundaries. Crossed nicols (X 40).



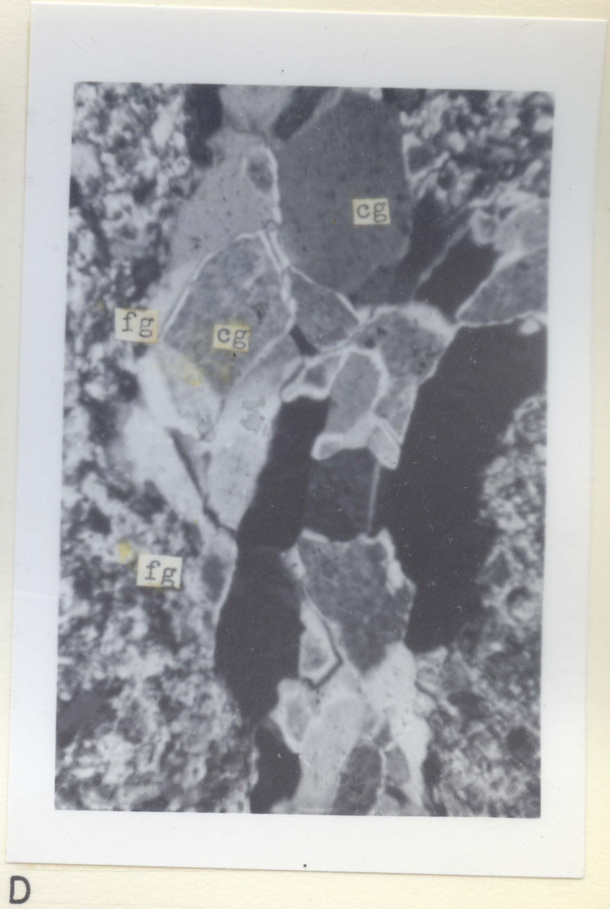
A



B



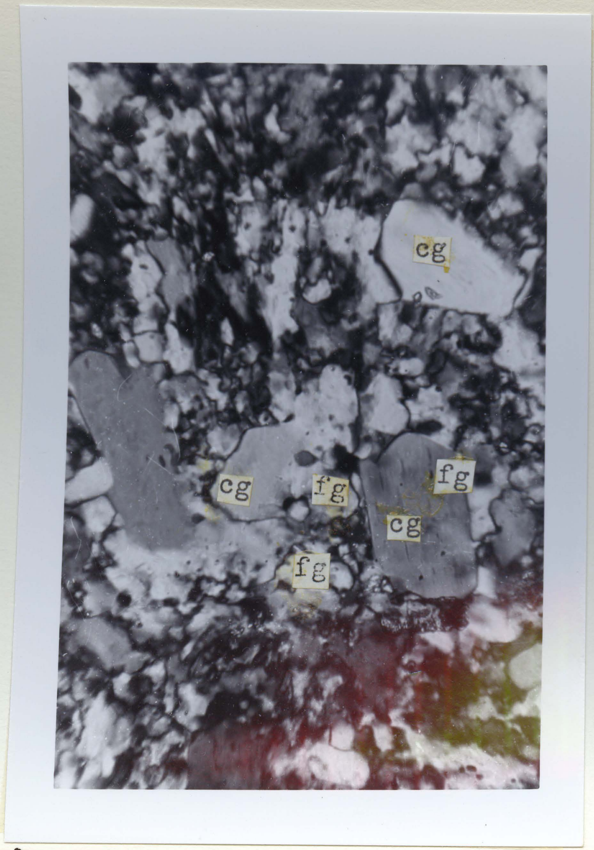
C



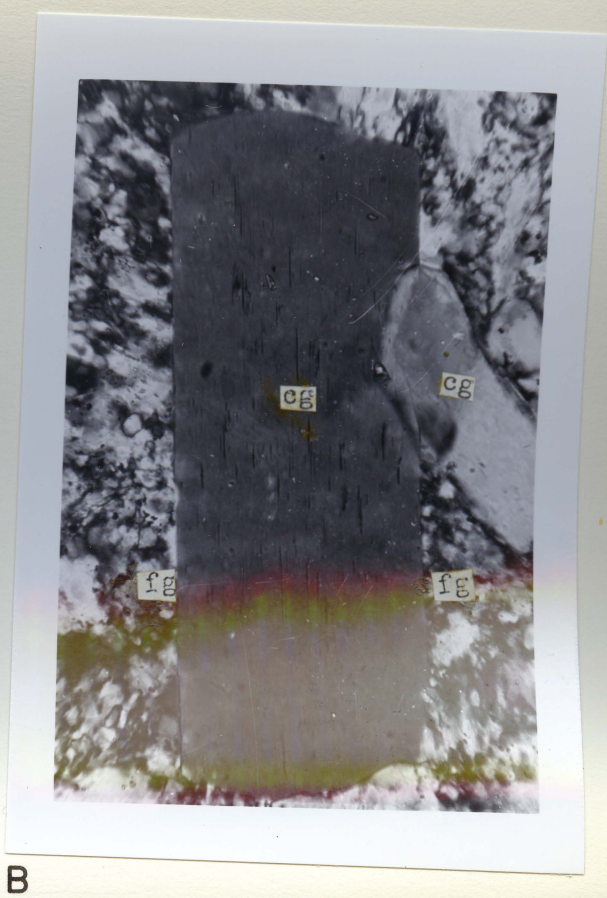
D

PLATE X

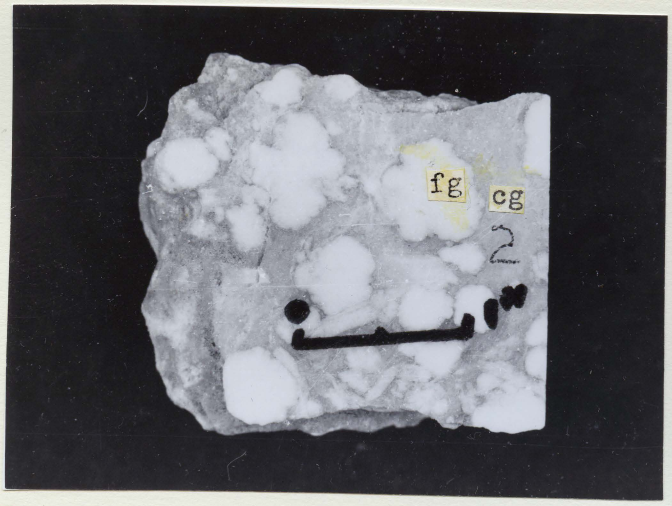
Plate X.



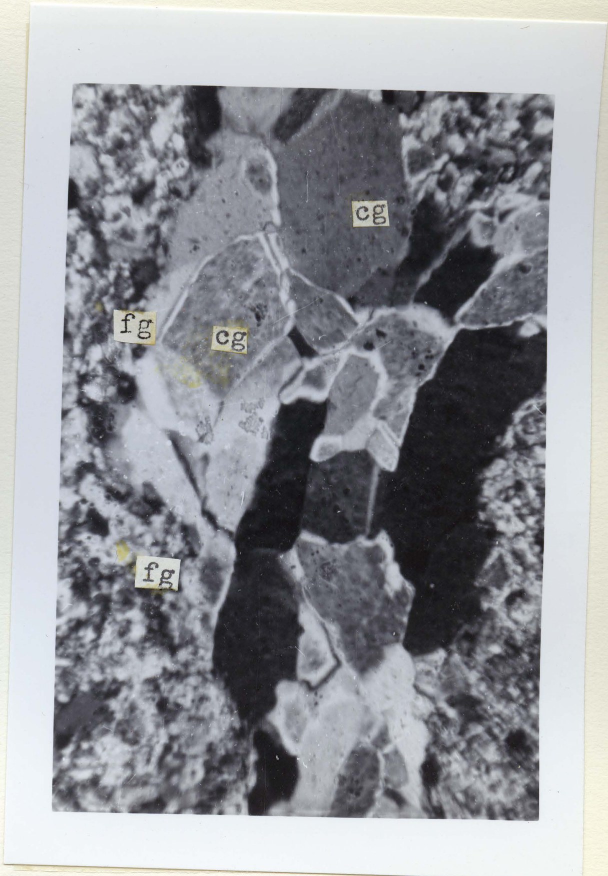
A



B



C



D

PLATE X

It is suggested that coarse gypsum crystals have grown at the expense of fine grained gypsum.

iv) Spheres of white, fine grained gypsum which weather out on bedding planes of coarse gypsum: Spheres of white, fine grained gypsum (Plate X-C) are common in the New Quarry and in the Recent Working. They range in diameter from .5 to 3 centimetres and commonly weather out on the bedding planes of coarse, grey gypsum beds.

In thin section, the spheres are seen to consist of gypsum grains ranging in size from .01 to .2 millimetre. The matrix is coarser grained, being composed of euhedral crystals of gypsum in the range .5 millimetre to 1 centimetre. The gypsum of the white spheres is similar to the fine-grained gypsum described under section "Fine grained, well stratified gypsum in p. 69 ." The marked planar grain-boundaries of the coarse gypsum, in contrast to the irregular grain-boundaries of the fine grained gypsum (Plate X-D), suggest growth of the coarse gypsum crystals at the expense of the fine gypsum.

v) Large, coarse gypsum crystals: These occur extensively in the New Quarry and are commonly associated with fine grained gypsum. Two types of coarse gypsum are recognized. One type occurs as irregular, tabular crystals and the other as aggregates of euhedral gypsum.

Tabular gypsum crystals commonly have transparent cores which constitute the bulk of the crystal. The transparent cores contain, in places, abundant inclusions of anhydrite. Some isolated inclusions of anhydrite in coarse gypsum have common optic and therefore crystallographic orientation (Plate XI). This suggests that they are remnants of partially replaced grains.

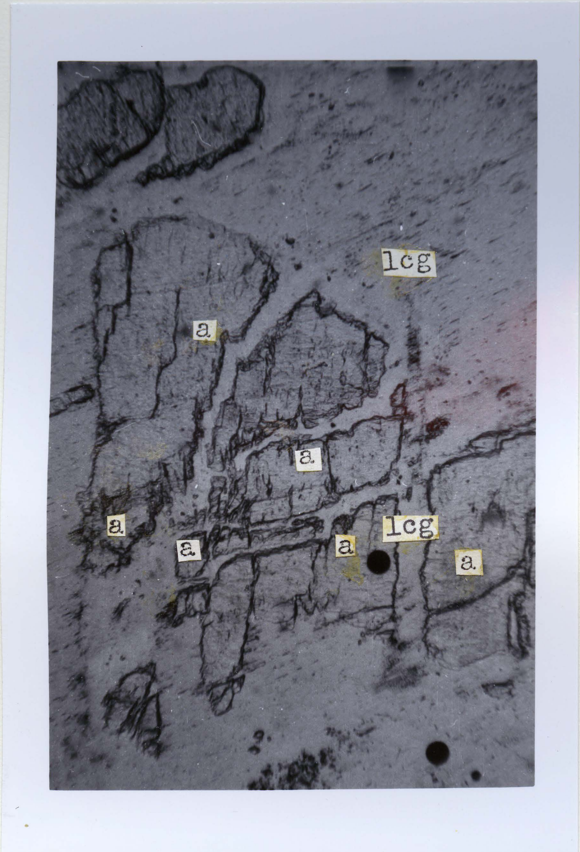
Tabular gypsum crystals are frequently found to be embayed

Plate XI. Photomicrographs of relic anhydrite crystals.

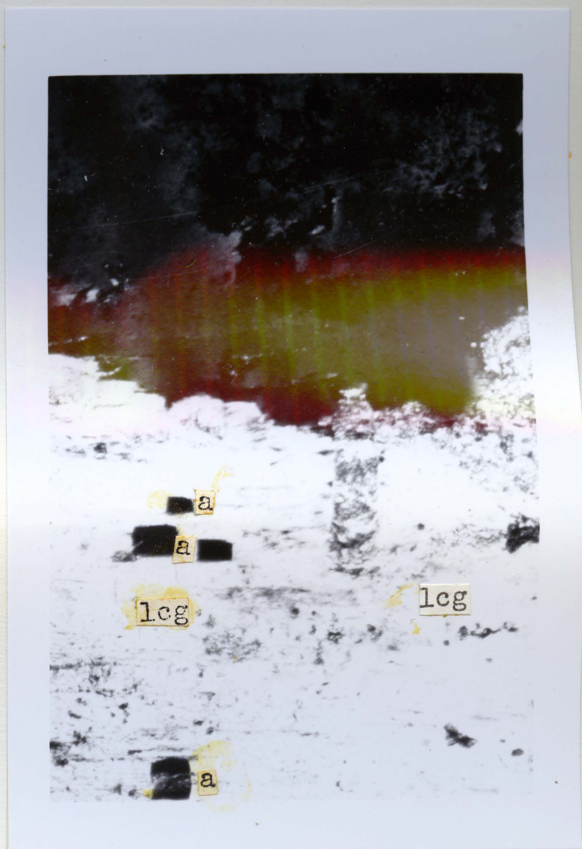
Location, northern part of the New Quarry.

A. Relics of anhydrite grains (a) embedded in large gypsum (lcg). Isolated portions of anhydrite have common optic orientation. Plane polarized (X 40).

B. Isolated inclusions of anhydrite (a) have common optic orientation in gypsum (lcg). Crossed nicols (X 11.5).



A



B

PLATE XI

Plate XII. Photomicrographs of large gypsum crystals partially recrystallized to fine grained gypsum. Location, southern part of the northern end of drainage ditch (Fig. 14), New Quarry.

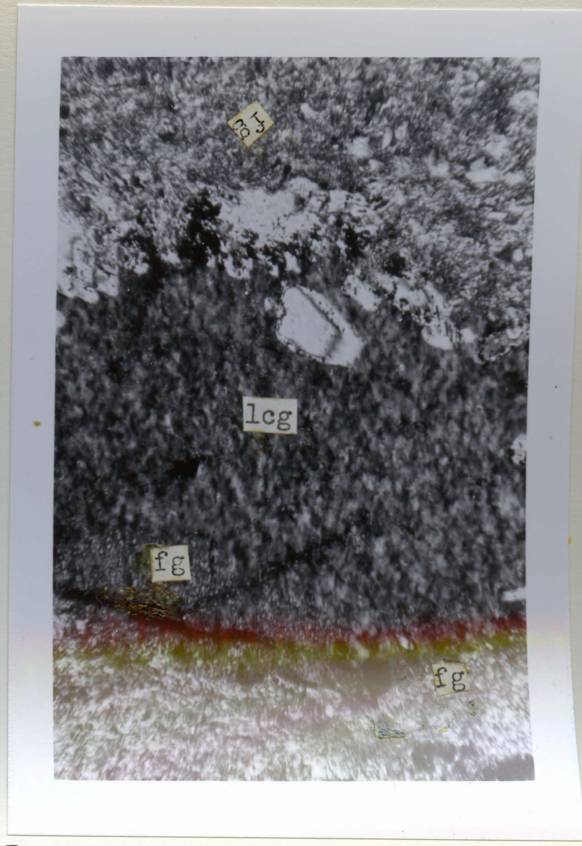
A. Coarse gypsum crystal (lcg) surrounded by finely crystalline gypsum (fg). In the lower left portion of the figure a coarse euhedral gypsum crystal (cug) has grown at the expense of the large gypsum crystal (lcg). Note the presence of a relic anhydrite grain (a) in the upper right portion of the crystal. Crossed nicols (X 40).

B. Large gypsum crystal (lcg) surrounded by fine grained gypsum (fg). Note the presence of finely disseminated gypsum grains (fg) within the large crystal. Crossed nicols (X 40).

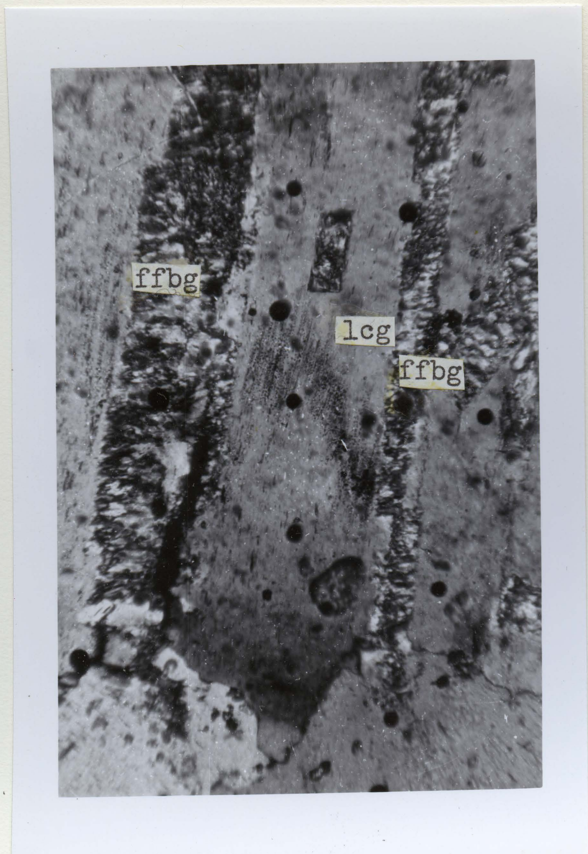
C. A large gypsum crystal (lcg) partly recrystallized by fine grained gypsum which has a fibrous texture (ffbg). Note recrystallization occurs preferentially along cleavage planes. Crossed nicols (X 40).

D. Ghost of an almost completely recrystallized, large gypsum crystal (lcg). Note that fine grained gypsum has assumed a fibrous texture (ffbg). Crossed nicols (X 40).

A



B



C

D

PLATE XII

and surrounded by fine-grained gypsum (Plate XII). They are seen to be partly or completely recrystallized to fine grained gypsum which commonly has a fibrous texture (Plate XII-C and D). Recrystallization of coarse gypsum crystals to fine grained gypsum has occurred preferentially along cleavage planes.

The coarse gypsum of the second variety, that is subhedral to euhedral grains, occur in a groundmass of fine-grained gypsum. The large gypsum euhedra do not contain inclusions of anhydrite and these grains are interpreted as having grown in situ at the expense of the fine grained groundmass. This conclusion is based on the planar form of the grain-boundaries for the large grains in contact with the fine grained gypsum (Plate XIII-A).

vi) Rosettes of fibrous gypsum: Grey coloured rosettes of gypsum occur locally and are elliptical to subrounded in shape and range from .5 to 3 centimetres in maximum diameter (Plate XIII-B). The rosettes are composed of radiating laths of coarse gypsum with minor associated clay, particularly near the centres of the rosettes (Plate XIII-C). There are no relic grains of anhydrite.

vii) Veins of fibrous gypsum: Fibrous gypsum veins occur extensively in both the New Quarry and the Old Quarry. Coarse fibres of gypsum are aligned perpendicular to bedding. The veins vary in thickness from a few millimetres to about 6 centimetres. A thin calcareous clay parting, parallel to bedding, occurs centrally in some of the veins (Plate XIII-D).

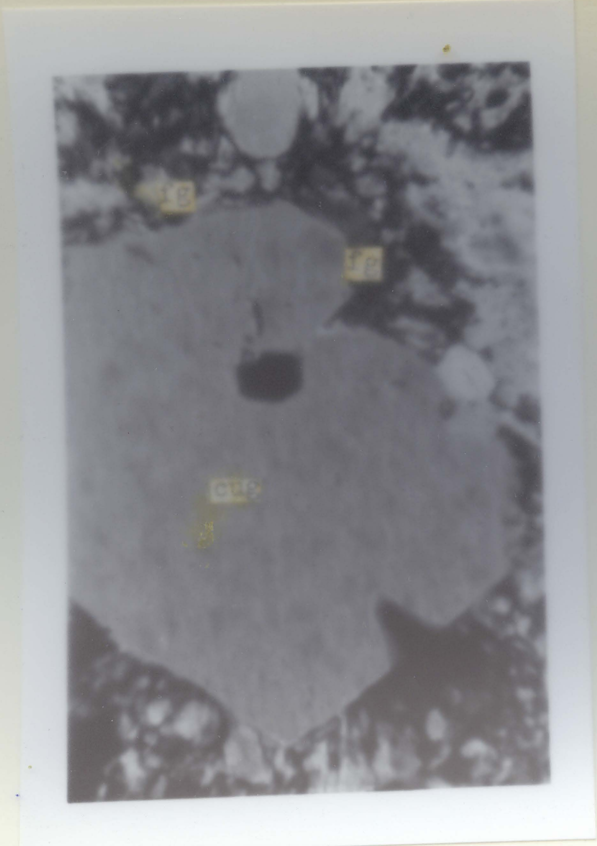
Since the fibrous gypsum veins lack porphyroblasts, pseudomorphs or relic minerals, they are interpreted to have grown by displacement rather than replacement. They appear to have formed selectively

Plate XIII-A. Photomicrograph of a coarse, euhedral crystal (cug) in a matrix of fine grained gypsum (fg). Fine grained gypsum has irregular grain-boundaries. Location, southern part of the northern end of the drainage ditch (Fig. 14), New Quarry. Crossed nicols (X 40).

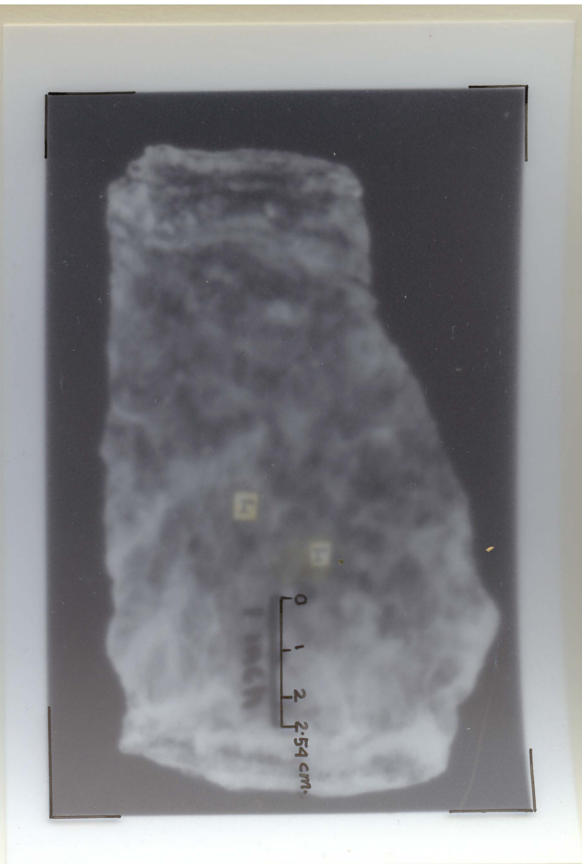
Plate XIII-B. Rosettes of fibrous gypsum (r). Location, drainage ditch, New Quarry (Fig. 14).

Plate XIII-C. Photomicrograph of a rosette. Rosettes are composed of radiating laths of coarse gypsum (cg) with minor associated clay (c). Plane polarized (X 11.5). Location, as for Plate XIII-B.

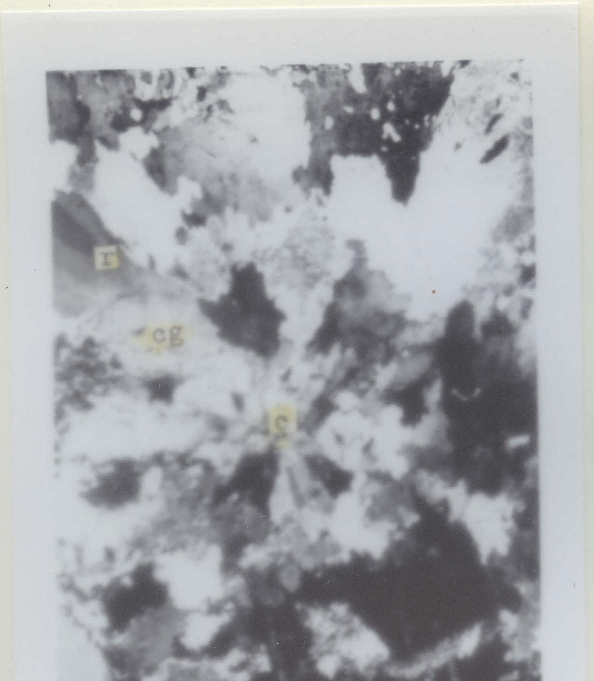
Plate XII-D. Photomicrograph of vein of fibrous gypsum (fbg). A thin calcareous clay parting occurs centrally in the vein. Crossed nicols (X 11.5). Location, northern end of the Old Quarry.



A



B



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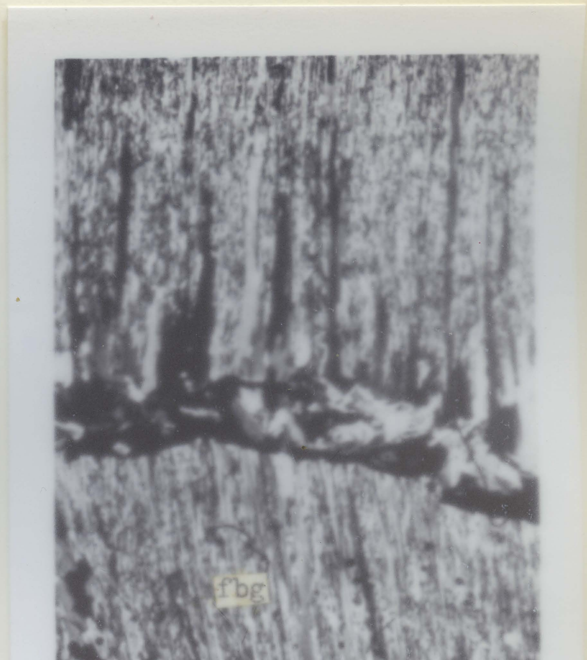
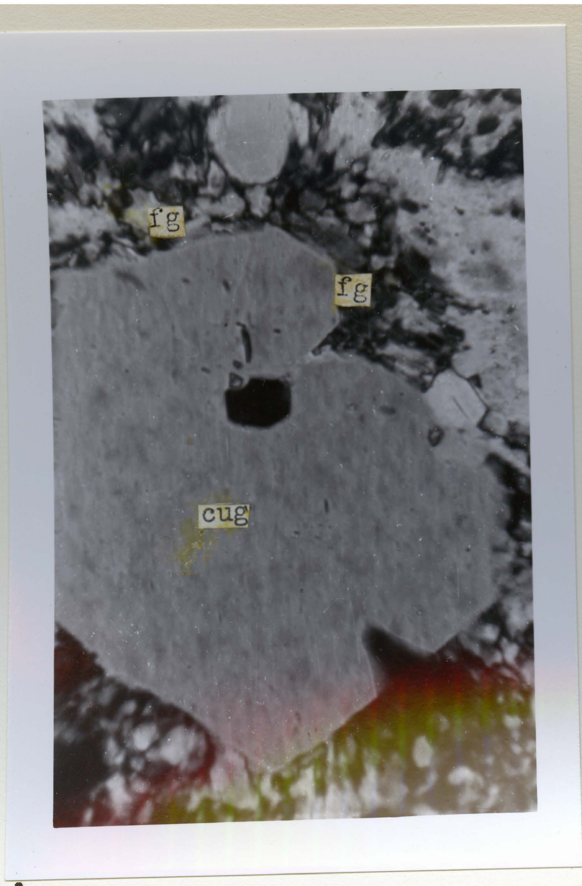


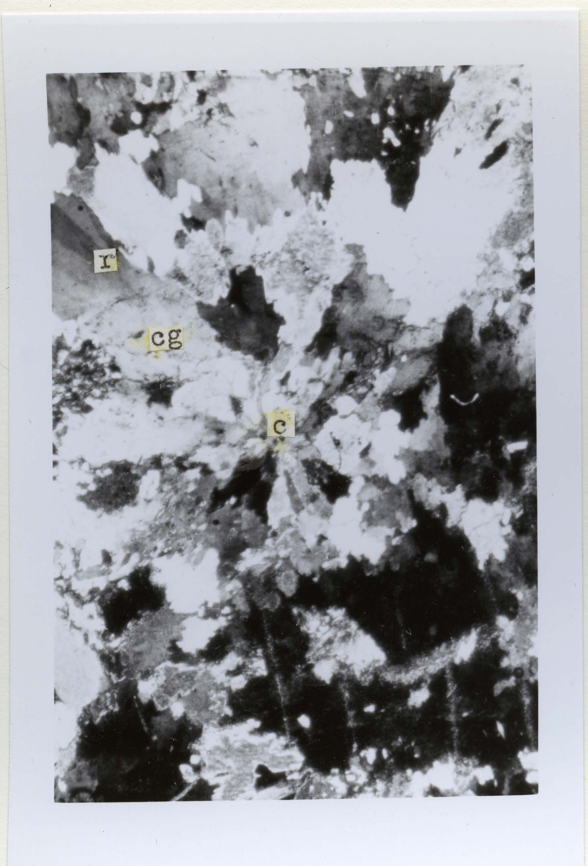
D

PLATE XIII

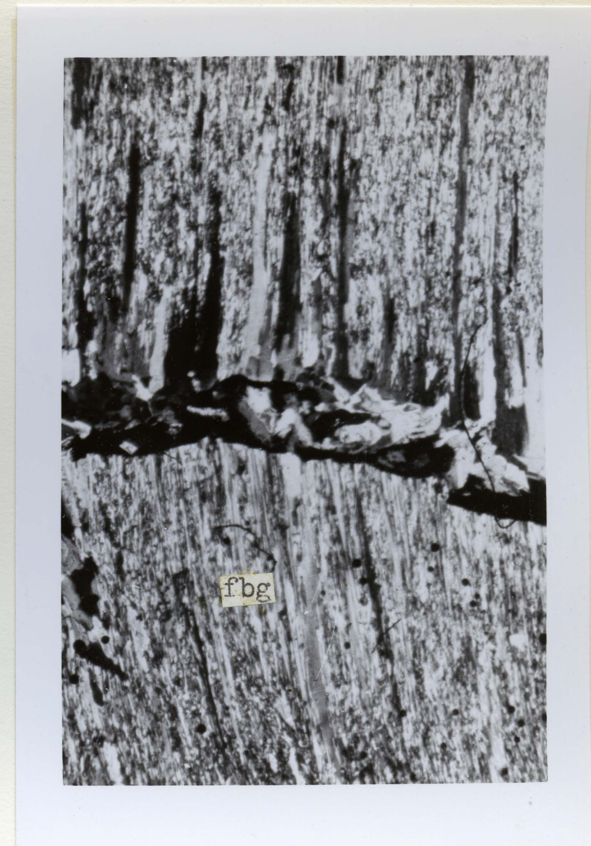


A

B



C



D

PLATE XIII

along planes of clay partings.

Elephant Hill

Three rock types are recognized:

i) bedded anhydrite;

ii) large crystals of gypsum associated with anhydrite;

iii) fine grained white gypsum.

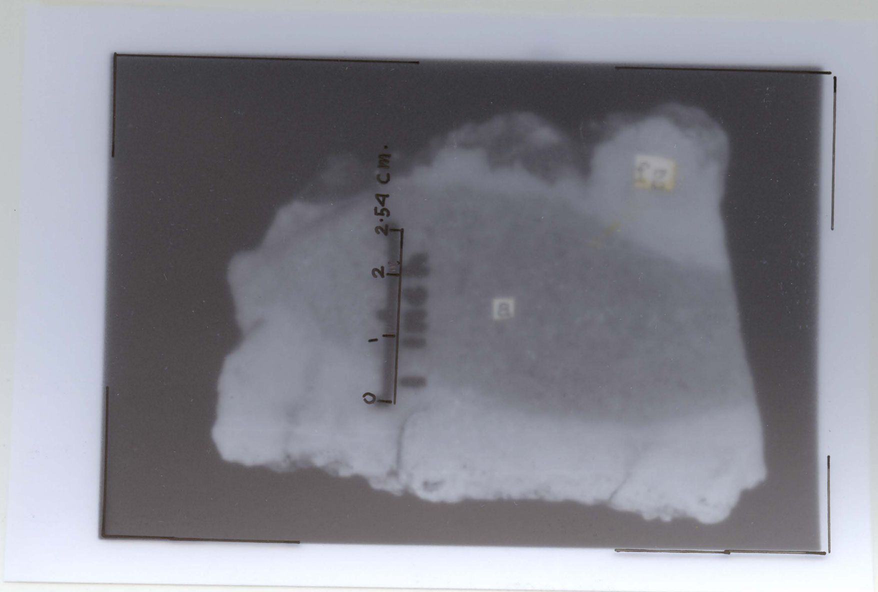
i) Bedded anhydrite: The anhydrite occurs interlayered with gypsum. The central portions of anhydrite beds are greyish-blue to bluish-white, but grade marginally upwards and downwards into overlying and underlying fine grained white gypsum (Plate XIV-A).

The anhydrite occurs as elongate crystals arranged in spherulitic aggregates which vary from 2.5 to 6 millimetres in diameter (Plate XV). Gypsum occurs along anhydrite grain boundaries and preferentially along planes of cleavage in anhydrite. Irregular, veins of fine grained gypsum radiate from the centres of spherulitic aggregates of anhydrite (Plate XV-A and B).

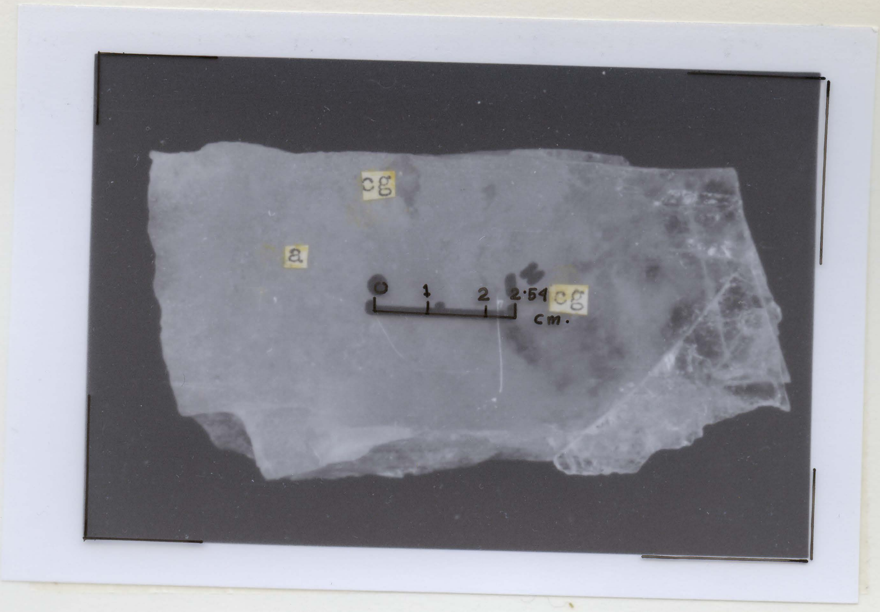
Thin sections reveal that the transition from anhydrite to gypsum occurs over about 5 millimetres. Irregular masses of anhydrite crystals occur isolated in gypsum and can be interpreted as remnant grains. The fine grained gypsum has a spherulitic structure (Plate XV-C and D) similar to that of the anhydrite, and this structure presumably resulted from the pseudomorphing of anhydrite. Anhydrite spherulites are present in various stages of replacement, gypsum occurring preferentially along anhydrite cleavages. No distortion of the original radial arrangement of anhydrite crystals is observed.

Plate XIV-A. A blue core of spherulitic anhydrite (a) with weathered white exterior of fine grained gypsum (fg). Location, southeast pit of the Elephant Hill.

Plate XIV-B. Anhydrite (a) - coarse gypsum (cg) contact. Sample from the south pit of the Elephant Hill.

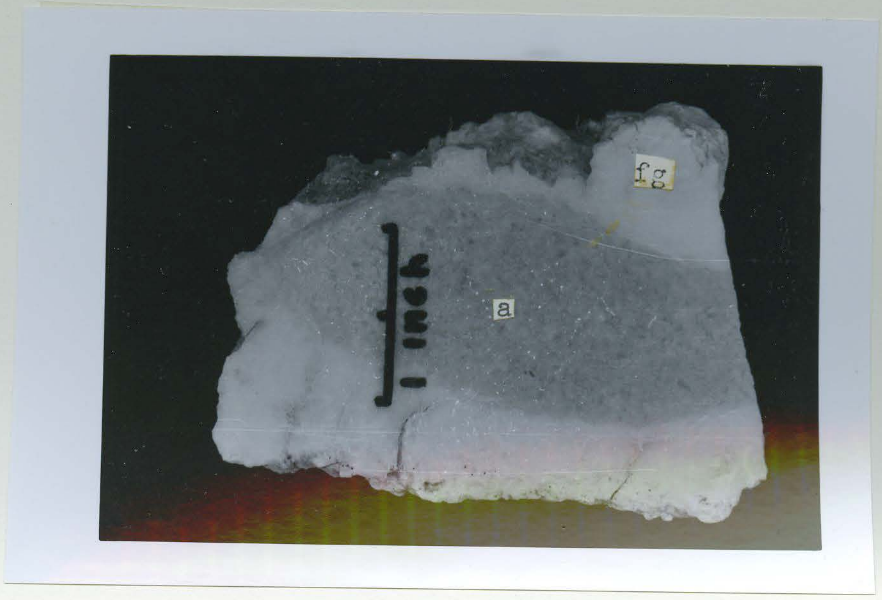


A

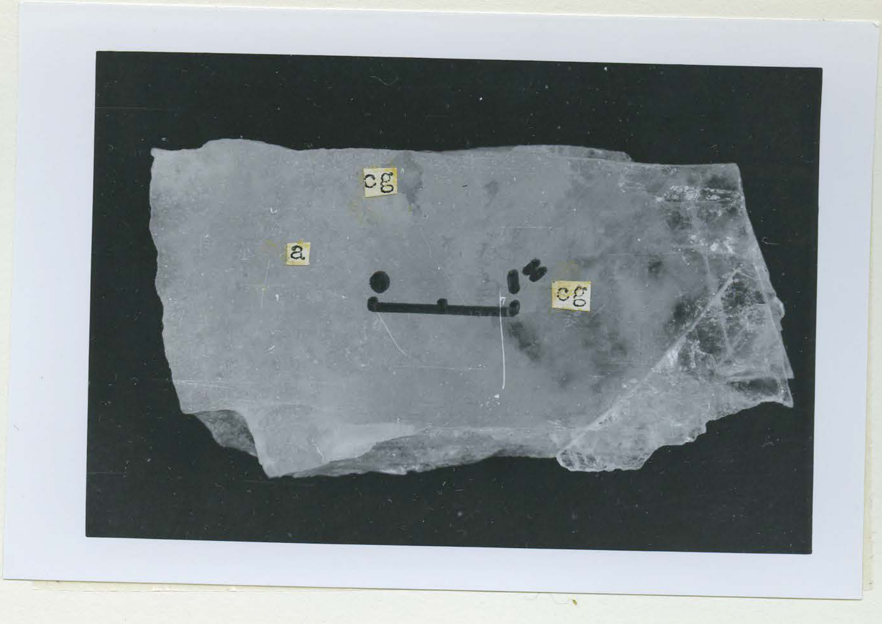


B

PLATE XIV



A



B

PLATE XIV

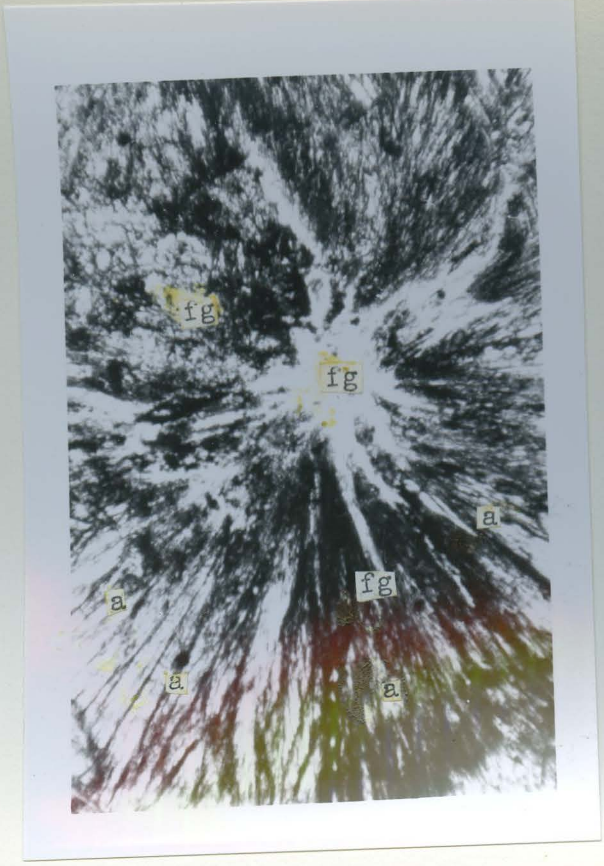
Plate XV. Photomicrographs of spherulitic anhydrite and associated weathered exterior. Location, same as for Plate XIV-A.

A. A single spherulite, 2.6 millimetres in diameter, composed of elongate anhydrite crystals (a). Fine grained gypsum (fg) with a fibrous texture occurs along cleavage planes and grain-boundaries. Plane polarized (X 40).

B. Elongate crystals of anhydrite (a) arranged in spherulitic aggregates with radial veins of fine grained fibrous gypsum (fg). Plane polarized (X 40).

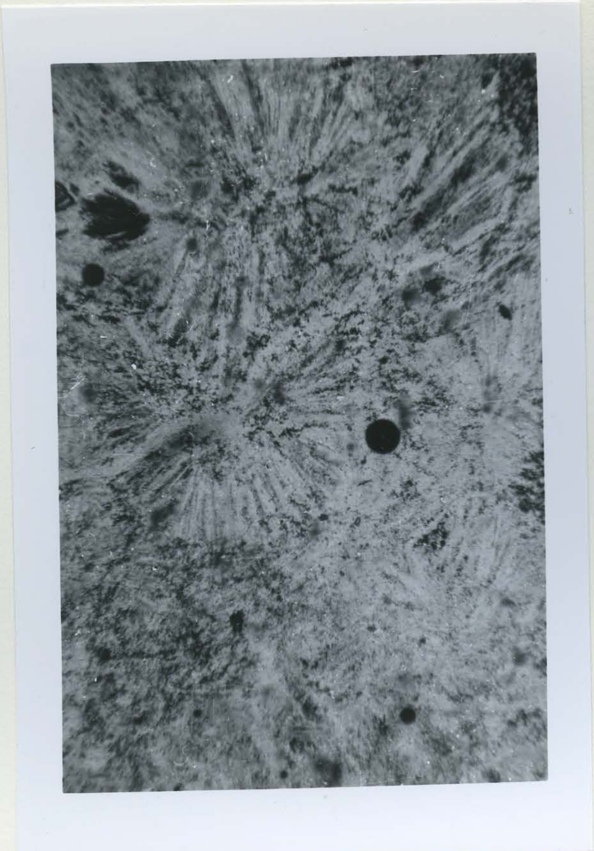
C. Spherulitic texture characteristic of anhydrite is preserved in the outer margin which is composed of fine grained gypsum. Note lack of distortion in the spherulites. Plane polarized (X 40).

D. Fine grained fibrous gypsum in the outer part of the anhydrite bed preserves the radial structure typical of anhydrite spherulites. Crossed nicols (X 40).



A

B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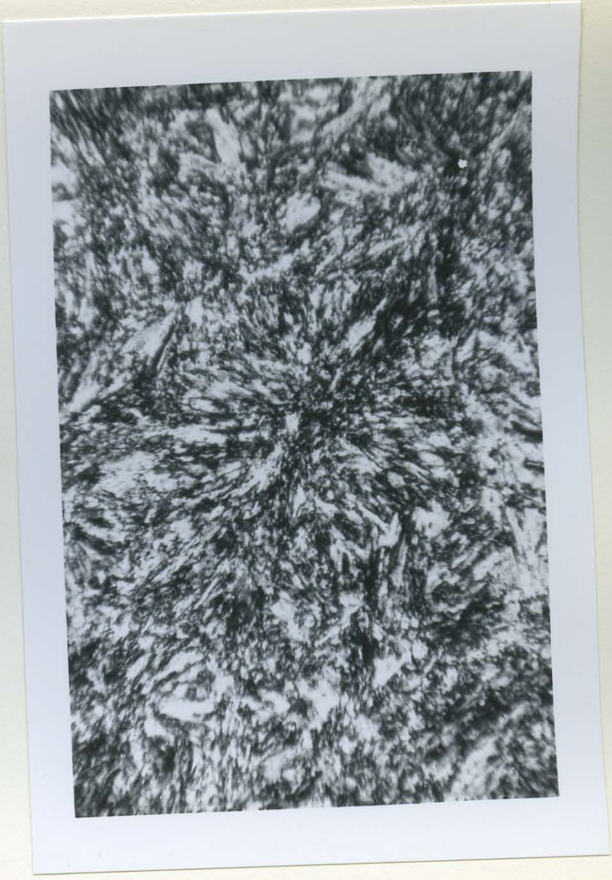

D

PLATE XV

ii) Large crystals of gypsum associated with anhydrite: Anhydrite in the south pit of the Elephant Hill quarry grades laterally to large gypsum crystals. The anhydrite is composed of spherulites (Plate XVI-A) of up to 2.5 millimetres radius. Similar spherulites occur as gypsum within large gypsum crystals and are interpreted as "ghosts" remaining after anhydrite replacement by gypsum (Plate XVI-B).

iii) Fine grained, white gypsum: The most abundant form of gypsum in the Elephant Hill consists of crystalloblastic grains of about .01 to 0.1 millimetre (Plate XVI-D). Coarse gypsum crystals occur embedded in a matrix of fine grained gypsum. These crystals are embayed and surrounded by finer grained gypsum. Plate XVI-C illustrates a coarse gypsum crystal, partially recrystallized to fine grained, fibrous gypsum. Recrystallization of coarse gypsum crystal to fine grained gypsum has occurred preferentially along the cleavage planes. Plate XVI-D shows the relic of a large, coarse gypsum crystal completely recrystallized to fine grained gypsum. It is inferred that the fine grained gypsum of the Elephant Hill is a product of recrystallization of coarse gypsum crystals leading to grain diminution.

Whippoorwill Quarry

Bluish-white, nodular anhydrite occurs in the Whippoorwill quarry (Plate XVII). The nodules vary from 10 to 40 centimetres in diameter and are concentrically layered. Typically, the outermost layer is composed of fine grained gypsum.

Plate XVI-A and B. Photomicrographs of anhydrite from the south pit of Elephant Hill.

A. Spherulitic anhydrite in contact with coarse, gypsum crystals (cg). Plane polarized (X 11.5).

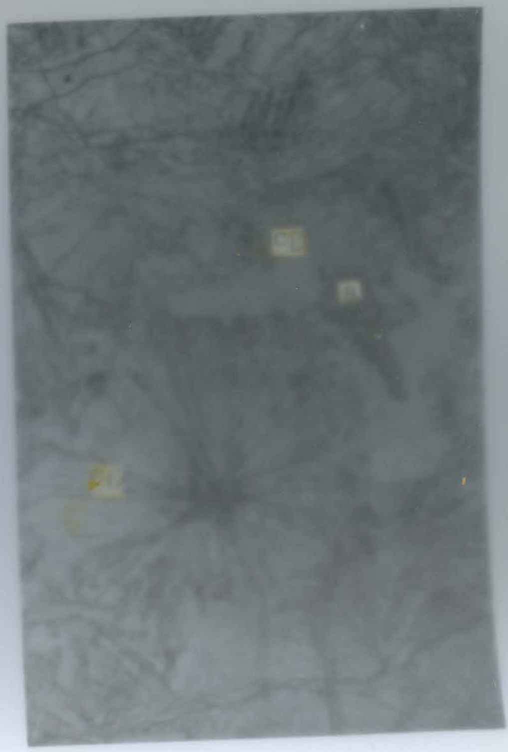
B. Coarse gypsum crystal (cg) with pseudomorphed spherulites of anhydrite. Plane polarized (X 11.5).

Plate XVI-C and D. Photomicrographs of fine grained, white gypsum in the southeast pit of Elephant Hill.

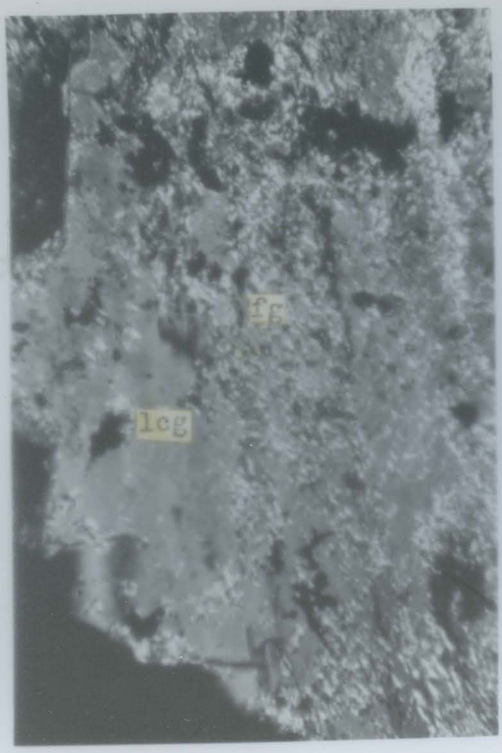
C. Remnant of large gypsum crystal (lcg). The crystal has been partially replaced by fine grained gypsum (fg). Crossed nicols (X 40).

D. Fine grained gypsum aggregates (fg). Note the relic of a large gypsum crystal (lcg) completely recrystallized to fine grained gypsum. Crossed nicols (X 40).

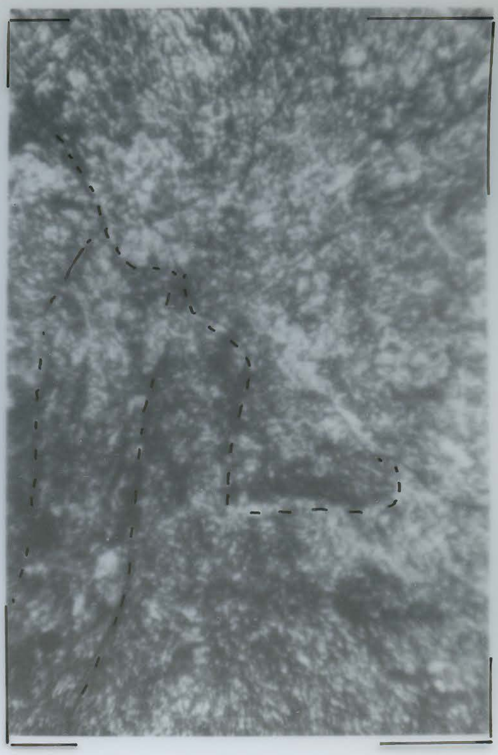
A



B



C

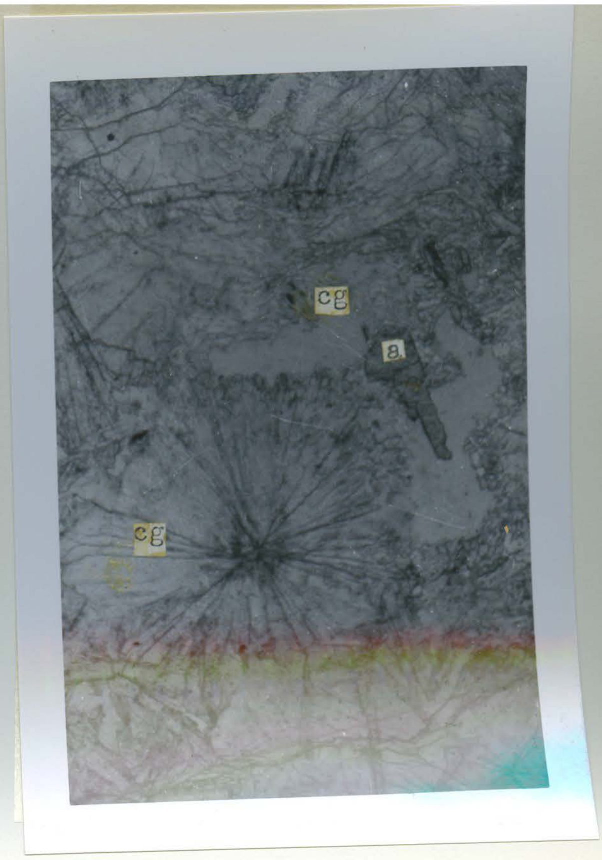


D

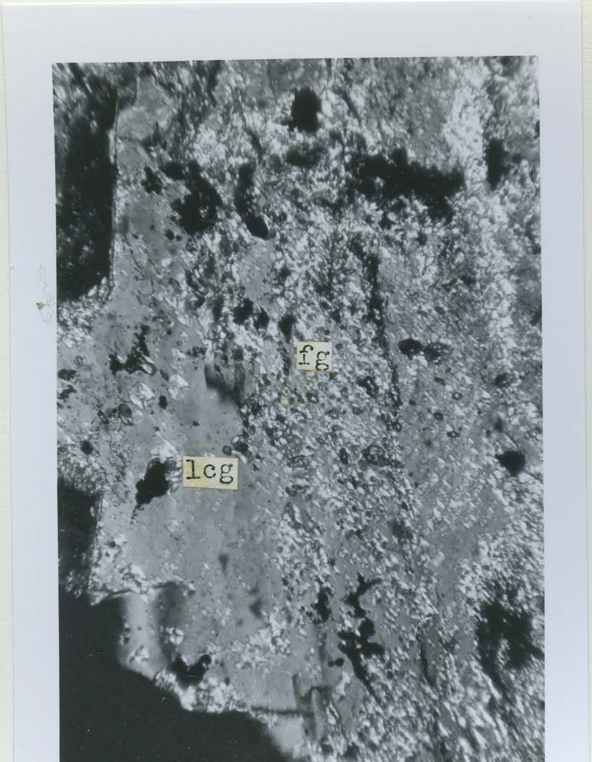
Plate XVI

PLATE XVI

A



B



C

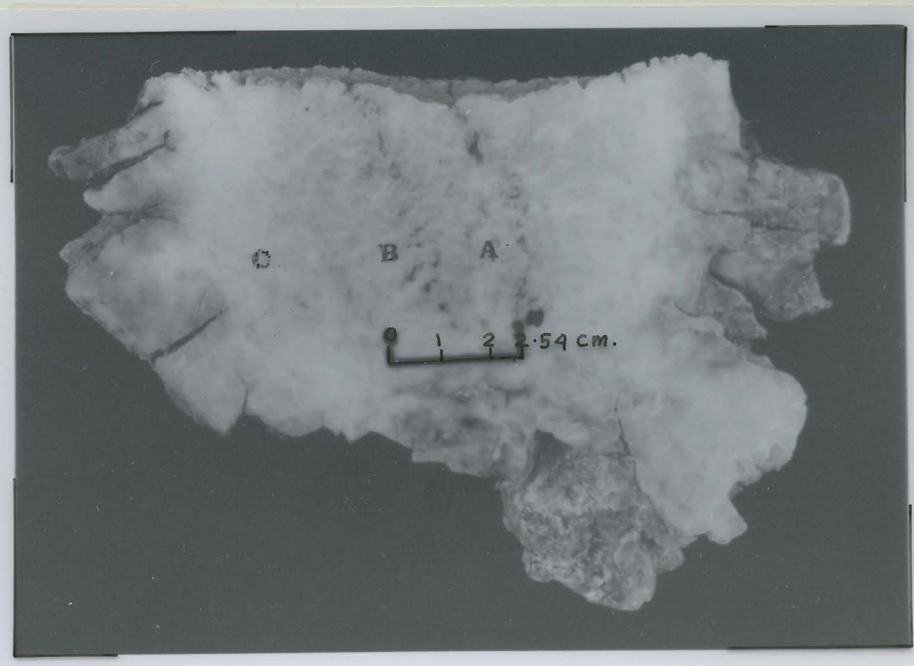
D

PLATE XVI

Plate XVII-A. Nodular anhydrite with an outer layer of white, fine grained gypsum at Whippoorwill Hill.

Plate XVII-B. Section cut through the nodule indicated in Plate XVII-A.

A

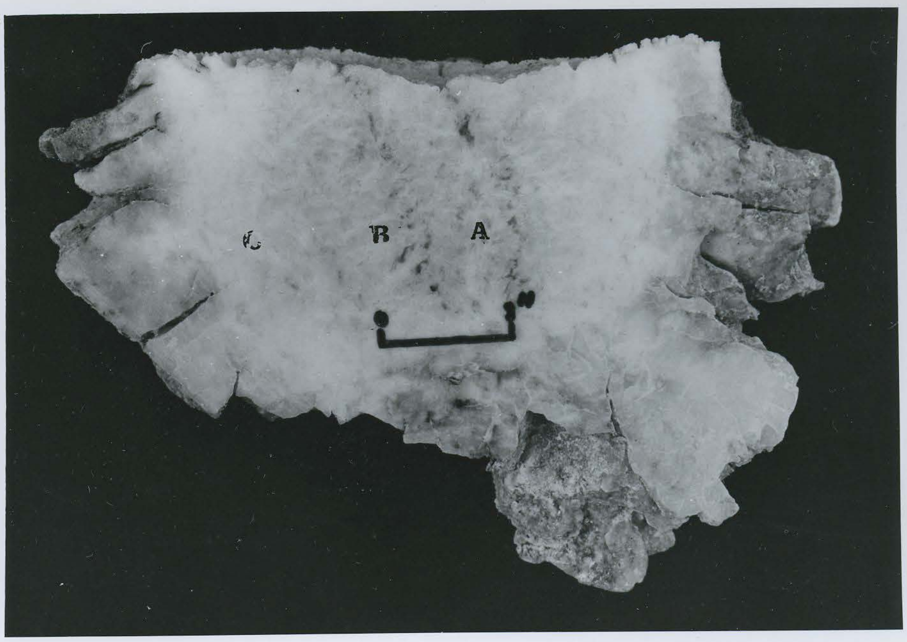


B

PLATE XVII

Plate XVII.

A



B

PLATE XVII

Several thin sections were made across a nodule. Region 'A' (Plate XVII-B), at the centre of the nodule, is composed of anhydrite with minor grey clay. The anhydrite grains are from .1 to .5 millimetre in size and occur as blades and felt-like masses having a spherulitic structure (Plate XVIII-A).

The region 'B' (Plate XVII-B) is characterized by aggregates of spherulitic anhydrite and associated fine grained gypsum. Fibres of anhydrite occur isolated in gypsum and gypsum occurs preferentially along anhydrite cleavage planes and grain boundaries (Plate XVIII-B).

A local concentration of clay occurs at the boundary between regions 'A' and 'B' (Plate XVII-B), but the boundary between 'B' and 'C' is gradational. Region 'C' is composed mainly of finely crystalline gypsum with relics of anhydrite grains (Plate XVIII-C). The radial spherulitic structure, characteristic of anhydrite, is found to be preserved in finely crystalline gypsum. The outermost part of the nodule is composed almost entirely of fine grained gypsum with only a few relics of anhydrite spherulites (Plate XVIII-D).

Interpretation

A variety of petrographic observations indicate that gypsum has replaced anhydrite. The evidence may be summarized: i) gypsum tends to enclose or surround anhydrite; ii) gypsum occurs preferentially along anhydrite cleavage planes and anhydrite grain boundaries; iii) fragments of anhydrite in optical, and therefore in lattice continuity, occur isolated in gypsum; iv) gypsum occurs as pseudomorphs after radially arranged aggregates of fibrous anhydrite,

Plate XVIII. Photomicrographs illustrating nodular anhydrite from Whippoorwill Hill.

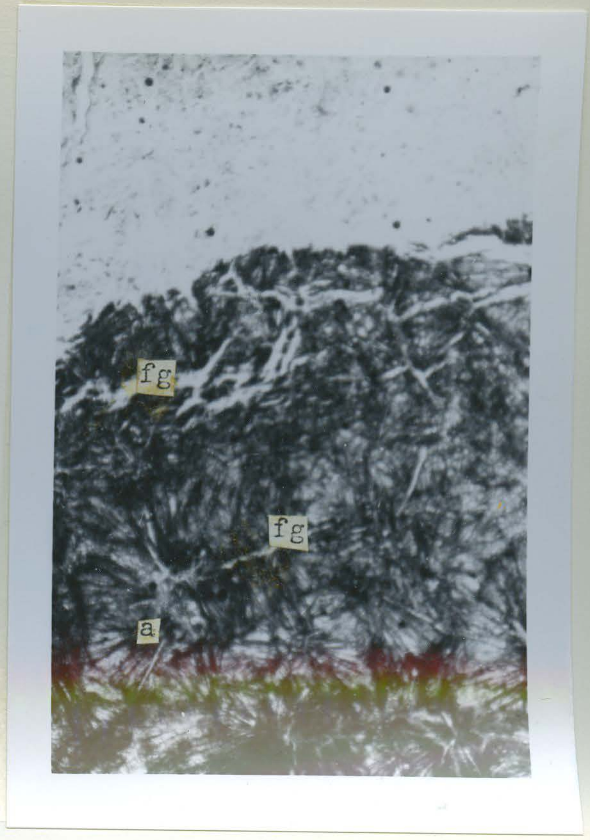
A. Anhydrite grains (a) occur as blades and felt like masses in region 'A' of Plate XVII-B. Plane polarized (X 11.5).

B. Elongate crystals of anhydrite (a) arranged in spherulitic aggregates with radial veins of fine grained gypsum (fg) in region 'B' of Plate XVII-B. Plane polarized (X 11.5).

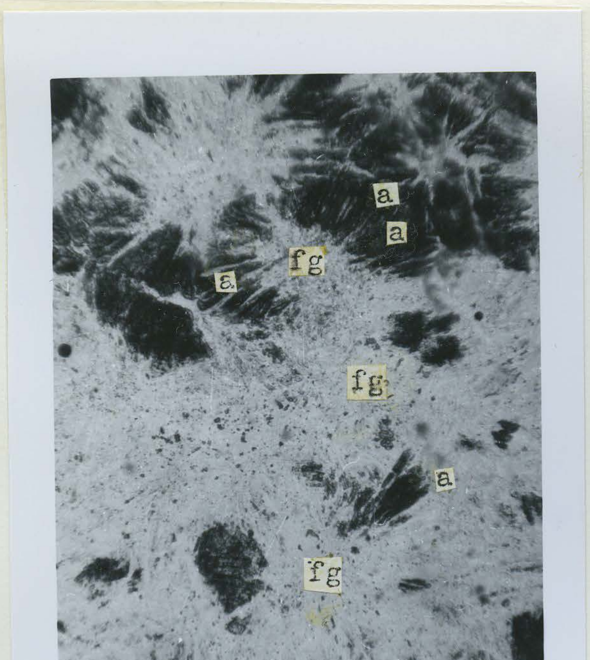
C. Relics of radial aggregates of anhydrite crystals (a) in a fine grained groundmass of fibrous gypsum (fg) (region 'C' of Plate XVII-A). Plane polarized (X 40).

D. From the outer part of an anhydrite nodule, an aggregate of fine grained fibrous gypsum (fg) with relics of anhydrite spherulites (dark). Crossed nicols (X 40).

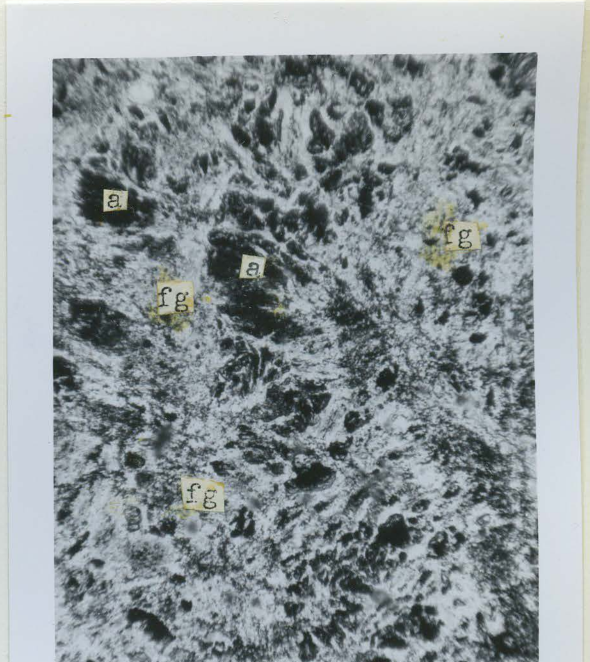
A



B



C



D

PLATE XVIII

referred to as spherulites.

Volume expansion: It has been inferred by many workers (Grabau, 1924, p. 758; Goldman, 1952, p. 10 and Pettijohn, 1959, p. 479) that the hydration of anhydrite to gypsum is molecule for molecule with an associated volume expansion. Complete hydration of anhydrite to gypsum would result in a volume expansion of 60.5 percent, assuming the initial and final porosity to be zero.

Petrographic evidence from the Gypsumville deposit suggests that no volume increase has accompanied the alteration of the anhydrite to gypsum. Where gypsum has partially replaced anhydrite laths the remnant portions of the laths have suffered no displacement relative to each other, a fact which is apparent from the perfect optic, and therefore, crystallographic alignment. This observation, made repeatedly in many samples, indicates that the anhydrite has been replaced but not displaced. Some displacement would be inevitable had volume expansion occurred.

The radial structure of the anhydrite crystal aggregates is completely preserved in gypsum pseudomorphs, without evidence of displacement or disruption. Again, this relationship was observed in many samples in various degrees of replacement. Such preservation of structure would not be possible had volume expansion occurred.

The conclusion is that the hydration of anhydrite occurred without volume change. Since the porosity of gypsum rocks and anhydrite rocks are approximately the same (see table below) this means that some calcium sulphate must have been leached during hydration.

Table of porosity data:

Sample no.	Location	Rock	Porosity in percent
WW1	Whippoorwill	Anhydrite (nodular)	3.34
WW2	Whippoorwill	Gypsum (outer margin of nodule)	2.86
NQ8	New Quarry, Gypsumville	Anhydrite	5.35
NQ33	New Quarry, Gypsumville	Anhydrite	5.00
NQ21	New Quarry, Gypsumville	Anhydrite	4.32
NQ20	New Quarry, Gypsumville	Gypsum	1.23
NQ22	New Quarry, Gypsumville	Gypsum	1.36
OQ8	Old Quarry, Gypsumville	Gypsum	1.26
NQ23	New Quarry, Gypsumville	Gypsum	1.06

Development of Gypsum crystals: The sequence of development of gypsum crystals during the hydration of anhydrite was complex and in other areas has formed the subject of varied interpretations by other workers (Goldman, 1952; 1957 and 1958 and Ognibin, 1957a and 1957b).

Goldman (1952, p. 11) claims that the initial stage of anhydrite-gypsum transformation is the formation of small randomly oriented gypsum crystals which, by a process of recrystallization gradually develop into a few larger crystals. Ognibin (1957, p. 68-73) maintains that the primary stage is the formation of large

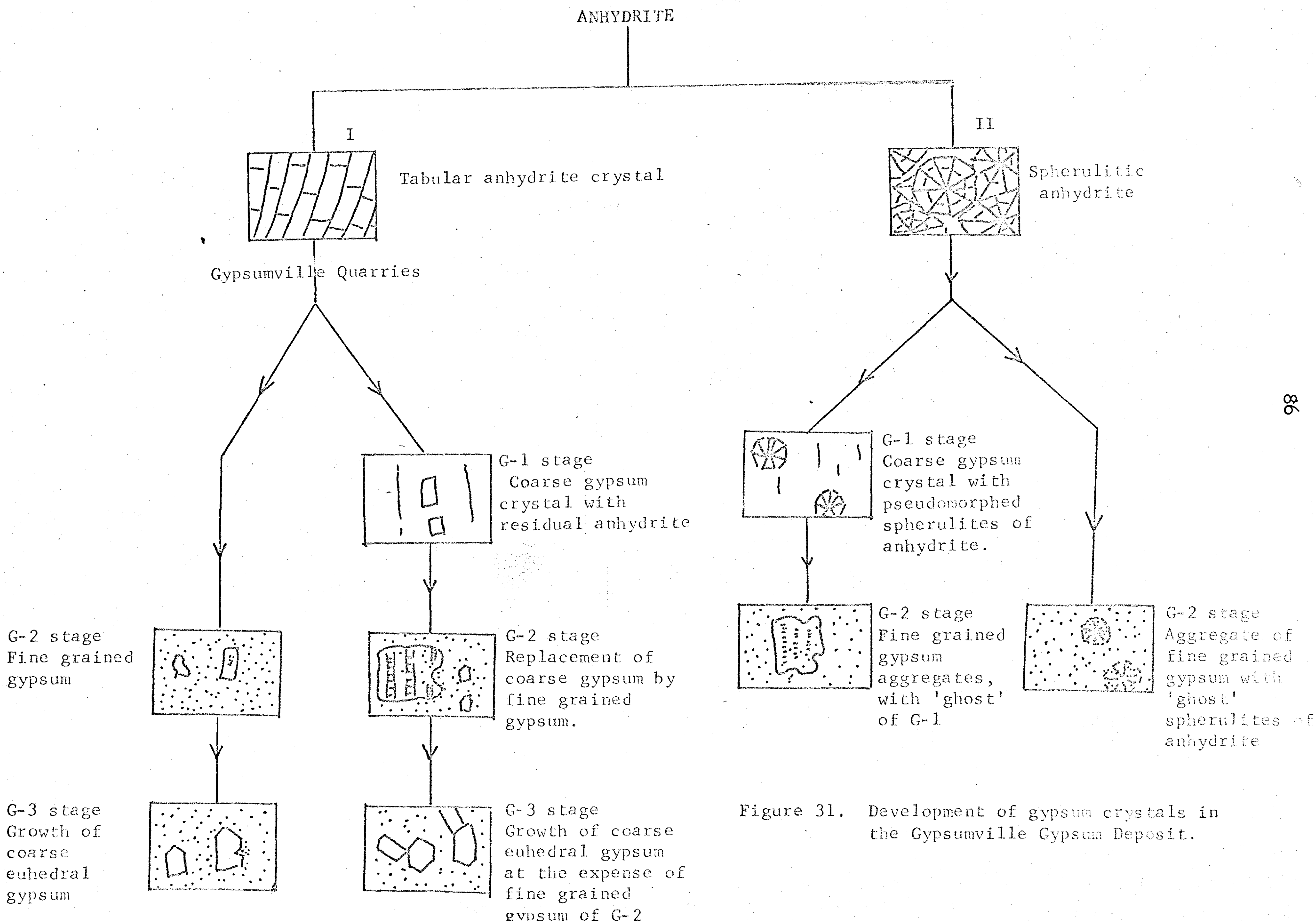


Figure 31. Development of gypsum crystals in the Gypsumville Gypsum Deposit.

"limpid selenite cores". These cores undergo volume expansion forming an inter-granular fine sized aggregates of gypsum.

The general sequence of gypsum crystal development, for the Gypsumville area, based on petrographic observation, is summarized in Figure 31 and has been interpreted as follows:

a) The growth of large, coarse gypsum crystals at the expense of the anhydrite (G-1 stage).

b) Recrystallization of coarse gypsum crystals and the formation of fine grained gypsum aggregates (G-2 stage).

c) Growth of euhedral or lath shaped, medium to coarse-textured gypsum crystals at the expense of fine grained gypsum (G-3 stage).

The most abundant form of gypsum, in the Gypsumville and Elephant Hill quarries, is a fine grained mosaic of anhedral grains. Locally the grains have been increased by grain growth to about 3 millimetres. Here designated as the second gypsum stage or G-2, this variety in many places a direct conversion from anhydrite (Plates IX, XV and XVIII). It most commonly occurs near or in contact with anhydrite rock, having by-passed the stage of locally formed early coarse gypsum crystals, here called G-1.

The G-1 stage is the earliest gypsum formed from anhydrite. Gypsum of this stage occurs as widely scattered crystals and as pockets and sheets through the fine grained gypsum and anhydrite. They are recognized by inclusions within them of numerous residual anhydrite grains (Plates XI and XII-A), which possibly were preserved because of rapid growth of gypsum crystals and subsequent isolation of anhydrite remnants from percolating water. As now seen, these coarse gypsum crystals are embayed, surrounded and obliterated by finer grained gypsum (Plates XII and XVI-C and D) and their present irregular outline and relic structures are the result of recrystallization to the surrounding fine grained gypsum.

There is also a younger growth of coarse gypsum crystals (Plate XII-A). These can be distinguished by their euhedral form and the absence of anhydrite inclusions. They are most conspicuous developed in the fine grained gypsum of G-2 (Plates IX-D and X). Such coarse gypsum crystals are assigned to stage G-3.

Summary

The gypsum of the Gypsumville outcrops formed by hydration of anhydrite. This does not imply that the anhydrite is a primary precipitate or deny the possibility of anhydrite having been derived from an earlier generation of gypsum. There is no evidence that a volume change resulted from the hydration of anhydrite to gypsum and the petrographic evidence indicates that gypsum has replaced anhydrite without change of volume.

SUMMARY

The Gypsumville gypsum deposit lies within the outcrop belt of the Silurian Interlake Group. Owing to the absence of visible contacts of gypsum with underlying or overlying rocks, the geological relationships of the deposit to associated sedimentary rocks are not certain. The age of the deposit had been a matter for speculation until the discovery, during present investigation, of fusuline foraminifera in shales underlying the gypsum. The fossil evidence indicates a Permian or younger age for the deposit.

The sulphate deposit in the Gypsumville and adjacent areas is approximately 130 feet thick and is underlain by a sequence of red and grey shales. At a depth of 40 or 50 feet, gypsum is underlain by anhydrite. The contact between gypsum and anhydrite commonly is sharp, but may be gradational over a few feet. Lenses of shale and dolomitic shale are interstratified with gypsum.

The deposit occurs as isolated, north-south and east-west trending ridges, immediately to the north and northeast of Gypsumville. Several of the ridges are anticlinal folds with intrastratal convolutions. In order to study their geometry and origin the orientations of about 200 folds were measured and plotted on Schmidt, lower hemisphere equal area nets.

Two groups of anticlinal folds are recognized: a well-developed set of N-S trending folds (set 1) and an older set of E-W to WNW-ESE trending folds (set 2). Both sets 1 and 2 consist of concentric to kink-style folds and range in size up to

$\frac{1}{4}$ mile in amplitude and a mile or more long; they differ only in orientation, set 1 trending N-S with nearly vertical axial planes and set 2 trending E-W, also with nearly vertical axial planes.

Several of the set 1 folds have minor set 2 folds developed on their limbs. A series of orientation diagrams for these folds indicate that large north-south trending set 1 folds are younger and superimposed on the smaller east-west trending set 2 folds.

The folds of the Gypsumville area could have been produced only by non-tectonic processes. Absence of evidence of post-Pre-Cambrian orogenic activity in this part of Manitoba rules out disastrophism as a cause of the formation of the folds. Expansion forces, due to the transformation of anhydrite to gypsum, have been discounted as a cause of folding on the grounds that: a) the style and geometry of the folds are markedly different from those cited for typical expansion folds; b) expansion theory can hardly explain superimposed folding in the area; and c) petrographic evidence indicates replacement of anhydrite by gypsum has been strictly volume for volume and not molecule for molecule. The folds may have formed as a result of glacial push and drag during Pleistocene time. Such an inference is based on: a) superficial nature of the folding in the area; and b) perpendicular orientation of two major inferred directions of ice-movement to the trends of the major fold axes of the area.

Small scale, complex and domal convolutions, which occur within beds, bear a strong resemblance to slump structures described in the literature. These intrastratal convolutions may have formed as a result of slumping which occurred not long after deposition.

Petrographic observations suggest that the gypsum of the outcrop has been derived from anhydrite by hydration. The evidence is that: a) gypsum tends to enclose or surround anhydrite; b) gypsum occurs preferentially along anhydrite grain-boundaries and cleavage planes; and c) gypsum occurs as pseudomorphs after spherulitic anhydrite. The microscopic evidence further shows that: a) there is no distortion of the replaced anhydrite crystals; and b) the spherulitic structure of the anhydrite crystal aggregates is undistorted in perfect gypsum pseudomorphs. The conclusion is that the hydration of anhydrite did not result in volume change and that the replacement was volume for volume.

Study of thin sections indicates that three growth stages are present in most beds at most localities: a) the growth of large, coarse gypsum crystals at the expense of the anhydrite (G-1 stage); b) recrystallization of coarse gypsum crystals and formation of fine grained gypsum aggregates (G-2 stage); and c) growth of euhedral or lath-shaped crystals at the expense of fine grained gypsum.

Although the present gypsum was derived from anhydrite, this does not imply that the anhydrite is a primary precipitate. It is still possible that the anhydrite was derived from an earlier generation of gypsum.

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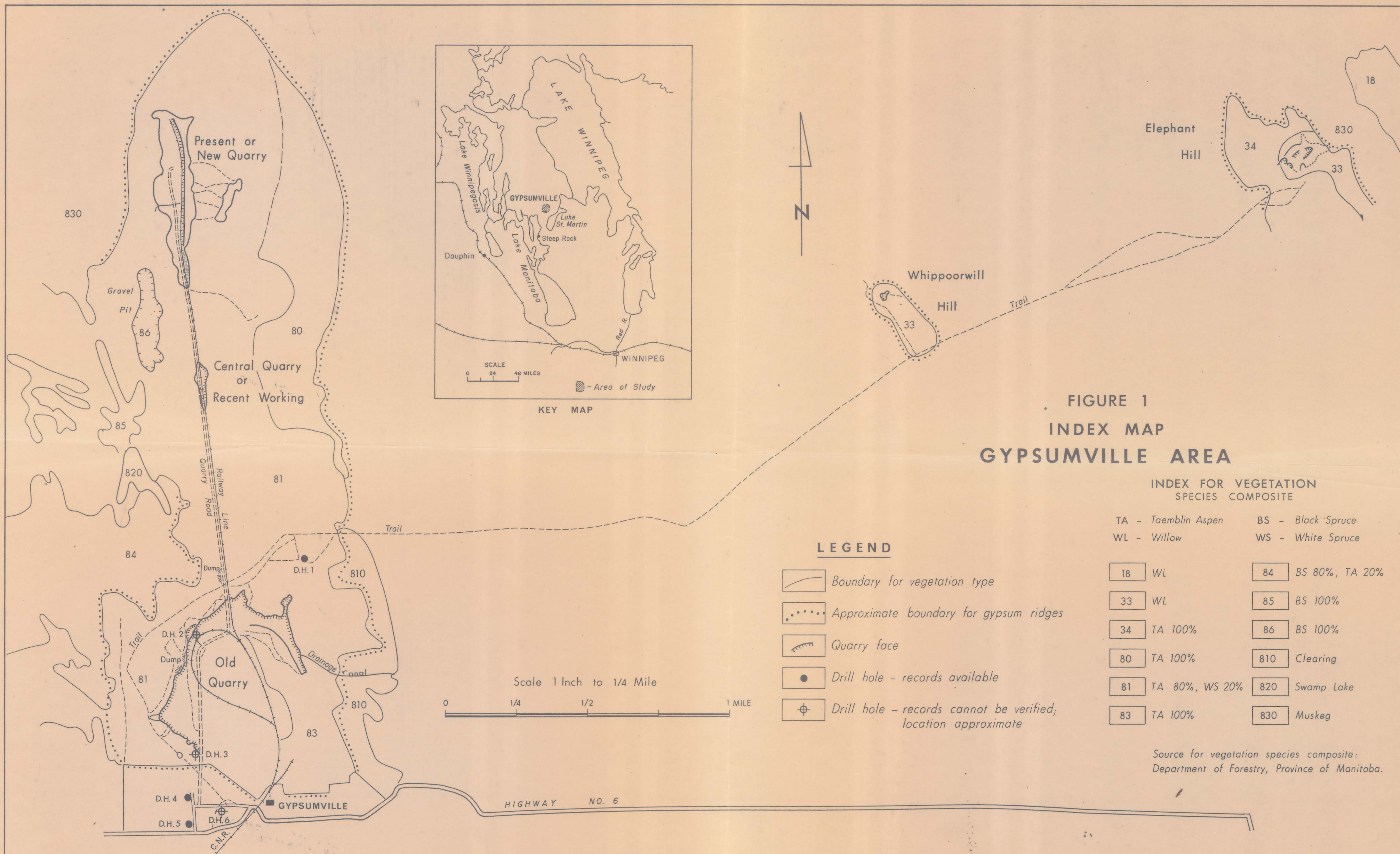

FIGURE 1
INDEX MAP
GYPSUMVILLE AREA

FIGURE 7
DISTRIBUTION OF FOLDED STRUCTURE
IN THE
GYPSUMVILLE QUARRY

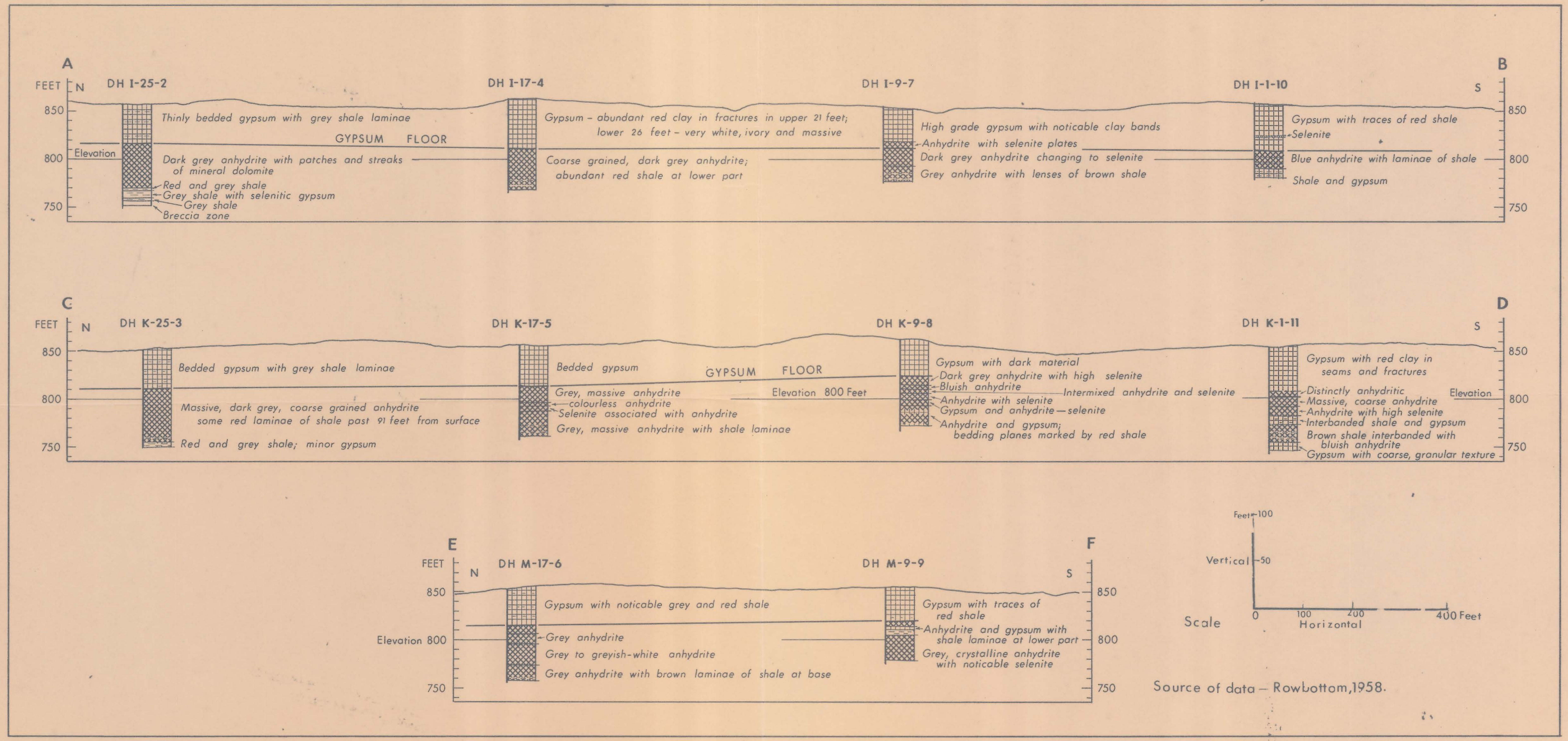

Figure 4 — Cross-sections constructed from drillhole data in the New Quarry (For location of drillholes see Figure 3)

Figure 14 — Diagramatic cross-section of the structure along the north-south running face of the New Quarry