

PETROGRAPHIC AND STRUCTURAL EVOLUTION OF GRANITES AND GNEISSES OF
THE GRENVILLE PROVINCE, GLAMORGAN AND MONMOUTH TOWNSHIPS, ONTARIO

by

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A thesis submitted to the School of Graduate Studies as
partial fulfillment for the M.Sc. degree in Geology.

April 1975

ABSTRACT

The map area lies approximately 200 miles west of Ottawa. The Glamorgan Hybrid Gneiss Complex of migmatitic rocks occupies approximately the northwestern half of the area. It is limited to the southeast by a metasedimentary belt comprising paragneiss, marble and quartzite of the Grenville Group. A narrow northeasterly trending zone of syenite and nepheline gneisses runs along the central part of the belt.

The migmatite complex is divided into two lithologic zones: a zone M_2 to the northwest and a zone M_1 to the southeast. The distinction between the two zones is based on the following petrographic criteria: 1) three types of granitoid and pegmatoid leucosomes are recognized in migmatites M_2 . Migmatites M_1 comprise only two types of leucosomes; 2) the gneissic melanosomes and paleosomes of the two migmatites can be separated on a mineralogical basis: by comparison with the melanosome of unit M_1 , quartz is more abundant in the melanosome of migmatites M_2 ; the percentage of microcline is fairly constant in the melanosome of migmatites M_2 , but varies much in that of migmatites M_1 ; calcite is often present in low amounts in the melanosome of migmatites M_1 , but is rarely found in the melanosome of migmatites M_2 ; 3) inclusions of metasedimentary rocks are scarce and hardly recognizable as such in unit M_2 but abundant and readily recognized in unit M_1 .

Inclusions of quartzite and paragneiss in migmatites M_1 trend northeast in the southeastern regions and become progressively northwest in the western and northern areas.

Five generations of pink granitic rocks have been recognized, most of them in concordant and slightly transgressive veins or as larger sill-like bodies

From cross-cutting and textural relationships, granitic rocks become younger to the east and southeast.

F₁, F₂ and F₃ folds are recognized on a small scale. D₁ structures are largely obscured by later deformations. Of the two major phases of deformation, the older D₂ created isoclinal folds with southeasterly dipping axial surfaces. In the migmatite complex and in the western part of the metasedimentary belt, the younger phase D₃ deformed F₂ folds about southeast plunging axes. Interference of D₂ and D₃ structures is common. To the southeast, beyond the belt of syenites and nepheline gneisses, cross-folding is not observed and deformation may merely be expressed as a crenulation or mineral lineation L₃.

The M₂-M₁ boundary is tentatively interpreted as a basement-cover contact transgressed by a migmatite front during the Grenvillian thermo-tectonic event. Thus the M₂ migmatitic gneisses are considered to stratigraphically underly the M₁ migmatites containing inclusions of recognizable metasedimentary rocks. The latter migmatites may represent the basal portion of the supracrustal rocks of the Grenville Group.

From the consideration of the relative mobility of migmatite components, it is concluded that both magmatism and anatexis have contributed towards the formation of migmatites.

ACKNOWLEDGMENTS

The author wishes to express his appreciation to Dr. A. J. Baer (supervisor) for his suggestion of the project and guidance during the research and the writing of the manuscript. Special thanks are given to the following persons: W. K. Fyson, R. Kretz and I. Ermanovics for valuable discussions of the problems and useful criticism of the manuscript; M. Lafontaine for his enthusiastic cooperation as field assistant; E. Hearn for helpful suggestions and criticism of the drawings; and Maryse Lapointe for careful typing of the manuscript.

The author is indebted to H el ene Francoeur, his wife, for her patience and support through the duration of the project and for invaluable help through her careful drawing of figures.

This study was made possible through the financial assistance of the National Research Council of Canada and the Faculty of Graduate Studies, University of Ottawa.

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INTRODUCTION

Location

The study area is located approximately 200 miles west of Ottawa and 35 miles west of Bancroft. The area includes 160 square miles in the Haliburton Highlands of the Grenville Province of Ontario, and covers parts of Glamorgan and Monmouth Townships (Fig. 1 and 2).

Topographic coverage at a scale 1 : 50,000 is provided by sheets 31 E/2 west, 31 E/1 east, and 31 D/16. Aerial photographic coverage is available from the National Air Photographic Library in Ottawa and from the Ontario Department of Lands and Forests.

Physiography, Access and Outcrop Exposures

The topography is that of a gently rolling relief rarely exceeding 300 feet. Percentage of outcrop exposures, ranging from 1 to 5 percent, increases slightly toward the northwest, across the map-area, as the cover of overburden becomes thinner. Roadcuts make up for the lack of good exposures. The shores of many lakes of the region are occupied by cottages so that numerous secondary gravel roads are maintained. However, several logging roads, used in the early 1900 and providing access to some parts of the two townships have become undrivable and are omitted from the map. The population is concentrated in the villages of Gooderham, Tory Hill and Wilberforce.

Previous work

Adams and Barlow (1910), in their classical memoir on the geology of the Haliburton and Bancroft area, recognized an " Older Granite Series " comprising large gneissic bodies occupying many square miles such as the Glamorgan Granite and the Cheddar Granite. They considered small discrete intrusions

LOCATION MAP

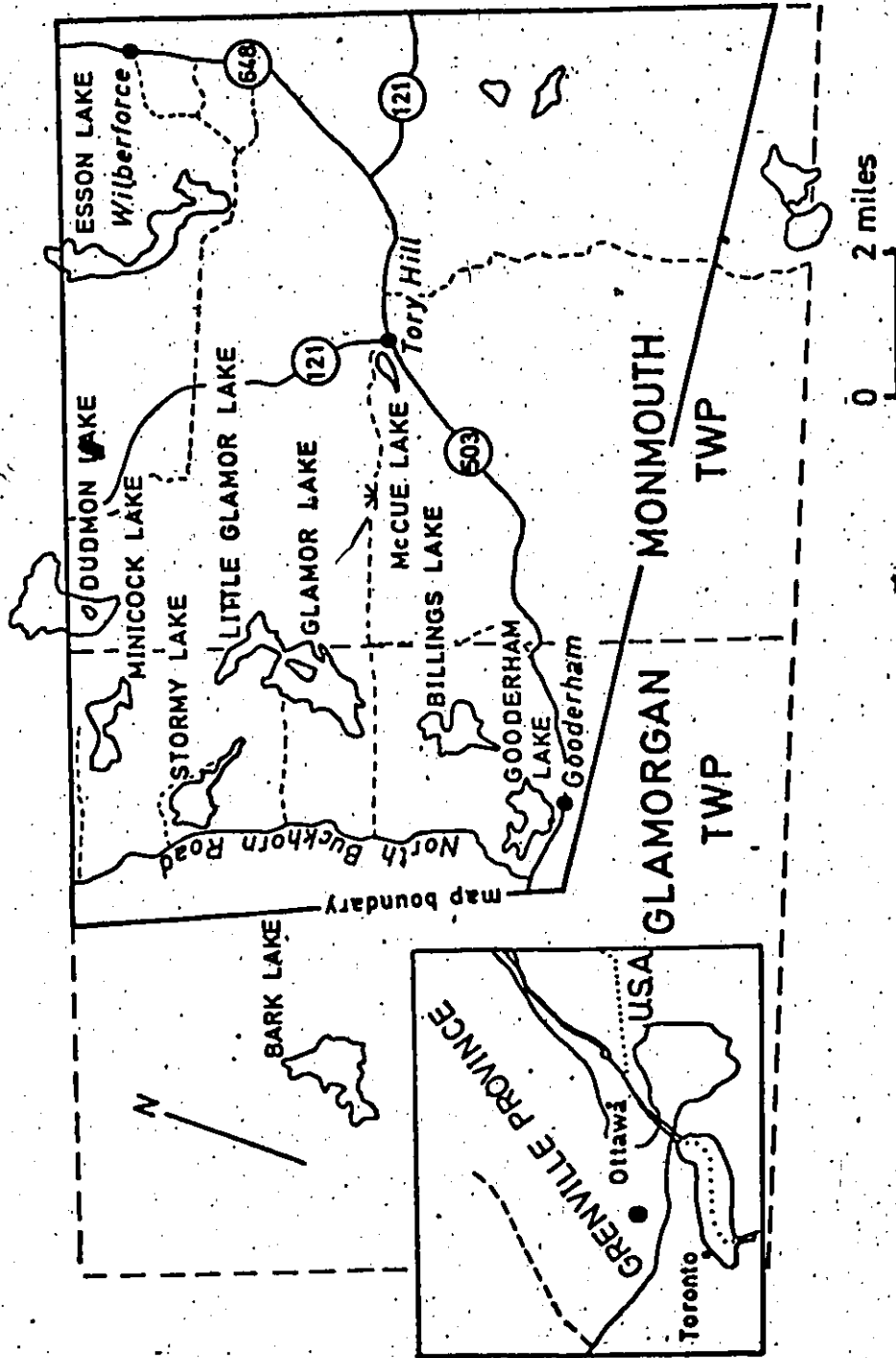


Fig. 1



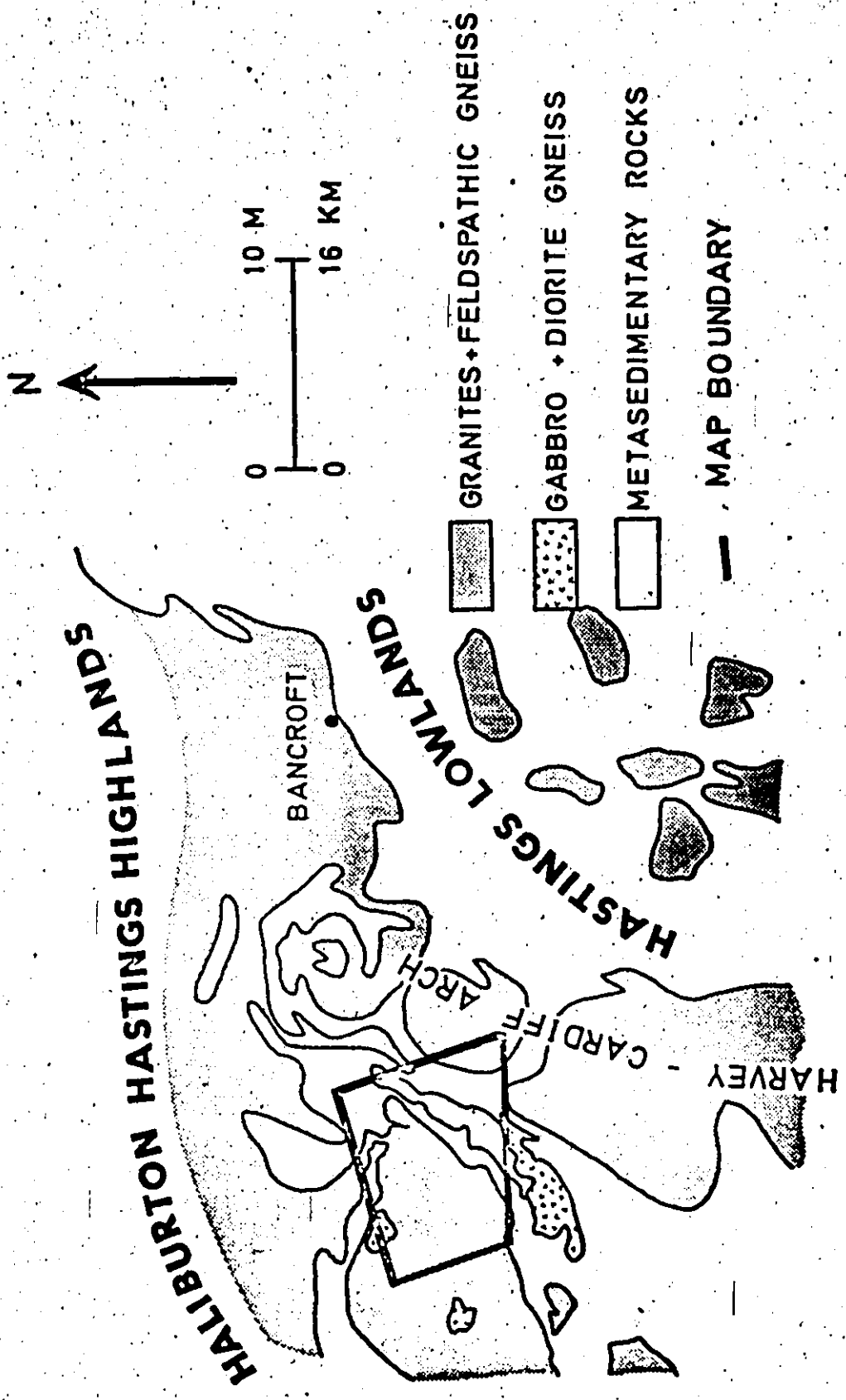


Fig. 2 Location map showing the geologic setting of the study area.

usually without much metasedimentary material and clearly discordant bodies with sharp contacts with the surrounding rocks to be the " Younger Granite Series ".

Their map was revised by Satterly (1943) in his review of mineral occurrences of the Haliburton County. In a similar report, Satterly (1956) compiled radioactive mineral occurrences in the Bancroft region.

Armstrong, in his regional mapping of Glamorgan and Monmouth Townships during the summers of 1955 and 1956, adopted the broad division of granitic rocks proposed by Adams and Barlow (1910). The report was written jointly with Gittins (1968) who directed his efforts into a study of the northeast trending belt of alkaline rocks, in central Monmouth Township, for which the area is well known. The report is accompanied by two geologic maps (maps nb: 2173 and 2174, scale: 1 inch = 0.5 mile).

Chesworth (1966, 1970a) subdivided the Glamorgan Gneiss Complex on the basis of petrographic observations and geochemical studies. He recognized an area of trondjhemitic granites, associated to the Bark Lake Diorite in Glamorgan Township, and surrounded by a zone of migmatitic gneisses with local occurrences of semi-conformable masses of younger pink granites. He suggested that the trondjhemites were the product of partial melting of paragneiss possibly under the influence of heat released by the Bark Lake Diorite. He proposed that the pink granite gneiss was derived from the same anatectic melt by differentiation. The area studied by Chesworth overlaps with the western part of the present study area.

A number of petrographic and petrological studies of the Glamorgan Gabbro Complex were carried out as Master's theses: Wenban-Smith (1967), Grieve (1967), Downing (1973). Recently, Richard, Grieve and Gittins (1975) published a paper dealing with the composition and formation of coronas in the Hadlington Gabbro, which is part of this Gabbroic Complex.

The major geological features of Monmouth and Glamorgan Townships are well visible on map nb: 1957b (Ont. Div. Mines) compiled by Hewitt (1957).

Present Investigation

Field work was performed in the autumn of 1972 and during the spring and summer of the same year.

Maps nb : 2173 and 2174 of the Ont. Div. of Mines were extremely useful prerequisites to the present study. Its purpose was to investigate the nature and possible origin of granites and gneisses of a part of the Haliburton Highlands and to collect structural measurements which could serve as premises to the geological interpretation of an area of such a complexity .

The main contribution of this study to the geology of Glamorgan and Monmouth Townships was to delineate zones of different tectonic complexity and to emphasize the lithological correlation or dissimilarities recognized between the different zones. A study of minor mesoscopic folds was indispensable for the understanding of regional structures. Many generations of granitic rocks were recognized; their internal fabrics, textures and deformation features are used to determine the relative periods that separated the metamorphic and deformational episodes.

Finally, conclusions reached in this study are correlated with results obtained from selected studies in adjacent parts of the Grenville Province.

In conclusion, a sequence for the evolution of the rocks in parts of the Haliburton Highlands, Ontario, is proposed.

PART A: ROCK UNITS

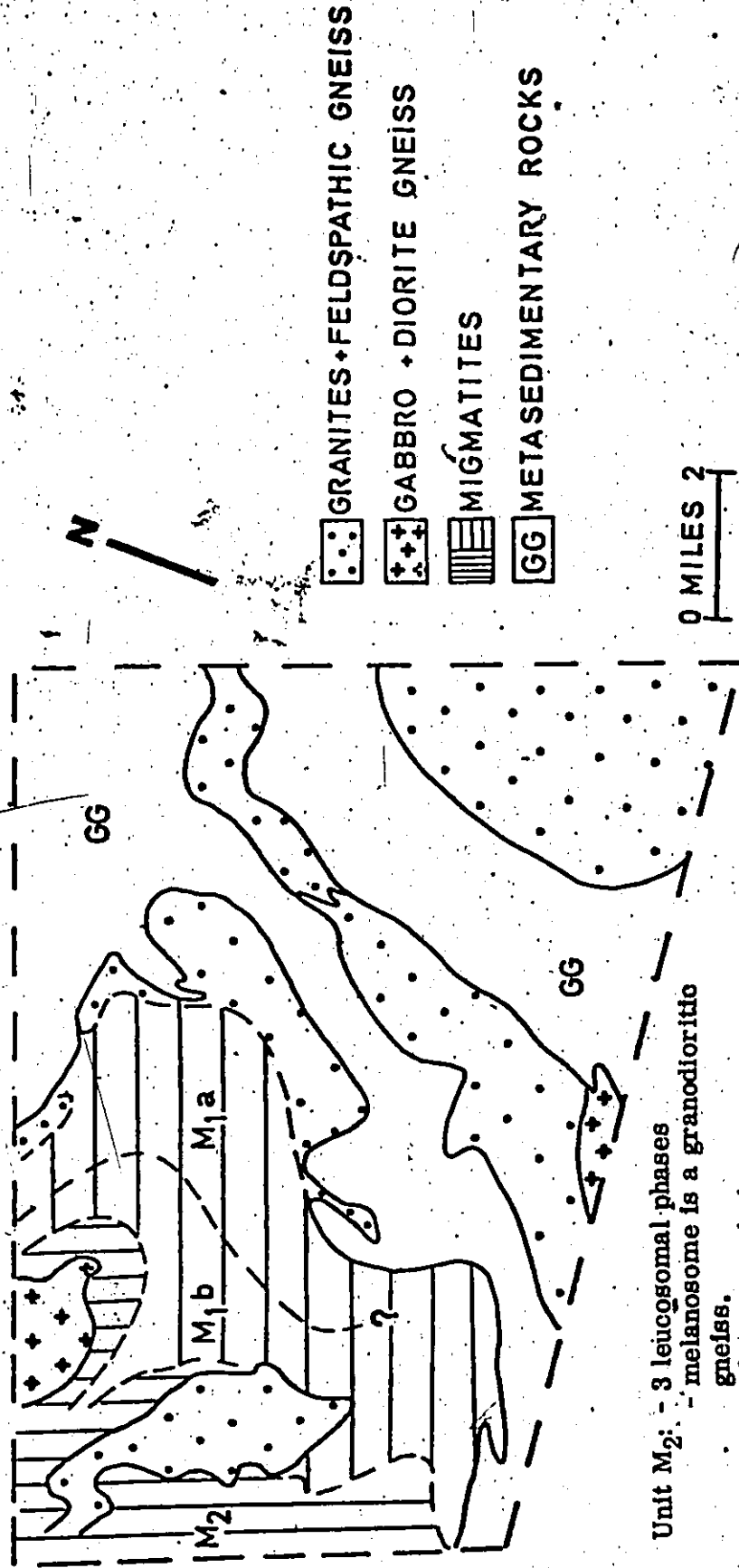
Introduction

The map area is divided into two main lithologic domains. A belt of metasedimentary rocks, 4 miles wide, crosses Monmouth Township diagonally, from southwest to northeast, and covers approximately the southeastern half of the map area. These rocks are correlated with rocks of the Grenville Group and are given the map symbol GG (Fig. 3). A narrow zone of leucosyenites and nepheline gneisses is confined to the central part of the belt. To the northwest of this first region, a complex of hybrid gneisses (Chesworth, 1970a) intimately mixed with material of pegmatitic, granitic and aplitic appearance is described, in this report, as a migmatite complex (map symbol M , Fig. 3). The migmatite complex is subdivided into 3 units (M_{1a} , M_{1b} , M_2) on the basis of the types of leucosomes and melanosomes of the migmatites, and according to the types of metasedimentary remnant blocks and their spatial distribution within the 3 units.

Intrusive igneous rocks are common in Glamorgan and Monmouth Townships. A northeast trending zone of pegmatitic granite, with abundant intercalations of quartzite and marble, is about half a mile wide and defines the eastern margin of the migmatite unit (Figure 4). A lens-shaped granitic mass, free of inclusions, and conformable with the regional foliation, crosses the boundary between unit M_2 and subunit M_{1b} of the migmatite complex. Part of a circular-shaped gneissic granite, the " Cheddar Granite ", lies in the southeastern corner of the map area. It is part of a series of 4 separate granitic bodies constituting the Harvey-Cardiff Arch trending in a northeasterly direction along the eastern margin of the Haliburton Highlands (Fig. 2). Late aplitic veins and granitic stocks, discordant with the surrounding rocks have been observed locally.

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GLAMORGAN AND MONMOUTH TOWNSHIPS



Unit M₂: - 3 leucosomal phases
 - melanosome is a granodioritic gneiss.

Unit M₁: - 2 leucosomal phases
 - melanosome is paragneissic

Fig. 3

GEOLOGY OF GLAMORGAN AND MONMOUTH TOWNSHIPS

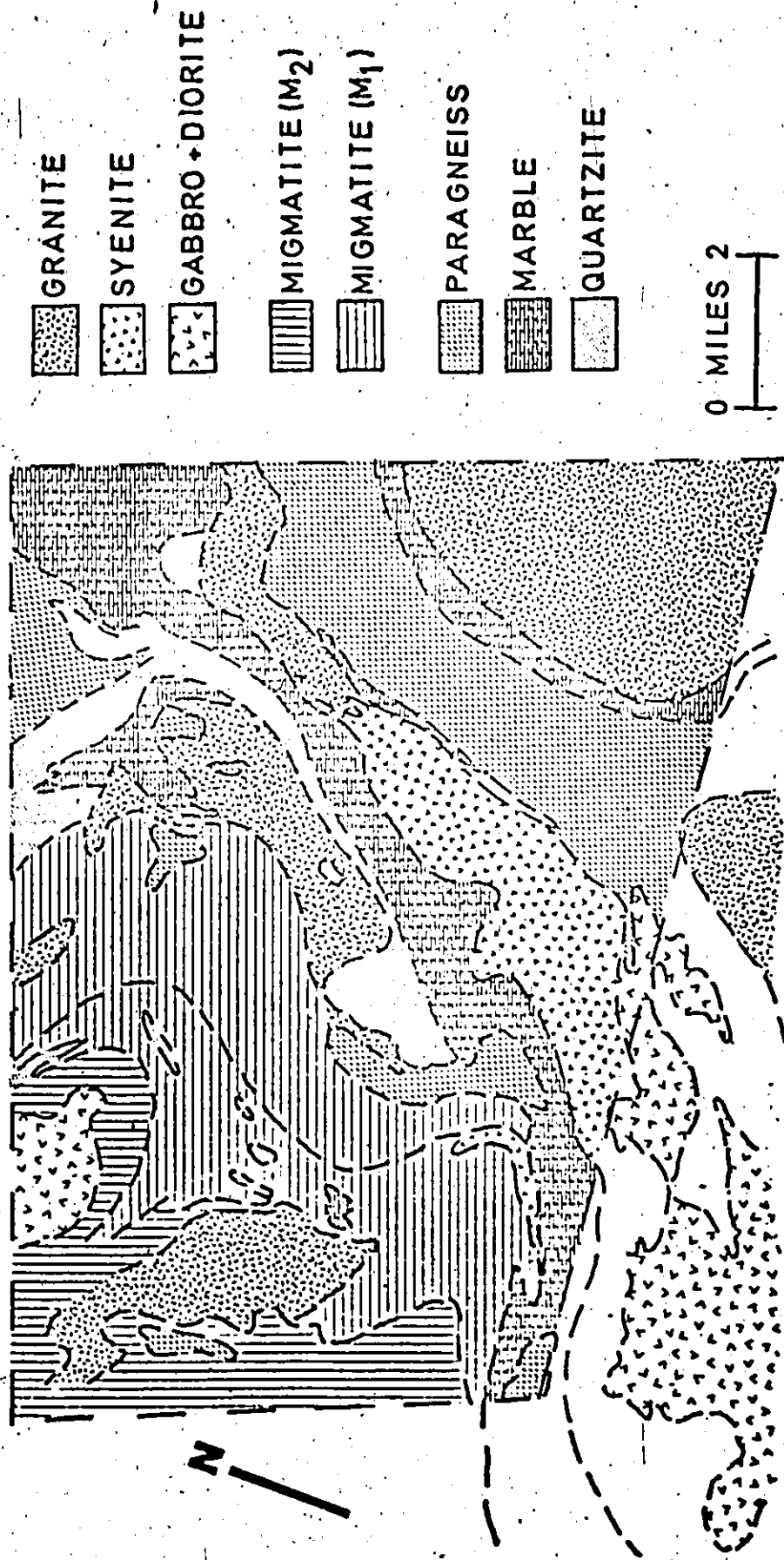


Fig. 4

TABLE I- TENTATIVE TABLE OF FORMATIONS

OF

GLAMORGAN AND MONMOUTH TOWNSHIPS

PRECAMBRIAN M ₂ - Metamorphism M ₁ Pre-Grenvil- lian metamorphism		Post-D ₃ : syenites and granites (Hadley type), aplite veins (type E granites).
		Late- D ₃ : granitic pegmatites (type D) (radio- active); metamorphic pyroxenites.
		Intrusive contact
	M ₂	D ₃
		Syn - D ₃ : pink granitic veins and dikes and larger granite bodies (Stormy Lake Granite) (type C).
		Intrusive contact
		Pre-D ₃ : diabase dikes and sills; granitic pegmatites (type B).
		Intrusive contact
		D ₂
		Late-D ₂ : nepheline syenite; nepheline gabbro; diorite; trondjhemite.
	Intrusive contact	
	Pre-D ₂ : granitic pegmatite (type A)	
	D ₁	
	Intrusive contact	
	Metasedimentary rocks of the Grenville Group: psammitic paragneiss, amphibolite, marble.	
	Disconformity ? marked now by the boundary between unit M ₂ and unit M ₁ .	
	Granodiorite gneiss of unit M ₂	

Mafic intrusives are common in the region. Diorite occurs in the northwest corner of the map area as an ovoid mass elongated in a southeasterly direction and conformable with the regional foliation. Sheet-like bodies of metagabbro occur just south of the map area within the belt of metasedimentary rocks. Small metadiabase dikes and sills occur throughout the area. They have been metamorphosed to amphibolites; but, chilled borders are recognized in some places.

I - Metasedimentary rocks of the Grenville Group (unit GG on map fig. 3)

Metasedimentary rocks of the Grenville Group vary greatly in composition from pure quartzite through quartz-plagioclase rocks containing biotite, pyroxene, and hornblende to calcareous amphibolites, marbles and calc-silicate rocks. All gradations are possible between these rock types.

Metasedimentary rocks of Glamorgan and Monmouth Townships were mapped in detail by Armstrong and Gittins (1968) from whose work part of the following is summarized. Petrographic observations relevant to the structural interpretation of the area are emphasized.

Quartzite (Map-unit Q, map in pocket).

Quartzite is a common rock type in Glamorgan and Monmouth Townships but uncommon in the surrounding townships. In Glamorgan Township it forms a belt, a quarter of a mile to half a mile wide, surrounding a granite mass immediately east of Salerno Lake. In Monmouth Township, it is part of the broad wedge of metasedimentary gneisses that can be followed diagonally toward the northeast corner. Thick quartzite sequences also outcrop on the shores of Glamor Lake and on the island in the northern part of the lake. Other minor occurrences can be observed adjacent to the diorite mass and north of Little

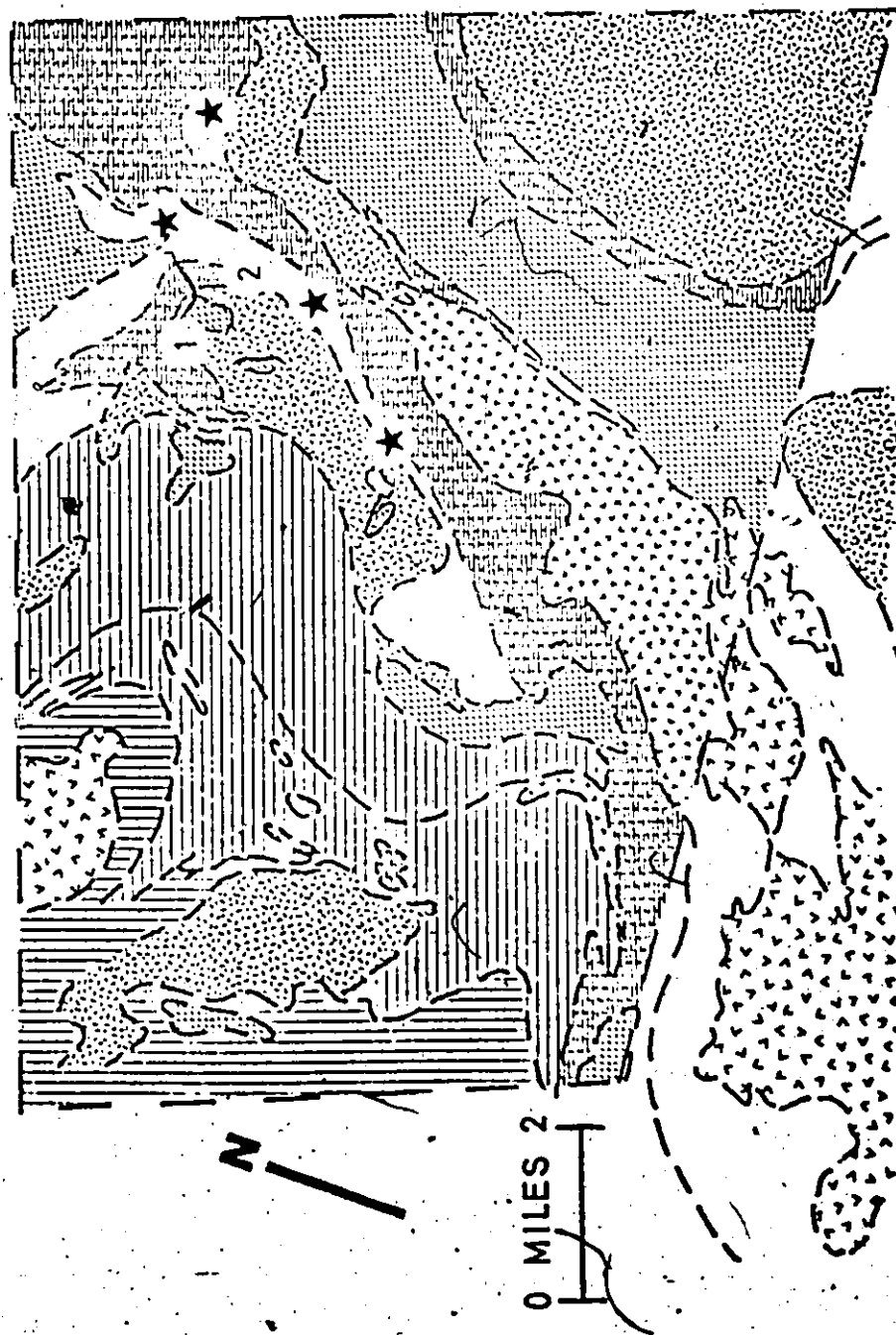
Glamor Lake. The belts of quartzite in Glamorgan and Monmouth Townships are not continuous with one another.

Quartzite generally forms beds 2 to 12 inches thick. Stratification is emphasized by variations in the grain size and variations in composition of alternating layers. Coarser grained layers are often characterized by exsolution cavities due to the dissolution of calcite. The rock generally contains various proportions of diopside, actinolite, and biotite. Diopside is the most abundant of these and may locally constitute up to 10 percent of the rock. Impure quartzite layers containing substantial amounts of feldspar are often associated with thin horizons of a rock composed almost entirely of feldspar plus a small amount of biotite. This rock is brown in color, granular, and weathers much more readily than the quartzite layers. The remarkably regular thickness and the continuity of these thin horizons, over the length of outcrop exposures, suggest that they may represent arkosic beds (Plate 1).

Flattening of the quartz grains along a plane parallel to the stratification is ubiquitous in quartzites of Monmouth and Glamorgan Townships. Narrow zones of finely laminated quartzites, with blastomylonitic textures suggestive of shearing, have been recognized at four localities within the quartzite belt, in Monmouth Township (Fig. 5), (Plate 2). The rock is finely laminated due to alternating layers of streaky quartz. A blue amphibole (glaucophane and /or riebeckite) constitute 2 to 5 percent of the rock and where present is always associated with these shear zones. Jointing is common in the quartzites. Three sets of vertical joints typically intersect the subhorizontal bedding surfaces (Plate 3).

GEOLOGY OF

GLAMORGAN AND MONMOUTH TOWNSHIPS



- GRANITE
- SYENITE
- GABBRO + DIORITE
- MIGMATITE (M₂)
- MIGMATITE (M₁)
- PARAGNEISS
- MARBLE
- QUARTZITE

- ★ MYLONITE ZONE IN QUARTZITE
- 1,2 INTERBANDING OF MARBLE AND QUARTZITE

(Fig 5)

Fig. 5 Location of mylonite zones in the belt of quartzite in Monmouth township.

Marble and calc-silicate rocks (Map unit 3)

All gradations can be found between white massive crystalline marble and calc-silicate rocks. These rocks range from massive to well foliated. The most common type is a medium to coarse-grained white marble with accessory graphite or phlogopite or both. Diopside-phlogopite marble and diopside marble are also common. The more silicated varieties contain a wide variety of ferromagnesian silicates together with apatite, quartz, feldspar and sphene. Chondrodite marble and coarse-grained tremolite marble are locally present. Scapolite was observed at one locality. Armstrong and Gittins (1968) also mention the occurrence of serpentine marble and forsterite-muscovite marble.

Calc-silicate rocks are often associated with some of the youngest pegmatitic bodies and seen to be the product of intensive metasomatism and marble recrystallization. Coarse calcite, salmon pink in colour, is common in pegmatitic granites and often fills fractures. Interbedding of marble and quartzite occurs on many scales. Alternating layers of quartzite and marble, each layer at least 50 feet thick, has been observed along the Sunset Cottage Road, 3/4 of a mile east of the junction with Highway 121 and approximately 1.5 miles west of Esson Lake (locality 1 on fig. 4). On the same road, further east and just west of the southern end of Esson Lake (locality 2 on fig. 4), in a zone of transition between quartzite and marble, the rock is a thinly banded quartz diopside gneiss.

Paragneiss-amphibolite group (Map unit 2)

Armstrong and Gittins (1968) have recognized is group of paragneiss-amphibolite. For convenience, the same classification is used here.

Compositions range from siliceous paragneisses containing quartz,

plagioclase, diopside, biotite or hornblende to calcareous gneisses richer in hornblende. These rock types grade into one another and are often interbedded suggesting that, despite their intense deformation, these rocks represent an original sequence of sandstone, siltstone, shale and limestones (Armstrong and Gittins, 1968). They form approximately 50 percent of the rock types in the metasedimentary belt, in Monmouth Township and are also distributed throughout the eastern part of the migmatite complex where they make up 30 to 40 percent of the lithology. Modal analysis of 2 samples (1108, a plagioclase-quartz-biotite-hornblende gneiss, and 1101-d, a scapolite-amphibolite) are given in table 5, p. 89.

II- Complex of migmatites (M)

Quartzo-feldspathic gneisses constitute the majority of rock types in the northwestern half of the map area. That area was first referred to as the " Glamorgan Granite " by Armstrong and Gittins (1968) and, later, as the " Glamorgan Hybrid Gneiss " by Chesworth (1966)*. This complex also includes the whole of Glamorgan Township and parts of Snowdon Township (i. e. approximately 250 square miles). These rocks vary somewhat in composition and texture and these variations are gradational. Granitic and pegmatitic material in veins generally concordant with the schistosity of the country rock contributed approximately 20 percent to the rocks in that area. Pegmatite bodies range from 2 to 10 feet in thickness but may reach 200 feet. This area is thus described as a complex of migmatites. The term migmatite is used in a purely descriptive sense (Menhert, 1968, p. 365 (see glossary)). For example, a migmatitic rock may have the following composition: 1) leucosome: (25-75%) pegmatitic granite; 2) melanosome: (25 - 75%) granodiorite gneiss, (5 - 25%) mafic schlierens.

* Armstrong mapped the area during the summers 1953 to 1955. The report written jointly with Gittins who later studied the belt of alkaline rocks of Monmouth Township, was not made available before 1968.

Isolated blocks of mappable size which have escaped significant migmatization are described as inclusions and may be called "resisters". Megascopic structures of migmatites are described and classified according to their competent and incompetent behavior following Sander (1948) and Mehnert (1968). This terminology is used irrespective of the number of rock forming stages. By means of the above nomenclature, the migmatite rock series may be described without genetic connotations.

Migmatites (Map-units M_1 (a, b))

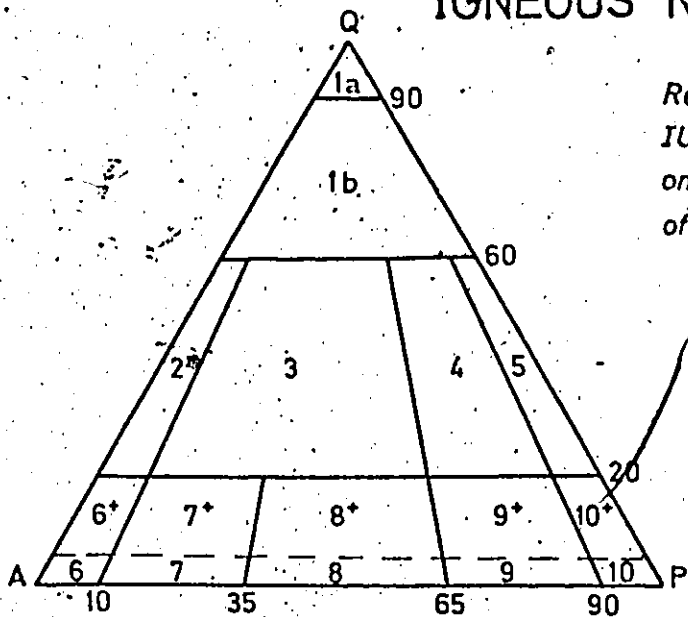
Lithologically, the area consists of psammitic gneisses and minor amphibolites mixed with material of pegmatitic, granitic and aplitic appearance. Remnant blocks or inclusions of marble and quartzite are widespread throughout the complex.

Leucosomes

Two distinct types (l_1 and l_2) of granitoid veins and dikes are represented in various proportions in portion M_1 of the migmatite complex. The classification of Granitic rocks is based on that given by the IUGS Subcommittee on the Systematics of Igneous Rocks (1972) (Fig. 6).

Type l_1 : the most abundant type is a reddish-pink granitic pegmatite occurring as veins or lenses conformable or oblique to the schistosity of gneisses. Edges of the veins are usually sharp. Larger sill-like bodies reaching 200 feet in width have been observed locally. The mineralogy of the rock is simple: plagioclase (36%), potassium feldspar (32-38%), and quartz (25-32%). Hornblende and biotite may be present in proportions of 0.5 to 2.0 percent. Percentages were obtained from modal analyses of two thin sections. Augen textures are common in these rocks where peripheral granulation of the feldspars has locally been

CLASSIFICATION AND NOMENCLATURE OF IGNEOUS ROCKS



*Recommended by the
IUGS Subcommittee
on the Systematics
of Igneous Rocks
(1972)*

MINERALS AND MINERAL GROUPS

- Q quartz
- A alkali feldspars (orthoclase, microcline, perthite, anorthoclase albite An₀₀₋₀₅)
- P plagioclase An₀₅₋₁₀₀, scapolite

$Q + A + P = 100$

Classification and nomenclature according to modal mineral content (measured in volume percent)

The section of the diagram including the feldspathoids has been omitted

- 1a Quartzolite (silicite)
- 1b Quartz-rich granitoids
- 2 Alkali-feldspar granite
- 3 Granite
- 4 Granodiorite
- 5 Tonalite
- 6+ Alkali-feldspar quartz syenite
- 7+ Quartz syenite
- 8+ Quartz monzonite
- 9+ Quartz monzodiorite / Quartz monzogabbro
- 10+ Quartz diorite / Quartz gabbro / Quartz anorthosite
- 6 Alkali-feldspar syenite
- 7 Syenite
- 8 Monzonite
- 9 Monzodiorite / Monzogabbro.
- 10 Diorite / Gabbro / Anorthosite

Fig. 8

observed (Plate 4). The flattening and elongation of quartz grains impart both a foliation and a lineation to the rock. In some cases extreme deformation and/or recrystallization of the rock resulted in laminations of quartz and feldspar grains. Under the microscope, cataclasis is the most striking feature of these granitoid pegmatites. Strings of fragmented grains of plagioclase, microcline and quartz are distributed around the edge of larger, strongly fractured grains of feldspar porphyroblasts with corroded edges (Plates 4, 5). Microcline porphyroblasts exhibit various kinds of perthites. In some cases, oriented lines of flame perthites have followed one of the earlier microcline twin planes. In other grains the perthization is developed along cracks and has been structurally controlled. Graphic quartz in microcline is rare and appears to be later than the fragmentation of the rock.

Type 1₂: a second type of leucosome is a pink to reddish fine to medium-grained granitoid rock. It is composed of plagioclase (38%), quartz (36%), microcline (25%), and biotite (0.5 - 2.0%). Spene and magnetite may be present in trace amounts. The preferred orientation of biotite flakes defines a weak foliation in the rock. Quartz grains are often observed to be elongated (rod-shaped or in needles) but generally not flattened (Plates 6 and 7). Near the eastern margin of unit M₁ these veins rarely exceed one foot in width and are conformable with the schistosity in the gneisses or slightly oblique to it. To the northwest, this foliated leucogranite is more abundant and it forms larger sill-like bodies. This granite is particularly widespread in the area of transition between unit M₁ and unit M₂ of the migmatite complex where the edge of the veins is sometimes rimmed with narrow layers enriched in biotite and hornblende. Type 1₂ is readily distinguished from 1₁ by its much finer grain size and by its internal fabrics (rod-shaped quartz instead of leaf-shaped quartz grains). Coarser

phases of this granite are present in larger sill-like occurrences. These pegmatitic phases, however, unlike type l_1 granitic pegmatite, are intimately mixed with the medium-grained phases of type l_2 granite. Furthermore, mineral constituents of type l_2 granites were not affected by cataclastic deformation.

Melanosome

The psammitic to calcareous gneiss is a fine to medium-grained brownish rock with the following mineral assemblage: plagioclase (28-50%), quartz (13-34%), microcline (8-14%), biotite (12%), and/or hornblende (10-15%). Spene, magnetite and apatite are common accessory minerals. Garnet occurs locally. Biotite imparts a good fissility to the rock which is easily broken in slabs. Under the microscope, the rock is granoblastic. With increasing hornblende content the rock grades into a calcareous amphibolite containing calcic pyroxene and minor calcite with scapolite. Plagioclase is sometimes completely replaced by scapolite. These rocks find their petrological equivalents in rock types (2P) and (2A) of the metasedimentary belt to the east and constitute the melanosome of migmatites M_1 .

Inclusions.

Remnant blocks of quartzite and marble are widespread within unit M_1 of the migmatite complex. These isolated blocks have escaped intense migmatization and may be considered as resisters.

The distribution of these remnant blocks in zones trending northeast and turning progressively to the northwest in the western and northern areas of the migmatite complex is well visible on map in pocket . A lithological boundary further subdivides unit M_1 into 2 roughly northeast trending zones: the boundary

separates a zone M_{1b} to the west, and a zone M_{1a} to the east and is based on the spatial distribution and the types of inclusions found within unit M_1 . Remnant blocks of marble and of quartzo-feldspathic-biotite-hornblende gneisses are evenly distributed throughout the complex. However, quartzite is rare east of a line passing along the east shore of Glamor Lake while very abundant to the west of this line. Quartzite blocks reaching one mile in length are common within the Glamor Lake region.

Migmatites (Map unit M_2)

The transition from migmatites M_1 to migmatites M_2 to the northwest is gradational. The distinction between the two units is established by the following petrographic criteria: 1) three types of granitic and pegmatitic leucosomes (l_1' , l_2' and l_3') are recognized in unit M_2 whereas the migmatites to the east comprise only two types of leucosomes (l_1 , l_2); 2) the gneissic melanosomes of the two units can be separated on a mineralogical basis; 3) inclusions of metasedimentary rocks are scarce and hardly recognizable as such in unit M_2 but abundant and easily recognized in unit M_1 of the migmatite complex.

Leucosomes

Type l_1' and Type l_2' : a pegmatitic and a finer grained granitoid component similar in all aspects to leucosomes l_1 and l_2 described for unit M_1 are recognized in unit M_2 . The difference lies in the more intimate mixture of these migmatite mobilizates with the gneissic melanosome of unit M_2 in contrast with the more commonly discordant nature of the leucosomes in unit M_1 .

Type l_3' : in unit M_2 a third type of pegmatitic leucosome is recognized, and distinguished from the two types previously described by the following features.

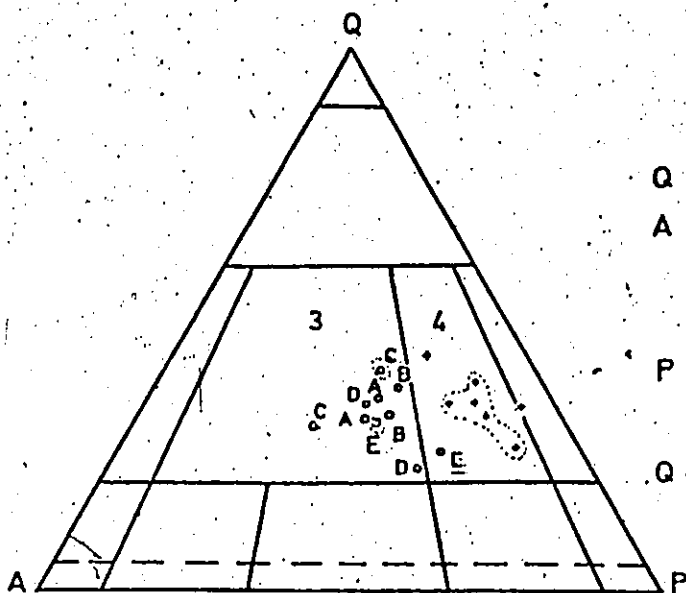
This granitoid pegmatite is pink on fresh surfaces and white to pink on weathered outcrops. It forms veins rarely exceeding one foot in width, concordant with the schistosity of the gneisses or slightly oblique to it. The veins are commonly observed to be isoclinally folded with the gneisses. The edge of the veins is sharp but irregular and usually rimmed with a thin film of biotite (.Plate 8). Boudinage is a common feature, usually not observed in the other migmatite mobilizates.

This deformation feature produces a characteristic pattern in the migmatites called pinch and swell structure by Ramberg (1955, 1956, p. 193-194) and also described by Menhert (1968, p. 22). Plate 9 illustrates a pinch and swell structure in the gneisses of Glamorgan Township. Under a microscope, the rock is similar to type l_1 granitic pegmatite. Cataclastic deformation of the mineral constituents and recrystallization of quartz grains into leaf-like grains are characteristic. K-feldspar blastesis is also characteristic of these two types of granitic pegmatites. Peripheral granulation of the feldspar indicates that cataclasis postdates the growth of the blastic feldspars.

Melanosome

In portion M_2 of the migmatite complex, the melanosome is a medium-grained quartzo-feldspathic gneiss. The grey to pale pink colour of the rock is distinctive. These gneisses are more homogeneous in composition and texture than the neighboring gneisses of unit M_1 ; in this respect, gneisses of unit M_2 bear similarities with rocks of plutonic habit. The mineralogy of the rocks is as follows: plagioclase (51%), quartz (31%), microcline (6%), biotite (9%), and hornblende (2%). Sphene, magnetite and apatite are common accessory minerals. The rock is thus granodioritic in composition (Fig. 7). The plagioclase is a sodic plagioclase with the average composition An_{25} (Chesworth, 1970a). By comparison with melanosome of unit M_1 , quartz is more abundant in the

Graphic plot of modal analyses of granodioritic gneisses and pink granitic rocks from Glamorgan and Monmouth Townships.



Q quartz
 A alkali feldspars (orthoclase, microcline, perthite, anorthoclase albite An₀₀₋₀₅)
 P plagioclase An₀₅₋₁₀₀, scapolite
 Q + A + P = 100

• grey gneisses of area M₂
 (A-E) • various types of pink granitoids (see text)
 ⊗ from Chesworth, 1966

3 granite
 4 granodiorite

According to modal mineral content (measured in volume percent)

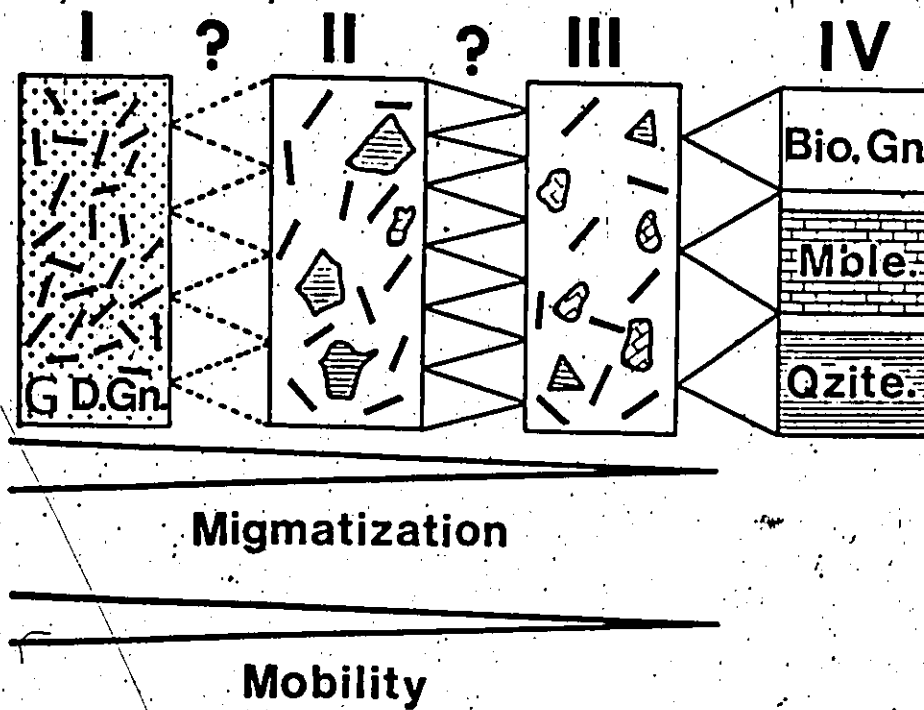
Fig. 7

melanosome of migmatites M_2 ; the percentage of microcline is fairly constant in the melanosome of migmatites M_2 , but varies much in the melanosome of migmatites M_1 ; calcite is often present in very low amounts in the melanosome of migmatites M_1 , but rarely found in the melanosome of migmatites M_2 . Chesworth (1966) in his study of the Glamorgan Gneiss pointed out the latter mineralogical difference. Using this information and taking the Bark Lake Diorite and associated trondhjemitic gneisses as a focal point, he drew a lithological boundary in the eastern part of his map area separating the migmatite area into an outer zone of migmatites where the non-granitic layers contain calcite, and into a central zone of migmatite, the non-granitic layers of which contain no calcite. This lithological boundary has been confirmed by the present study and is used to separate migmatites M_1 and M_2 in the southwest corner of the map area. To the northeast, it joins the $M_1 - M_2$ boundary as defined during the present study.

Inclusions

Mafic restites, composed primarily of hornblende and biotite, occur sporadically in the gneisses of unit M_2 . Where observed, the rock appears as light and dark streaks or more or less elongated shapes with tapering ends. (Plate 10). Such heterogeneities in the migmatites have been described by Mehnert (1968, p. 39) and called schlieren structures. Apart from these dark bands, inclusions are scarce in unit M_2 of the migmatite complex. Quartzite relics, a few inches to one or two feet in length and extremely deformed, were observed at three localities only along the Buckhorn Road, north of Stormy Lake.

Figure 8 is a schematic representation of the distribution of lithologies from northwest to southeast across the map-area.



- W Gradational contact
- Pink granitic material in veins and dikes.
- Remnant blocks of marble and quartzite.

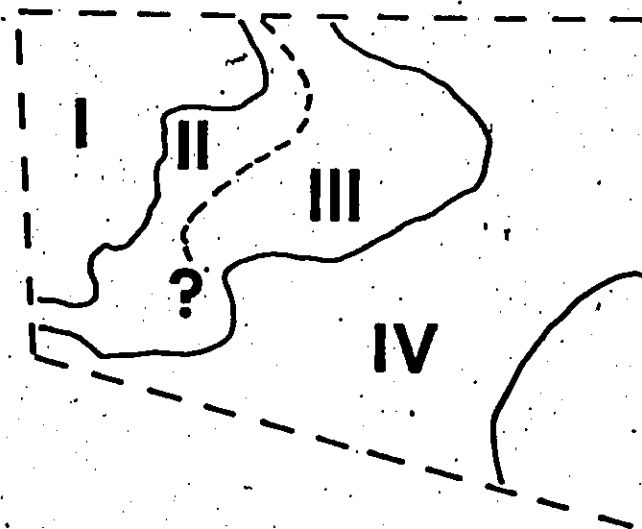


Fig. 8 Distribution of lithologies across the map area.

Areal variation in character of migmatites

Introduction

In the foregoing section, migmatite components have been investigated with respect to their mineralogical composition and texture. A comprehensive analysis of megascopic features of such complex migmatites often shows evidence of several rock-forming stages.

Complex interpenetration structures are observed in migmatites of Glamorgan and Monmouth Townships that can not be explained as a first approximation by a single act of formation. Megascopic structures of migmatites are described and classified according to their competent and incompetent behaviour following Sander (1948) and Mehnert (1968).

Megascopic structure of migmatites

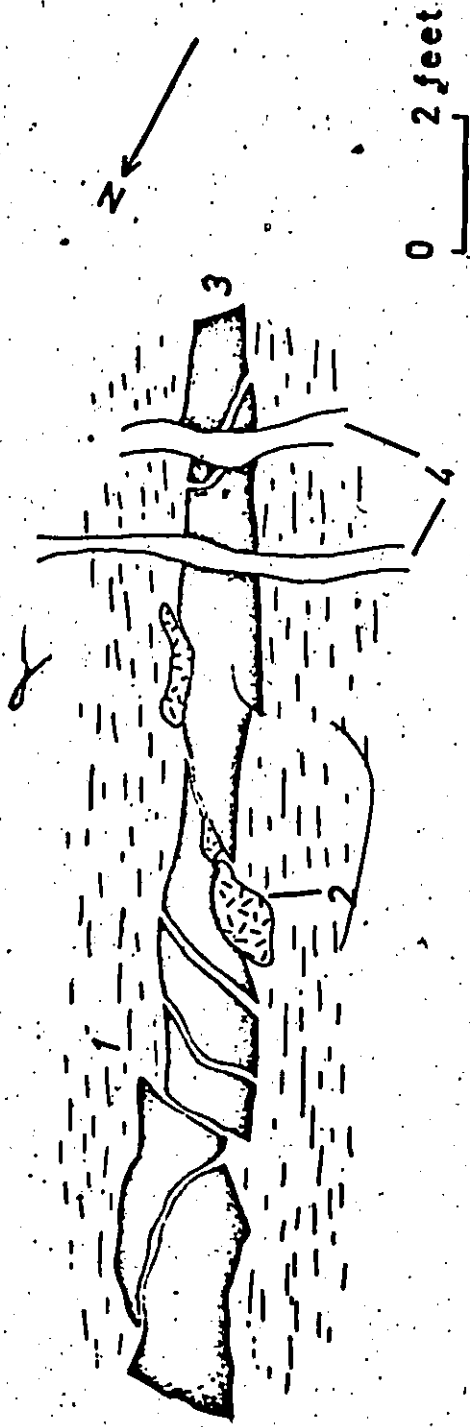
A gradational change in lithology is observed from the belt of metasedimentary rocks, to the southeast, to unit M_1 of the migmatite complex. Lithologies of the non-migmatized supracrustal tectonites can be followed without difficulty into the migmatized area. In this zone of transition, pegmatitic arterites surround angular blocks of quartzite and plagioclase-quartz-biotite gneisses. The structure of the migmatites is thus described as agmatitic. Even though the fragments of country rock are characterized by sharp and angular edges, they have hardly been displaced. The continuity of parallel alignment of planes of schistosity in the surrounding rocks is a noticeable feature suggesting emplacement of the pegmatitic mobilizates without deformation (Plate 22).

Proceeding toward the northwest from the eastern margin of unit M_1 , migmatites become layered or banded (Plate 23). The melanosome is a plagioclase-quartz-biotite-hornblende gneiss. Calcareous hornblende-diopside-

plagioclase and/or scapolite rich rocks become increasingly abundant, but marbles become scarce. Remnant blocks of quartzite are abundant in the Glamor Lake region where type l_1 and type l_2 pegmatitic leucosomes have been recognized. These migmatites have been termed stromatic migmatites as some layers may adopt pegmatoid or granitoid character. According to Mehnert (1968, p. 18) the term " stromatic " was first applied by Foye (1916, p. 791) in the form " stromatolithic " to banded rocks of the Haliburton District, so that this area is the type area for such migmatites. The two migmatite mobilizates are usually concordant with schistosity of the gneisses.

Still farther to the northwest, in the zone of transition between unit M_1 and unit M_2 of the migmatite complex, heterogeneities in the layered migmatites are even more strongly developed. Here migmatites consist of alternating layers of a grey granodioritic gneiss (type M_2 melanosome) with layers of pink foliated medium-grained granite (type l_2' leucosome), and with pegmatitic leucosomes of type l_3' and type l_1' . Here leucosomes are commonly rimmed along edges with thin zones enriched in hornblende and biotite. These components generally parallel gneissosity in migmatites. Thin aplitic veins cut the gneissic layering of migmatites at right angle (plate 24). Particularly good exposures of these polymigmatites can be observed on the northeast shore of Stormy Lake. Pinch and swell structures are characteristic of l_3' pegmatitic leucosomes (Plate 9). It can thus be inferred that these mobilizates behaved competently during deformation subsequent to their emplacement. Partial remobilization of these mobilizates is also suggested however: detached and rotated boudins of type l_3' mobilizates now appear to cut younger basic veins, 6 inches to 1 foot in width, fragmented into ladder structures in pink foliated granite (Fig. 9).

Field relationships between a metadiabase, a deformed granitic pegmatite vein and late aplite vein in quartzo-feldspathic gneiss.



Partly remobilized type A granitic pegmatite (2). It now appears to cut a younger metadiabase (3) emplaced concordantly in a pink to grey quartzo-feldspathic gneiss (1). Late aplite (4) veins penetrated the surrounding rock along fractures. This is evidenced by displacements along the edges of aplite veins of already fractured angular blocks of metadiabase (North shore of Stormy Lake)

Fig. 9

In unit M₂ of the migmatite complex, along the Buckhorn Road, the melanosome of migmatites is a medium-grained grey to pink granodiorite gneiss more homogeneous as a whole than gneisses of neighboring migmatites to the southeast. Locally, however, the highly contorted nature of these migmatites is shown by plastically deformed elongated mafic inclusions with tapering ends that define schlieren structures in the migmatites. It is generally considered that the mobility of migmatites with schlieren structures was higher than that of rocks with simple penetration structures, such as agmatites (Mehnert, 1968, p. 39).

The high mobility of migmatites M₂, is also suggested by the following petrographic observation: plate 19 illustrates a granitic pegmatite, (type l₃' mobilize), tightly folded with the grey gneisses. The pegmatitic vein is transverse, at low angle, to the gneissosity of the surrounding rock. Thus it is obvious that it intruded the country rock after the development of the rock gneissosity but before the end of deformation. The style of deformation of the pegmatitic vein, i. e., the fold shape, is exactly similar to that of the enclosing gneiss. Thus the two rock components behave similarly during deformation, i. e. their state of mobility was identical. The structure described above outlines an F₂ fold. As demonstrated on page , metamorphism reached its peak during D₂. This type of granitic pegmatite is commonly seen to be deformed into boudins. This deformation most likely occurred during a later deformation. Type l₁' and type l₂' leucosomes are relatively abundant in area M₂ of the migmatite complex.

III - Intrusive igneous rocks

Intrusive igneous rocks are common in Glamorgan and Monmouth Townships and comprise granitic, syenitic and mafic rocks, mainly gabbro and diorite.

Granitic rocks (Map unit 8)

The term granite is used here in accordance with the igneous rock nomenclature as established, in August 1972, by IUGS Subcommittee on the Systematics of Igneous Rocks. The main classification is shown in Fig. 6. The different types of pink granites discussed below are plotted on Fig. 7 according to their modal mineral content (measured in volume percent).

Very little attention has been given to these rocks in the previous geological surveys of the area. Adams and Barlow (1910) recognized granitic rocks of two distinct ages. They recognized an " Older Granite Series " comprising large gneissic bodies occupying many square miles such as the Glamorgan Granite, the Anstruther Granite and the Cheddar Granite. They considered small discrete intrusions usually without much metasedimentary material and clearly discordant bodies with sharp contacts against the surrounding rocks to be the " Younger Granite Series ". Armstrong and Gittins (1968) adopted this broad division of granitic rocks in their mapping of Glamorgan and Monmouth Townships. Chesworth (1968) in his remapping of Glamorgan Township subdivided the Glamorgan Granite Complex on the basis of field observations and geochemical studies. He recognized a series of trondjemitic granites (grey granite gneiss) and suggested that the granite was the product of partial melting of paragneisses possibly under the influence of heat released by the Bark Lake diorite intrusion. He proposed that the pink granite gneiss was derived from the same anatexic melt by differentiation.

The colour and textures of granites, their cross-cutting relationships, and the fact that not all granites were subjected to deformation make a better classification of the granites possible in Glamorgan and Monmouth Townships.

Petrography of granitic rocks

Introduction




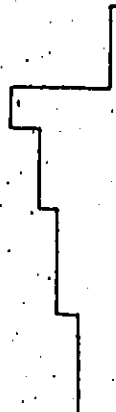
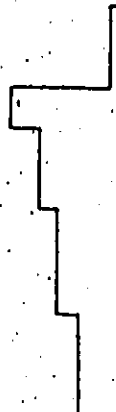
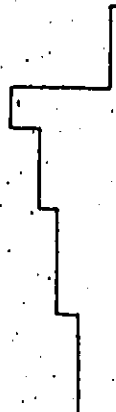









Five groups of granitic rocks can be distinguished on a textural basis (table 2). These granites occur in vein rarely exceeding 10 feet in width, concordant with schistosity of surrounding rocks or slightly oblique to it or as larger sill-like bodies (e. g. the Stormy Lake Granite).

Type A pegmatitic granite veins are only found within migmatites M₂. Type B granitic pegmatites and type C granites are by far the most abundant granites (table 2) and where they occur in vein or dikes, they constitute the leucosomal portions of migmatitic rocks. Type D and type E granites are scarce and mostly occur within rocks of the metasedimentary belt (unit GG on fig. 3).

Type A: previously described as leucosomes l₃' on p.

Type B: an area of pegmatitic granite, half a mile wide and elongated northeast defines the eastern margin of the Glamorgan Migmatitic Complex. This body is described, in this report, as a phacolith introduced into the surrounding rocks along the planes of bedding-schistosity. Intercalations of quartzite and marble are abundant throughout the mass. This zone of granitic pegmatite terminates at its northeast and southwest extremities where northeast trending foliations become progressively oriented in a northwesterly direction. At the northeastern end, an extension of the granitic pegmatite, nearly detached from the main body is parallel to the northwest trending schistosity of surrounding rocks (Fig. 4). Mineralogically and texturally, the rock is similar to type l₁ and

TABLE 2 : Pink granitic rocks of Glamorgan and Monmouth Townships.

TYPE OF GRANITE	MODE OF OCCURRENCES	C H A R A C T E R I S T I C S	DISTRIBUTION AND RELATIVE ABUNDANCE			
			AREA M ₂	AREA M _{1b}	AREA M _{1a}	AREA CG
A Granite pegmatite	<ul style="list-style-type: none"> - In veins, usually less than 10" in width. - The veins are concordant or transgressive, leucosome L₁. - Edges of the veins are irregular and rimmed with a thin film of biotite. 	<ul style="list-style-type: none"> - Colour: white on weathered surfaces. - Grain size: med. to coarse. - Massive-granular (a result of the fragmentation of the mineral constituents) to foliated (leaf-shaped quartz grains). - Microblastic feldspars with peripheral granulation. 	<ul style="list-style-type: none"> - Tight folding of the veins. - Swelling is a common feature. - Cataclastic deformation of the mineral constituents. 			
B Granite pegmatite	<ul style="list-style-type: none"> - 1) Large sill-like bodies (units of mappable size). - 2) In veins, concordant or transgressive (leucosomes L₁ and L₂). <p>Contacts with the country rock are usually sharp and regular.</p>	<ul style="list-style-type: none"> - Grain sizes: med. to coarse. - Flattening and elongation of quartz grains. - Augen textures: elongated microblastic feldspars with peripheral elongation. 	<ul style="list-style-type: none"> - Moderate folding of the smaller veins. - Cataclastic deformation of the mineral constituents. 			
C Granite	<ul style="list-style-type: none"> - 1) Large sill-like bodies (e.g. the Sorey Lake Granite). - 2) In veins concordant or transgressive (leucosomes L₂ and L₃). 	<ul style="list-style-type: none"> - Grain size: fine to medium-grained. - Weak foliation due to alignment of biotite grains. - Liticated: quartz grains are rod-shaped or in needles but not flattened. - Pegmatitic phases are associated to the larger sill-like occurrences (no sharp contacts between the two phases). 	<ul style="list-style-type: none"> - Occasional folding of sill-like bodies around NW trending, SE plunging axes. - Fracturing of the mineral constituents not accompanied by granulation. 			
D Granite pegmatite - Pegmatite - granite	<ul style="list-style-type: none"> - Irregular pockets or patches or discordant veins. - Associated to stann zones in the marble. 	<ul style="list-style-type: none"> - Grain size: med. to coarse. - Massive (interlocking grain boundaries) to weakly foliated (leaf-like quartz grains). - Graphic quartz is common. 	<ul style="list-style-type: none"> - Fracturing of the mineral constituents not accompanied by granulation. 			
E Granite - Aplite	<ul style="list-style-type: none"> - 1) Units of mappable size clearly discordant into the country rock (e.g. the Hadley Granite). - 2) Late cross-cutting Aplite veins. 	<ul style="list-style-type: none"> - Grain size: fine to medium-grained - Hypidiomorphic-equigranular features. - Very weak foliation due to alignment of rare biotite grains... 	<ul style="list-style-type: none"> - No mesoscopic deformation features. - Microscopic features: oscillatory zoning in quartz, fractured surfaces of feldspar grains. 			

l_1' pegmatitic veins found in abundance throughout the migmatite complex. Augen textures, flattening and elongation of quartz grains, and cataclastic deformation of mineral constituents are characteristic features.

Type C: a lens-shaped fine to medium grained foliated granite, conformable with the regional foliation, transects the lithological boundary between unit M_1 and unit M_2 of the migmatite complex (Fig. 8). This granite is free of foreign inclusions. Contacts with the surrounding rocks are commonly gradational, but sharp contacts have been observed locally (Plate 11). Modal analyses of this granite are given by Chesworth (1966). The rock is composed of plagioclase (30%, An_{10}), quartz (36%), microcline (21%), perthite (0-11%), and biotite (0.5-2.0%). The preferred orientation of biotite flakes defines a weak schistosity in the rock. Quartz grains are generally elongated (rod-shaped) but not flattened. This granite is thus similar in texture and composition to the numerous granitic veins of type l_2 and l_2' which played an important role in the migmatization of surrounding rocks.

Type D: this rock is a reddish leucocratic granitic pegmatite. Massive to weakly foliated, it is composed of microcline (39%), quartz (31%) and plagioclase (27%). This particular granitic pegmatite occurs as irregular pocket in metasedimentary rocks of Monmouth Township (Plate 12). It is commonly associated with skarn-zones in the marbles. The adjacent rocks generally contain a variety of silicate minerals often with crystal forms: hornblende, diopside, actinolite, apatite, sphene and scapolite. Interlocking grain boundaries and hypidiomorphic textures are common (Plate 13), but partial fragmentation of the mineral constituents and the development of leaf-shaped quartz grains has also been observed. Graphic textures are developed locally in some of these pegmatites and suggest that the rock crystallized from a eutectic melt. Where

graphic textures are present, plagioclase is less abundant and appears as fragmented grains included in larger perthitic microclines with graphic quartz, the latter mineral having crystallized in definite optical orientation (Plate 14).

These observations suggest that portions of these rocks were in a liquid state to the exception of plagioclase, the only mineral to have crystallized while different parts of these granitic bodies were being deformed mechanically.

Type E: emplacement of the granites of this category occurred late during metamorphism and deformation of rocks of Monmouth and Glamorgan Townships. They occur in two main forms: 1) as thin undeformed aplite veins cutting the gneisses and the previously described granites. The rock is a fine-grained pink granular and leucocratic aplite close to a cotectic granite in composition; i. e. plagioclase (37%, An₁₅), quartz (32%), microcline (23%), perthite (5%) (Chesworth, 1966). These veins are not common but have been observed along the Buckhorn Road (Plate 15). 2) Small rare granitic stocks (Hadley-type, highway 500, half-way between Tory Hill and Gooderham); clearly discordant with the surrounding rocks have been observed locally. The rock is fine to medium-grained and composed of plagioclase (50%), quartz (27%), microcline (20%) and biotite (1%). Because of the fine-grained nature of the rock and due to the lack of plagioclase grains with good albite twinning, the An content of the granite could not be determined. However, by comparison with other types of pink granitic gneisses, the percentage of anorthite should be < 10%. This granite, plotted as point (E) in figure 7, lies in the granodiorite range of the diagram. However, the presence of albite in the rock would shift the point toward the left, in the diagram, within the granite range. Magnetite and apatite are common accessory minerals. The orientation of the biotite flakes defines a weak schistosity in the rock, but hypidiomorphic-equigranular textures predominate (Plate 16).

Relative ages of granitic rocks.

Relative ages between the 5 groups of granitic rocks are determined on the basis of textures, cross-cutting relationships, and deformation features of the granites.

With the exception of late aplitic dikes and of a few small granitic stocks, (type E granites) the granites and granitic pegmatites are characterized by internal fabrics indicative of syn or pre-kinematic emplacement. Type A and type B granitic pegmatites have been subjected to cataclastic deformation and partial recrystallization. They are therefore considered to be prekinematic types. Type C granite, a fine to medium-grained lineated leucogranite but without evidence of cataclasis, would have been emplaced during the last phase of deformation in Glamorgan and Monmouth Townships. Type D granitic pegmatites are massive to weakly foliated suggesting emplacement late during the final stages of deformation in the area. Table 3 summarizes these conclusions.

TABLE 3.: RELATIVE AGES OF PINK GRANITIC ROCKS.

Relative ages	granites	relatively to the last deformation
young	Type E	late to post-kinematic
	Type D	late-kinematic
	Type C	syn-kinematic
old	Type B + A	pre-kinematic

The age relationships above are confirmed by cross-cutting relationships. Type E cuts type C, B and A; type C cuts types B and A; type B cuts type A. Type D granitic pegmatites are restricted in extent to zones of skarn in the marbles.

Cross-cutting of the other types of granites by type D has not been observed. Some of these cross-cutting relationships are illustrated on plates 17, 18, 19 and 20.

Three distinctive phases of deformation are recognized in the region. They are discussed in chapter III of Part B. F_1 , F_2 , and F_3 folds are recognized on a minor scale throughout the map area. The style of deformation of the various granites or the absence of deformation features allows determination of the time of emplacement of the granitic rocks relative to the three phases of folding. Type A granitic pegmatites cut S_1 schistositys but are folded by F_2 (plate 19). Assuming that S_1 schistositys were developed during a first phase of folding, then type A granitic pegmatites were emplaced between the two periods of folding. Type B granitic pegmatites are folded by F_3 folds but post date the development of F_2 folds in the majority of cases. Consequently, their emplacement may overlap with deformation D_2 but preceded deformation D_3 . Type C granites are locally folded with F_3 folds, locally axial planar to these folds. (Plates 20, and 21). Type C granites are therefore considered to be contemporaneous with the third and last phase of deformation in Glamorgan and Monmouth Townships. Type D granitic pegmatites are not seen to be folded with the country rock but, as already mentioned, internal fabrics are indicative of late-kinematic emplacement. Type E granites are undeformed. Fig. 10 shows the distribution of the five generations of pink granitic rocks found throughout the map area and their relation to the three phases of deformation. Considering that type E granites are relatively rare, it becomes evident that granites become younger toward the east and southeast. Type B and type C granitic pegmatite and granite are by far the most abundant generations of granitic material in the region. These granites constitute the leucosomal portions of migmatites and from this it can be deduced that the main act of migmatization in part preceded and in part was contemporaneous with

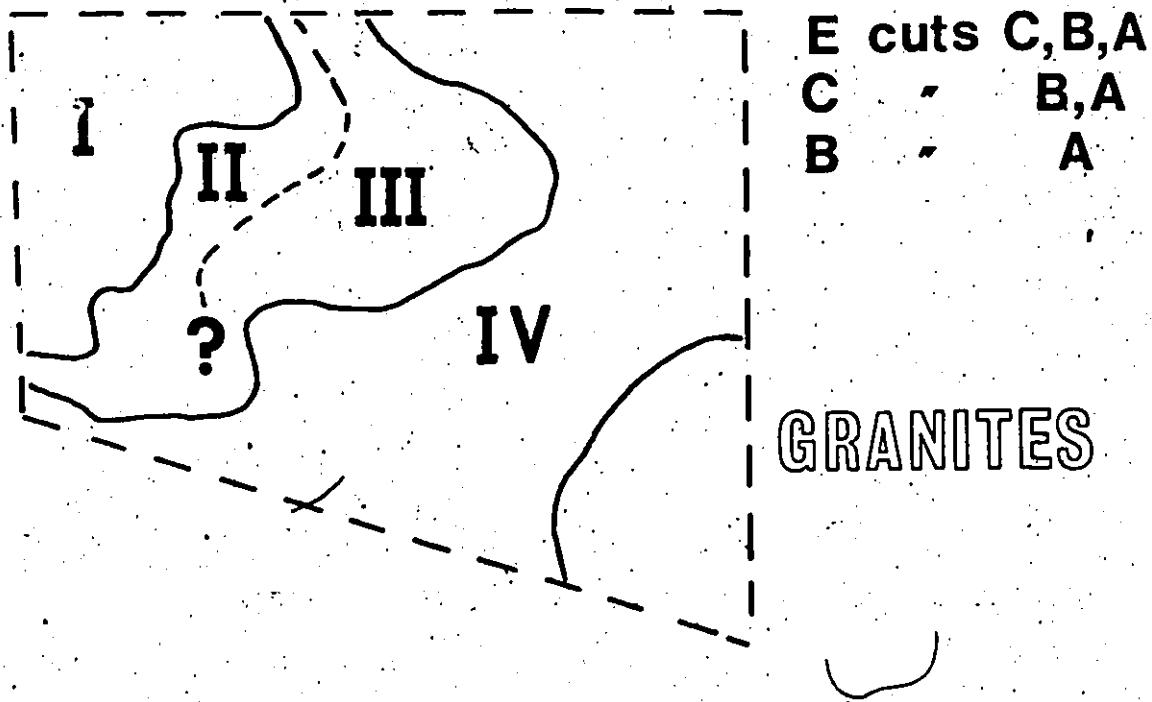
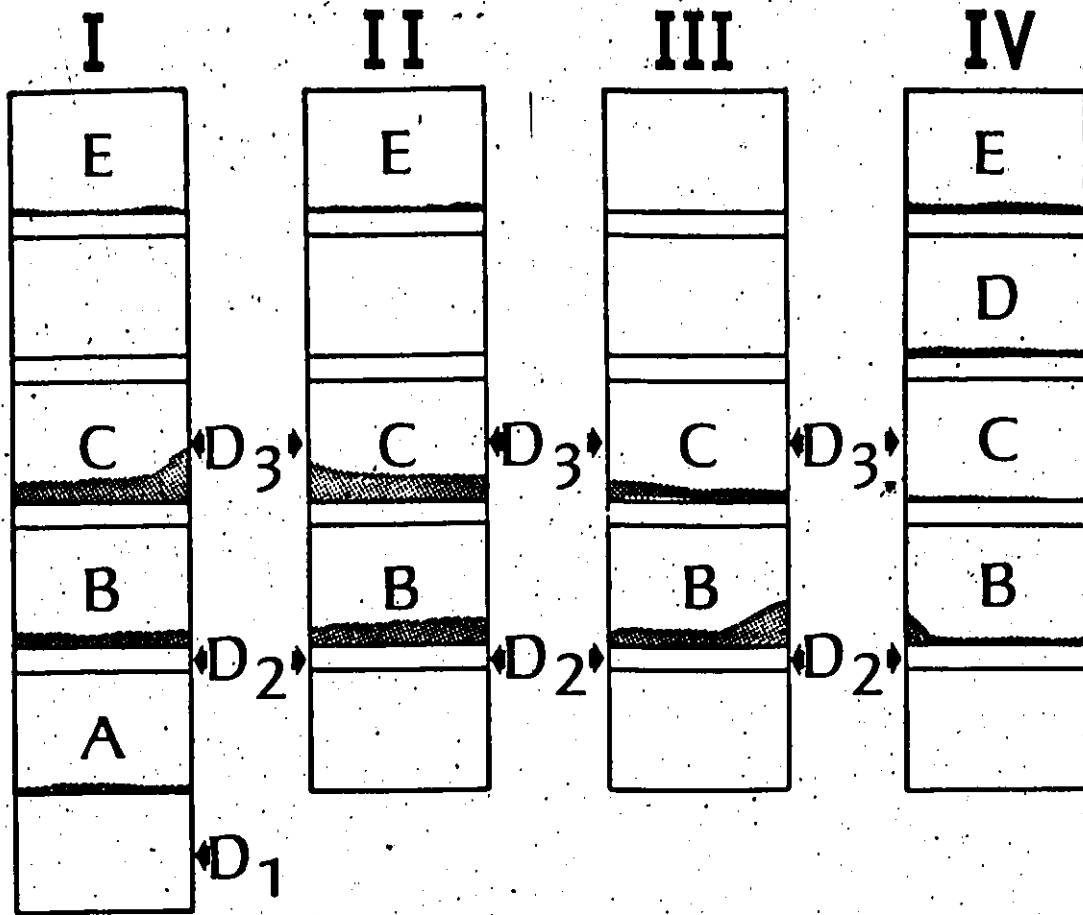


Fig. 10 Distribution and relative abundance of various types (A-E, table 2, p 30) of pink granites across the map area.

deformation D_3 but was post D_2 .

Mafic intrusives (map unit 5)

Diorite (5 Di): two diorite bodies are found within the Glamorgan migmatitic complex. One of these diorites is located at the western extremity of Bark Lake in Glamorgan Township (Bark Lake is located outside the map area (Fig. 2)); the other covers the Minicock Lake region in the northwest corner of the map area. The two bodies constitute ovoid massed oriented NW-SE. They both reach two miles in length, and one mile in width. The Minicock Lake Diorite is coarse-grained, massive, and contains plagioclase and about 10% hornblende as the principal mineral constituents. However, edges of the diorite mass are characterized by a poorly developed gneissosity and there biotite is the predominant mafic mineral. Chemical analyses of the Bark Lake Diorite are given by Chesworth (1966) who reports a little normative quartz. He also mentions amphibole grains with distinct cores of clinopyroxene.

Gabbro (metagabbro) (5MG): a large gabbroic complex occurs in Monmouth and Glamorgan Townships, within the belt of metasedimentary rocks, just south of the map area (Fig. 4). First described as a continuous mass extending from Green's Mountain to Hadlington Lake in Monmouth Township by Armstrong and Gittins (1968), the gabbro complex was mapped as three separate bodies (the Glamorgan, Monmouth, and Hadlington Gabbros) by Wenban-Smith (1967).

The Hadlington Gabbro, a basic to ultrabasic complex occurs as four sill-like bodies dipping to the northwest that have undergone minor differentiation from peridotite to troctolite (Grieve, 1967).

The Glamorgan Gabbro comprises seven rock units ranging from gabbroic to anorthositic in composition (some of the gabbroic varieties contain nepheline). It was emplaced as a sheet, prior to or contemporaneously with regional metamor-

phism (Downing, 1973). Wenban-Smith (1967) demonstrated that, within the Glamorgan Gabbro, a poorly developed gneissosity trending northwest is superposed on fluidal textures oriented northeast. He describes the planar structure as an arrested stage of development of gneissosity. From a quantitative structural study of the area, summarized on page 69 of part B of this report, the Glamorgan Gabbro can be interpreted to have been emplaced during deformation D_2 . From this and from the lack of D_3 structures, it can be deduced that it behaved as a rigid unit during D_3 .

Metadiabase (.5Db): a number of small amphibolite bodies concordant with or cutting the stratification and/or schistosity of surrounding rocks occur throughout Glamorgan and Monmouth Townships. Chilled borders have been recognized locally. These metamorphosed intrusive bodies are useful time indicators since they can be observed to cut older structures.

Summary and conclusions

Lithologies of the metasedimentary belt can be traced northwesterly into portion M_1 of the migmatite complex. The melanosome of these migmatites is similar in all aspects to the paragneiss-amphibolite group of the belt of metasedimentary rocks. Remnant blocks of quartzite and marble are widespread within unit M_1 . These migmatites comprise two leucosomal phases (Type B and Type C granitic pegmatites and granites, respectively; Table 2) which are also found in abundance in migmatites M_2 . However migmatites to the northwest (unit M_2) are characterized by a third leucosome (Type A in table 2) older and distinctive from the previous types by the common deformation of these veins into very tight folds and boudins. The veins are also usually rimmed with a thin film of biotite, and are typically white on weathered surfaces. The melanosome of migmatites M_2 is typically grey in colour, granodioritic in

composition and contains characteristic mafic schlierens. The melanosome of migmatites M₂ is more homogeneous as a whole than the melanosome of migmatites M₁ and, in this respect, bears some similarity to rocks of plutonic habit. Metasedimentary rocks are scarce in migmatites M₂ and where observed occur as extremely deformed relics, mainly quartzitic in composition.

The form of interpenetration of migmatite components shows that the complexity of migmatite structures increases from southeast to northwest across the map-area.

Five generations of pink granitic rocks have been recognized. These granites occur in veins rarely exceeding 10 feet in width, concordant or slightly oblique to schistosity of surrounding rocks or as larger sill-like bodies. The composition of the various types of granites is similar and approaches that of cotectic granites.

Type B and C granites are by far the most abundant granites, and where in vein or dikes, constitute the leucosomes of migmatitic rocks. From the determination of the time of emplacement of these granites relative to the three known phases of deformation, it was concluded that the main act of migmatization was in part earlier and in part contemporaneous with the third and last phase of deformation, but that it postdates deformation D₂.

Armstrong and Gittins (1968) have put forward the idea that the presence of quartzite in a narrow belt extending northeasterly through Monmouth Township implies the erosion of a granite terrain during sedimentation of the Grenville Group. Metasedimentary rocks are widespread in portion M₁ of the migmatite

complex and constitute the melanosome of these migmatites . These rocks are therefore considered to be migmatized equivalents of rocks of the Grenville Group and may represent the basal section of the supracrustal metasedimentary rocks to the southeast. It therefore implies that the source of supply for these rocks lie farther to the northwest. Migmatites M_2 , to the northwest are characterized by pegmatitic veins (Type A), not found in migmatites M_1 . These pegmatitic veins were emplaced into already highly deformed rocks prior to the major metamorphic and deformational event of the area. The northeast trending boundary between region M_1 and region M_2 of the migmatite complex may thus be more than a simple lithological boundary; it may represent the boundary between a former basement and its cover.

PART B: STRUCTURES

Introduction

A detailed study of the regional deformation structures in Glamorgan and Monmouth Townships is undertaken in the following pages. The recognition of multiple phases of deformation allows a better understanding of the petrographic evolution of the rocks of the area.

It is difficult to distinguish S_1 , S_2 and S_3 surfaces. Mimetic crystallization, the scarcity of index minerals that could show the preservation of older fabrics (e.g. garnets), and the common absence of axial planar fabrics in minor folds, are major obstacles to the determination of successive phases of deformation. Consequently, cross-folding, granitic veins and dikes of different ages relative to deformation (S) and the geometry and orientation of minor folds are important diagnostic criteria for the recognition of multiple phases of deformation.

Two major deformations, D_2 and D_3 , are recognized in Glamorgan and Monmouth Townships. An earlier primary phase may be present but is largely observed by later deformations. Table 4 summarizes the structures produced during the three successive tectonic pulses for each of the two structural domains of figure 20.

Structural elements that were measured include: stratification, foliations, joints and lineations.

I- Field criteria used in the recognition of structural elements.

a) Planar fabrics:

1- Stratification.

Stratification is particularly well preserved in quartzite sequen-

TABLE 4

CHARACTER OF D₁, D₂ AND D₃ STRUCTURES IN GLAMORGAN AND MONMOUTH TOWNSHIPS.

Structural Domain I NE trends in SE part

(Figure 20),

	D ₁	D ₂	D ₃
Scale	Mesoscopic	Mesoscopic	Mesoscopic
Surface folded	No F ₁ fold observed	S ₀ // S ₁	S ₀ // S ₁ , S ₂
Fold profile		Isoclinal	Moderately open to tight asymmetric similar folds to isoclinal folds.
Axial surface foliation		None observed	Rare cases where weak crenulation cleavage (b ₃).
Axial lineation		None observed	L ₂ mineral lineation; L ₃ crenulation lineation.
Orientation		Axial surfaces strike NE and dip toward the SE; axes of major F ₂ folds are plunging to the SE. Scarce minor F ₂ folds (Monmouth and Cardiff type) have subhorizontal NE trending axes.	The tight similar asymmetric folds are SE plunging with axial surfaces dipping NE. Scarce minor F ₃ isoclinal folds (Cardiff type) are coplanar with F ₂ folds.

Structural Domain II NE to NW Trends in NW Part

(Figure 20),

	D ₁	D ₂	D ₃
Scale	Mesoscopic	Mesoscopic	Mesoscopic
Surface folded	Lithologic layering. S ₀ (?)	S ₀ (?) // S ₁	S ₀ (?) // (S ₁ , S ₂)
Fold profile	Isoclinal, interfolial, detached fold hinges.	Isoclinal	Tight upright subhorizontal to tight inclined asymmetric similar folds.
Axial Surface Foliation	S ₁ foliation	S ₂ foliation. (Recrystallized quartz pods in hinge area of F ₂ folds).	S ₂ planar fabrics in folded granitic pegmatite veins.
Axial Lineation	Hinge line of F ₁ folds on S ₁ surfaces.	Crenulation of S ₁ in hinge zone of F ₂ folds.	L ₂ mineral lineations at intersection of axial surfaces of F ₂ and F ₃ folds;
Orientation	Recumbent; folds plunge SE at 20 degrees.	Fold axes plunge SE (15-30 degrees); axial surfaces vary in attitude.	Fold axes plunge SE (15-30 degrees). Axial planes dip SW and/or NE.

ces where it is emphasized by successive layers 2 to 12 inches thick showing variations in grain size and difference in composition from one layer to the other. Layers of pure quartzite are commonly followed by layers rich in diopside and layers rich in feldspar.

2- Foliations.

In this report, schistosity is used specifically for rocks in which tabular and flaky minerals, preferentially oriented, define a planar fabric in the rocks. Flattening of feldspar and/or quartz grains is responsible for flaser structures commonly developed in granitic pegmatites and quartzites of Glamorgan and Monmouth Townships.

3- Joints.

Jointing is common in Glamorgan and Monmouth Townships. However, in this report, joints have not been the object of systematic studies and their relationships to the deformational history of the area are not well understood.

b) Linear fabrics:

1- Mineral lineations.

In this report, the term lineation refers almost wholly to the dimensional elongation of minerals and mineral aggregates. The different types of mineral lineations are summarized as follows:

- the elongation of the flattened quartz grains along their "c" axes in quartzites and some granitic pegmatites;
- quartz lenses in the medium-grained pink granite (type C);
- the parallelism of eyed-shaped feldspars in granitic pegmatites characterized by the development of augen structures;
- the parallelism of hornblende grains in amphibolite and in hornblende-rich

gneisses;

- elongate aggregates of diopside in some pegmatites and gneisses;
- elongate aggregates of graphite in fine-grained graphitic marbles with fluidal textures.

2- Crenulation lineations.

Wrinkles, with a wavelength of a few millimeters on the schistosity planes of plagioclase-quartz-biotite-hornblende gneisses define linear fabrics parallel with mineral lineations. Under the microscope, they appear as an undulation of the schistosity produced by the preferential alignment of biotite flakes. These crenulation fabrics are hard to distinguish, in the field, from lineations due to the intersection of two tectonic surfaces at low angles. The latter phenomenon was observed locally in gneisses characterized by a segregation of felsic minerals (quartz and feldspar) and mafic minerals (mainly hornblende) where later biotites have crystallized at low angle (usually less than 20 degrees) to the rock gneissosity.

3- Fold axes.

Axes of minor folds only were measured since folding on a regional scale is not readily recognized in the field because of lack of marker horizons. It was possible to obtain systematic measurements throughout the map area; however, due to the scarcity of outcrop exposures, the majority of minor folds observed occur along road cuts and on lakes shores. Minor folds can be the size of a large outcrop, 200 or 300 feet in length, or may be a few inches or less in size.

II- Types of foliations

Three types of foliations were recognized in Glamorgan and Monmouth Townships: 1) a composite S_1 - S_2 schistosity parallel to bedding in metasedimentary rocks; 2) S_2 schistositities at a slight angle to earlier S_1 (?) fabrics preserved as relics in highly deformed quartzitic inclusions in M_2 migmatites; 3) rare

S_3 surfaces axial planar to F_3 folds or S_3 schistosity developed at a slight angle to a composite S_1 - S_2 schistosity. No strong penetrative S_3 foliation is recognized in the region.

Composite S_1 - S_2 foliation.

The earliest folds recognized within the complex of metasedimentary rocks are minor isoclinal folds bending both a lithological layering and a metamorphic layering. Not even weak penetrative axial surfaces were recognized in these early structures. Because of the absence of intersecting "S" planes, as in the hinge zone of minor folds, it was possible, in most cases, using the above relationships, to determine whether the foliation is a primary or a secondary structural surface. In a garnetiferous gneiss, adjacent to the eastern margin of the Cheddar Granite in Cardiff Township, the schistosity-gneissosity is deflected around garnet porphyroblasts containing fine-grained inclusions of biotite arranged in trails subparallel to foliation developed in the rock outside the garnet. However, because the fabric within the garnet porphyroblast is slightly bent, the enclosed fabric is believed to be a relic schistosity. In some cases, parts of the same garnets deflecting the gneissosity of the rock cut this metamorphic foliation suggesting that their growth continued after crystallization of the rock gneissosity. Figure 11 illustrates the relationship between a garnet porphyroblast and the rock foliation in a garnetiferous gneiss from Cardiff Township. The garnet porphyroblast show evidence of prekinematic, of synkinematic and of postkinematic growth. It indicates that the growth of the garnets started before development of the schistosity-gneissosity of the enclosing rock and outlasted it. Syntectonic (syn D_2) high grade metamorphism of the Grenville Group metasediments is recorded by Divi (1972, p. 100) in his structural analysis of Grenville rocks near Bancroft, and by Carmichael (1968, p. 9) in the Whetstone Lake Area. According to Divi (1972, p. 100) the rocks were in the amphibolite facies during pre- D_2 and post- D_2 times, as

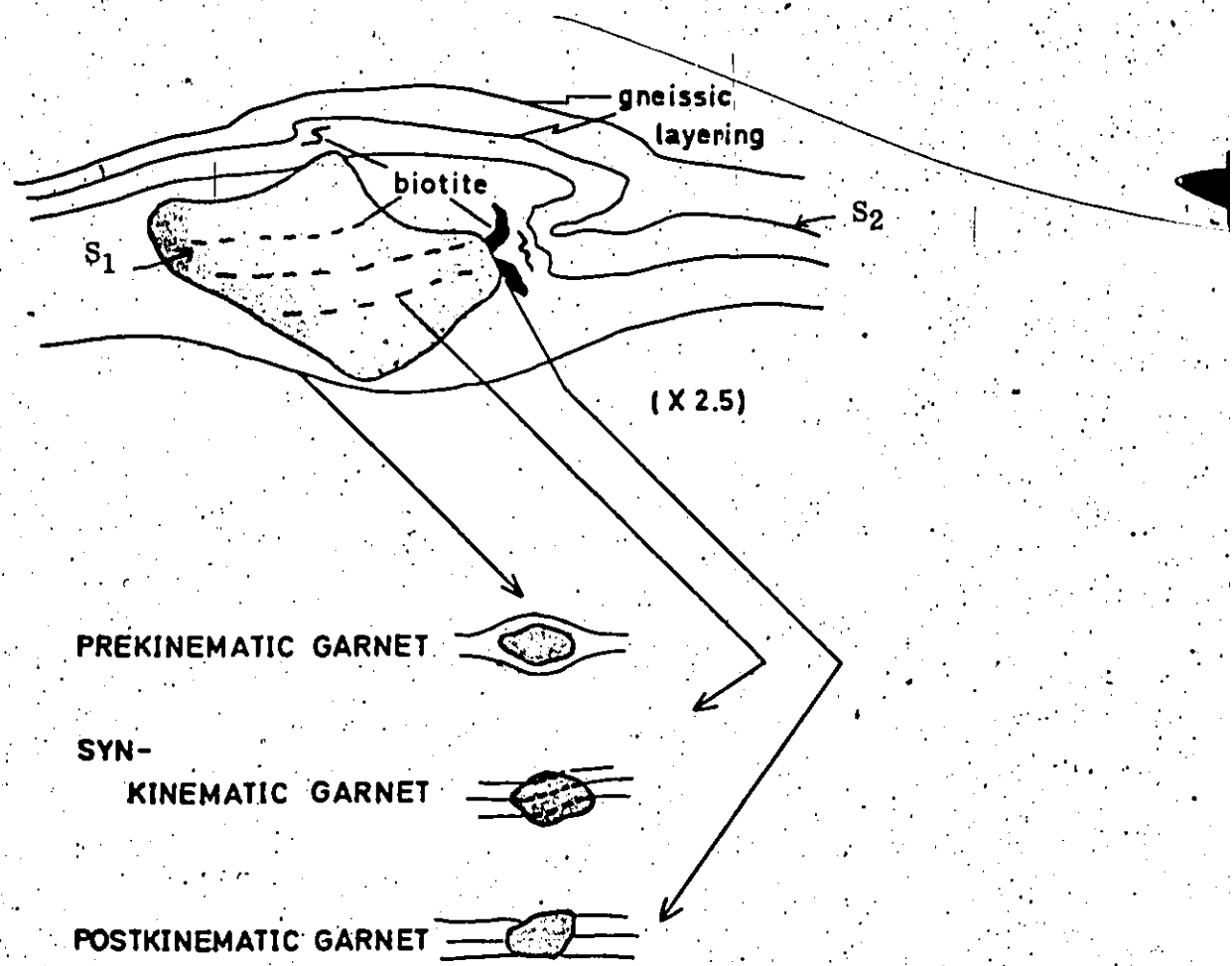


Fig. 11: A garnet crystal in a psammitic gneiss of Cardiff township showing evidence of pre, syn and post-kinematic crystallization.

shown in part because of the occurrence of pre- D_2 and post- D_2 garnet porphyroblasts. Consequently, correlations with studies of the two authors mentioned above would indicate that the foliation developed in metasedimentary rocks of Monmouth Township is a secondary tectonic surface S_2 and the relic fabric discussed above is a surface S_1 .

The gradational nature of the contact between the belt of metasedimentary rocks, to the southeast, and unit M_1 of the migmatite complex has been discussed on page 24. There is no truncation of trends and/or lithologies from one area to the other. However, with migmatization increasing toward the northwest and due to the predominance of plagioclase-quartz-biotite-hornblende gneisses over quartzite and marble in migmatites M_1 , primary layering is gradually erased toward the northwest: primary layering is readily recognized in quartzite and marble, but obscured by gneissosity in the psammitic paragneiss. Therefore in unit M_1 , the foliation is also considered to be a tectonic surface S_2 .

In unit M_2 of the migmatite complex, older fabrics are only recognized within scarce remnants (?) of metasedimentary rocks. Felsic layers in the form of lenses, composed predominantly of quartz with minor feldspar, diopside, biotite and sometimes garnet are occasionally observed in the granodiorite gneiss. Coarse crystallization within the pods has partly obliterated original fabric orientations, but in the finer grained varieties, the preservation of an internal foliation commonly oblique to the gneissosity-schistosity of the surrounding rock has been observed locally (plate 25). In places garnet aggregates partly envelope this fabric. The enclosed foliation is believed to represent a bent relic fabric. There is no truncation of trends between portion M_1 and portion M_2 of the migmatite complex and the foliation in M_2 migmatites can be considered as an S_2 tectonic surfaces by correlation with the foliation in rocks to the southeast and by reference to Divi's work in the Bancroft region. The relic

fabric enclosed within the felsic lenses of M_2 migmatites can similarly be considered as S_1 surfaces. However, if it is assumed that S_1 and S_2 are parallel in M_2 migmatites, similarly to S_1 and S_2 in unit M_1 and GG of Fig. 3, then the relic fabrics discussed above may be pre- S_1 surfaces.

This correlation with studies of Carmichael (1968) and Divi (1972) is valid only if it is assumed that rocks of Monmouth and Glamorgan Townships have been subjected to progressive metamorphism from initial stages of deformation, during D_1 , to stages of more intense metamorphism, during D_2 deformation. However, in the area under study, the conditions of temperature and pressure that produced mineral assemblages characteristic of the almandine-amphibolite facies appear to have prevailed long enough to erase traces of progressive metamorphism. Consequently, original fabrics were largely obscured by a period of regional metamorphism correlated with deformation D_2 in the Bancroft region, to the east.

S_3 foliations.

No strong penetrative S_3 foliations was recognized in Monmouth and Glamorgan Townships. However, gneisses containing layers of quartz and feldspars alternating with layers containing more mafic minerals (usually hornblende) in which later biotites have crystallized obliquely to the original gneissosity have been observed locally. This new fabric is thought to be an S_3 foliation. Interestingly enough, in gneisses containing little or no hornblende, the S_1 - S_2 schistosity defined by the preferential alinement of biotite flakes is commonly crenulated parallel to S_3 . At a few localities within the migmatite complex, micas of the melanosome defining an S_1 - S_2 schistosity have maintained their original S planes whereas the mineral constituents of the leucosome show partial recrystallization. Fig. 12 illustrates a vein of granitic pegmatite folded into an F_3 fold.

CROSS SECTION VIEWED FROM THE NORTH

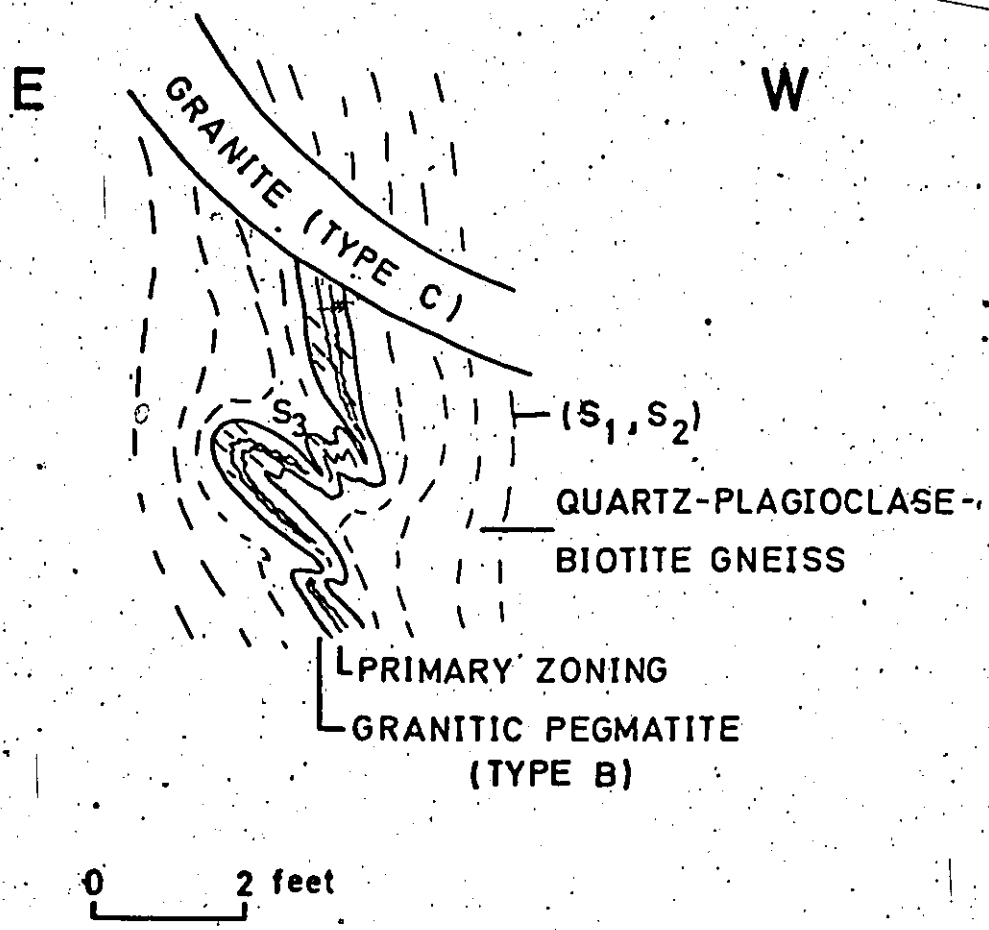


Fig. 12: Profile of a folded granitic pegmatite vein (8P(B)) in quartz-plagioclase - biotite gneiss (2Pb), cut by a later dike of granites (8 l (c)). Locality: road cut on gravel road south of Glamor Lake.

The vein is characterized by the development of an axial S_3 surface not observed within the surrounding plagioclase-quartz-biotite gneiss.

Orientation of foliation planes.

In Monmouth and Glamorgan Townships, composite S_1 - S_2 foliations show regional variations in attitude corresponding to northeast and northwest trends (Fig. 13 and Fig. 14).

In the metasedimentary belt (Monmouth Township) foliation planes trend northeast and dip to the southeast at angles varying from 30 to 55 degrees. Moving northwesterly from the metasedimentary belt, into the migmatite complex, northeast trends predominate as far as Glamor Lake. West of a line passing through Billings Lake and Glamor Lake, foliations curve progressively to the northwest and dip steeply to the southwest or to the northeast. Areas between Dudmon and Esson Lake in the northern segment of the map-area, are characterized by northwest trends.

The distribution of remnant blocks of metasedimentary rocks, within migmatite area M_1 , in zones following the foliation pattern is a striking feature. However, along the eastern margin of the migmatite complex, foliations are transverse to lithological boundaries in areas where northeast trends curve towards a northwesterly direction. This interference pattern is commonly observed on the nose of plunging folds. Thick accumulations of marble, in those areas, also suggest folding. During metamorphism and deformation, marble horizons will react plastically and thicken in the hinges of folds.

The M_1 - M_2 lithological boundary strikes north-northeasterly. However, transposition of the foliation pattern on the lithological boundary has produced curvilinear trends such that, on a local scale, the M_2 - M_1 boundary is irregular

TRACE OF FOLIATION PLANES AND LINEATIONS

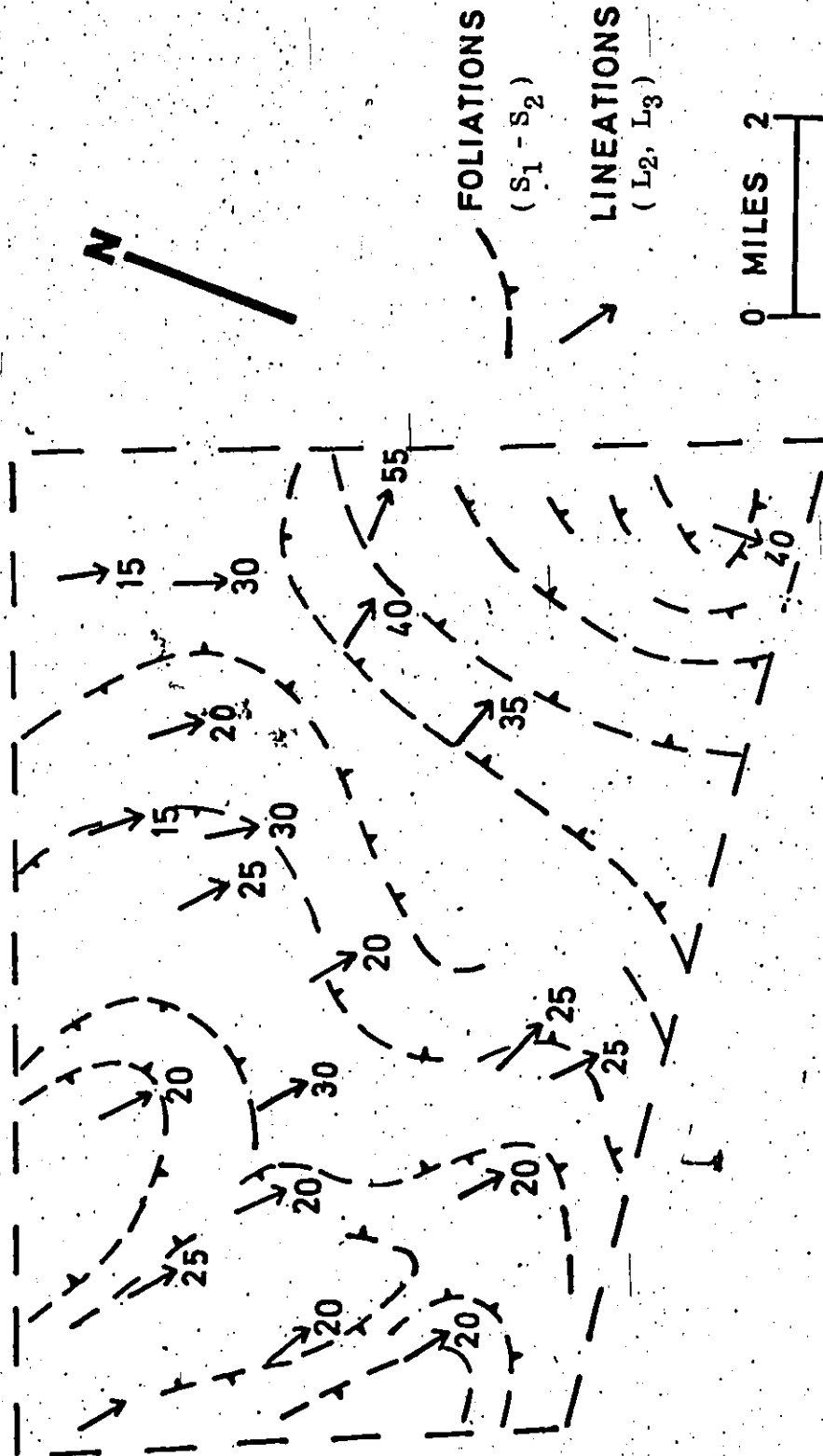
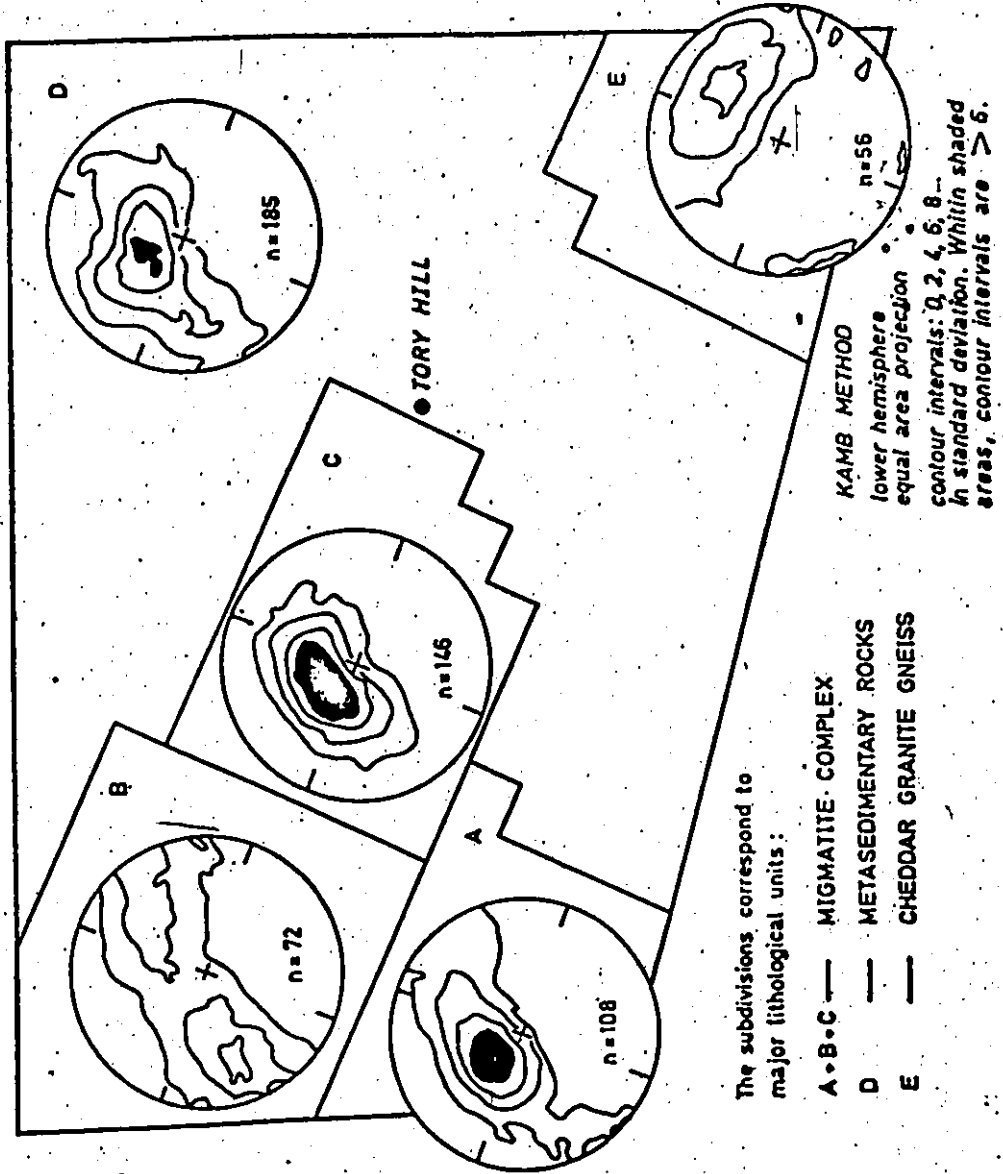


Fig. 13

GLAMORGAN AND MONMOUTH TOWNSHIPS

FOLIATIONS



(Fig. 24)

and semi-conformable to the regional northwest trending foliation (Fig. 4).

This boundary is transgressed by a migmatite front which further obliterates it.

Conclusion

In summary, the peak of metamorphism in the region is correlated with the development of an S_2 foliation in rocks of the Grenville Group near Bancroft. Reactivation of primary tectonic surfaces or transposition of primary layering along the foliation plane during D_2 deformation has resulted in the formation of stratiform gneisses. Consequently, in the majority of cases S_1 and S_2 surfaces can not be distinguished and for convenience, the regional foliation is described as a composite S_1 - S_2 foliation.

The regional foliation varies in attitude from northeasterly trends, in the southeast part of the map area, to northwesterly trends, in the northwestern part. Lithological boundaries are conformable to the regional foliation except in areas where northeasterly trends are transposed in a northwesterly direction.

III- Minor folds.

The following is a discussion of mesoscopic minor folds observed in various localities of the study area.

Two major phases of deformation are recognized in Glamorgan and Monmouth Townships. An earlier primary phase may be present but has not been recognized with certainty.

a) Minor folds in the metasedimentary belt of Monmouth Township (unit GG, Fig. 3)

F_1 folds: no F_1 folds have been recognized in metasedimentary rocks of Monmouth Township. It may be that D_1 structures are largely obscured by later deformations.

F_2 folds: the earliest folds recognized in the area are northeast trending

subhorizontal and isoclinal. Axial planes strike northeast, dipping 10 to 20 degrees toward the southeast. Fold limbs do not thicken at the hinges. The folded surface is assumed to be a surface S_{1+} . This metamorphic layering is parallel to bedding both in the hinge zones and on the limbs of these minor folds. Thus these structures are described as F_2 folds (Plate 29). Axial planar fabrics have not been observed.

F_3 folds: the next phase of deformation that developed in these rocks refolded F_2 folds into 1) tight asymmetric similar folds around southeast shallow plunging (20-30 degrees) axes (Plate 30 and 31); and 2) in some rare instances, into northeast trending subhorizontal isoclinal folds coaxial with F_2 folds (Plate 32). These two different fold patterns produced during D_3 occur on the same outcrop, in a series of impure quartzite layers, along highway 500, approximately 7 miles northeast of Wilberforce. The axis of F_3 folds is rotated in space from a southeast to a northeast direction causing a change in the fold shape from northwest-tight to moderately open asymmetric folds to northeast trending isoclinal folds, overturned toward the northwest, and coaxial with F_2 isoclinal folds. This fold pattern is illustrated on fig. 15 and on plates 31 and 32.

East of the belt of syenites and nepheline gneisses, interference of D_2 and D_3 structures has not been observed in rocks of the Grenville Group and deformation D_3 may merely be expressed as a crenulation or mineral lineation L_3 .

b) Minor folds in migmatite unit M_1

Because of the scarcity of outcrop exposures, and due to the lack of good access in this part of the map area, very few minor folds were observed in migmatite unit M_1 .

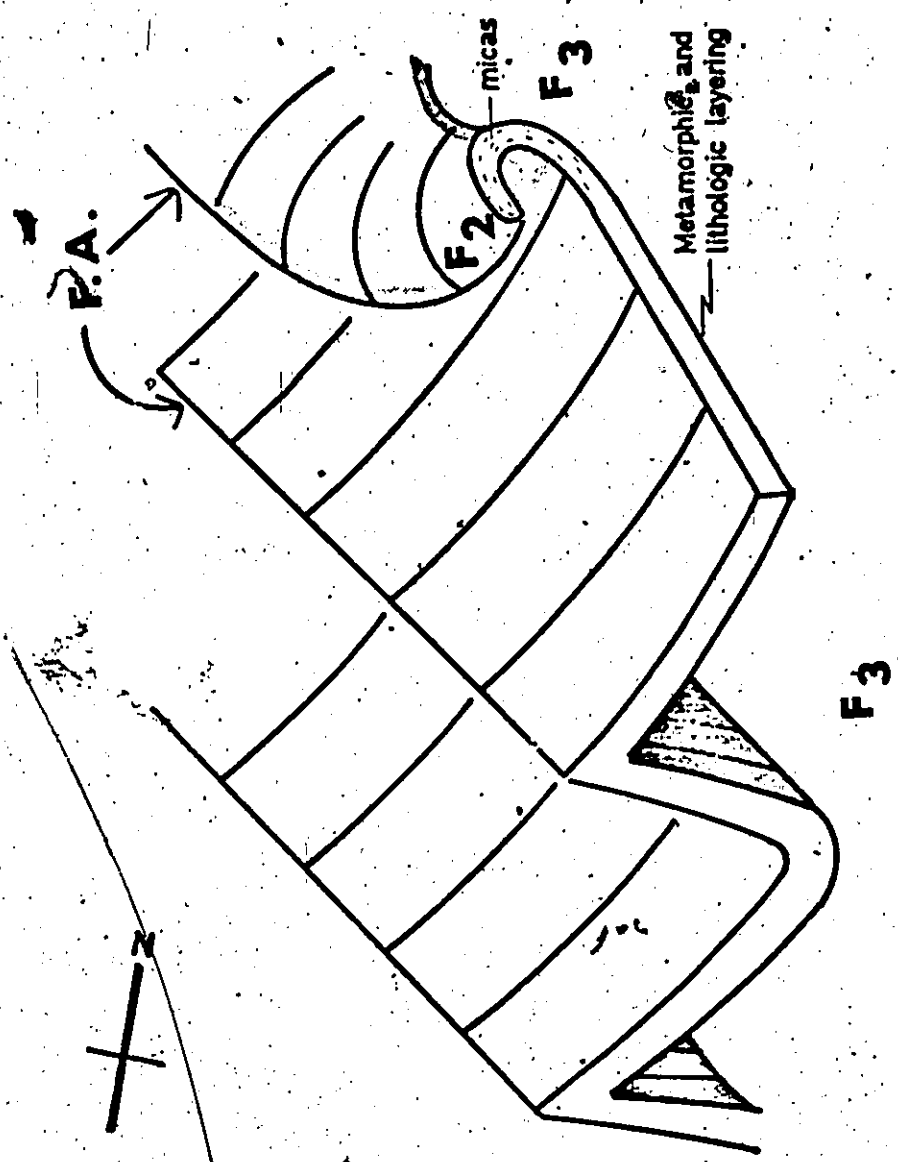


Fig. 15: F₃ NW trending asymmetric folds in a series of impure quartzite layers. Also rotation in space of the fold axis of a fold F₃ from a NW direction to a NE direction to produce an overturned isoclinal F₃ fold coaxial to F₂ folds. Locality: Road cut along Highway 500, approximately 7 miles northeast of Wilberforce, Cardiff township.

F₂ folds: Few small scale reclined interfolial folds can be observed along the western margin of unit M₁, on the eastern shore of Gooderham Lake. Folded surfaces are thin leucocratic quartz-feldspar layers in a quartz-feldspar-biotite gneiss. The schistosity of the melanosome is axial to the folds. Recrystallization of biotite grains is suggested by their polygonal arrangement in the hinge areas of the folds. The schistosity may thus be considered as a secondary tectonic fabric and the minor scale folds as D₂ structures. The intersection of fold hinges on the foliation planes defines L₂ lineations plunging 20-25 degrees toward the southeast. Axial planes strike northeast and dip to the southeast.

F₃ folds: open to tight asymmetric northwest trending folds with southeast plunging (25 degrees) axes are described as F₃ folds because their orientations and their geometry are similar to those of D₃ structures in the metasedimentary belt in Monmouth Township.

The following is a description of specific examples of F₃ folds in relation to the two most common types of granitic veins and arterites in Monmouth and Glamorgan Townships.. South of Glamor Lake, a concordant vein of granitic pegmatite (type B) is tightly folded in a biotite-quartz-feldspathic gneiss (Plate 20), (Fig. 12). The vein is characterized by zoning with a core of quartz and edges being richer in feldspar. This zoning is thought to be a primary feature developed during emplacement of the vein. A secondary planar fabric, defined by platy quartz and feldspar grains, is developed across the zoning. This fabric is axial planar to the folded leucocratic vein. The granitic pegmatite is considered to have been emplaced along a composite S₁-S₂ schistosity in the surrounding gneiss late during deformation D₂ or some time before deformation D₃. On the same outcrop, it is seen to be cut by a synkinematic D₃ granitic arterite (type C) discordant with the gneiss and roughly parallel to the axial planar fabric developed in the folded granitic pegmatite. From these relationships and by comparison with

minor folds from other localities, the structure is described as a F_3 fold with the accompanying development of an axial S_3 surface. Micaceous of the palcosome, outside the pegmatitic vein, have maintained their original S-planes whereas the mineral constituents of the leucocratic vein show partial recrystallization. In this case, deformation in the gneiss was controlled by the granitic pegmatite which behaved as a competent unit relative to the gneiss, since the folding pattern vanishes within a few feet from the pegmatitic vein. Elsewhere, granitic veins (type C) are commonly seen to be folded around southeast shallow-plunging axes and to define F_3 folds (Plate 21). These granites are characterized by the development of mineral axial lineations, i. e. lineations parallel to axes of F_3 folds, suggesting synkinematic (syn- D_3) emplacement.

Axial planes of F_3 folds vary in attitude within M_1 migmatites from northerly to southerly directions. To the southwest, axial planes dip toward the south-southwest. Here, the Glamorgan Gabbro has been the controlling factor. The gabbro possibly acted as a rigid body during D_3 .

c) Minor folds in migmatite M_2

These migmatites are exposed along the Buckhorn Road and on the northeast shore of Stormy Lake which represents the transitional zone between the two subareas of the migmatite complex.

F_1 and F_2 folds: F_1 folds have not been recognized with certainty in the area. However, the presence of particular deformation features may be interpreted as relics of a primary phase of folding. Recumbent interfolial detached folds hinges (quartz-rich pods) occur at a few localities, along the Buckhorn Road, in the Stormy Lake region (Plates 34 and 35). Similar features in other localities may be detached hinges of F_2 folds since they also bend a metamorphic layering (Plates 36 and 37). It is also possible that the latter folds represent F_1 folds and pre- D_1 structures. A possible argument

for this interpretation is that gneisses of unit M_2 may be older than metamorphic tectonites of the Grenville Group (Areas M_1 and GG, Fig. 3) and the bent metamorphic layering in the detached fold hinges of unit M_2 possibly existed before Grenvillian deformation occurred. This interpretation is supported by the fact that these structures are cut post- D_1 , pre- D_2 granitic pegmatites (Type A).

Along the Buckhorn Road, within an area of foliated pink granite (the northwestern extension of the Stormy Lake Granite) mafic segregation tightly folded within the granite, appear as elongated lenses parallel to the foliation and closed at both ends by sharp bending of the mafic layers. This feature could be explained by two successive phases of isoclinal folding around shallow plunging southeast trending axes. Further tightening of the structure would have occurred during a third phase of more open folding, contemporaneous with the emplacement of the granite. The structure is observed on the limb of an F_3 fold. Little is known about the original orientation of F_1 and F_2 folds. Possible step by step formation of the structure is illustrated in fig. 16.

In some rare instances, recrystallization has preferentially obliterated original S-planes in folded quartzitic layers with development of a new axial planar fabric S_2 , the schistosity in the surrounding gneiss being folded around the hinge of these isoclinal folds (Plate 28). The elongation / flattening ratio of quartz grains in some of the coarser quartzite lenses is approximately 10:1 defining a strong axial lineation L_2 plunging 20 to 25 degrees to the southeast. Crenulation of foliation in hinge zone of F_2 folds also defines L_2 lineations (Plate 9).

F_3 folds: a third phase of folding is recorded in these rocks. It formed open to tight, similar, upright to inclined asymmetric folds around northwest trending axes plunging at low angle to the southeast. These folds are best

CROSS SECTION VIEWED FROM THE NW

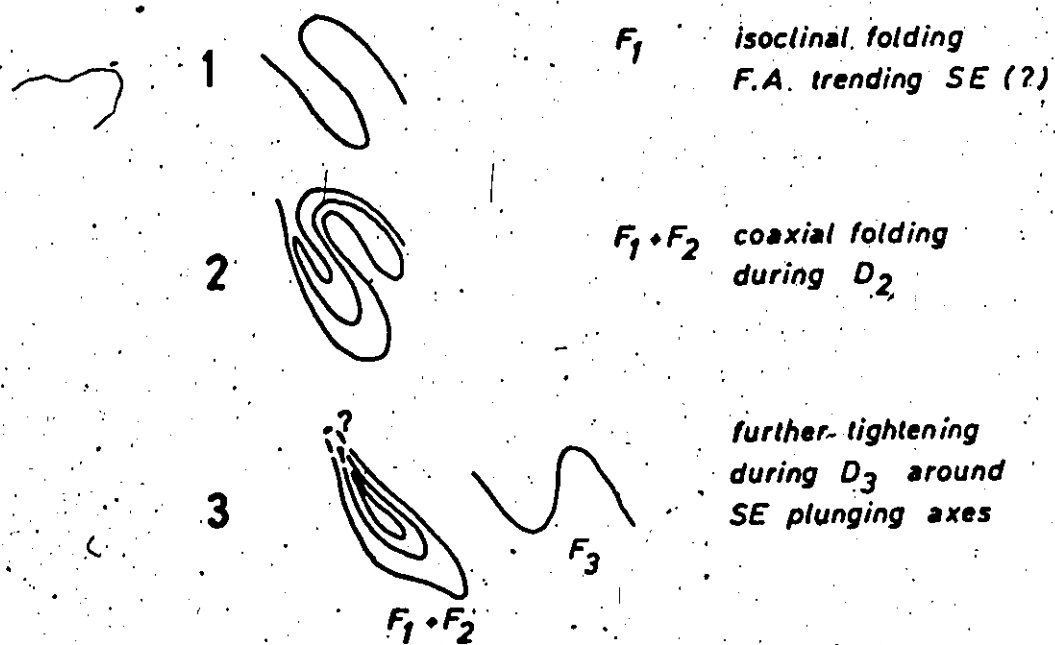
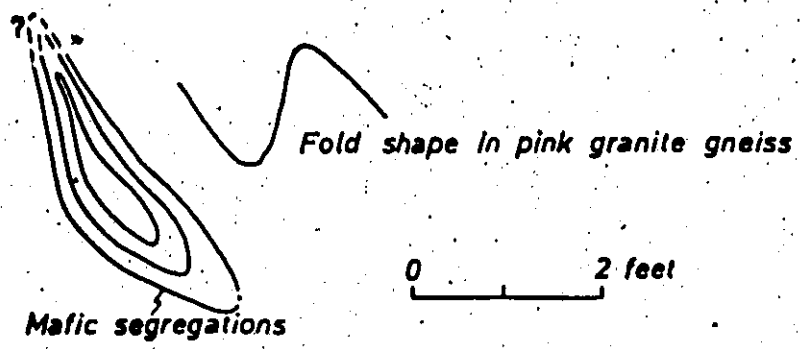


Fig 16: The orientation of F_2 and F_3 folds in the northwestern part of the map-area suggests that the structure illustrated above was formed through 3 successive phases of coaxial folding around shallow plunging SE axes. However little is known about the original orientation of F_1 and F_2 fold axes. Locality: road cut on the Buckhorn Road 2.3 miles north of Stormy Lake.

observed within pink foliated granite along the Buckhorn Road near Stormy Lake (Plate 38). Upright folds are restricted to areas between the Minicock Lake Diorite and the Stormy Lake Granite.

Fig. 17 summarized the structures produced during the three successive phases of deformation across the map area.

IV- Lineations (L_2 and L_3).

Mineral lineations and crenulation lineations (L_2 and L_3) are extensively developed in rocks of Glamorgan and Monmouth Townships. When plotted on the lower hemisphere of a stereogram, they define a maximum, in the southeast quadrangle, trending 133 degrees and plunging 15 to 35 degrees to the southeast (Fig. 18). The lineation plunges uniformly southeast regardless of the direction of foliation (Fig. 15 and 18).

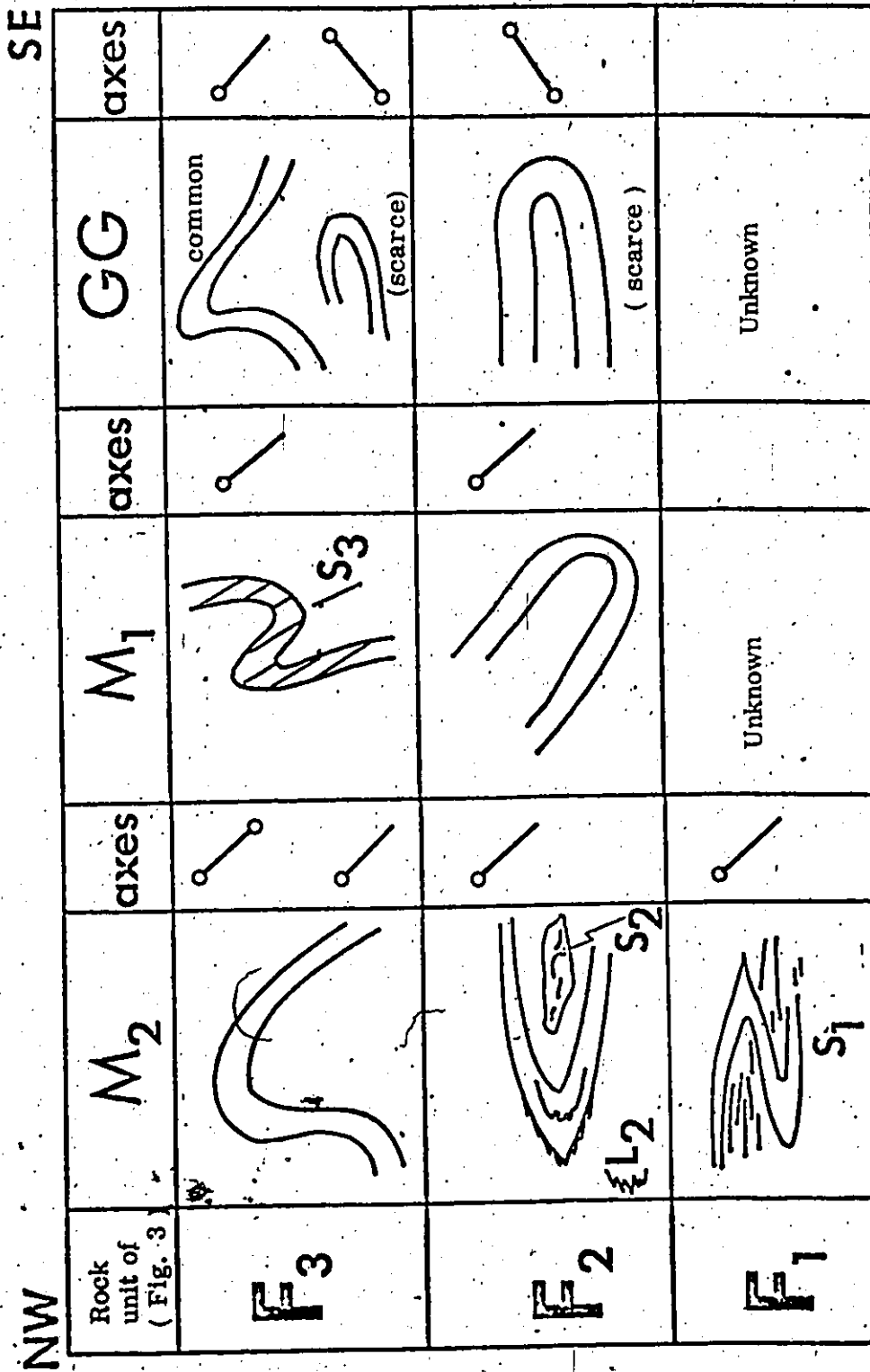
L_2 lineations.

- L_2 lineations are defined by: the intersection of the hinge line of F_2 folds with S_2 foliation plane;
- quartz-rich lenses in the hinge zone of F_2 folds (the ratio of the longest to the shortest axis of quartz grains within the pods is approximately 10:1);
- the crenulation of foliation in the hinge area of F_2 folds.

L_3 lineations.

- L_3 lineations are defined by: rod-shaped quartz grains in the medium-grained leucogranite (type C) emplaced during D_3 ;
- the crenulation of composite S_1 - S_2 foliation in areas where interference of D_2 and D_3 structures is common (i. e. in the southeastern half of the map area, west of the belt of nepheline gneisses and syenites). Here mineral lineations and crenulation lineations lie on the axial plane of isoclinal F_2 folds and are

Fold profiles of F₁, F₂ and F₃ minor folds, with orientation of fold axes, for each of the three major lithologic units of map figuré 3.



(Figure 17)

GLAMORGAN AND MONMOUTH TOWNSHIPS

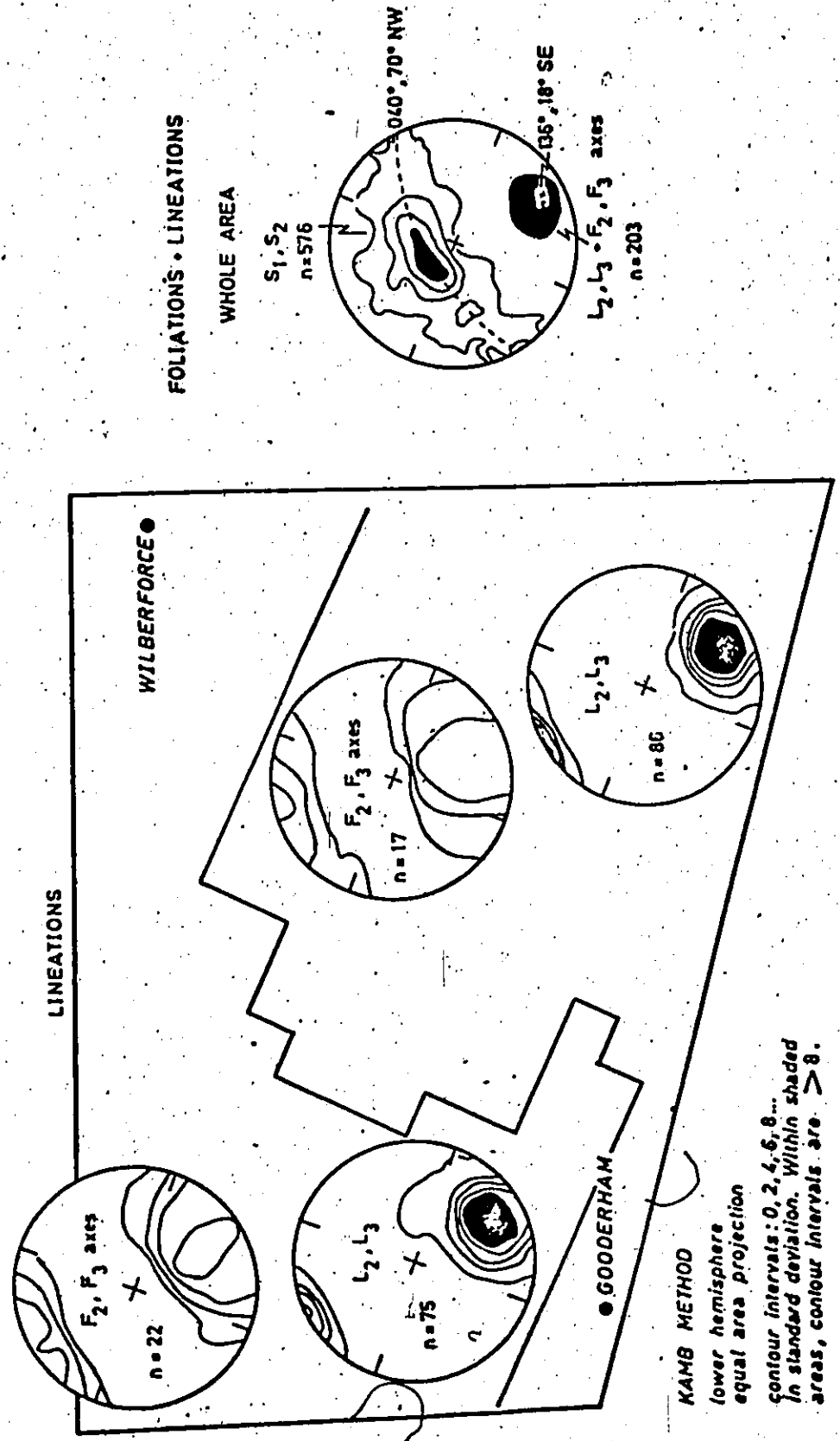
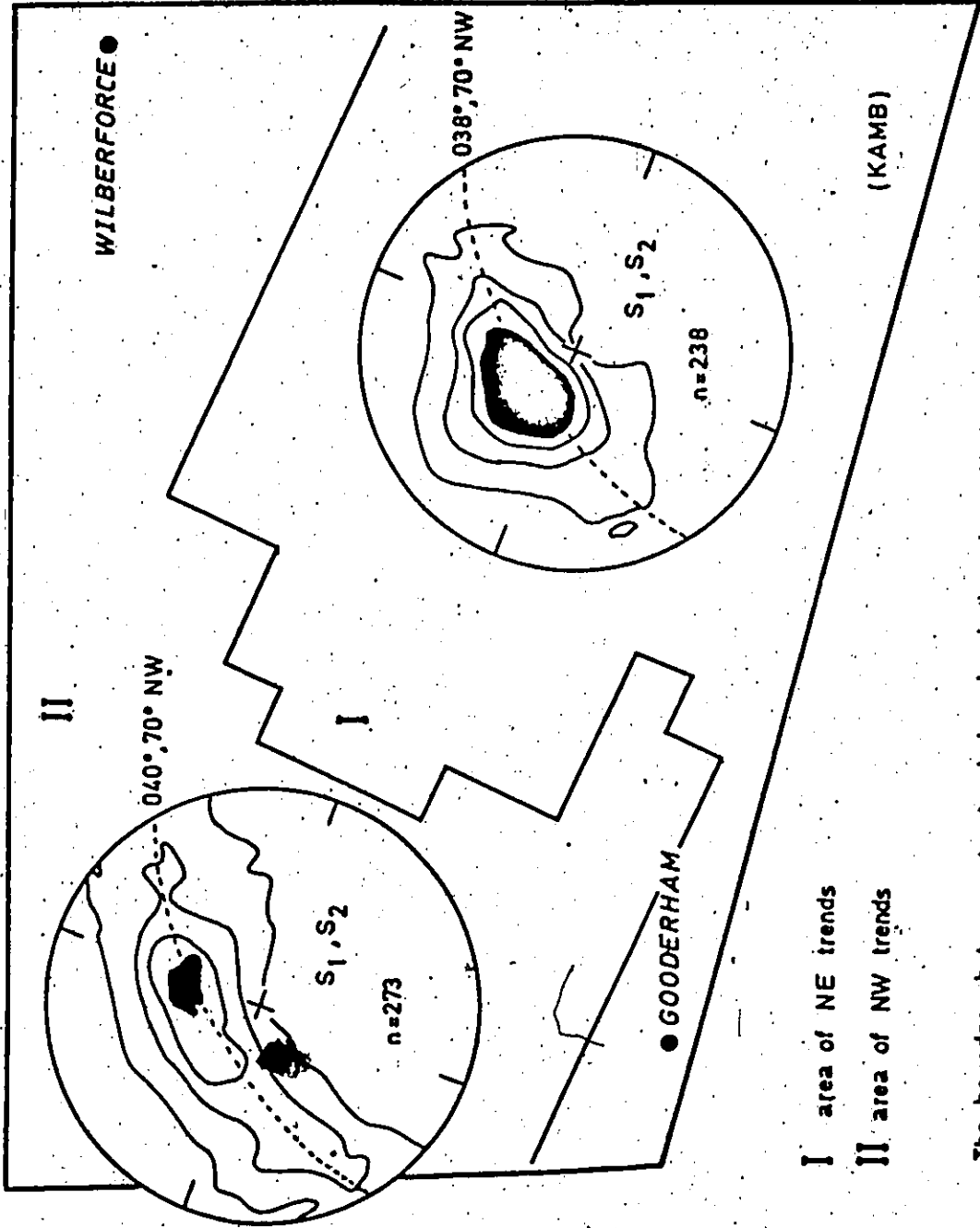


Fig. 18 Stereonet projection of L₂ and L₃ lineations and F₂, F₃ fold axes in structural domains I and II as defined in figure 19.

GLAMORGAN AND MONMOUTH TOWNSHIPS

FOLIATIONS



The boundary between structural domains is based on the homogeneity in the orientation of composite S₁; S₂ foliations.

Fig. 10

subparallel to axes of southeast plunging F_3 folds. These lineations are thus considered to be L_3 lineations developed at the intersection of axial surfaces of F_2 and F_3 folds.

- the intersection at low angle of a schistosity S_3 (recognized locally, only, in the gneisses of unit M_1) with the composite S_1 - S_2 schistosity.

In many places, it is not possible to determine whether a lineation is L_2 or L_3 .

V- Regional structures.

On the basis of homogeneity of orientation of composite S_1 - S_2 foliation planes the map area is divided into two structural domains (Fig. 19). The domain boundaries transect lithological boundaries, suggesting that deformation was moderately controlled by variations and differences in competency of lithological units. This conclusion is also supported by focal field observations. For example, the style of deformation, in minor folds, corresponding to each of the two major phases of deformation in Glamorgan and Monmouth Townships is similar throughout the map area. Also it can be shown that two rock components of different competency behaved with the same mobility during deformation D_2 (p. 27). These features suggest that deformation was plastic in Glamorgan and Monmouth Townships.

Area of northeast trends.

In areas of northeast trends (structural domain I, Fig. 19) the presence of major isoclinal folds with northeast trending axial surfaces dipping southeast is suggested by:

-1) lithological units distributed in zones following the foliation pattern;

-2) the repetition across strike of biotite - gneisses, marble and quartzite units, with dips systematically to the southeast, could suggest tight folding; this tight folding may result from two phases of coaxial folding. However, since minor folds F_1 have not been recognized, and because metamorphism, (from correlations with studies of Divi (1972, p. 100)), may have reached its peak during deformation D_2 to produce the dominant foliation S_2 , deformation D_2 is considered to be largely responsible for the outcrop pattern in Monmouth Township.

Rare cases of minor F_2 northeast trending subhorizontal folds have been observed in rocks of that area and in adjacent areas; however they are not considered to be geometrically significant. The possible orientation of major F_2 folds is discussed in the next chapter.

Large scale refolding of the previous structures around northwesterly axes is suggested by the following features: in areas of transition from northeast to northwest trends, foliations are transverse to lithological boundaries. This arrangement is commonly observed on the nose of plunging folds. Thick accumulations of marble in areas where the regional northeast foliation is bent in a northwesterly direction is also suggestive of folding. During metamorphism and deformation, marble horizons will react plastically and thicken in the hinges of folds. These regional folds plunge at low angle toward the southeast and are geometrically correlated with minor F_3 southeast plunging, asymmetrical folds.

Cross-folding was not observed in a narrow zone of metasedimentary rocks, east of a line defined by the nepheline gneisses and syenites. A possible explanation for this, is that northwest trending F_3 folds are not developed in this particular zone. However, F_3 folds could be isoclinal folds coplanar with F_2 folds. This latter possibility suggested by the local occurrence of northeast

trending F_3 isoclinal folds coaxial with F_2 folds, on a small scale, along a line adjacent to the narrow zone mentioned above, but where interference of D_2 and D_3 structures are still visible. Fig. 13 illustrates this type of deformation. In the zone where interference of D_2 and D_3 structures has not been observed, mineral lineations plunge 30 to 50° toward the southeast.

Poles to foliation planes, in structural domain I, were plotted on the lower hemisphere of a stereogram and contoured by the Kamb method (Fig. 19). The density maximum centered at N280°, 75°NW, is thought to represent the pole to the modal axial plane of isoclinal folds, i. e. axial surfaces, dipping southeast at a low angle. Spreading of the poles into a northeasterly trending girdle (Fig. 19), is attributable to refolding of the previous structures around shallow plunging southeast axes of F_3 folds. However, in a narrow zone of paragneisses adjacent to the Cheddar Granite, the northeasterly trending foliation typically dips 30 to 50 degrees to the southeast down the dip of foliation.

Area of northeast to northwest trends.

To the northwest, in structural domain II, foliation planes vary in strike from northeast to northwest and vary in dip from steep northeast or southwest to low angles southeastward. When poles to foliation are plotted on a stereonet and contoured by the Kamb method (Fig. 20), they define a northeast girdle the orientation of which is identical to that of the previous figure (Fig. 20). However, extremities of the girdle are more strongly developed and the maximum considerable weakened. This reflects the strong imprint of northwest trending F_3 folds on rocks of the area.

As shown in figure 19, the pole to the girdle common to domain I and domain II coincides with the average direction of the L_2 and L_3 lineation and F_2 and F_3 fold axes.

VI- Interpretation

Introduction

As shown throughout the map area, L_2 and L_3 lineations and most measured F_2 and F_3 fold axes plunge uniformly southeast regardless of the trend of foliation planes.

Origin of southeast plunging lineations and fold axes.

From his structural studies of the Adirondacks, Buddington (1956) noted that lineations subperpendicular to major fold axes are commonly correlated with strongly overturned isoclinal folds especially in zones adjacent to rigid border units. This relationship is inferred to be a consequence of strong forward motion in the principal direction of movement. If this interpretation is applicable to the area adjacent to the Cheddar Granite, where the foliation strikes northeast at right angle to the foliations axes of major F_2 folds should be subhorizontal and should trend northeast. However, there is little evidence for such an axial direction.

Hewitt (1957) noted that the Highland Gneiss Complex is separated from metasedimentary rocks of the Hastings Lowlands by a series of normal faults that trend parallel to the foliation and dip to the south or southeast. They are underlined by zones of strong mylonitization. Hewitt (1962) contrasted the dominant northeast trending axial lineation of metasedimentary rocks of the Hastings Lowlands with the southeast plunging lineations of the Highland Complex and thought that the latter developed as an " A " lineation parallel to an upward movement of the Highland Block from the southeast.

Best (1966) argued that the mylonites probably originated late during the metamorphic history of the region and do not form a structural boundary

between the two areas. Rather, the distinction between the two areas would be basically a lithological one with progressive changes in structural character between rocks of the two areas. He proposed that near rigid border units folds would progressively tighten, and that fold axes and axial lineations would rotate into the downdip direction of maximum extension. More recently, Divi and Fyson (1973) were able to demonstrate, on a statistical basis, that a progressive tightening of F_2 fold axes toward the Highland Gneiss Complex, in the Bancroft region, is accompanied by a rotation of L_2 lineations and F_2 fold axes from low-plunging northeast-southwest axes with low rake angles to steeply southeast plunging axes with high rake angles.

These southeast plunging lineations extend to within the studied area of the Highland Complex. Therefore it may be concluded that axes of major F_2 folds, also plunge southeast within the Highland Complex. However, the fact that within the Highland Complex lineations plunge uniformly southeast over a wide area can not be explained only on the basis of the mechanism proposed by Best (1966) and latter demonstrated by Divi and Fyson (1973). As mentioned earlier in this report, a study of minor structures in the Highland Gneiss Complex, west of the northeast trending Harvey-Cardiff Arch, shows that a third phase of deformation absent in metasedimentary rocks of the Lowlands, east of the arch, developed open to tight F_3 folds around southeast plunging axes. A new L_3 lineation parallel with L_2 developed at the intersection of axial surfaces of F_2 and F_3 folds as suggested on Fig. 19. A metamorphic episode contemporaneous with this third phase of deformation is evidenced by post D_2 -pre D_3 dikes and sills of deformed metadiabases. The Harvey-Cardiff Arch, considered to be the southeastern boundary of the Highland Complex, may have behaved as a rigid unit during deformation D_3 thus protecting the Lowland areas from effects

of the third phase of deformation. Emplacement of the arch probably took place contemporaneously with deformation D₂ since L₂ lineations extend across the boundary between the Highland and the Lowlands.

Origin of stratiform foliation

It was mentioned earlier (page 39) that the granodioritic gneisses of M₂ migmatites may be part of a former basement stratigraphically underlying metamorphic tectonites of unit M₁ of the migmatite complex and metasedimentary rocks of unit GG (Fig. 3), to the southeast . If migmatites M₁ represent the basal section of rocks of the Grenville Group as suggested on page , it is possible that the so-called supracrustal metamorphic tectonites of unit M₁ and of unit GG, unlike metasedimentary rocks of the Hastings Lowlands to the east, may have been part of the infrastructure of the crust during the Grenvillian thermo-tectonic event(s). Wynne-Edwards (1965) emphasized the fundamental structural difference between catazonal (i. e. infrastructural) stratiform gneisses which have bedding plane foliation that accentuates their primary stratification, and these rocks of lower metamorphic grade, which exhibit axial plane or transposition foliation that obliterates their bedding. Within the Hastings Lowlands, progressive regional metamorphism can commonly be traced as far as the appearance of sillimanite (Wynne-Edwards, 1965, Divi and Fyson, 1973). However, although the mineralogy and the grade of metamorphism may be similar in the two areas, characteristic sillimanite-bearing schists and gneisses present in the Lowlands have not been found among the stratiform quartzo-feldspathic gneisses of the Highlands. A progressive transition from the mesozone to gneisses of the catazone (in the sense of Wynne Edwards, 1965) is thus not demonstrated for the Highlands. In terrains of low to medium metamorphic grade, however, mimetic crystallization, along pre-existing structural planes, usually accompanies

the initial stages of metamorphism. During progressive metamorphism, transposition of foliation transverse to bedding is common and may obliterate primary layering. If this process is pushed to completion as suggested by Wynne-Edwards for rocks of the Highlands, transposition of primary layering along foliation planes will result in the formation of stratiform gneisses. The psammitic gneisses of the study area may have formed by this process. This is suggested by the work of Best (1966) and Divi and Fyson (1973). They observed a progressive tightening of F_2 folds towards the Highlands and the development of a penetrative foliation S_2 , expressed in part by transposed lithologic layering and sheared out folds. Competent units, such as quartzite, tend to resist deformation and no minor folds were observed in these rocks. However, the quartzites are characterized by quartz grains flattened parallel to bedding and evidence of intense deformation is further supplied by mylonitization of this horizons parallel to bedding.

Summary

Two major phases of deformation are recognized in Glamorgan and Monmouth Townships.

F_1 , F_2 and F_3 folds are recognized on a small scale. D_1 structures are largely-obscured by later deformations. Isoclinally folded, recumbent and detached hinges of quartzitic layers with an axial foliation are recognized at a few localities. Of the two major phases of deformation, the older D_2 created isoclinal folds with southeasterly dipping axial surfaces. In the migmatite complex and in the western part of metasedimentary belt, the younger phase D_3 deformed F_2 folds around southeast plunging axes. Interference of D_2 and D_3 structures is common. To the southeast, beyond the belt of syenites and

nepheline gneisses, deformation D_3 may merely be expressed as a crenulation or mineral lineation L_3 . The Glamorgan Gabbro and syenites in a central zone within the belt of metasedimentary rocks and the Cheddar Granite along the eastern edge of that zone acted as rigid units during deformation D_3 . For this reason, deformation D_2 is largely responsible for the outcrop pattern in the southeastern half of the map area. In areas to the northwest, farther away from the possible rigid border units, a strong imprint of northwest trending F_3 folds on D_2 structures is characteristic.

To conclude, the area has been subjected to two major phases of deformation. The last deformation refolded the previous structures around southeast plunging axes. Thus these northwesterly trends are not Hudsonian trends, but were developed during late stages of the last deformation.

The boundary between M_2 and M_1 migmatites may well represent a transition from basement to cover rocks. However, pre-Grenvillian deformation has not been recognized with certainty in rocks to the northwest. Older structures may be obscured by later deformation and by intense migmatization.

PART C: METAMORPHISM

The grade of metamorphism is remarkably uniform throughout Glamorgan and Monmouth Townships and mineral assemblages are characteristic of the Almandine amphibolite facies (Armstrong and Gittins, 1968). However, since metamorphic assemblages in rocks from Glamorgan Township bear similarities with those of amphibolite facies rocks in both the Scottish Highlands and the Abukuma Plateau, metamorphism in Monmouth and Glamorgan Townships is considered to be of Miyashiro's low pressure intermediate type (Chesworth, 1971). Chesworth (1971) also mentions the occurrence of staurolite and cordierite in the scarce pelitic rocks of Glamorgan Township and of sillimanite in adjacent parts of the Grenville Province. From these observations and by reference to Richardson's (1968) experimental work, he suggests that metamorphic conditions would have ranged from 3.5 to 7 kilobars total pressure and from 580 to 700 degrees centigrade.

Polymetamorphism in the region is suggested by the occurrence of deformed and metamorphosed post D₂ diabase dikes and sills. For instance, in the belt of metasedimentary rocks (Monmouth Township) a metadiabase sill, 2-3 feet thick cuts the nose of a minor F₂ fold. It is bent in turn by a larger F₃ fold. Figure 20 illustrates a metadiabase discordant into a greyish-green garnetiferous quartzo-feldspathic gneiss along the Buckhorn Road, north of Stormy Lake. The contacts of the dike are irregular showing minor displacements parallel to the foliation in the surrounding rock. Emplacement of the dike is therefore considered to predate the last tectonic event in Glamorgan Township. Recrystallization within the mafic dike was probably contemporaneous with this last deformation. The parallelism of the resultant planar fabric with that outside the dike suggests that the diabase was recrystallized during a period when original

CROSS SECTION VIEWED FROM THE SE

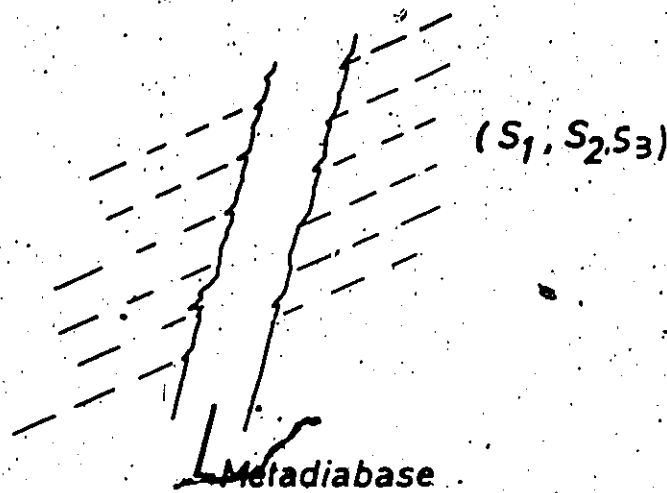


Fig. 20 *Metadiabase dike discordant into a greyish-green garnetiferous quartzo-feldspathic gneiss along the Buckhorn Road north of Stormy Lake. The contacts of the dike are irregular showing minor displacements parallel to the foliation in the surrounding rock.*

Emplacement of the dyke is therefore considered to predate the last tectonic event. Locality: Road cut along the Buckhorn Road, 3.1 mile north of Stormy Lake, Dysart township.

structural surfaces were reactivated.

Through the map-area, metadiabase dikes are commonly seen to be folded around southeast plunging axes. The dikes cut late or post D_2 , pre- D_3 granitic pegmatite (type B) (Plate 39). Therefore, this metamorphism should be synchronous with deformation D_3 or at least post D_2 . Emplacement of the diabase probably took place during a period of relative structural quiescence during which metamorphism decreased. Metamorphic pyroxenites associated to late kinematic - D_3 granitic pegmatite (type C) in zones of skarns in the marbles, suggest that metamorphism outlasted deformation D_3 at least locally. The possibility that the granodioritic gneisses of unit M_2 may be the product of a metamorphism older than the Grenvillian metamorphic events has to be considered since these highly deformed rocks are characterized by mafic schlierens cut by the oldest generations of granitic rocks (Type A), themselves tightly folded with the country rock. These deformation features were not observed in adjacent units to the southeast.

PART D: ROCK FORMING PROCESSES



This chapter summarizes the different rock forming processes discussed in this report. It also attempts to use the differential mobility of migmatite components as a tool to decide which of metasomatism, anatexis or magmatism contributed most to migmatite formation. Finally, in order to establish the geological framework of Glamorgan and Monmouth Townships, conclusions reached in this study are correlated with results obtained from selected studies dealing with other parts of the Grenville Province of Ontario.

As shown in part A (pp. 24), the complexity of migmatite structures increases as one proceeds northwesterly from the southeastern corner of the map area. The non-migmatized metamorphic tectonites of unit GG (Fig. 3) grade into migmatites with simple agmatitic structures in subunit M_{1a} of the migmatite complex. These, in turn, grade into stromatic or banded polymigmatites in subunit M_{1b}. M₂ migmatites are characterized by the presence of plastically deformed mafic inclusions or schlierens which are absent to the southeast. This is interpreted to mean that, at the present level of erosion, mobility of migmatites increases toward the northwest.

Migmatization also increases toward the northwest in Glamorgan and Monmouth Townships: a greater number of leucosomal phases are recognized in area M₂ of the migmatite complex and, in general, migmatite mobilites become increasingly abundant toward the northwest. However, the granitoid components common to the three migmatite areas are markedly more abundant in the zone of transition between unit M₂ and unit M₁. Rocks of unit M₁ are migmatized equivalents of rocks of the Grenville Group. They may represent the basal section of metamorphic tectonites of unit GG (Fig. 3) to the southeast,



because lithologies of the non-migmatized supracrustal metamorphic tectonites can be followed without difficulty into the migmatized area. From this and because the increase in mobility of migmatites toward the northwest is accompanied by an increase in migmatization it is suggested that a northwesterly trending section through Monmouth and Glamorgan Townships represents a passage into progressively hotter and therefore presumably deeper levels of the earth's crust.

Migmatites of unit M_2 are characterized by the presence of type A pegmatitic leucosomes older than the more common type B and type C leucosomes found throughout the map area. These pegmatitic mobilizates, diagnostic of Migmatites M_2 , cut the schlieren structures typical of this migmatite area. From this it is concluded that rocks in unit M_2 were migmatized and deformed prior to the formation of the M_1 migmatites. Consequently, the boundary between unit M_2 and unit M_1 could represent a major unconformity between a basement and its cover. This lithological boundary is diffuse and partly obliterated by a migmatite front and by at least two successive phases of deformation. Its approximate delineation is shown on the accompanying geological map, in pocket.

The formation of migmatite rocks, in general, (the term migmatite is defined on p. 96) can be explained in a number of ways:

- 1) by introduction of granitic material into the country rock from deeper levels of the crust (magmatism);
- 2) from partial melting of country rock giving rise to a felsic melt (anatexis). If the melt migrated for relatively short distances and then intruded the country rock, this type of anatexis is referred to as ectexis. If the melt was formed in situ, the term entexis is used;
- 3) by addition of K-feldspar through metasomatic processes, accompanied by a segregation of mafic and felsic portions within the rock;

- 4) by metamorphic differentiation.

In cases of magmatism and anatexis by ectexis, granitic components will commonly be found to cut the rock foliation. Synkinematic granites may intrude the country rock parallel to foliation; these granitic veins, however, are usually without dark rims by contrast with concordant granitic leucosomes formed by metamorphic differentiation and/or metasomatism.

The pegmatitic and granitic mobilizates, type B and type C respectively (Page 30 , figure 9) constitute neosomes formed during the latest and most widespread migmatitic event in the region. The locally intrusive nature of these granitic components is established from the following observations:

- 1) type B and type C mobilizates are commonly oblique to foliation of the surrounding gneisses and are usually without dark rims;
- 2) a close similarity exists between these mobilizates and larger intrusive granitic bodies in Glamorgan and Monmouth Townships. For example, type C mobilizates are mineralogically and texturally identical to the Stormy Lake Granite. This lens-shaped granite, conformable with the regional foliation, transects the boundary between unit M_1 and unit M_2 at high angles. Furthermore, the center of the granitic mass is free of foreign inclusions. From the above observations and correlations, granitic rocks in Glamorgan and Monmouth Townships appear to have been injected into the country rock. As a result, metamorphic differentiation and metasomatism are probably ruled out as major migmatite forming processes. The banded polymigmatites along the western margin of unit M_1 differ in that granitic components, parallel to the rock gneissosity, are rimmed with biotite and/or hornblende rich layers. Here, origins by metamorphic differentiation or metasomatism are probable. This could readily be explained if the M_2 - M_1 boundary represents a transition from a former basement

to its cover as previously suggested. This boundary would possibly act as a plane of weakness during deformation. Movements confined to this plane would have increased the mobility of adjacent rock units. It would also have eased the circulation of fluids such as water and/or possible K-feldspar metasomatizing fluids.

Did the granite crystallize from partial melting of paragneiss ~~after~~ migration of the melt on a relatively short distance, or were the granites introduced into the country rock from deeper levels of the earth's crust ? From a geochemical study of the Glamorgan gneiss, Chesworth (1966) concluded that partial melting of paragneiss produced migmatites and, locally, trondjemites, possibly using up heat released by the Bark Lake Diorite Intrusion. Further differentiation of the felsic melt would have given rise to the pink granites. He based his conclusions on the facts that 1) relationships between these rock types are gradational in the field, and 2) the bulk composition of migmatites is identical to that of the paragneiss. With some restrictions, this interpretation would be compatible with the idea of remobilization of an older basement because Chesworth's conclusions can only be applied to M₂ migmatites. Texturally and chemically, M₁ migmatites are paragneisses with injected pink granitic material. M₂ migmatites are only paragneissic with respect to their mineral assemblage and with respect to their total composition, i. e. to the composition of the leucosome and the melanosome together. If migmatites of unit M₂ are derived from an older basement through remobilization, such differences between the two migmatites ~~areas~~ could easily be accounted for. Furthermore, it can be shown that the sequence of events proposed by Chesworth was episodic through time: for instance, the grey sodic gneisses of unit M₂, because of their high sodium content, are possibly metamorphosed equivalents of rocks of dacitic composition (Chesworth, 1970b). It is not clear whether this metamorphic event took place

contemporaneous with or was earlier than deformation D_1 in the region. However, since M_2 migmatites are characterized by deformation features not seen in migmatites to the southeast, it is thought to be an older event that may predate deposition of the Grenville Group. Subsequent to this, both presumed basement and cover rocks would have been subjected to several pulses of deformation and migmatization during the Grenvillian thermo-tectonic event. Metamorphic fabrics of gabbroic rocks in Glamorgan and Monmouth Townships indicate that the gabbros were emplaced during deformation D_2 (see page 36). Assuming that the Bark Lake Diorite and Minicock Lake Diorite were also emplaced at approximately that time, the trondjemites should have the same age, according to Chesworth. Still later, the potassic granites may have been derived from further differentiation of the trondjemites as already suggested by Chesworth (1966). Therefore the source of potassic granites would lie in unit M_2 to the northwest, possibly in a former basement. Consequently, the granodiorite gneisses of unit M_2 would be the parent rock of the felsic melt which gave rise to the potassic granites. Therefore, the anatexis model would apply to M_2 migmatites. According to Chesworth (1970a), the trondjemitic melt would have formed in situ. Thus the initial stages of anatexis in Glamorgan Township should be referred to, more correctly, as entexis which implies little or no migration of the felsic melt. The potassic granites were possibly derived from further differentiation of the trondjemitic melt. These granites (Types B, C, D, and E) intruded the granodiorite gneisses of unit M_2 . Since the grey gneisses are considered to be the parent rock of the potassic granites and because potassic melt migrated, this more advanced stage of anatexis is referred to as ectexis. The molten potassic material migrated farther still and intruded rocks of the cover to the east and southeast. Since rocks of units M_1 and GG (Fig. 3) were intruded by granitic material foreign to them, it is more appropriate to talk of magmatism. These conclusions are supported

by the fact that granitic rocks become younger toward the east and southeast as illustrated in Fig.10, page .

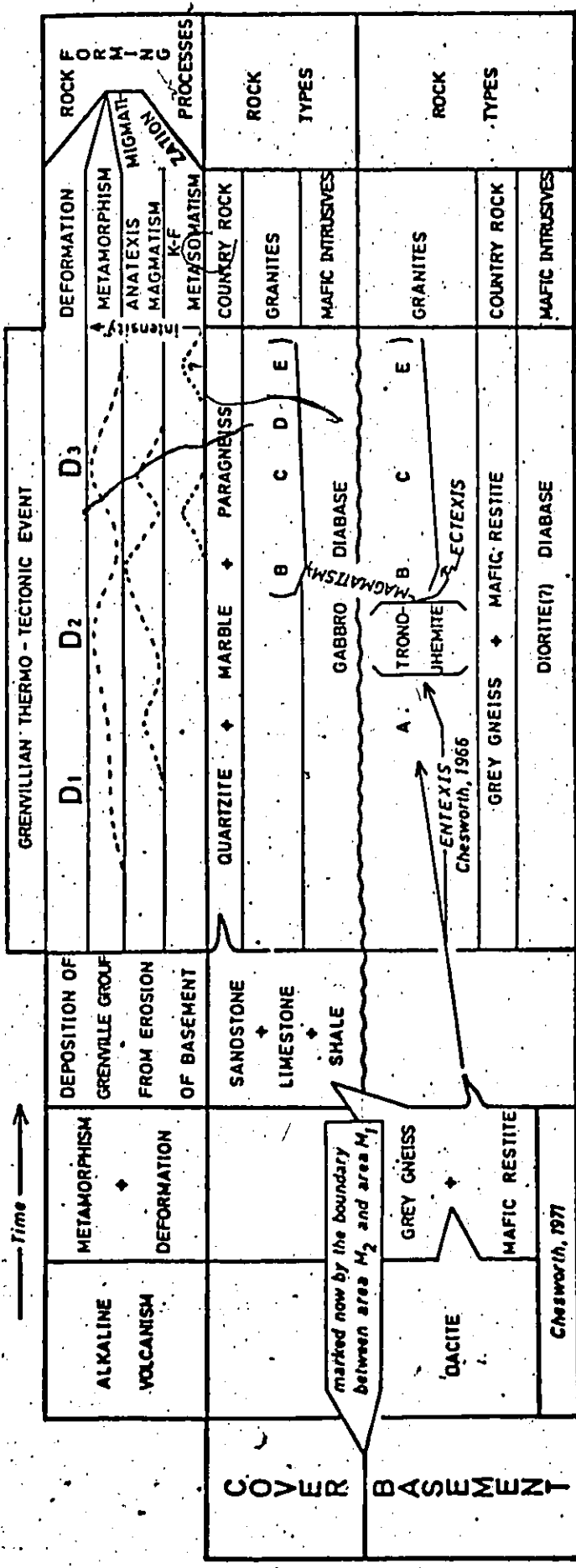
Although metasomatism is not considered here to have been a major factor in the evolution of rocks in Glamorgan and Monmouth Townships, its effects should not be underestimated. Some petrographic features suggest that metasomatic addition of K-feldspar has taken place locally: for instance, feldspathization in the form of K-feldspar blastesis is common in the melanosome and the leucosome of migmatites. The presence of deformed elongated K-feldspar porphyroblasts, often with peripheral granulation, is characteristic of type A and type B granites but is not observed in younger synkinematic type C granites. The occurrence of interstitial microcline in the grey gneisses of unit M_2 and in the paragneisses and quartzites of unit M_1 and unit GG (Fig 3) to the southeast may have resulted from intercrystalline hydrothermal solutions or may be a primary component of the rock. Sodium metasomatism also occurred to a minor extent: plagioclase grains interstitial to microcline porphyroblasts and sending perthitic bodies into the microclines along the twin planes has been observed. In some instances these metasomatic fluids have migrated along cracks in fractured microcline porphyroblasts indicating a tectonic influence.

Figure 21 illustrates the major events in the history of the rocks of Glamorgan and Monmouth Townships.

The petrography and structural evolution of rocks of Glamorgan and Monmouth Townships bears striking similarities with that of rocks of the western boundary of Renfrew County (eastern Ontario). These supracrustal metamorphic tectonites of the Grenville Group are known as the Radcliffe Hybrid Gneiss.

" It is shown that the latter complex (Radcliffe Hybrid Gneiss) can be subdivided by qualitative structural analysis into two units of differing tectonic complexity. A polymigmatitic unit

PETROGRAPHIC EVOLUTION IN PARTS OF GLAMORGAN AND MOUNMOUTH TOWNSHIPS



GRENVILLE PROVINCE OF ONTARIO
(FIG 21)

displaying the effects of at least five phases deformation and containing at least the same number of leucosomal phases lies to the northwest of a less complex migmatitic unit displaying three phases of deformation and only two leucosomal phases. The former is identified as pre-Grenvillian basement and the latter as the basal portion of the Grenville Supergroup cover sequence which was transgressed by a rising migmatite front during Grenville Orogeny" (Appleyard, 1974, p. 2).

The two areas can thus be considered to expose the same erosional level of a northeasterly trending continuous rock series.

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APPENDICES •

APPENDIX I

EQUAL AREA PROJECTION

The plotting of the structural readings were carried out by computer (Fig. 19, 20, 24). The program used, made available by Dr. K. J. Rosen-gren of the Department of Geophysics and Geochemistry, Australian National University, was slightly modified by Carrara (1972).

Three different types of diagrams are obtained for each group of data:

- 1) Scatter diagram
- 2) Contour diagram by Schmidt method
- 3) Contour diagram by Kamb method

The diagram contoured by the Kamb method only were used. For diagram with a large number of data (over 200) the Kamb and Schmidt methods do not differ appreciably. However, the Kamb method is particularly useful for diagrams with a small number of points.

This method measures the statistical significance of orientation densities; i.e., it measures the probability that the observed orientation density could have resulted from random sampling of a population that lacks preferred orientation. This probability is determined by the following method as described by Kamb (1959, p. 1908): "the area A of the counter (0.01 in Schmidt method) is variable and chosen in such a way that, if the population (of the readings) lacks preferred orientation, the number of points E expected to fall within a given area A, is three times the standard deviation (σ) of the number of points that will actually fall within the area (σ) under random sampling of the population. This ensures that the observed orientation densities, if obtained by random sampling of a non-preferentially oriented population will not fluctuate widely

from the expected density E/A . Observed densities that differ from E/A by more than two or three times the standard deviation σ (for random orientation) are then likely to be significant ". Consequently, the contour lines are drawn at intervals of 2 (0, 2, 4) where the expected density E is 3 for no preferred orientation.

Stereonets (Fig. 19, 20, 24) are lower hemisphere. Shaded areas indicate areas where contour intervals in standard deviation are > 8 (lineation stereonets); and contour intervals $>$ than 6 (foliation stereonets).

APPENDIX II

TABLES

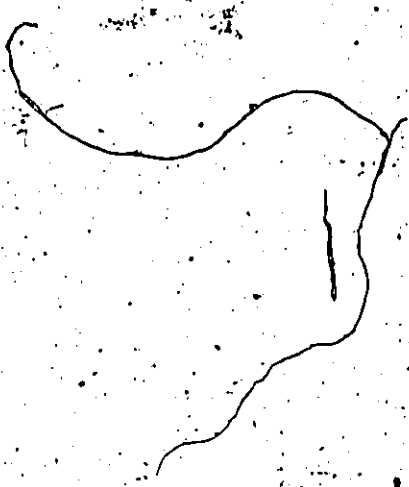


Table 5: Modal analyses (volume per cent)

Paragneiss amphibolite group

Field number	1108	0901	0912	1101-d	0909	4603
Plagioclase	34.0	51.1	26.0	---	---	---
Scapolite	---	---	---	47.6	60.1	55.0
Quartz	10.0	12.1	19.0	6.0	2.2	---
Microcline	19.0	13.1	---	---	---	---
Biotite	21.0	4.3	14.0	12.3	3.4	---
Hornblende	8.0	13.8	36.0	25.6	28.4	---
Clinopyroxene	---	---	3.0	---	---	39.5
Garnet	5.0	---	---	---	---	---
Calcite	2.0	---	---	---	---	---
Sphene	---	---	---	0.5	0.9	5.0
Apatite	---	1.4	0.6	0.4	0.3	0.5
Magnetite	---	3.0	---	---	---	---
Allanite	---	0.05	---	---	---	---

Rock types
 their appartenance
 to one of the major
 lithological units
 of Fig. 3

Paragneiss from unit GG
 Paragneissic paleosome of migmattites from unit M1b
 Paragneissic paleosome of migmattites from unit M1b
 Paragneiss amphibolite from unit GG
 scapolite- amphibolite paleosome of migmattites from unit M1a
 scapolite- amphibolite paleosome of migmattites from unit M1a
 scapolite- amphibolite paleosome of migmattites from unit M1a
 scapolite- amphibolite paleosome of migmattites from unit M1a

Table 6: Modal analyses (Volume per cent)
Granodioritic gneisses of unit M₂ (Fig. 3)

<u>Field number</u>	<u>4805</u>	<u>4506-a</u>	<u>1914</u>	<u>C7</u>	<u>D1</u>	<u>F2</u>	<u>H4</u>	<u>K2</u>
Plagioclase	51.4	28.0	28.8	45.9	51.1	48.2	44.4	48.3
Quartz	31.1	31.0	34.1	35.1	30.2	32.1	32.3	23.6
Microcline	5.8	10.0	8.7	9.8	10.6	11.9	14.8	7.7
Biotite	9.6	15.0	12.0	6.2	6.7	6.8	7.4	12.6
Hornblende	2.1	11.0	9.4	1.5	trace	trace	---	6.7
Accessories	trace	3.3	5.5	1.5	1.4	1.4	1.1	1.1
Plag. Comp.				An ₂₅	An ₁₉	An ₁₅	An ₂₁	An ₂₈

Modal Analyses of sample nb C7, D1, Fe, and K2 were taken from Chesworth (1966).

Table 7: modal analyses (volume per cent)

Pink granitic rocks

Type (A-E) (See, text, p. 25)	A	B	B	C	C	D	D	E	E
Field number	3106	3105-A	0911	4501	1005	6001	1001	J-3	0305
Plagioclase	36.0	36.0	19.0	37.0	27.0	38.0	39.0	37.0	50.5
Quartz	32.0	25.0	33.0	38.0	31.0	36.0	34.0	32.0	26.9
Microcline	32.0	38.0	26.0	25.0	39.0	25.0	26.0	29.0	20.0
Biotite	---	---	trace	trace	---	1.0	0.01	trace	0.8
Hornblende	---	0.02	---	---	3.0	---	---	trace	---
Apatite	---	---	---	---	---	---	---	---	---
Sphene	---	---	trace	---	---	trace	---	---	---
Magnetite	---	---	trace	---	---	---	trace	0.8	---

Vein rocks except sample 4501 (Stormy Lake Granite) and sample 0305 (Hadley Granite)

N. B. Modal analysis of sample j-3 is from Chesworth (1966).

Table 4 Modal analyses (volume per cent)

Cheddar Granite (pink granite gneiss)

Field number	IX-C	0204	0712	I-A	V
Microcline	22.5	19.2	17.3	18.2	20.0
Quartz	21.6	45.6	8.9	25.9	34.0
Plagioclase	52.1	33.3	55.4	47.6	38.8
Amphibole	2.8	0.4	11.9	2.8	5.0
Biotite	0.2	trace	3.0	0.5	
Magnetite		13.6		3.7	0.7
Sphene	0.3	trace	2.8	0.7	0.5
Apatite	0.1	0.1	0.5	0.1	
Calcite	0.1				0.4

N.B. The Cheddar Granite is the circular-shaped granitic body in the SE corner of the map area. It is part of the Harvey-Cardiff Arch (Fig. 2).

K

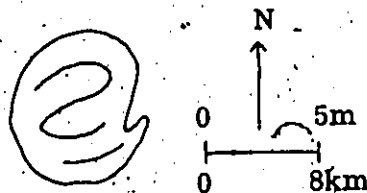
APPENDIX III

THE CHEDDAR GRANITE

A rapid survey of the Cheddar Granite shows that the circular granitic body is not a dome, but that on the average, foliations within the gneissic granite dip in a southerly direction (Fig. 21) suggesting tight folding and outlining a major F_2 fold, with axial surfaces striking east.

Figure 22

Map view of the Cheddar Granite showing the trace of foliation planes.



To speculate further on the origin of this granitic mass, the dominance of an easterly foliation within the granite could indicate that the foliation rotated from a northeasterly * to an easterly direction during D_3 , therefore implying that the granite was not completely rigid at that time.

* Axial Surfaces of F_2 Folds within metasedimentary rocks of Glamorgan and Monmouth Townships strike northeasterly and dip towards the southeast (page

).

APPENDIX-IV

GLOSSARY

GLOSSARY

The following list of definitions is based on that given by R. V. Dietrich and K. R. Mehnert at the 21st International Geological Congress, in Copenhagen, 1960 (Part XXVI, Suppl. Vol., Section 1-21, pp. 59-68).

* = Term derived from other sources.

- Agmatite:** Migmatite with breccia-like structure.
- Anatexis:** Melting of rock (modified by supplementary terms such as: differential, selective, partial or complete melting).
- Arterite:** Migmatite formed by the injection of magma.
- Augen gneiss:*** A granulated gneiss containing " porphyroblasts " or ungranulated remnants chiefly feldspar; cf. mortar structure (Moorhouse, 1959, p. 414).
- Blastesis:** The preferential growth of a particular mineral.
- Blastomylonite: *** A rock composed of granulated material recrystallized so that the cataclastic texture is vague (Moorhouse, 1959, p. 414).
- Cataclastic:** Pertaining to a texture found in metamorphic rocks in which brittle minerals have been broken and flattened in a direction at right angle to the pressure stress.
- Ectexis:** Formation of a migmatite by in situ formation of a melt; cf. entexis.
- Entexis:** Formation of a migmatite by intrusion of a melt; cf. ectexis.
- Flaser structure:*** The texture shown by a rock containing lenticles of uncrushed rock in a granulated, streaky matrix of the same material (Moorhouse, 1959, p. 414).
- Grenville Group:*** A supracrustal group consisting of marble, quartzite, aluminous gneiss and minor volcanics, widely distributed in southeastern Ontario and southwestern Quebec (Baer, Fraey and Ayres, 1972, p. 18).
- Grenvillian Orogeny:*** The last major period of folding and metamorphism affecting the Grenville Province; it is thought by many to have given rise to the prevalent K-Ar ages of about 950m. y. (Stockwell, 1970; Wynne Edwards, 1967). According to

- others, this "age", however, may represent a thermal event (uplift ?) independant of folding and metamorphism evidence of an orogeny affecting the whole province at this time has yet to be demonstrated (Harper, 1967; Baer, 1971), (Baer, Fraey, Ayres, 1972, p. 18).
- Granitoid:** Comprehensive field term for a rock group of granite-like composition and texture.
- Hydrothermal:** 1) any natural; hot water-rich solution. 2) hot-water-rich solution derived from a magma.
- Hypidiomorphic: *** Synonym for subhedral.
- Leucosome:** Leucocratic part of a migmatite, generally rich in quartz and feldspar; cf. melanosome.
- Leucocratic:** A term applied, here, to light-colored rocks, especially igneous rocks, containing less than 5% of dark minerals.
- Melanosome:** Melanocratic part of a migmatite, rich in mafic minerals; cf. leucosome.
- Metablastesis:** Preferred crystallization of a mineral (e.g. feldspar), or a group of minerals, both by isochemical recrystallization or by metasomatism (with no evidence for the existence of a separate mobile phase).
- Migmatite:** Megascopically composite rock consisting of two or more petrographically different parts, one is the country rock in a more or less metamorphic stage, the other is of pegmatitic, aplitic, granitic, or generally plutonic appearance.
- Migmatization:** Formation of migmatite.
- Mimetic crystallization *:** Process by which recrystallization is "assumed" to take place with the new grains growing around "seeds" or small nuclei which acquired their orientation by these processes before enlargement (e.g. recrystallization parallel to bedding surfaces in sedimentary rocks) (Moorhouse, 1959, p. 419).
- Mobilizate:** Geochemically mobile phase formed by mobilization.
- Mortar structure: *** The texture shown by augen gneisses -lenticular grains enclosed in granulated material (Moorhouse, 1959, p. 414); cf. augen gneiss.
- Neosome:** Newly formed part of a migmatite; cf. paleosome.
- Paleosome:** Parent rock of a migmatite; cf. neosome.

Resister: The term stresses the fact that one rock may offer greater resistance to granitization than another by virtue of its chemical composition or its " impenetrable " mineral fabric.

Restite: Geochemically immobile part of a rock during partial mobilization of rock components.

Schlieren: Irregular streaks or masses with blended outlines in migmatites.

Stromatites: Migmatite with layered structure.

PLATES

Plate 1

Stratification in quartzite emphasized the presence of thin arkosic horizons which weather more readily than the quartzite (Q). Locality: 1 mile north of Tory Hill, Monmouth Township.

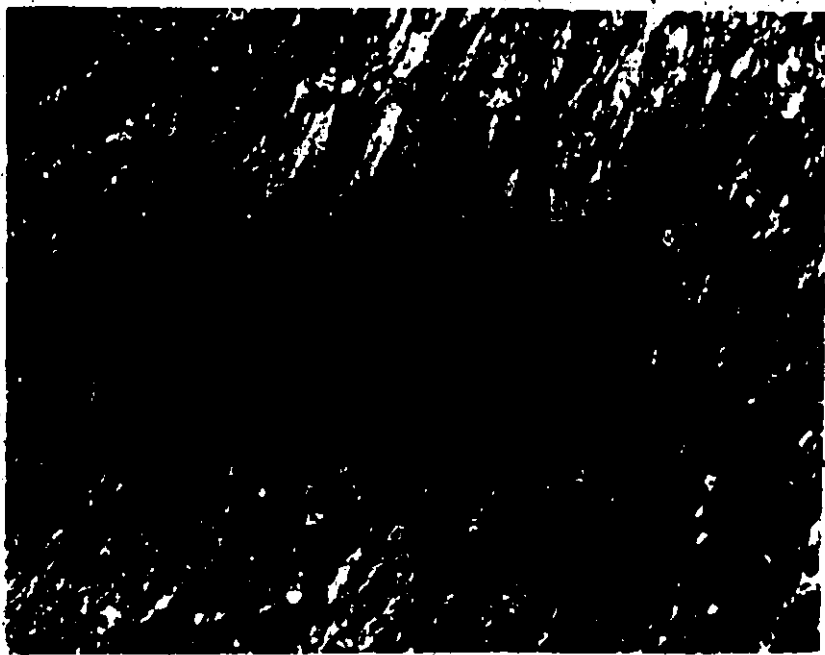
Plate 2

Finely laminated quartzite with blastomylonitic textures (Q). Laminations are due to alternating layers of straky quartz. Crossed nicols.

PLATE 1



PLATE 2



(X 8)

Plate 3

Three sets of vertical joints typically intersect the subhorizontal bedding surfaces of quartzite units (Q). Locality: 1 mile north of Tory Hill, Monmouth Township.

PLATE 3



Plate 4

Mortar structure in granitic pegmatite (type B in table 2, p.30 , or leucosome L₁). Part of an elongated microcline porphyroblast exhibiting peripheral granulation. The microcline is set in a matrix of fractured quartz and feldspar grains and of streaky quartz with oscillatory extinction. Crossed nicols.


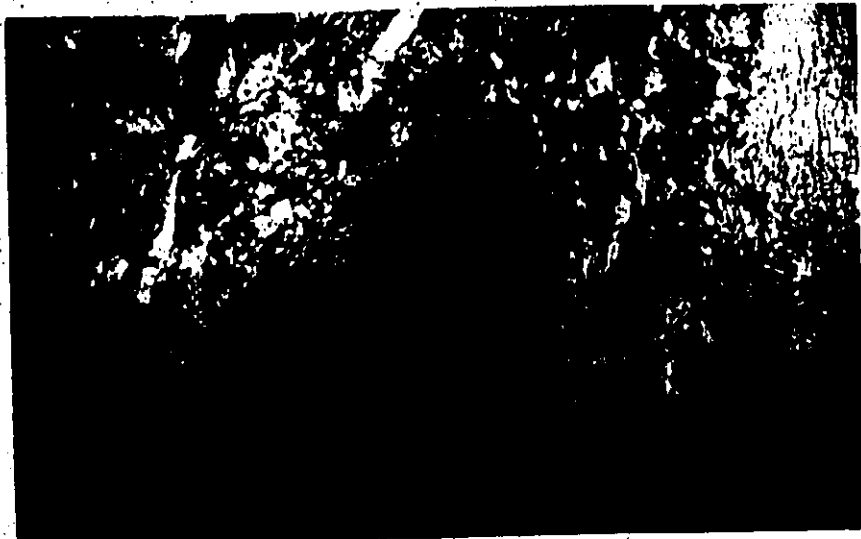


Plate 5

Flaser structure in granitic pegmatite type B (see table 2 on page 30) characterized by cataclastic deformation of the mineral constituents: A matrix of fragmented grains of plagioclase, microcline and quartz is distributed around larger feldspar porphyroblasts with corroded edges and around elongated quartz grains. Crossed nicols.

PLATE 4



(X 3.5)

PLATE 5



(X 3.5)

Plates 6 and 7

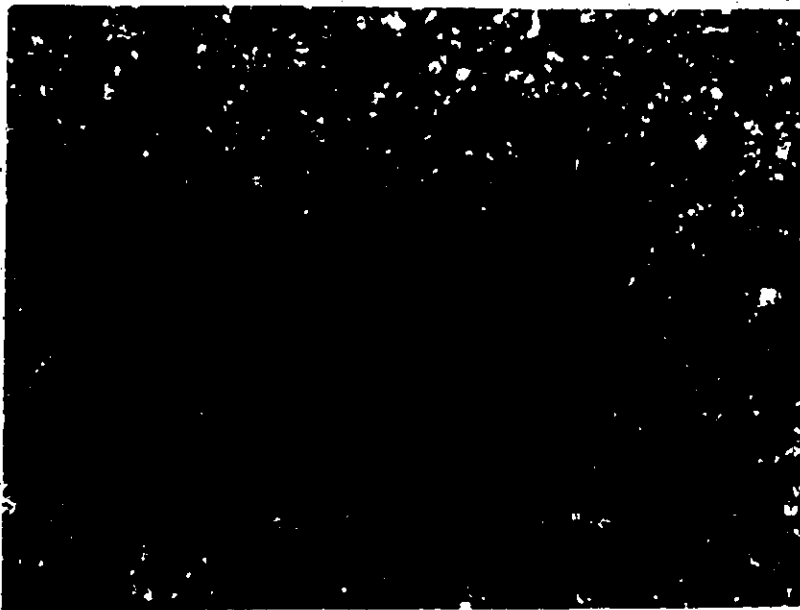
Plates 6 and 7 represent 2 sections of a fine to medium-grained leucogranite (referred to as type "C" granite on page 30) cut 90 degrees to each other. In plate 6, quartz grains are elongated and preferentially oriented defining a strong mineral lineation. In plate 7, quartz and feldspar grains are equidimensional. Quartz grains are thus rod-shaped or in needles. Crossed nicols.

PLATE 6



(X 5)

PLATE 7



(X 5)

Plate 8

Type A granitic pegmatite (8P) (table 2) in grey granodiorite gneiss (4gr). Edges of the granitic pegmatite are sharp but irregular and rimmed with a thin film of biotite. This granitic pegmatite is diagnostic of migmatite unit M_2 (Fig. 3). Locality: Road cut along the North Buckhorn Road, 0.5 mile north of Stormy Lake, Glamorgan Township.

Plate 9

Pinch and swell structure resulting from the boudinage of a type A granitic-pegmatitic layer (8P) in the banded polymigmatites along the boundary between unit M_2 and unit M_1 (Fig. 3). Northwest trending, southeast plunging isoclinal F_2 fold with crenulation of composite $S_1 - S_2$ gneissosity in the hinge area of the fold (section viewed from the southeast). Locality: north shore of Stormy Lake, Glamorgan Township.

PLATE 8



PLATE 9



Plate 10

Schlieren structure in migmatites: mafic schlierens, in granodiorite gneisses (4gr) cut by a slightly transgressive type A granitic pegmatite (8P). Locality: Road cut along Northern Buckhorn Road, 0.75 mile south of Stormy Lake, Glamorgan Township.

Plate 11

Sharp contact of the Stormy Lake Granite (8l) with grey granodiorite gneiss (4gr). Locality: eastern extrimity of Stormy Lake (lake shore), Glamorgan Township.

PLATE 10

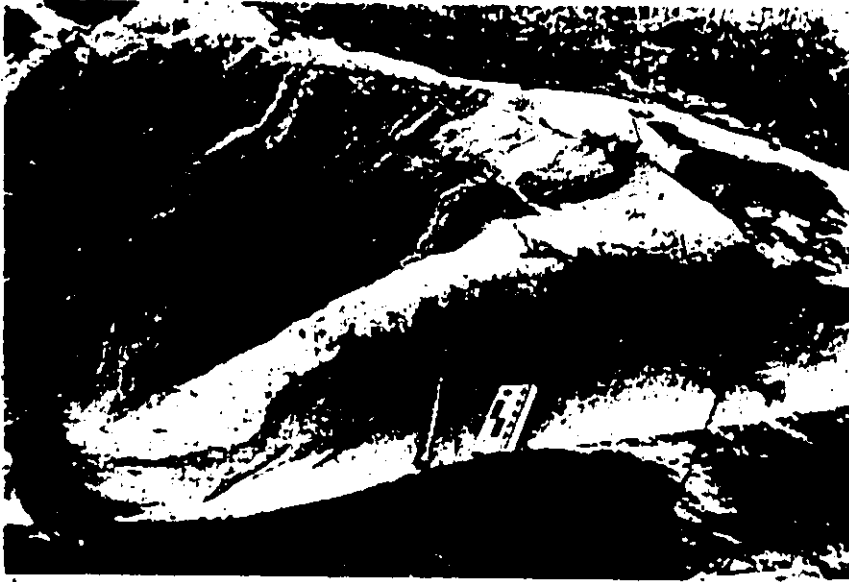


PLATE 11



Plate 12

Type D granitic pegmatite (8P) in contact with a biotite-rich paragneiss (2Pb) of unit GG (Fig. 1). This type of granite usually occurs as irregular patches or pockets in the belt of metasedimentary rocks of Monmouth Township. Locality: roadcut along highway 121, 3.5 miles east of the eastern limit of the map-area. Cardiff Township.

PLATE 12



Plate 13

Massive texture of type D granitic pegmatite (8P). Interlocking grain boundaries and hypidiomorphic textures are characteristic of this granite; however, numerous cracks on the surfaces of individual grains indicate that the rock was subjected to mechanical deformation. Crossed nicols.

Plate 14

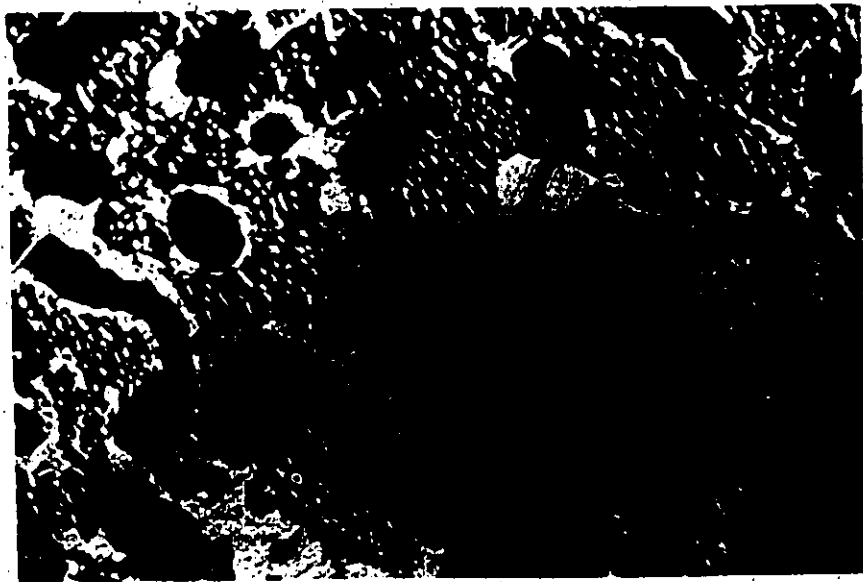
Graphic texture in type D pegmatitic granite (8P). The microphotograph represents part of a large microcline-perthite grain containing inclusions of fragmented plagioclase grains in different optical orientations. Graphic quartz, at extinction, cuts across the microcline-perthite and the plagioclase grains and is surrounded by a halo of plagioclase alteration. The thin section was cut at right angle to the "C" axis of quartz grains. Crossed nicols.

PLATE 13



(X 5)

PLATE 14



(X 5)

Plate 15

A thin, undeformed, dike of leucocratic aplite (type E granite) cutting the granodiorite gneiss (4gr) of unit M₂ (Fig. 3). Locality: North Buckhorn Road, Glamorgan Township.

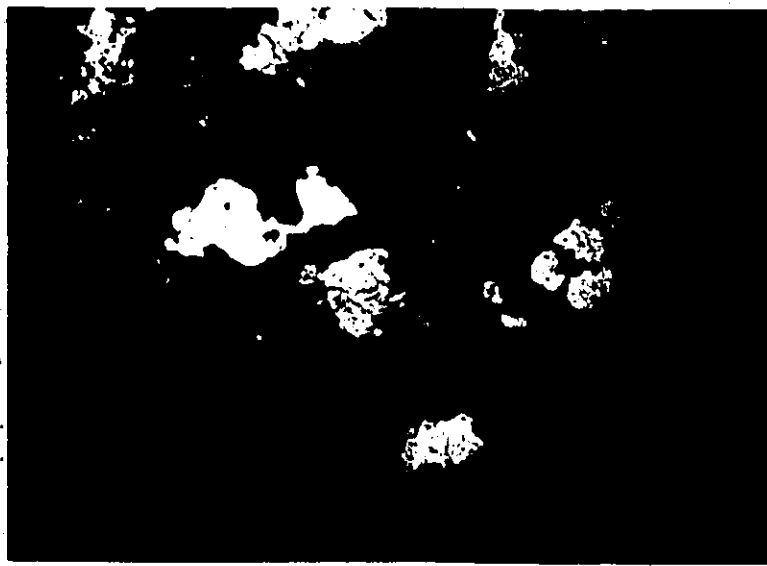
Plate 16

Hypidiomorphic-granular texture of the Hadley Granite (type E granite).
Crossed nicols.

PLATE 15



PLATE 16



(X 5)

Plate 17

A dike of type B granitic pegmatite (8P) cutting across a conformable type A granitic pegmatite (8P) vein. These granites are themselves cut by a discordant vein of a type C medium-grained leucogranite (8 l) (see diagram below). Locality: roadcut along the North Buckhorn Road, 1 mile north of the junction with highway 503, Glamorgan Township.

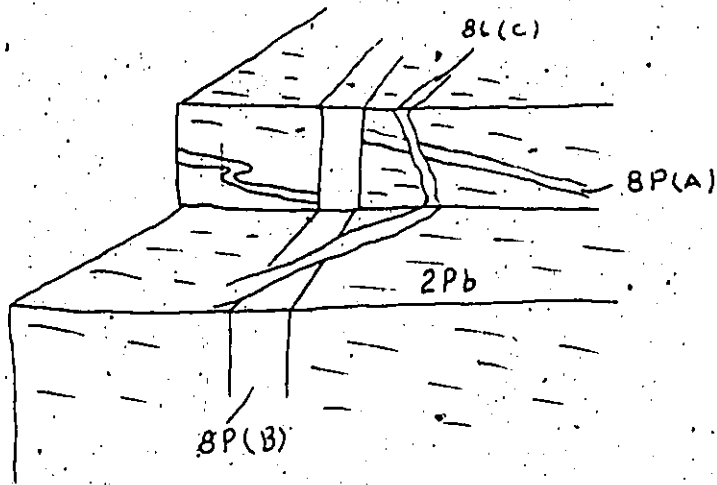


Plate 18

Type A granitic pegmatite (8 P) cut by type C medium-grained granite (8 l) vein in granodiorite gneiss. Note the metablastic feldspars within the pegmatitic layer. Locality: Roadcut along the Northern Buckhorn Road, 2 miles north of the junction with highway 503.

PLATE 17



PLATE 18

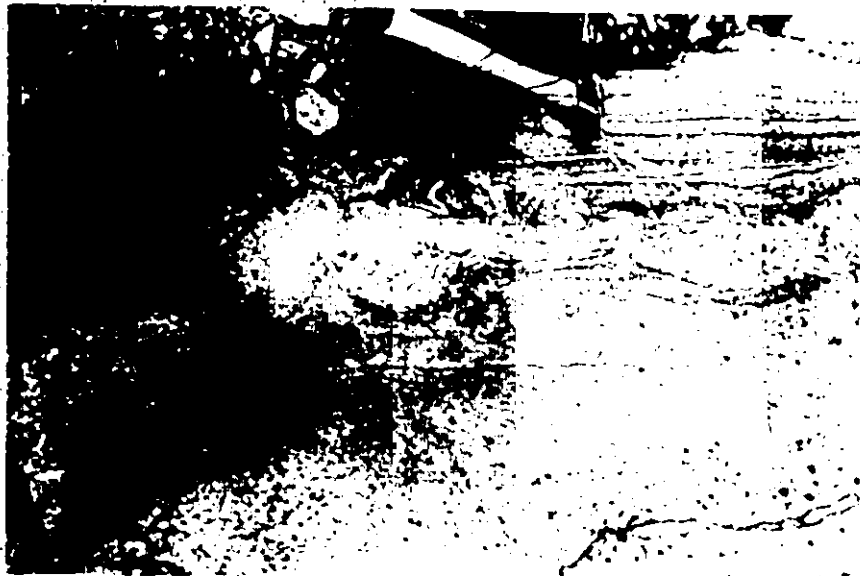



Plate 19



A slightly transgressive type A granitic pegmatite (8P) tightly folded in a granodiorite gneiss (4gr). Note that the style of deformation of the pegmatitic vein, i.e. the fold shape, is exactly similar to that of the surrounding gneiss despite the difference in competency of the two rock components. Locality: North Buckhorn Road, Glamorgan Township.

Plate 20

A concordant vein of type B granitic pegmatite (8P) folded in a quartz-plagioclase-biotite gneiss and cut by a type C medium-grained lineated leucogranite (81). Locality: Roadcut on gravel road, south of Glamor Lake, Glamorgan Township (c.f. fig. 16).

PLATE 19

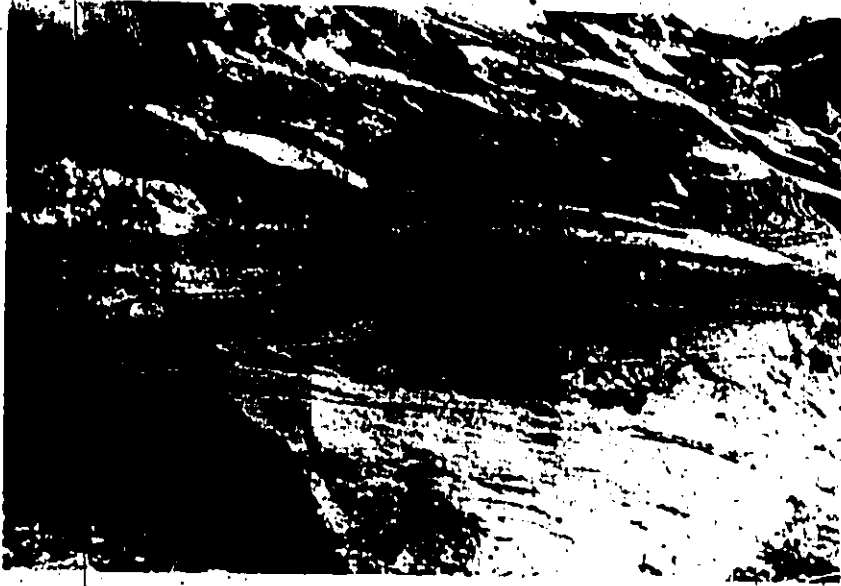


PLATE 20



Plate 21

A sill of type C medium-grained biotite granite (8 b) in contact with a biotite-hornblende-plagioclase rocks (2Pb, 2Ph). The contact between the two units outlines a northwest trending-southeast plunging F_3 fold. Section viewed from the southwest. Locality: Roadcut along the North Buckhorn Road, 1.25 miles south of Glamor Lake, Glamorgan Township.

Plate 22

Agmatitic structure in migmatites of unit M_1 (fig. 3): type B pegmatitic dikes (8P) surround angular blocks of quartzite (Q) and of plagioclase-quartz-biotite gneiss (2Pb). Locality: 1 mile to the north-northwest of Torry Hill, Monmouth Township.

PLATE 21



-contact

8b(C), 2Pb, 2Ph

PLATE 22



Plate 23

Stromatic structure in banded migmatitic rocks: these migmatites have been termed stromatic migmatites as some layers may adopt pegmatoid or granitoid character following Mehnert (1968). Locality: highway 503, approximately 2 miles west of Gooderham.

Plate 24

Banded polymigmatitic rocks cut at high angle by post-kinematic aplite veins. Locality: north shore of Stormy Lake, Glamorgan Township.

PLATE 23



PLATE 24



Plate 25

A quartz rich lens with preservation of an internal (S_1 or Pre-Grenvillian Tectonic Surface (?)) foliation oblique to the (S_1 - S_2) schistosity-gneissosity of the surrounding granodiorite gneiss (4 gr) . Locality: Roadcut along the North Buckhorn Road, Stormy Lake area, Glamorgan Township

PLATE 25



Plates 26 and 27

Quartz-rich lenses, aligned parallel to the schistosity-gneissosity of the surrounding granodiorite gneiss (4gr.). The lenses enclose a relic (?) foliation (S_1 or pre-Grenvillian tectonic surface (?)) oblique to the surrounding S_1 - S_2 foliation, but parallel to a line joining the separate lenses suggesting that they originally formed a continuous layer. Locality: Roadcut along the North Buckhorn Road, Glamorgan Township. (See Fig. 11).

PLATE 26



PLATE 27

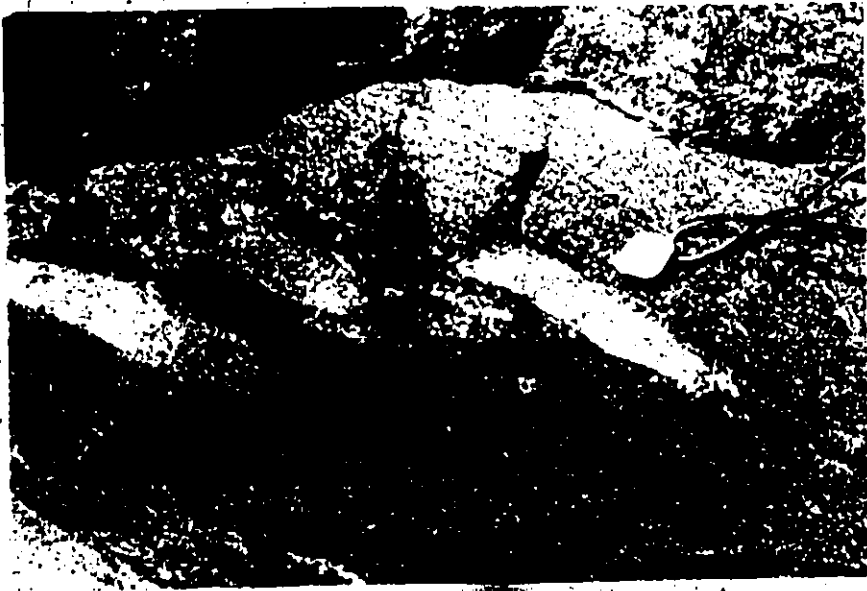


Plate 28

Recrystallized quartz-lens, in the nose of an isoclinal F_2 fold, defining an axial S_2 surface. The bent schistosity in the surrounding granodioritic gneiss (4gr) has maintained original "S" planes. Locality: Roadcut along the North Buckhorn Road, 0.5 mile north of Stormy Lake, Glamorgan Township.

Plate 29

Impure quartzite layer (Q) folded into a subhorizontal isoclinal northeast trending F_2 fold in marble (3). Locality: roadcut along highway 121, 0.75 mile east of Tory Hill.

PLATE 28



PLATE 29



Plate 30

Northwest trending-southeast plunging asymmetric F₃ fold in plagioclase-quartz-biotite gneiss (2Pb). The position of the hammer indicates the orientation of the fold axis. Section viewed from the northwest. Locality: Road-cut along HWY 121, 0.75 mile to the southeast of Dudmon Lake.

PLATE 30



Plate 31

Northwest trending-southeast plunging asymmetric similar F_3 fold in a series of impure quartzite layer. Section viewed from the southeast. Locality: Roadcut along highway 500, 7 miles northeast of Wilberforce, Cardiff Township.

Plate 32

Northwest trending subhorizontal coaxial F_2 and F_3 folds. Note the bent axis of F_3 folds in the center of the photograph. Section viewed from the northeast. Locality: roadcut along HWY 500; 7 miles northeast of Wilberforce, Cardiff twp. (c.f. Fig. 15).

N. B. Plates 31 and 32 are from the same outcrop and represent 2 sections at right angles to each other. The position and orientation of the hammer on the outcrop is the same for the two plates.

PLATE 31



← | plate
32

bent F. A.

PLATE 32



Plate 33

Northwest trending-southeast plunging F_2 fold in granodiorite gneiss (4gr). The structure is cut by a dike of type B granitic pegmatite (8 P). Section viewed from the northwest. The arrow points toward a hidden face of the outcrop where the structure illustrated on plate 34 was observed. Locality: road-cut along the North Buckhorn Road, Glamorgan Township.



Plate 34

A massive quartz-rich pod outlining the detached hinge of a recumbent interfolial F_1 fold in granodiorite gneiss (4gr). Locality: North Buckhorn Road, Glamorgan Township.

PLATE 33



plate
34

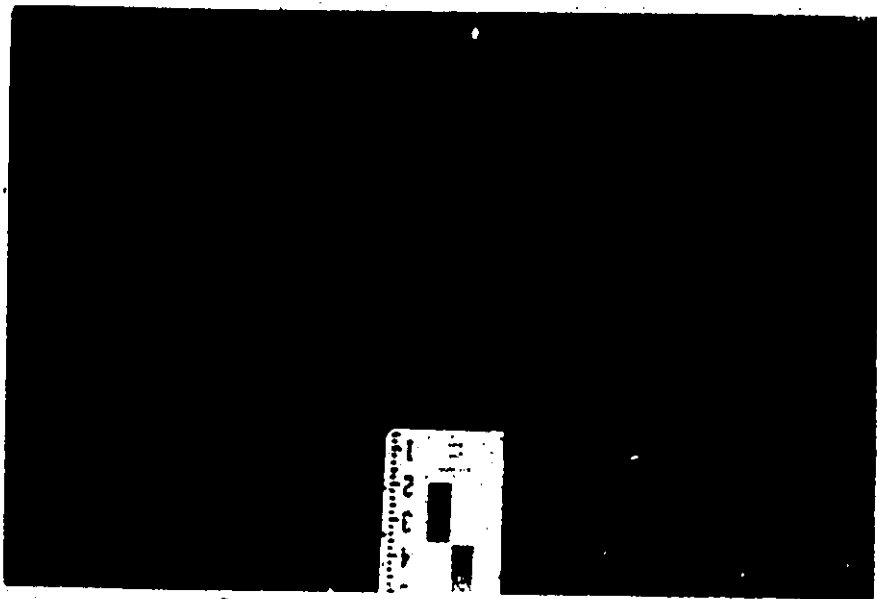
PLATE 34




Plate 35

Detached hinge of a recumbent, isoclinal F_1 fold outlined by a massive quartz-rich pod in granodiorite gneiss (4gr). Locality: roadcut along the North Buckhorn Road, Glamorgan Township.

PLATE 35





Plates 36 and 37

Detached fold hinges in granodiorite gneiss (4gr). The metamorphic layering both within and outside the quartz-rich pods is bent around the fold hinges. These structures are cut by a dike of type A granitic pegmatite (8P). Locality: North Buckhorn Road, Glamorgan Township.





PLATE 36



PLATE 37





Plate 38

Northwest trending upright subhorizontal similar F_3 folds in biotite granite gneiss. Locality: North Buckhorn Road, 1.8 mile north of Stormy Lake, Glamorgan Township.



Plate 39

Metadiabase (5Db) dike cutting a conformable type B granitic pegmatite (8P). A northwest trending-southeast plunging F_3 fold in biotite quartzo-feldspathic gneiss (2Pb) abuts againsts the mafic dike and deforms the contacts of both the granitic pegmatite and mafic dike. Locality: North Buckhorn Road, 1 mile north of the junction with HWY 503, Glamorgan Township.

PLATE 38



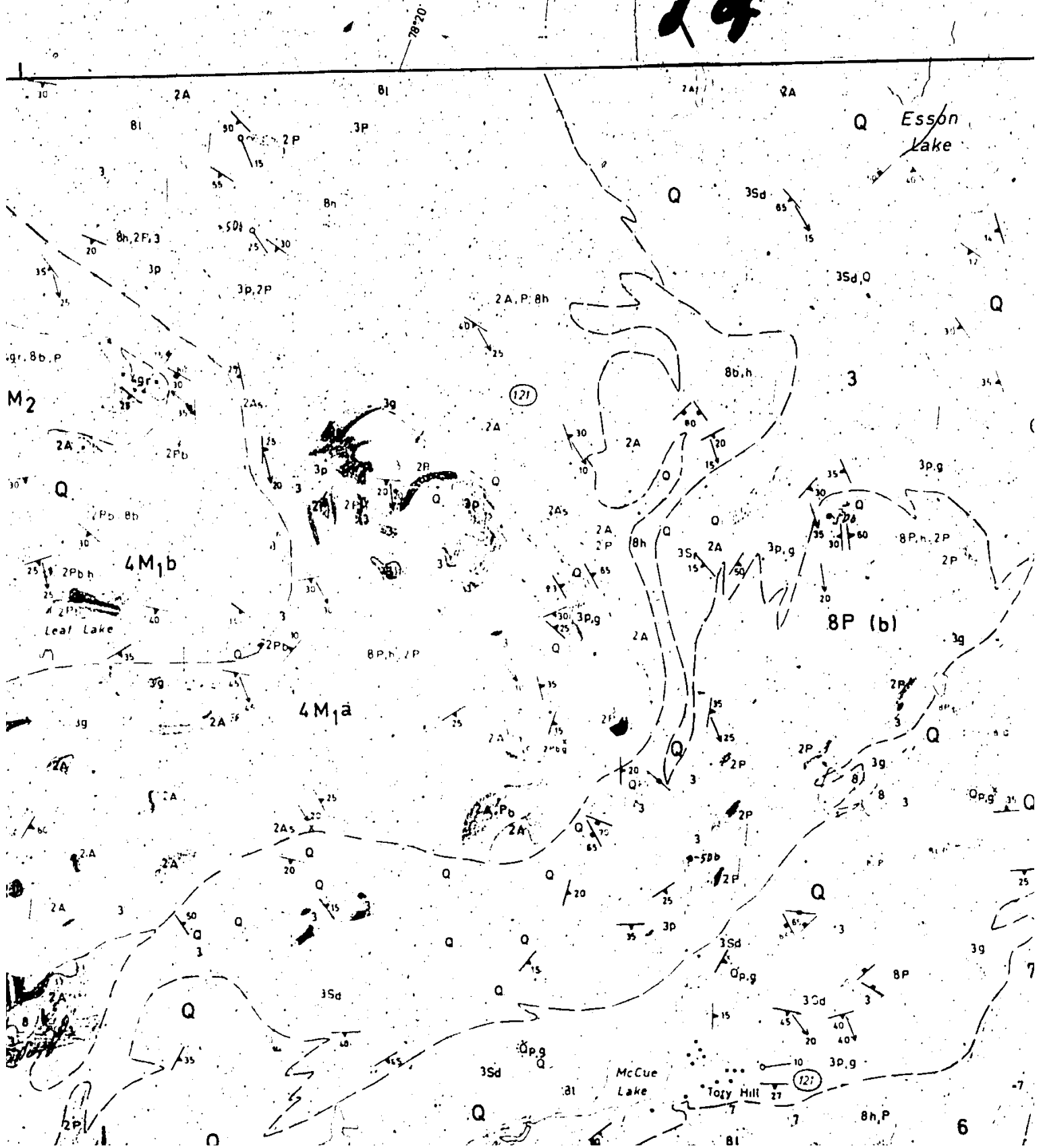
PLATE 39

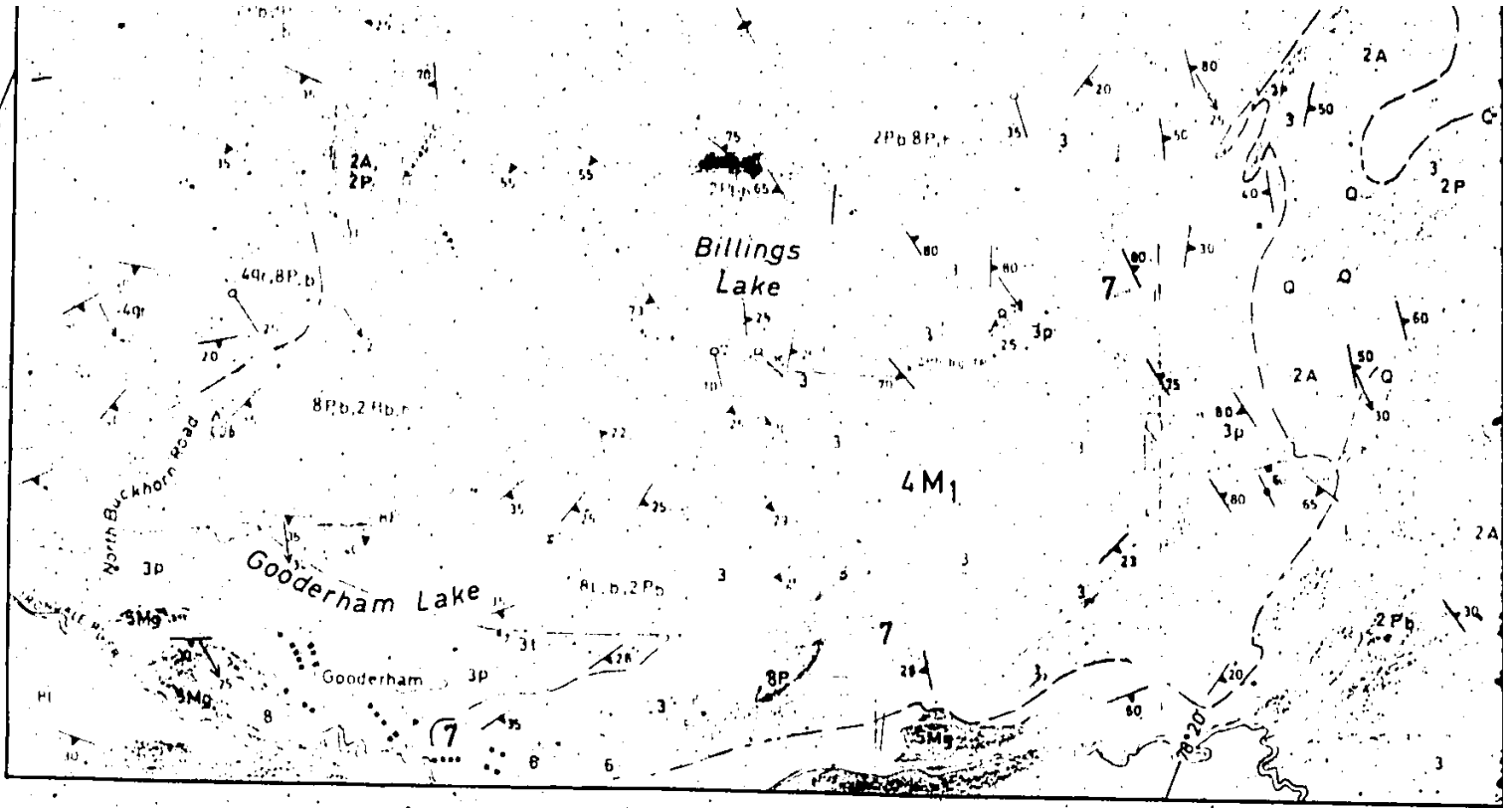


AMORGAN AND MONMOUTH TOWNSHIP

HALIBURTON COUNTY, ONTARIO

24





GLAMORGAN

MONMOUTH

4 of.

8

4M1

3

7

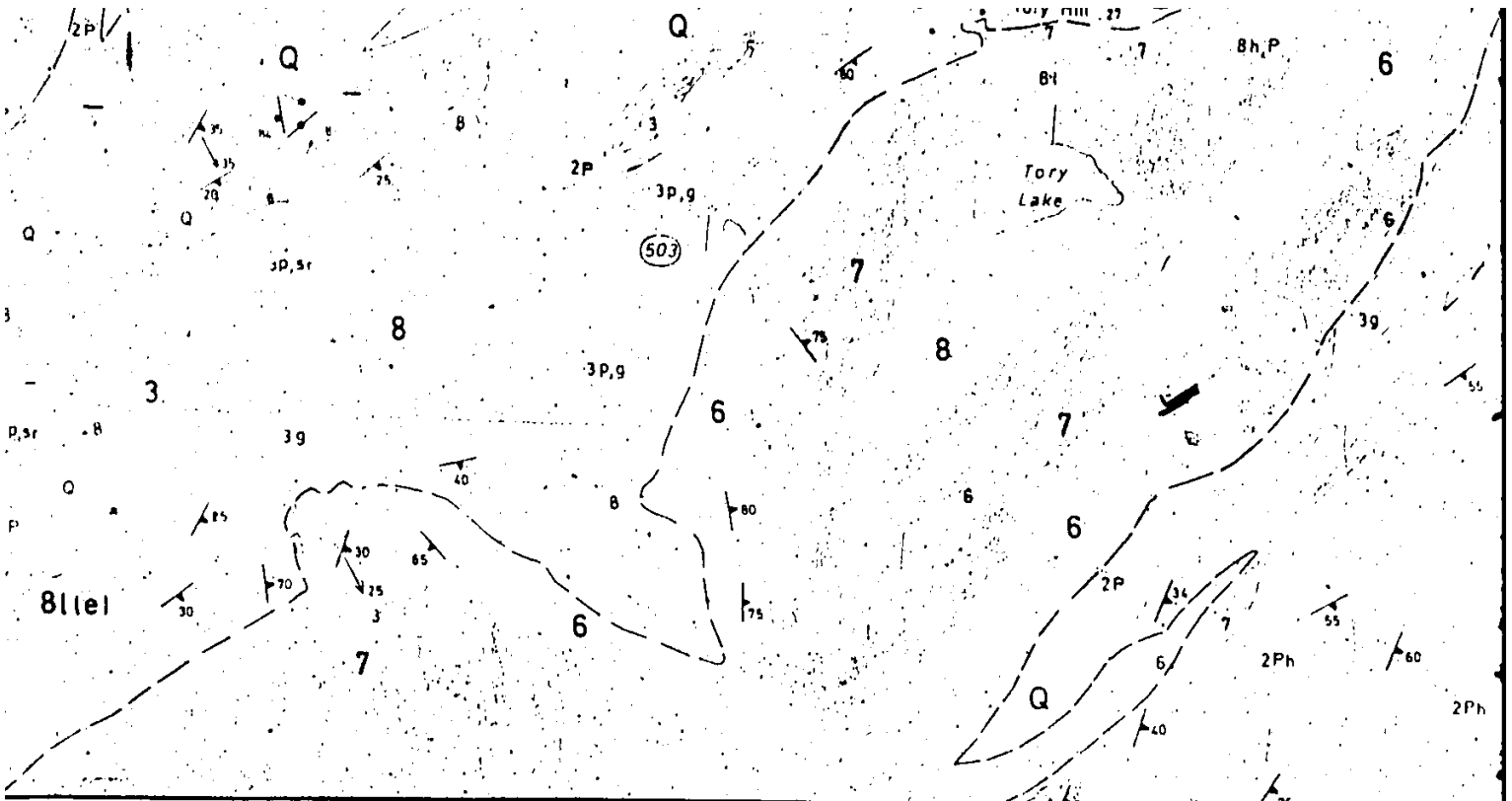
6

4M2

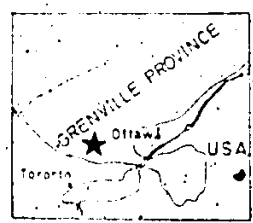
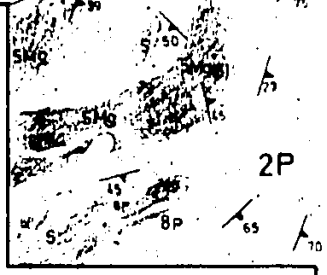
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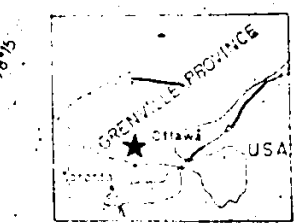
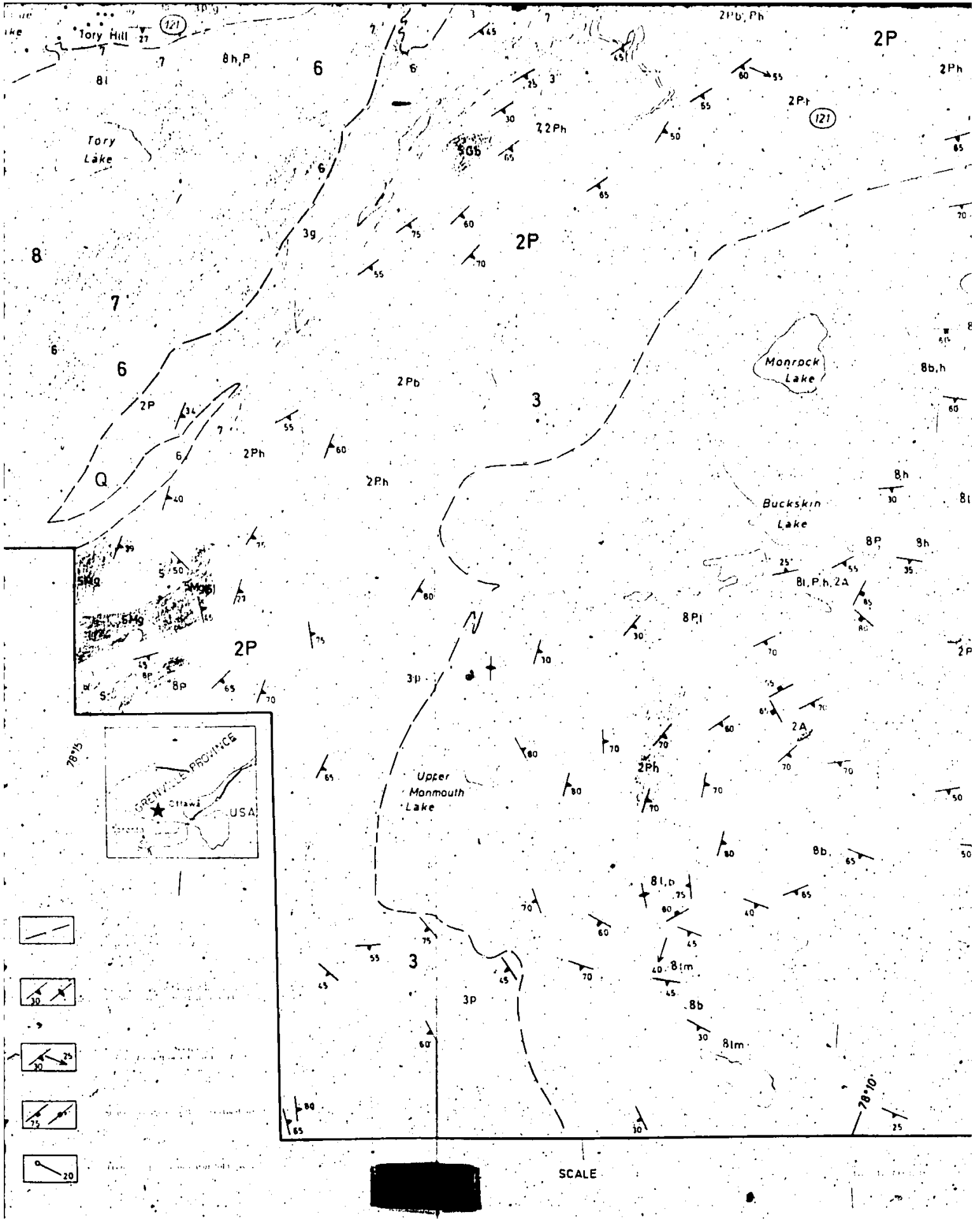
5 of 1



Legend symbols and their corresponding geological descriptions.

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SCALE