METAMORPHIC PETROLOGY

OF

THE GILLAM AREA, MANITOBA.

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Master of Science.

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by

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ABSTRACT

Following mapping of the Gillam area, Northern Manitoba, by Dr. I. Haugh and S.C. Elphick, during the summer of 1968, and publication of a preliminary report in the Manitoba Mines Branch Geological Paper 3/68, further work was done on samples by Mr. Elphick. This was an examination of the petrology and mineralogy of the gneisses, using 300 thin-sections and 150 slabs stained for potash feldspar. Plagioclase compositions were measured in 80 thin-sections. 40 samples from various areas were point counted for modal mineral composition. With these data the original map was revised, a more detailed stratigraphic sequence drawn up, and a plagioclase anorthite content distribution map drafted.

Two periods of folding are recognisable both on geologic and aeromagnetic maps. The earlier period involved the formation of west-north-west, near isoclinal folds, with axial planes steeply dipping to the north. Metamorphism produced sillimanite, under moderately low pressure conditions (Abukuma type). The second metamorphic event involved formation of broad Z-folds, axial planes trending north-east, refolding the earlier isoclines Metamorphic grade was lower than the first event, and was of lowest sillimanite or greenschist facies. During the first episode iron was a mobile constituent, as proven by various textural relations displayed by the magnetite. Calcium distribution in plagioclase was established during this period, and results indicate strict dependence of plagioclase-anorthite-content on bulk calcium content of each gneiss.

INTROIT

This thesis was specificly designed to be read with the contents of the back pocket spread before the reader's eyes; this especially applies to Chapter V, which contains the detailed petrology of this area. For the readers convenience, the area has been divided into sub-areas, which have been treated as logically as possible. For instance, Chapter V, Section 1, Wapicho Rapids to Kettle Rapids Dam, is considered from west to east. This covers Station Location Maps #15 and #18. The stations are considered from west to east, and the geology may be traced on the large-scale maps in the back pocket.

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CHAPTER I

SUMMARY OF PETROLOGY

The gneisses in the Gillam area are the high-grade regionally metamorphosed types common in the Churchill Province of the Canadian Shield. They are interpreted as derivatives from greywacke and arkosic sediments, originally deposited in a geosynclinal sequence with the greywacke, or deeper-water sediments, laid down first, followed by the arkosic, or shallow-water terrestrial type deposits.

These have first been highly folded and metamorphosed under Abukuma type conditions, with high temperatures and low to moderate pressures. This has caused the formation of cordierite and sillimanite in rocks of appropriate bulk chemical composition. During this period the anorthite content of the plagioclase was governed by the bulk calcium content of the gneisses themselves. The folds generated during this period were tight, nearly isoclinal, with axial planes trending north-west, and steep dip, probably to the north.

A second regional metamorphic event was superimposed on this fabric, represented by open Z-folds. This event was at chlorite-epidote grade, and caused inversion from high-grade to low-grade mineralogy in the more reactive assemblages, notably those with high calcium and moderate water content.

These two events have been followed by two periods of brittle shearing, the second accompanied by some sulphide emplacement. Possibly related to this event are some late faults, with chlorite, muscovite, and some talc on the slip surfaces.

The gneisses have been subdivided into two types; those bearing magnetite, and those without. This distinction was first noticed during mapping, and once it was obvious that the magnetite-bearing units form a distinct and mappable horizon in the stratigraphic succession, it allowed interpretation of the folding, and correlation of scattered outcrops, using the aeromagnetic maps. The full succession established in the area is shown in Table I (Page 4).

The petrology of the area has been described by Haugh and Elphick (1968), Figure 1 (Page 5), is taken from that report (with revision by the author based on the study of samples).

This detailed knowledge of the stratigraphy allows good correlation across the whole area, despite the limited outcrop. The area has been subdivided on the basis of outcrop pattern, each area being described separately in Chapter V. Chapter II deals with granitic activity in the area, and Chapter III deals with the metamorphic history of the region. Chapter IV is a summation of the interpretation of original lithology possible for the gneisses of the Gillam area.

It is important to note that many of the unit boundaries are gradational, especially the pelitic-arkosic gneiss boundary. The only unit with sharp contacts is the amphibolite. Also important is the realisation that although two distinct metamorphic events can be recognised in the area, this does not exclude the possibilty of earlier periods of metamorphism, now partially or completely masked by the cordierite-sillimanite event.

Figure 1 (Page 5) is a general review of the important geologic boundaries.

Figure 2 (Page 6) shows the breakdown into subareas used in

Chapter V.

Figure 3 is the index for the station-location maps, to be found in the back pocket.

TABLE 1

GNEISSIC SEQUENCE IN THE GILLAM AREA

Presumed Top of Original Sedimentary Sequence			
	Unit	Map unit No.	Mineralogy
Contains layers and pods of epidote albite mineralogy	Biotite-magnetite gneiss.	4	Biotite, magnetite, plagioclase, quartz, +garnet, +microcline, +sillimanite.
	Hornblende-biotite-magnetite gneiss.	3	Hornblende, biotite, plagioclase, quartz, +magnetite, +microcline, diopside.
Contains isolated amphibolite layers	"Arkosic" gneiss.	2	Biotite, plagioclase, quartz, microcline, +garnet, +sillimanite.
	"Pelitic" gneiss.	1	Biotite, plagioclase, quartz, garnet, +microcline, +sillimanite.

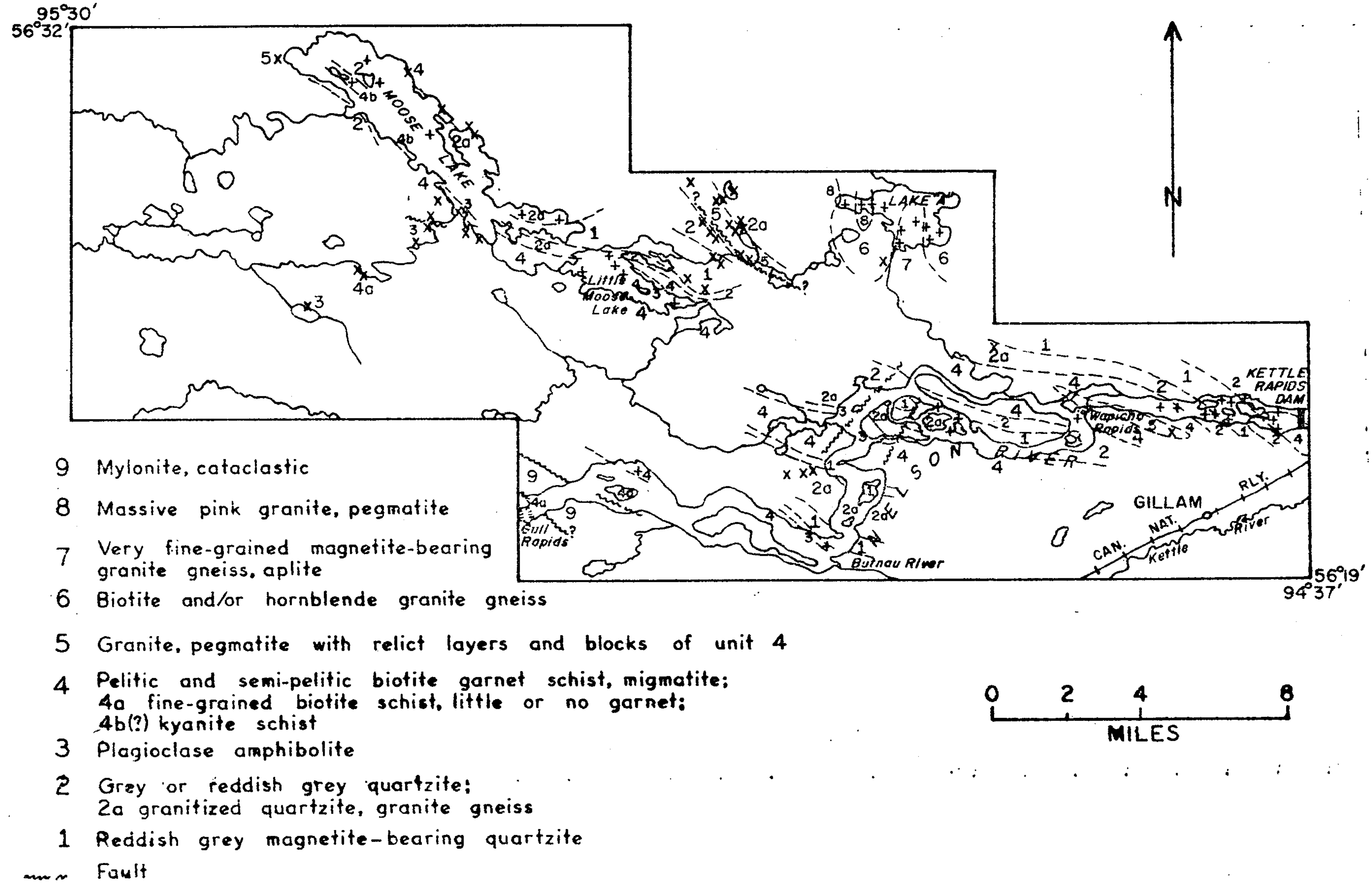
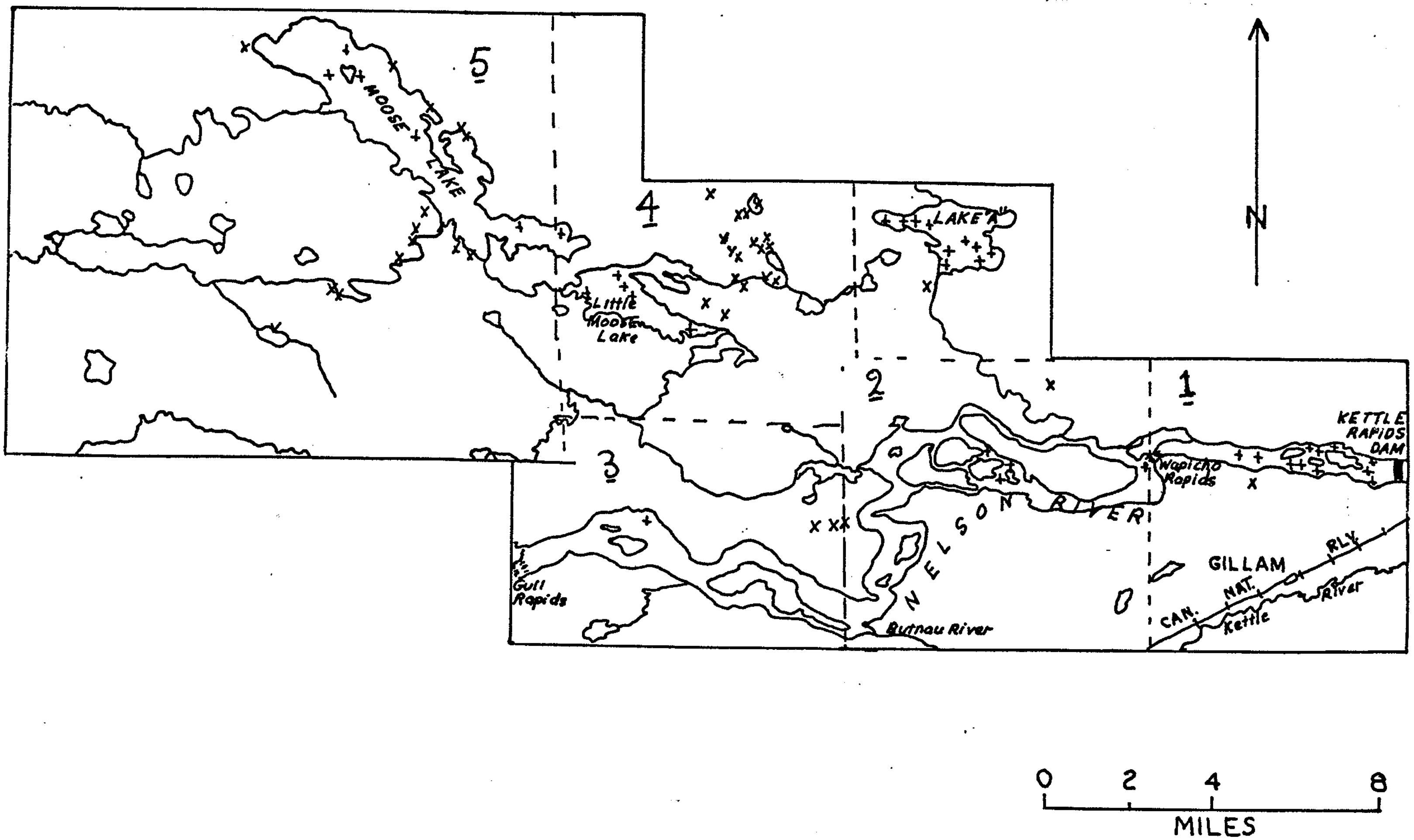


Figure 1

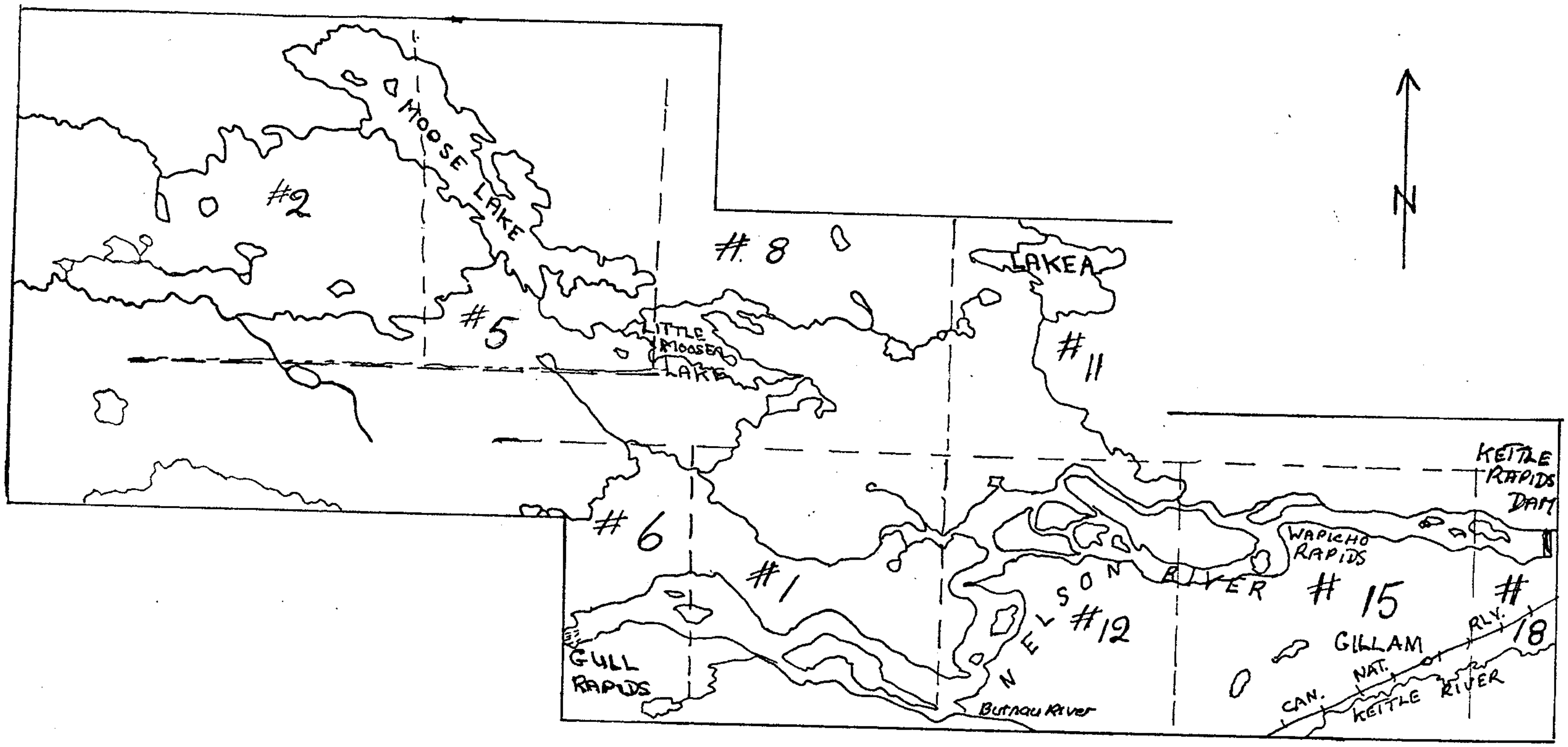
Map showing general geology of area.

FIGURE 2



Map showing division of area into sub-sections, which are described individually in Chapter V

FIGURE 3



Map showing areas covered by station location maps in back pocket.

CHAPTER II

GRANITES

In the Gillam area, little can be learned from the granites. This is partially due to the long and complex metamorphic history of the area, and partially due to the role of anatectic granites.

In various areas, cross-cutting relationships are seen between various types of granites. Lack of continuity on outcrop, however, precludes comparison between different parts of the map-area, leading to compositionally determined granite provinces. The only granite whose relationship is clear is a microcline quartz granite, carrying minor plagioclase, biotite and muscovite. Where seen it is always fresh in appearance, cross-cuts all other units, and has epidote alteration on joint surfaces. Hence, it must be a very late stage granite.

Common throughout the area is a coarse-grained white granite, composed of approximately 25% quartz, 35% plagioclase and 40% microcline. Common accessories are biotite and apatite. This granite is often contaminated, and appears to have intruded very slowly, rafting the pelitic gneiss apart.

Unfortunately, the compositional range of the anatectic granites is large. Noticeably, a microcline-poor gneiss will contain granite 'lit' lacking in microcline. This causes a broad scatter in the plot of modal components for the area, as distinct from the separate concentrations expected from differing granite suites. The composition spread indicates that the majority of granites found are of anatectic origin/

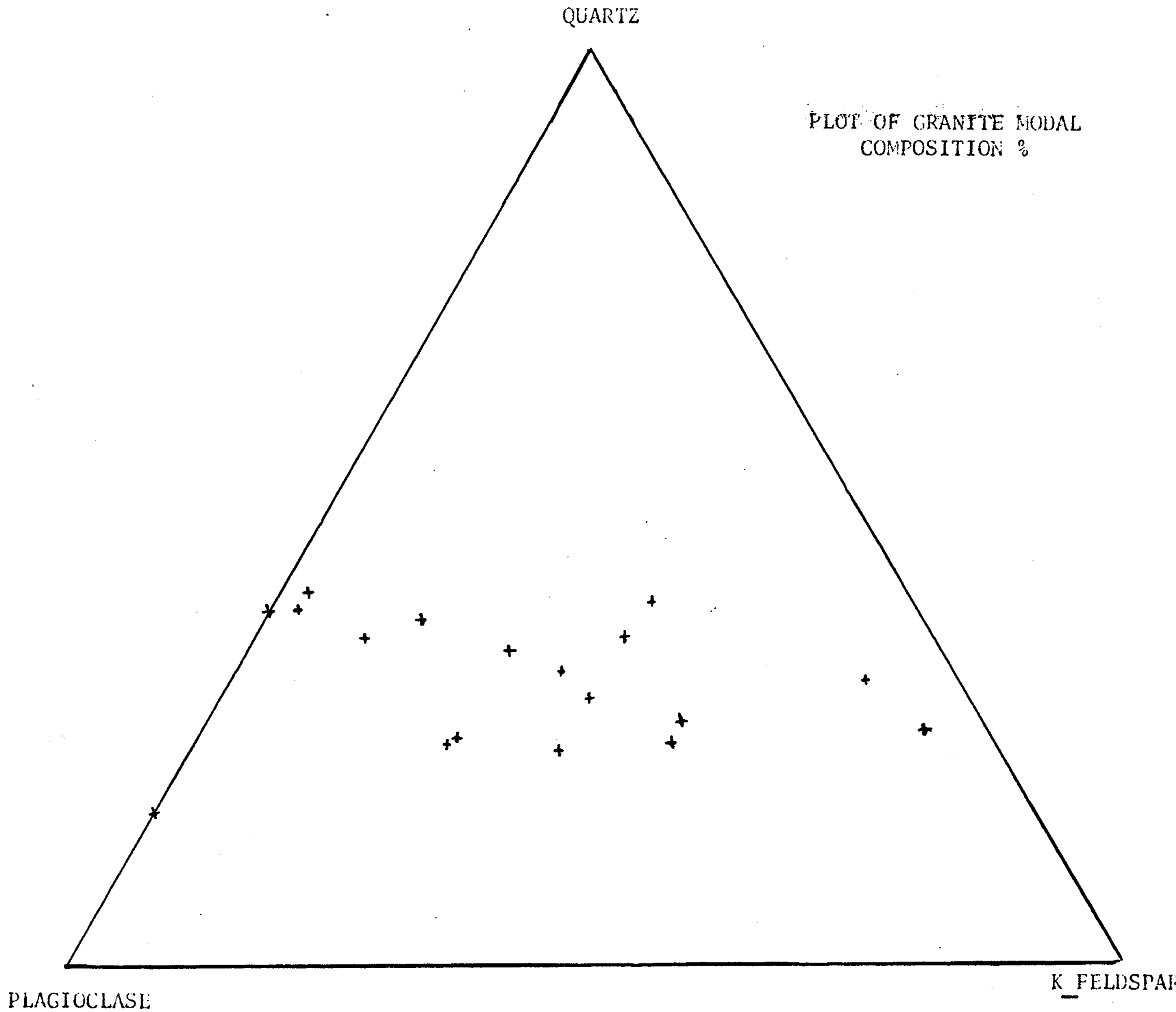

QUARTZ
PLOT OF GRANITE MODAL
COMPOSITION %
PLAGIOCLASE
K_FELDSPAR

Figure 4

CHAPTER III

METAMORPHISM

Detailed examination of textures and reactions is discussed in Chapter V. The following is a comprehensive survey of the data for the whole area.

Two distinct metamorphic events have been deduced from the data. The first was a high-grade event, involving the formation of sillimanite, cordierite, garnet and probably orthoclase. The various phases of this event are indicated by the fabric in outcrops of pelitic gneiss in Little Moose Lake, namely, growth of garnet and sillimanite, folding, and reinforcement of sillimanite and biotite growth axial planar to the folding. Completion of this series of events led to formation of the primary metamorphic fabric through-out the area. This fabric is defined by parallellism of the biotite foliation and long axes of the sillimanite knots. The indicator minerals, biotite, garnet, cordierite and sillimanite, are found intergrown in several localities, proving they belong to the same metamorphic episode. Various growth stages are shown by the sillimanite, from early nucleation along grain boundaries to complex knots intergrown with cordierite.

The plagioclase composition through-out the area is considered as being directly related to this period of metamorphism. Evidence for this is the low anorthite content of plagioclase in pelitic gneiss with good granulitic texture. This plagioclase has average anorthite content of 32%, is intimately associated with sillimanite, yet shows no sign of instability, such as zonation. Yet zonation, and myrmekitic texture, are found in plagioclases from gneisses with a strong biotite cross-foliation, such as in the arkosic gneiss of area 4, Little Moose Lake. A map of measured plagioclase composition for typical gneisses was drawn up from measurements taken on 80 thin-sections. Anorthite content was measured by measurement of albite twin extinction onto the trace of (010) cleavage, viewed parallel to (100) on a five-axis universal stage (Deer, Howie and Zussman, 1963. Rock Forming Minerals, Volume 4, page 138. Longmans.) At least four consistent readings from different grains were required.

All measurements were made on unaltered and unzoned plagioclase crystals, where possible. Where only zoned crystals were available, measurement was made at the core. It is interesting to note that the outer margins of zoned crystals contain up to 10% less anorthite than the cores. Relating the cores to the sillimanite-grade event, and margins to the medium-grade event, this is a large percentage change.

Two factors must be considered when examining changes in plagclase composition within a metamorphic province. One is the pressure-temperature dependence of the mineral composition, the second is the effect on this composition of the bulk calcium content of the rock. The effect of pressure and temperature on plagioclase composition has been discussed by Wenk (E. Wenk, 1962. Schweiz. Miner. Petrogr. Mitt., volume 42, pages 139-152.), who wrote:

> "Firstly, a rise in the anorthite content of the pagioclase in similar assemblages points to an increasing grade of metamorphism, i.e., primarily to an increasing temperature, according to what is known about the feldspars; and, secondly, the thermodynamic equilibrium is mostly, if not always, attained approximately during metamorphism. Otherwise it would not be possible to explain why the anorthite content remains constant in areas of constant P,T conditions and why it rises systematically in a particular direction."

This view of plagioclase composition dependence assumes that the effects of bulk chemical composition may be ignored, if comparison is restricted to rocks of similar mineralogy.

In the present author's opinion, this is an over-simplified view of the problem, although as a pragmatic approach to a complicated subject it is justifiable. The difficulty in this area of geology is to decide which effects are relevant, within the order of accuracy desired, so that the final problem may be stated in terms of as few variables as possible. Traditional approaches using graphical techniques immediately limit the number of controllable variables, a draw-back not encountered using statistical techniques such as multiple correlation analysis.

The problem of plagioclase compositional dependence is a case in point. Here one is faced with three independent variables, namely, pressure, temperature and bulk rock composition. It is the present author's opinion that no single one of these may be neglected.

Examination of the plagioclase composition distribution map (see back pocket) shows dependence of plagioclase composition of host rock mineralogy. This dependence is amplified by the compositional spread of the units involved. Typical treatment of this aspect of the problem would be to consider only one unit in the area, for example, the pelitic gneiss, and assume that the effect of bulk rock calcium content is negligible. The map, however, shows that it is possible to correct for this particular effect.

For further illustration, Figure 5 (Page 13) shows a plot of plagioclase anorthite content against bulk rock calcium oxide content for random samples across the map area. The linearity of this graph might lead one to suppose that bulk calcium content is the main factor governing plagioclase composition in the Gillam area, and that the variability

PLOT OF CaO (WEIGHT %) IN
WHOLE ROCK AGAINST An CONTENT
OF CONTAINED PLAGIOCLASE.

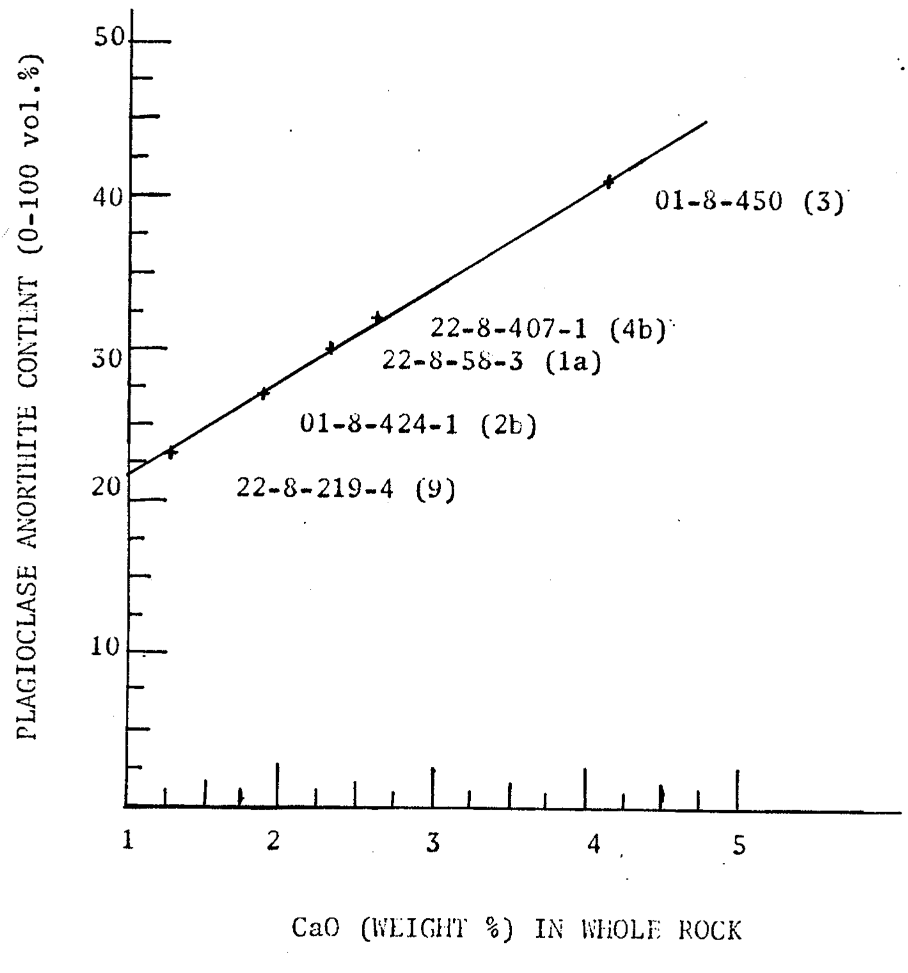


FIGURE 5

of pressure and temperature during the high-grade event was restricted in the Gillam area.

This logic is doubtlessly correct, but the important point of the discussion is that the problem has again been reduced to the either/or approach. In other words, relevant and obtainable data about pressure-temperature distribution has been lost by enlarging the permitted error spread.

It is outside the present writer's franchise to carry this investigation any further. Information about plagioclase distribution in the Gillam area does show, however, that it is unwise to neglect any major variable when discussing compositional changes in metamorphic minerals, not only because it increases error spread in the final results, but also because information is lost. In problems of this type the only possible approach is to use statistical correlation techniques, where a percentage significance level may be calculated for each variable.

In summary, the plagioclase anorthite content appears mainly dependent on bulk rock calcium content, indicating even pressure-temperature distribution throughout the area during the first period of metamorphism. Further study would be required to establish pressure-temperature gradients across the area using the plagioclase compositions, although this appears perfectly feasible. (For further discussion see Winkler page 149)

Iron as a mobile constituent, is indicated by textural relationships displayed by magnetite. The presence of cordierite throughout the area indicates that metamorphism was of high temperature-moderate pressure type, i.e. Abukuma type. The facies indicated by all the data is sillimanite-orthoclase.

The folds generated during this period of metamorphism were tight, nearly isoclinal, axial planes trending north-west, dipping north-east at a high angle. This is inferred from correlation between outcrop patterns and the magnetic map for the area.

The second period of metamorphism in the Gillam area was of considerably lower grade than the first. It resulted in the breakdown of sillimanite in many places to muscovite. At the Kettle Rapids Dam area, evidence is presented showing that sillimanite knots have suffered later folding, with accompanying degradation, the muscovite formed being parallel to the cross-fold axial planes. Biotite, except in restricted high calcium environments, remained stable during this period, as evidenced by the biotite cross-foliation throughout the area.

Several distinct mineralogical changes can be related to the later cross-fold event. These are:

1) Sillimanite instability.

2) Remobilisation of potash feldspar.

3) Recrystallisation of calcium-rich layers in the magnetite gneisses.

4) Zonation of plagioclase, myrmekitic intergrowths.

5) Reaction of garnet-biotite assemblages.

One of the most important effects was the remobilisation of the potash feldspar. Interstitial textures of microcline are common throughout the whole area, and the control the microcline content exerts on the fabric of the gneiss is specifically noted on Little Moose Lake. Here, the original texture was granulitic, a texture preserved in the majority of microcline-free gneisses, those carrying microcline now have a highly inequigranular texture. The observed fabrics may be explained by assuming that the potash feldspar was originally in the form of equigranular grains of orthoclase. During the cross-folding, this inverted to microcline, and in many cases was actually remobilised, giving interstitial textures. Microcline porphyroblasts formed in the more massive rocks, such as pelitic-semipelitic gneisses. The final product of this is seen in area 3 (Figure 2, page 6.), for example, in the augen-gneiss.

The formation of the epidote-rich layers and boudins has been discussed in the section on Little Moose Lake, and are explained in terms of response of high-anorthite plagioclase to lower-grade conditions. The reaction may be displayed as:

$$\text{High-An plag.} + H_2O \longrightarrow \text{Low-An plag.} + \text{Epidote.}$$

The iron for the epidote is supplied by breakdown of biotite.

Common throughout the area, and of great interest, is the reaction between early formed biotite and garnet during the second period of metamorphism. This rection is quite obvious in thin-section, and occurs mainly in the pelite. The normal colour for biotite in this unit is rust-brown to pale straw. Near some garnets, however, the biotite shows a consistent colour change depending on their separation. Near the garnet, the biotite colour has changed to pleochroism from medium green to pale straw. This is due to localised diffusion of metal atoms around the garnet.

The folds generated during this second period of metamorphism were large open Z-folds, sometimes with axial planar shearing, as seen in area 3.

Somewhere in the metamorphic sequence, the mylonite belt must have a position. It was not formed during the peak of the sillimanite-grade metamorphism, as shown in the relevant section. Nor can it be directly related to the period of Z-folding, for, as just mentioned, the axial planar shearing associated with these folds strikes north-east, while the mylonite strikes north-west, across the area.

Associated with the mylonite is an early shear set, generally striking north-west, now annealed, which gave no introduction of material to the host rock.

Later than this last, and probably one of the last events in the area, was the formation of a second set of shears with accompanying potash metasomatism; these shears being especially well developed near the mylonite. This caused the formation of chlorite from biotite, breakdown of plagioclase, and the formation of epidote along the shear planes. In the most extreme metasomatised area, epidote may be seen on joint faces in hand specimen, with accompanying metasomatism and potash enrichment of the host rock. This reaction is well developed in area 3, but is fairly common throughout the whole Gillam area. It appears related to late microcline granites, and is a common reaction for this type of granite.

Thus two periods of folding and two periods of shearing have been demonstrated.

CHAPTER IV

SEDIMENTARY ORIGIN OF THE GNEISSES

The gneissic sequence found in the Gillam area invites comparison with well-preserved geosynclinal sedimentary rocks. The most extensive unit, and the one considered basal in the sequence, is the pelitic gneiss. Comparison of this unit with an average of typical greywackes (Pettijohn, Sedimentary Rocks, page 307, table 52a.) shows the remarkable similarity between the two. (See Appendix III) This does not prove that the pelitic gneiss must have originally been greywacke, but that the present pelitic gneiss could thus have been derived. The extent of the unit and its relationship to the other units, however, lends weight to this interpretation.

Consider the outcrop pattern of the gneisses in the Gillam area. The true thickness of the pelitic gneiss is indeterminate, as no true base is seen to this unit. The thickness of the arkosic gneiss is quite constant, allowance being made for folding in sub-area 3. The magnetite-biotite gneiss thickness is indeterminate, for the overlying unit is not exposed. But the biotite- magnetite-hornblende gneiss shows the characteristics of a gneiss derived from a littoral deposit. It is impersistent, even across a synform, as seen at Kettle Rapids dam. However, the gneiss does show an increase in thickness travelling from west to east across the map area. In the west half, the unit is very impersistent and often appears to be absent from the sequence. This impersistence may be explained by suggesting that this high-calcium unit was deposited in a restricted aqueous basin type of environment. But a more speculative approach is to suggest this gneiss was originally bio-dependent, the high calcium content being a reflection of the work of biological agents, perhaps algae. Under this type of interpretation the arkosic gneiss, unit 2, may be derived from a near-shore arkosic and psammitic sediment.

The original sequence envisioned for the Gillam area is thus: a thick sequence of greywackes and argillites, overlain by more psammitic sediments as the basin of deposition becomes shallower, in turn overlain by more calcium-rich rocks, derived possibly from organic sources.

This is very speculative, and may be far from reality, but it does illustrate that some idea of original sedimentation may be gleaned from detailed appraisal of gneissic stratigraphy. To decribe a rock as a biotite-garnet-plagioclase-quartz gneiss might be accurate, but it is not informative as to structure and origin. The gneissic sequnce detailed in this report is repeated on the gross scale, with some changes, from Gillam to Snow Lake, and from Snow Lake to Southern Indian Lake. Yet little or nothing remains of the original sedimentary series directly recognisable in terms of original lithology. To ignore the high-grade gneisses, or to describe them strictly on an 'as is' basis, is the equivalent of throwing the fish out of the window, and eating the plate.

CHAPTER V

SECTION 1

WAPICHO RAPIDS TO GILLAM DAM

(All outcrop locations are to be found on station location map #15, unless otherwise stated.)

The most complete lithologic sequence is exposed on the islands in the Nelson River immediately upstream of the Gillam dam-site, and contains all members of the sequence in their correct order. The lithologic units define a large synclinal structure, whose axial plane trends north-west. This has been subjected to later cross-folding. The units exposed are discussed from west to east, from Wapicho Rapids to the dam-site.

The most westerly unit, at Wapicho Rapids, is migmatitic pelitic gneiss, occurring as large blocks 'floating' in an inequigranular white granite. The pelitic gneiss is moderately equigranular, fine-grained, a mosaic of biotite, plagioclase, and quartz, containing poecilitic garnet porphyroblasts up to 0.5 cm. diameter. A more mafic layer of the pelitic gneiss on outcrop 01-8-4 contains garnets up to 2 cms. in diameter. The granite is highly inequigranular, ranging in grain size from 1 mm. to pegmatitic patches with plagioclase crystals some 4 cms. long. It is composed predominantly of plagioclase and quartz with minor microcline and biotite. The granite also contains blocks and layers of amphibolite, for example on outcrop 22-8-444. None of the blocks and layers in the granite appear rotated, as shown by the consistency in the foliation readings in the Wapicho Rapids area, many of which were measured on blocks and layers totally isolated in the granite. This must mean that the granite was intruded during the peak of metamorphism, and was injected slowly, so that the various layers were literally 'floated' apart.

To the east, the grain-size of the pelitic gneiss gradually decreases, as does the biotite and garnet content. Outcrop 01-8-7 shows the first obvious change to the finer-grained grey arkosic unit, carrying narrow layers of definately more psammitic material. These are medium grey on fresh surface, and are composed mainly of plagioclase and quartz, with a moderate to low biotite content. Quite characteristic of these psammitic horizons are the scattered biotite-garnet segregations, showing a core of highly diffuse and granular fine-grained garnet, with a rim enriched in biotite relative to the surrounding psammite.

Outcrop 01-8-9 is a well layered psammitic gneiss, carrying quartz, plagioclase, and biotite, all inequigranular. The biotite is very variable in grain size, light brown to pale gold in plane light, with the laths sub-parallel to the gneissosity defined by slight biotite concentrations, and quartz stringers. There is, however, on dip surfaces, a definite second biotite foliation at 40° to the gneissosity. This gneiss is somewhat anomalous in carrying a moderate amount of minor apatite, ilmenite with leucoxene borders, and pyrite. Thin sections also show some secondary sericite, after plagioclase, and some alteration of biotite to chlorite. At this outcrop the pelitic gneiss has definitely given way to the psammitic gneisses, though the contact is gradational. This next set of gneisses is afterward referred to as the grey arkosic gneisses, indicating possible original lithologic type before high-grade metamorphism. This set of gneisses can be subdivided into 3 sub-units, viz.:

Type A) This is the most common sub-unit, and is a light to medium grey gneiss, (often showing slight gneissosity) with fine-grained biotites with good parallel orientation. Typical of this type are outcrops 01-8-13, 22-8-332-33, 370, 371. Sometimes this unit appears massive on outcrop, and sometimes it is migmatitic, with fine granite "lit" , and good gneissic texture, but both are obviously closely related. This type is very similar to outcrops 22-8-286-294 (station location map #12) further west, and shows the same features in thin section. Most of these rocks carry secondary muscovite.

Type B) The second type of grey arkose is characterised by its white colour on fresh surface, which reflects the very low biotite content, less than 5%. It carries plagioclase, microcline and quartz, with subordinate biotite, which is present as well-separated flakes, usually scattered throughout the rock. In more biotite rich layers the biotite concentration may rise to 10%. This unit is highly restricted in outcrop on the west side of the synclinal fold across the islands, and is found on outcrops 01-8-15, 22-8-445, 446,372. These outcrops define the outcrop pattern on this side of the fold, and show that there is apparently little cross-folding in this part of the area.

Type C) The third type of grey arkose is dark grey black on fresh surface, much richer in biotite than the previous two sub-units, and apparently richer in quartz, giving the surface a good sparkle. It is slightly gneissic, but is microcline poor. This unit outcrops on 01-8-16, 22-8-343,342. Thus it appears to lie just above