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Felsic-Mafic Ratios and Silica Saturation Ratios--their Rationale and Use as Petrographic and Petrologic Indicators

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CONTENTS

ILLUSTRATIONS

TABLES

Abstract

A felsic-mafic ratio, $F = \dfrac{SiO_2 + Na_2O + K_2O}{FeO + Fe_2O_3 + MgO + CaO}$,

and a silica saturation ratio, $S = \dfrac{SiO_2}{Al_2O_3 + Na_2O + K_2O + MgO + CaO + FeO + Fe_2O_3}$,

when combined on a graph categorize crystalline rocks according to their composition and silica saturation. Nockolds' average rock compositions provide a standard against which any rock may be compared. The method also lends itself to petrologic inferences about the origin of granitic rocks, i.e., whether magmatic or metamorphic-metasomatic processes were involved. Bolstered by agreement with two other independent methods (one using included biotite and the other $\Sigma Al_2O_3 + Na_2O + K_2O$ in the rock) regarding origin the petrologic inferences are proven to be valid. Several geologic examples from the literature involving plutonic rocks show that petrologic inferences derived from the F-S method agree with geologic field data.

INTRODUCTION

This report introduces a novel classification of crystalline rocks, herein called the F-S method, that leads to inferences concerning their origin. The method is most applicable to quartz-bearing rocks no more mafic than tonalite, but the method yields useful information on all crystalline rocks. In particular, the question posed is whether granitic rocks can be classed as magmatic or metamorphic-metasomatic. The validity of the petrologic inferences concerning origin, suggested by the F-S method, are corroborated by two other completely different methods; one using biotite analyses and the other using the $\Sigma Al_2O_3 + Na_2O + K_2O$ in the rock. It is difficult to refute the agreement demonstrated by three dissimilar methods regarding the origin of a test set of 12 plutonic rocks and their contained biotites (Young, 1984).

The really difficult part of dealing with a subject such as this, about which very little is known, is the terminology. I have followed Gokhale (1968) in his distinction between metamorphic-metasomatic and magmatic rocks, although in some (many?) cases distinctions may be inherently blurred.

Magmatic is taken to mean fully molten rock with or without phenocrysts. Metamorphic-metasomatic is meant to include everything from only solid state reactions to partial melting involving largely in situ development, in short, granitization. Metamorphic-metasomatic processes will therefore include:

> ultrametamorphism = melting of rock and creation of magma in situ = partial melting, and metamorphic differentiation = segregation of certain minerals in lenses and bands accomplished by metamorphic processes, e.g., migmatite, restite, boudins.

Unfortunately, ultrametamorphism and metamorphic differentiation are concepts about which little is known. For instance, is it correct to use the phrase 'melting of rock' and 'creation of magma' in regard to ultrametamorphism. The obstacle to a complete understanding of these terms is that long stretches of time at elevated temperatures and pressures are necessary to effect them. Therefore, these processes cannot be duplicated in the laboratory. By contrast, magmatic processes are relatively short lived and usually produce textures that are unambiguous.

COMPARISON OF THE F-S METHOD WITH OTHER ROCK CLASSIFICATIONS

The igneous rock classification of Johannsen (1939) and the Streckeisen (1976) classification of quartz-bearing igneous rocks are based on modal analysis and use the quartz-alkali feldspar-plagioclase (QAP) ternary diagram. Despite the general similarity between the Johannsen and Streckeisen classifications, they both may yield different names for the same rock because they employ different demarcation lines and define alkali feldspar differently.

The F-S method of rock classification that will be defined in this report is based on major element chemistry and is not directly comparable with the other two classifications. However, it has several benefits, namely:

1. It yields compositional equivalent names that correlate with average rock types of Nockolds (1954);
2. numerate values are obtained for F (felsic-mafic ratio) and S (silica saturation ratio) which may facilitate comparison or correlation with other rocks;
3. although chemical data are desirable, modal analysis and/or specific gravity data will approximate points 1 and 2;
4. metamorphic rocks as well as plutonic or volcanic rocks can be assigned compositionally equivalent names;
5. use of this method leads to petrologic inferences regarding origin.

THE F-S METHOD

Concept and Rationale

The felsic-mafic ratio (F) and silica saturation ratio (S) combine to form the F-S method, which is primarily useful for obtaining compositional equivalent names that correlate with average rock types of Nockolds (1954). The felsic-mafic ratio (F) is defined as:

$$F = \frac{SiO_2 + Na_2O + K_2O}{FeO + Fe_2O_3 + MgO + CaO},$$

in weight percents, and was devised by Young (Segerstrom and Young, 1972, p. 34-35).[1] The rationale behind F is that if all crystalline rocks (volcanic, plutonic, and metamorphic) are considered without genetic assumptions or presumptions, it is perceived that they show all gradations from very felsic (composed of quartz and alkali feldspar) to very mafic (composed of minerals rich in iron, magnesium, and calcium), namely a gradational binary series. This is an alternative way of looking at rocks, as opposed to the double ternary QAPF diagram. The original definition of "mafic" does not include calcium although Ca is associated with mafic rocks, and therefore finds its rightful place in the denominator of the F ratio. Futhermore, the plagioclase feldspar series is found in the most felsic to the most mafic rock, thereby providing difficulties for mineral-based rock classifications. The F ratio avoids this mineralogical problem by

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[1] The term, felsic-mafic ratio, as used in this report is different from, and not to be confused with, the felsic index, $(Na_2O + K_2O) \times 100/Na_2O + K_2O + CaO$, of Simpson (1954), and the mafic index, $(FeO + Fe_2O_3) \times 100/MgO + FeO + Fe_2O_3$, of Wager and Deer (1939).

recognizing the gradual change in the Na:Ca ratio in plagioclase feldspars from felsic to mafic rocks.

Primarily useful for plutonic and volcanic rocks, F is also useful as a descriptor of metamorphic rocks because it indicates their chemical equivalency to plutonic or volcanic rocks.

Using Nockolds' (1954) compilation of rock analyses, values of F were calculated in the following manner for the average compositions of the rock types listed in table 1. The average F of 72 granites is 18.4, and the average F of 22 rhyolites is 23.8. The weighted F for the compositional pair (granite-rhyolite) is 19.7. F values for the other pairs were calculated in the same way. Boundary values of F between rock types represent natural logarithmic midpoints between average values of F for each rock type.

The F lithologic boundary values are also shown on figure 1 along the ordinate which delimits F logarithmically. Note that each rock type is roughly equivalent in length on the logarithmic scale. The lines labelled oversaturation, saturation, and undersaturation are approximate trend lines.

The felsic-mafic ratio (F) does not confer a uniqueness upon any particular rock because slightly different values of Si, Na, K, Fe, Mg or Ca for different rocks may yield the same F. This defect, if it is a defect, is unavoidable. Mertie (1964) at one time thought he had a system of describing the chemistry of a rock uniquely in 2 dimensional cartesian coordinates, but LeMaitre (1965) showed that the system was invalid and Mertie (1965) concurred. Nevertheless, because the felsic-mafic ratio (F) is a single number that chemically characterizes a rock, it may be useful as a parameter that can be plotted against other parameters to illustrate relations.

The silica-saturation ratio (S), in weight percentages, is defined as:

$$S = \frac{SiO_2}{Al_2O_3 + Na_2O + K_2O + MgO + CaO + FeO + Fe_2O_3},$$

The rationale behind the ratio is that, in silica-oversaturated rocks, SiO_2 predominates over all the other oxides, whereas in silica-undersaturated rocks these same oxides are relatively abundant relative to SiO_2. To be sure, the presence of quartz and feldspar in a rock denotes oversaturation, feldspar without quartz denotes saturation, and feldspathoids denote undersaturation, but the S ratio (for a particular F ratio) goes a step further and indicates the degree of saturation.

Values of S are listed in table 2 from the same rocks that provided the F values in table 1, and the average values were calculated in the same manner as the F values.

Normative percent quartz (qz) or olivine (ol) for the rock types listed in table 2 indicate that tonalite and the more felsic rocks are all quartz-rich (i.e., silica-oversaturated), and that monzonite and the more mafic rocks are saturated. The silica-oversaturated rocks from felsic granite to tonalite on figure 1 lie along a straight line whose downward continuation intersects the point represented by the tholeiitic basalts and dolerites. The points represented by the pairs monzonite-latite, diorite-andesite, and gabbro-basalt fall to the left of this straight line in the field of saturated rocks. Positions of other saturated and undersaturated rocks are indicated. Because feldspars are petrologically important in saturated rocks, the positions of the endmembers are shown on figure 1. Orthoclase (S=1.83) and albite (S=2.20) are ultrafelsic, having an infinite value of F because no Fe, Mg, or Ca exist

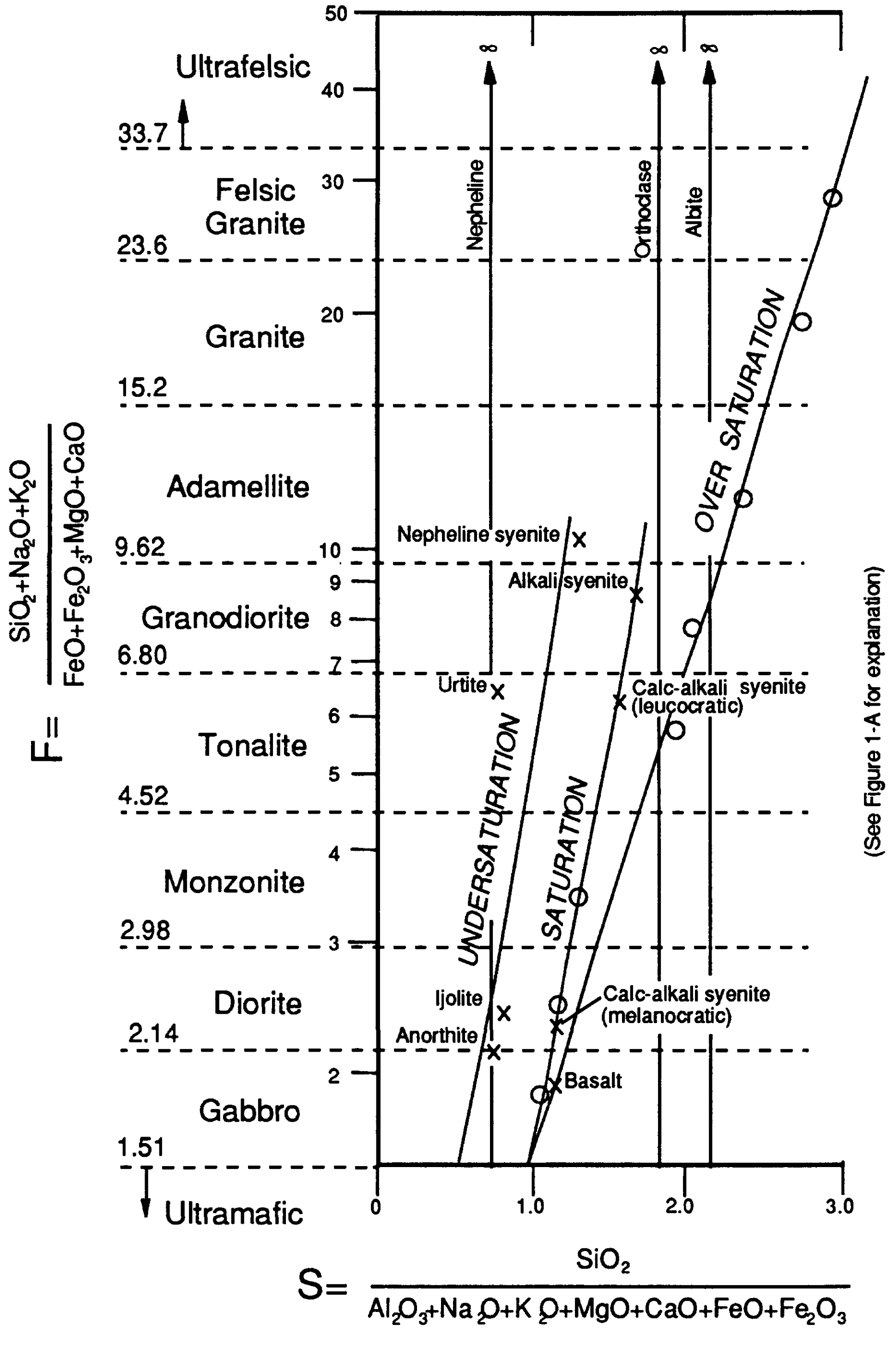


Figure 1. Graphic plotting of crystalline rocks with F, a felsic-mafic ratio, and S, a silica saturation ratio.

Figure 1-A. EXPLANATION FOR FIGURE 1.

All oxides in weight percent

○ Nockolds' average rocks (see Table 1)

X Rocks are from Nockolds (1954)

a. Nepheline Syenite-average of 80. Normative % ne 23.3, ol 0.2
b. Alkali Syenite-average of 25. Normative % qz 1.7
c. Calc-alkali syenite (leucocratic) -average of 18. Normative % qz 2.0
d. Calc-alkali Syenite (melanocratic) -average of 6. Normative % ol 11.8
e. Urtite-average of 6. Normative % ne 64.5
f. Ijolite-average of 11. Normative % ne 43.7
g. Normal tholeiitic Basalt (and Dolerite)-average of 137. Normative % qz 3.5

in the theoretical endmember. The same may be said for nepheline (S=0.73). Anorthite (S=0.76) is the undersaturated endmember and is also mafic (F=2.15). Discriminating among oversaturated, saturated, and undersaturated rocks is relatively unambiguous, except for mafic rocks, where only saturation or undersaturation is the rule.

Calculation of F for any crystalline rock indicates what compositional rock type it most resembles. Therefore, the rock names used in figure 1 are only compositional-equivalent names. Calculation of S for any crystalline rock will indicate its degree of silica saturation for a particular F value. For instance, a nepheline syenite may be as felsic as an adamellite, but its plotted position on figure 1 would indicate its undersaturated nature.

The Utility of Specific Gravity

One of the most fundamental properties of a rock is its specific gravity. However, it does not play a role in any rock classifications, largely because it would not be a meaningful indicator on a standard QAPF double ternary diagram. On the other hand, specific gravity becomes very meaningful when it is used with the felsic-mafic concept (F). Crystalline rocks show gradual increase in specific gravity from felsic to mafic types as measured by F.

Probably the most exhaustive work on the correlation of specific gravity and rock composition has been done by Kopf (1966, 1967). Saxov and Abrahamsen (1964) and Platou (1968) have also grappled with the specific gravity-rock composition problem.

The air pycnometer has made specific gravity determinations easy and relatively fast, unlike the usual pycnometric method, which requires temperature standardization and painstaking technique. Both powder and bulk-rock specific gravities may be determined. McIntyre, Welday, and Baird (1965) discussed the use and precision of the air pycnometer, especially compared with that of the Jolly balance. Even more important, however, is the capability of the air pycnometer to determine powder specific gravities, which the Jolly balance cannot do.

Bulk-rock specific gravity determination is generally adequate for plutonic and metamorphic rocks, but it is inadequate for volcanic rocks, which often have much pore space. Thus powder specific gravity determinations are necessary for volcanic rocks and are desirable for any rock type.

The air pycnometer can routinely measure the volume of bulk or powder samples of 15 to 18 cm^3 to within ± 0.03 cm^3. In combination with weights measured on a micro-balance to the nearest milligram or less, resulting specific gravities are correct to ± 0.004 to ±0.008 g/cm^3, yielding relative errors of about ±0.02 percent.

The Relation between Specific Gravity (ρ) and the Felsic-Mafic Ratio (F)

Figure 2, taken from Young and Olhoeft (1976), shows the relation of F to ρ using F and specific gravity data on powder samples of 56 Tertiary igneous rocks and 8 Precambrian metamorphic rocks. Olhoeft was able to show that the 64 data points fitted a natural logarithmic curve whose equation is

$$\rho = 2.643 + 0.444e^{-F/4} \qquad (1)$$

with a standard deviation of ±0.057. To find F from ρ, the equation is

$$F = -4 \ln \frac{\rho - 2.643}{0.444} \qquad (2)$$

From equation (1) values for ρ were calculated for the boundary values of F (table 1) shown in figure 2. Table 3 shows the ranges in F and ρ for each of the 10 rock types from ultrafelsic to ultramafic. It is apparent that specific gravity (ρ) is of limited use in distinguishing rocks more felsic than adamellite, but it is useful to distinguish rocks more mafic than granite. The felsic-mafic ratio (F) rather than ρ must be used to unequivocally distinguish rocks more felsic than adamellite.

Some mafic rocks will exhibit lower measured specific gravity than would be expected because of hydration caused by alteration or weathering; the more hydrated a rock is, the lower will be its specific gravity.

Transformation of a Modal Analysis into a Felsic-Mafic Ratio (F)

By using a modal analysis and the specific gravities of the constituent minerals the specific gravity of the rock can be calculated; F can be derived with equation (2).

Alternatively, one could calculate the chemical composition of the rock. This method, however, requires that the chemical composition of each mineral be known. In addition, the volume percentage (acquired by modal analysis) of each mineral must be multiplied by its specific gravity to yield weight percentage. Hence, unless the composition of each mineral is known precisely, an unusual case, and its specific gravity known exactly, also unusual, inaccuracy will affect the calculated chemical analysis. The modal analysis method is simpler yet makes no claim to high accuracy. Nevertheless, it should yield a good approximation of the F value, especially when averages are used instead of single determinations.

If no modal analysis is possible, especially in the case of glassy volcanic rocks or those of too-fine grain, then a measured specific gravity of the rock may be used to evaluate F with equation (2), with recognition of its approximate value.

Two examples (tables 4 and 5) illustrate the use of the F-S method to calculate F and S from chemical analysis and to calculate F by means of modal analysis and specific gravity, all on the same rock specimen. These results are compared with those obtained by means of the Streckeisen and Johannsen classifications.

The lack of correspondence in rock name determination between the Streckeisen and Johannsen methods on one hand and the F-S method on the other suggests that the double ternary QAPF rock classifications used and relied on by most geologists do not maintain name/composition integrity.

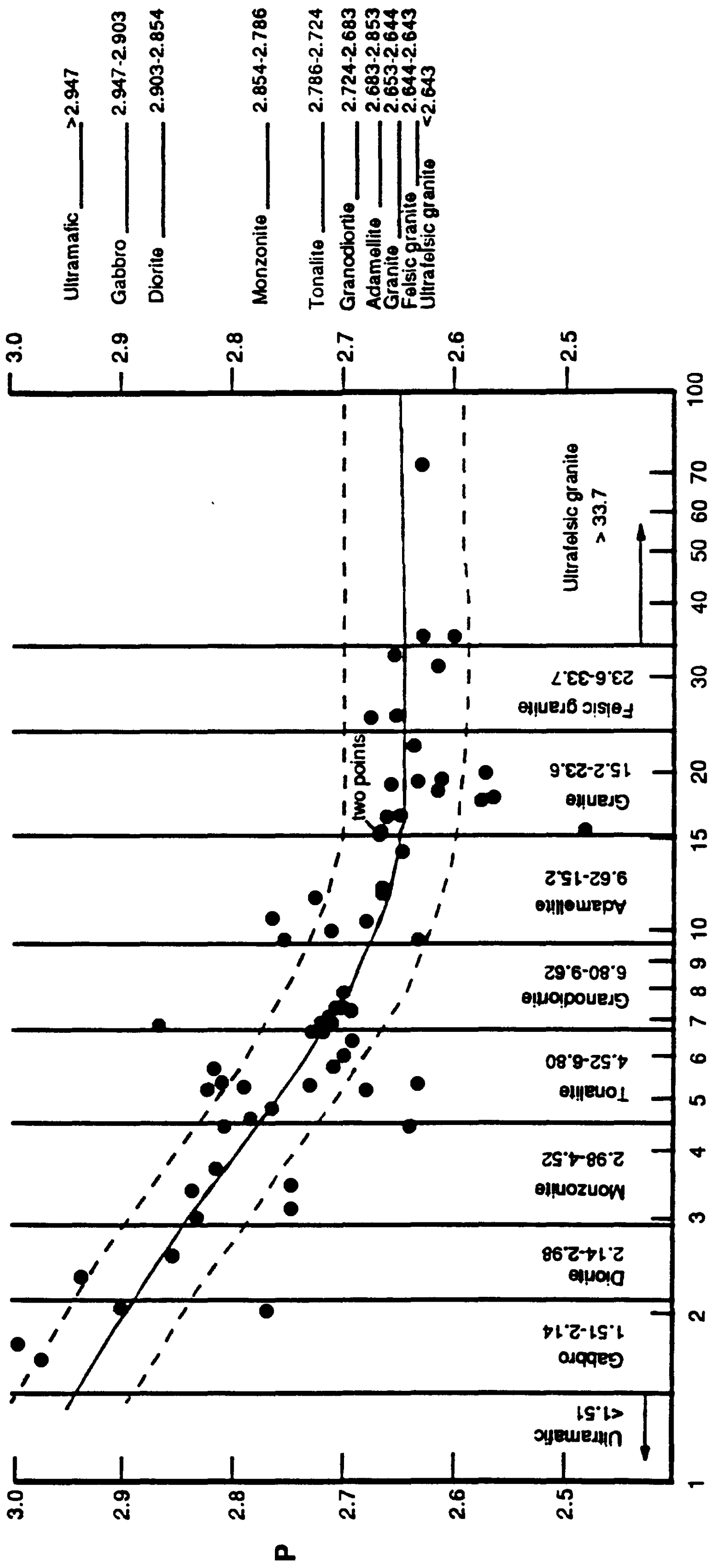


Figure 2. The relation of specific gravity (ρ) to felsic-mafic ratio (F).

Evaluation of the Accuracy of Finding F from Specific Gravity and/or Modal Analysis Data

If no chemical analysis of a rock is available, how accurate is the determination of its F by means of modal analysis or specific gravity, or both? For any one rock sample, the F arrived at by modal analysis or specific gravity, or both, may be only an approximation of its true chemical F, but an average of many rock samples yields an F that closely corresponds to the average chemical F, as shown in the following two cases (tables 6 and 7).

Thus, averages of either columns B, C, or D (table 6) correspond closely enough with the average of column A to yield the same rock name. In this case, D corresponds the best with A.

Thus, averages of either columns B, C, or D (table 7) correspond closely enough with the average of column A to identify the rock as a granite (felsic type) or a felsic granite. In this case, B corresponds the best with A.

Petrologic Inferences as a by-product of the F-S method

The F-S method may provide information about the crystallization or recrystallization history of granitic rocks. This is not surprising, because it would be expected that a crystallizing granophyre, for example, of F = 20 (namely a granite in composition) would have a high S ratio (2.75 or greater) because many cations other than Si^{+4} would have been removed from the melt in its process of formation by earlier crystallization of olivine, pyroxene, biotite, and calcic plagioclase. On the other hand, many plutonic rocks of metamorphic-metasomatic ancestry, again for example of F = 20, would tend to have lower S ratios (2.5 or less) because most of the cations other than Si^{+4} would not have been removed, as in the case of the granophyre.

And so, these expectations seem to be realized. On figure 3, six granophyric rocks and a rhyolite from tonalitic to ultrafelsic composition plot on the high S side of the oversaturated trendline. Using the criteria just given, we may definitely call these magmatic rocks. In contrast, Boulder Creek Granodiorite and Silver Plume Granite plot on the low S side of the oversaturated mainline. We may tentatively call these rocks predominantly metamorphic-metasomatic. Not all plutonic rocks plot as metamorphic-metasomatic with the use of figure 3. For instance, the Redskin Granite and Pikes Peak Granite from Colorado and four granites from Yemen mainly plot on the high S side of the oversaturated trendline (magmatic) on figure 3. The twelve plutonic rocks plotted in figure 3 were chosen for this purpose because their contained biotites were also analyzed chemically, which provides another approach to this line of reasoning. The biotite analyses are discussed in the next section.

Corroboration of Petrologic Inferences by Biotite Analyses

Biotite is the only mafic mineral common to most granitic rocks. As such, it is particularly useful as a sensitive indicator of petrogenetic conditions. Using chemical data on biotites from 49 metamorphic-metasomatic and magmatic granitic rocks Gokhale (1968) has been able to show graphically that the contrasting origins of these rocks are almost unequivocal--only 3 plotted points out of 49 did not fit the pattern.

The method is as follows--the weight percents of MgO, $Fe_2O_3 + TiO_2$, and FeO + MnO in each biotite are summed to 100 percent and the proportions are plotted on a ternary diagram (fig. 4). When this has been done for the 49 biotites, those from metamorphic-metasomatic rocks plot in the MgO-high part of the ternary diagram and those from magmatic (igneous) rocks plot in the MgO-low part of the diagram. One explanation, and possibly the only meaningful one, for this divisive behavior is that magmatic rocks will have had most of the Mg^{2+} removed from the magma by its early incorporation into olivine and pyroxene, leaving little Mg^{2+} in the remaining silicic melt to be incorporated by later-forming biotite. Of course, this train of events will not happen in metamorphic-metasomatic rocks because of the lack of a complete melt, and, instead abundant Mg will be available for incorporation into recrystallizing biotite. Although the separation line between metamorphic-metasomatic and magmatic rocks is drawn at 20 percent MgO of their contained biotites it really is not an either/or situation. All variations between a complete melt and complete subsolidus reactions may happen, and dependent on the degree of fluidity obtained, the MgO content of the biotite may vary from virtual zero to 50 percent.

The foregoing analysis is probably too simplistic because many variables may affect the eventual composition of a granitic rock. Nevertheless, the clear separation of the two fields of origin in Gokhale's diagram (fig. 4) begs for explanation.

Biotites from the twelve plutonic rocks that were plotted on the F-S diagram (fig. 3) in the last section were analyzed chemically. On figure 5 these biotites are plotted in exactly the same way as the 49 biotites in figure 4. Without exception, the biotites from the Boulder Creek Granodiorite and the Silver Plume Granite plot in the metamorphic-metasomatic field and the biotites from the Redskin and Pikes Peak Granites and the four granites from Yemen plot in the magmatic (igneous) field. Unfortunately, there are no data on biotites from the granophyric rocks and rhyolite shown on figure 3.

Corroboration of Petrologic Inferences from $\Sigma Al_2O_3 + Na_2O + K_2O$

The $\Sigma Al_2O_3 + Na_2O + K_2O$ in granitic crystalline rocks tends to be lower in magmatic (igneous) granitic rocks than in metamorphic-metasomatic rocks. This tendency is apparently so because early-crystallizing minerals, such as calcic plagioclase, capture available alumina in a magma, leaving less alumina for the final crystallization, as often happens in a granophyre. In most metamorphic-metasomatic granitic rocks, however, total alumina, at any one place, is incorporated in the final rock product. Again, these two very different processes--magmatic versus metamorphic-metasomatic--will show gradational results depending on the degree of fluidity obtained by the rock in its formation. Syenitic rocks, of course, whether magmatic or metamorphic-metasomatic, will also tend to have high $\Sigma Al_2O_3 + Na_2O + K_2O$.

That these two geologic processes may leave their imprint on rock chemistry is borne out by figure 6, which shows that the lowest $\Sigma Al_2O_3 + Na_2O + K_2O$ values are held by the seven granophyric rocks and the rhyolite, the same rocks that showed strong oversaturation in silica in the F-S diagram (fig. 3). The twelve plutonic rocks that demonstrated the difference between magmatic and metamorphic-metasomatic granitic rocks in the F-S and biotite methods, are also plotted on figure 6. Results are almost unequivocal; the Boulder Creek Granodiorite and the Silver Plume Granite show the highest $\Sigma Al_2O_3 + Na_2O + K_2O$ values (metamorphic-metasomatic tendency) and the Redskin and Pikes Peak Granites and the four granites from Yemen show the lowest $\Sigma Al_2O_3 + Na_2O + K_2O$ (magmatic tendency). On figure 6 the region between 22 and 23 percent $\Sigma Al_2O_3 + Na_2O + K_2O$ contains a question mark, which means that rocks in this region may not clearly be magmatic nor metamorphic-metasomatic.

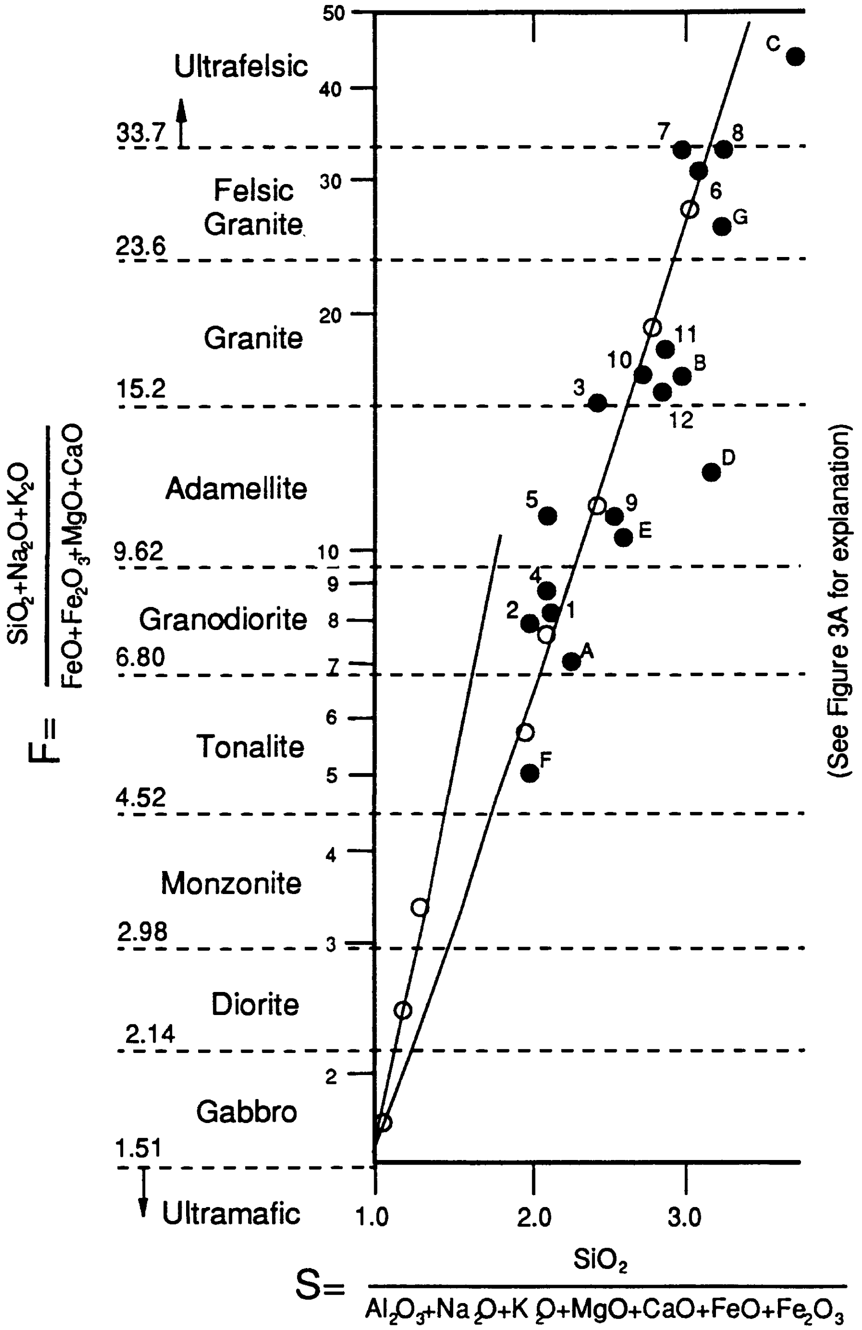


Figure 3. Granophyric (igneous) rocks and plutonic rocks plotted on an F-S diagram.

Figure 3-A. EXPLANATION FOR FIGURE 3.

○ Nockolds' average rocks

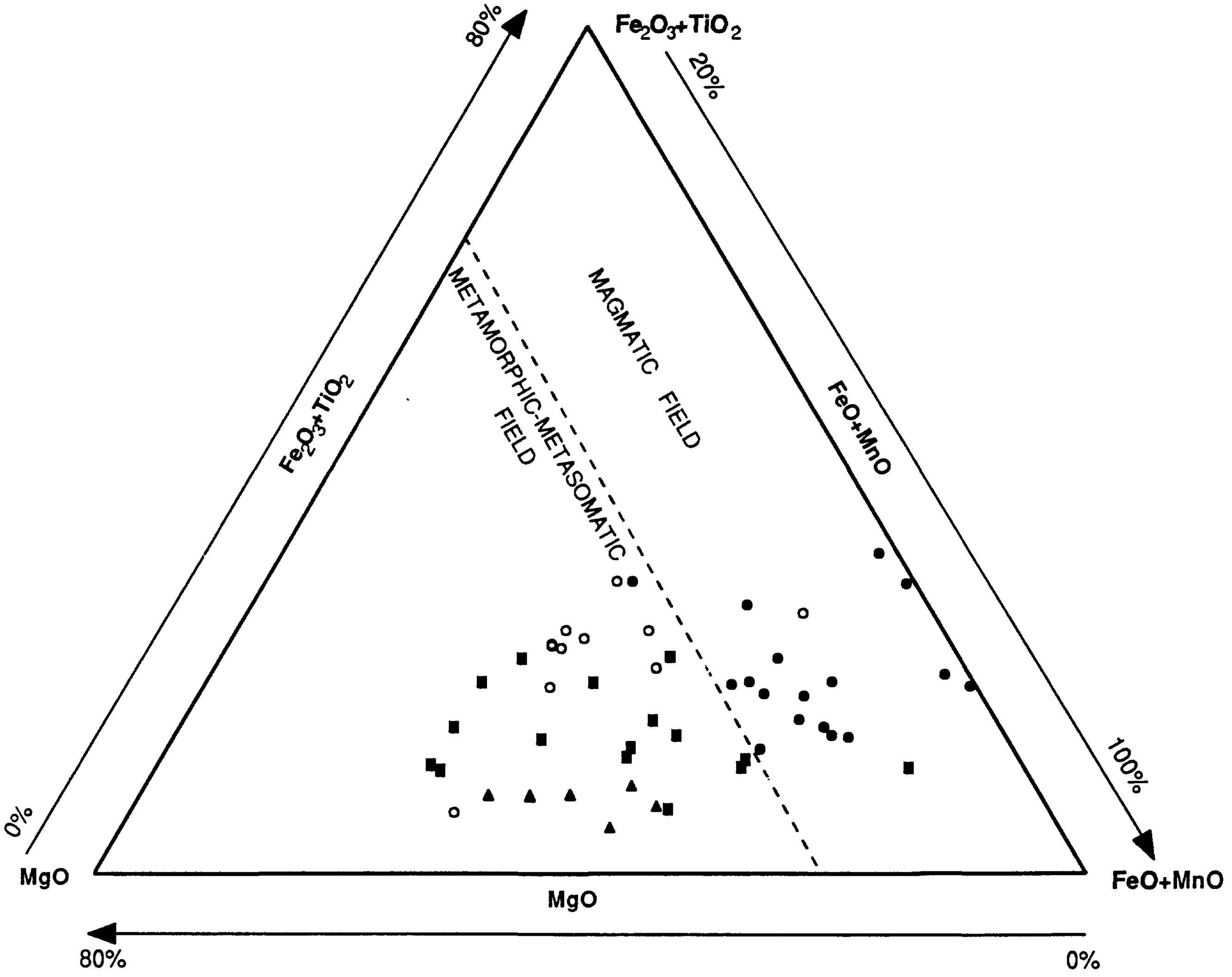
● A, B, and C - Granophyres, Duluth Gabbro Complex, Taylor (1964)
D - Granophyre from a gabbro-granophyre complex in northern Wisconsin, Leighton (1954)
E and F - Intermediate rocks from a gabbro- granophyre complex in northern Wisconsin, Leighton (1954)
G - Rhyolite overlying the Endion Sill, Duluth, Minnesota, Ernst (1960)

Metamorphic-metasomatic

1. Boulder Creek Granodiorite, Colorado (Sample 4, Gable, 1980)
2. Boulder Creek Granodiorite, Colorado (Sample 392, Gable, 1980)
3. Silver Plume Granite, Colorado (Sample T 309a-68, Gable, written commun., 1984)
4. Silver Plume Granite, Colorado (Sample T 345-68, Gable, written commun., 1984)
5. Silver Plume Granite, Colorado (Sample T 435-68, Gable, written commun., 1984)

Magmatic

6. Redskin Granite, Colorado (Sample BA-657, Hawley and Wobus, 1977)
7. Redskin Granite, Colorado (Sample BA-687, Hawley and Wobus, 1977)
8. Pikes Peak Granite, Colorado (Average of 3, Hawley and Wobus, 1977, page B 52)
9. Granite from Hajji, Yemen (Average of 3, Kabesh and Aly, 1982)
10. Granite from Kohlan, Yeman (Average of 3, Kabesh and Aly, 1982)
11. Granite from Al-Guba, Yemen (Average of 3, Kabesh and Aly, 1982)
12. Granite from Sada, Yemen (Average of 3, Kabesh and Aly, 1982)



EXPLANATION

● Biotites from igneous granites (Gokhale, 1967; Nockolds, 1947; Deer et al, 1962)

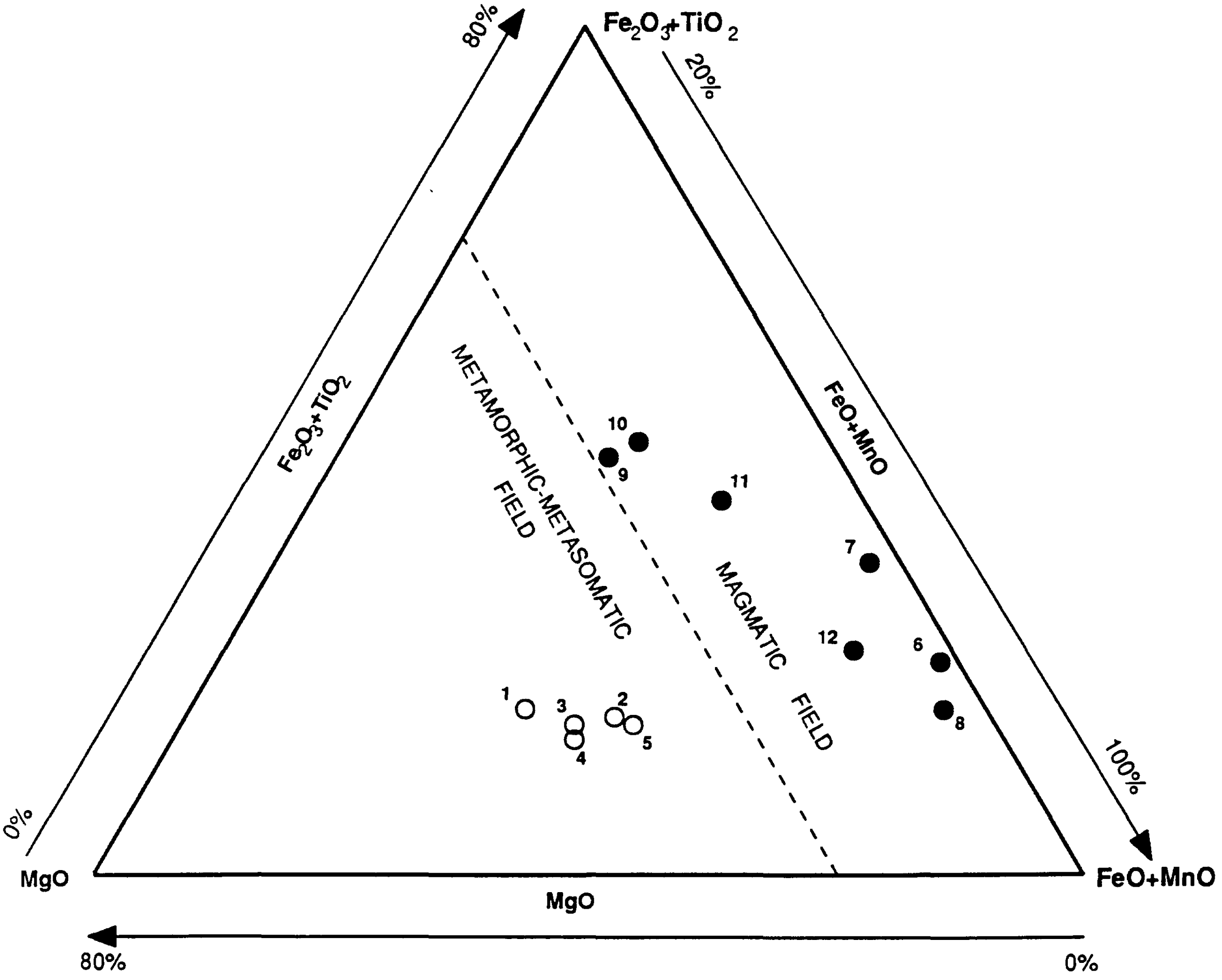
○ Biotites from metamorphic-metasomatic granites (Peikert, 1963; Naik, 1965)

■ Biotites from metamorphic-metasomatic rocks: schists and gneisses (Deer, et al, 1962)

▲ Biotites from metamorphic-metasomatic rocks: acid charnokites (Machigad, 1967)

- - - - Line of separation between biotites of magmatic environment from those of metamorphic-metasomatic environment

Figure 4. Gokhale's method of distinguishing magmatic (igneous) granitic rocks from metamorphic-metasomatic granitic rocks using biotite analyses.



NOTE: Points 1-12 correspond with the set of twelve test granites described in Figure 3.
(Biotite from point 8 is from sample TR-96)

Figure 5. Biotite analyses from magmatic granitic rocks and metamorphic-metasomatic granitic rocks.

In summary, the results of three different methods concur on the origin of a test set of twelve plutonic rocks.

APPLICATION OF THE F-S METHOD TO GRANITIC ROCKS

Ideally, to test the F-S method, chemical analyses of a pluton and chemical analyses of included biotite ought to be available. This, indeed, is the case for (1) the Ellison Lake pluton of southwestern Nova Scotia and (2) a set of three interconnected plutons in northern Cape Breton Island, Nova Scotia.

(1) Ellison Lake Pluton

The Ellison Lake pluton is an irregular body of about 3 by 7 km, located 3 km northeast of the South Mountain batholith in southwestern Nova Scotia. See figure 7, taken from Allen and Barr (1983). The pluton is a medium-grained monzogranite grading to granodiorite and intrudes predominantly metasedimentary rocks ranging from Cambrian to early Devonian. Xenoliths are exceptionally abundant in the pluton and, according to Allen and Barr, are undoubtedly derived from slates and metagreywackes of the Halifax and Goldenville Formations, respectively.

Three biotites from the Ellison Lake pluton were analyzed by Allen and Barr (1983). When Al_2O_3, MgO, and FeO (total Fe as FeO) are summed to 100 percent the following results obtain (analyzed amounts in parentheses):

Sample	Al_2O_3	MgO	FeO
10-24	(18.93) 39.5	(6.30) 13.2	(22.61) 47.3
10-24 (replicate)	(19.80) 40.3	(6.41) 13.0	(22.92) 46.7
15-17	(19.34) 39.0	(6.19) 12.5	(24.07) 48.5

To use these data figure 4 will not work, but Gokhale (1968) also provided an alternate ternary diagram using Al_2O_3, MgO, and FeO. In that diagram the demarcation line between biotites from igneous rocks and those from metamorphic-metasomatic rocks was drawn at 15 percent MgO.

In the biotites cited from the Ellison Lake pluton note that the MgO values are all less than 15 percent indicating that these biotites formed under igneous conditions.

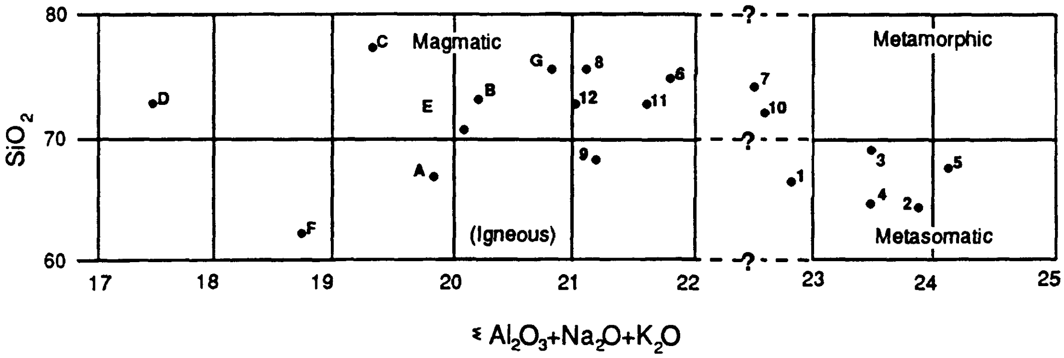
Corroborating evidence that the Ellison Lake pluton is igneous is obtained with the F-S method. Allen and Barr (1983) give the mean composition of 14 analyzed samples of the Ellison Lake pluton (table 8). From that data F = 9.28 (compositional equivalent = granodiorite) and S = 2.24. These two values plot as a point on the right side of the oversaturated trend line on figure 1, thus indicating the rock in question is magmatic (igneous).

Further corroborating evidence is obtained with the $\Sigma Al_2O_3 + Na_2O + K_2O$ method. These three values for the mean of the 14 analyzed samples sum to 21.99. Reference to figure 6 indicates magmatic igneous conditions.

Thus, three different methods indicate that the Ellison Lake pluton is magmatic (igneous).

(2) Plutons in northern Cape Breton Island, Nova Scotia

White Point, Black Brook, and Warren Brook plutons interconnect and occupy about 350 km^2, figure 8, taken from Wiebe (1975). According to Wiebe, the plutons, enveloped by migmatite, intrude a complex terrane of metamorphic rocks and older plutonic rocks. Fine- to medium-grained leucocratic



EXPLANATION

Points A through G correspond with Granophyres and Rhyolite in Figure 3

Points 1-12 correspond with set of twelve test Granites in Figure 3

Queries between 22 and 23% Σ $Al_2O_3+Na_2O+K_2O$ indicate uncertainty of interpretation of origin

Figure 6. Granophyric (igneous) rocks and plutonic rocks plotted on a $\Sigma Al_2O_3 + Na_2O + K_2O$ vs. SiO_2 diagram.

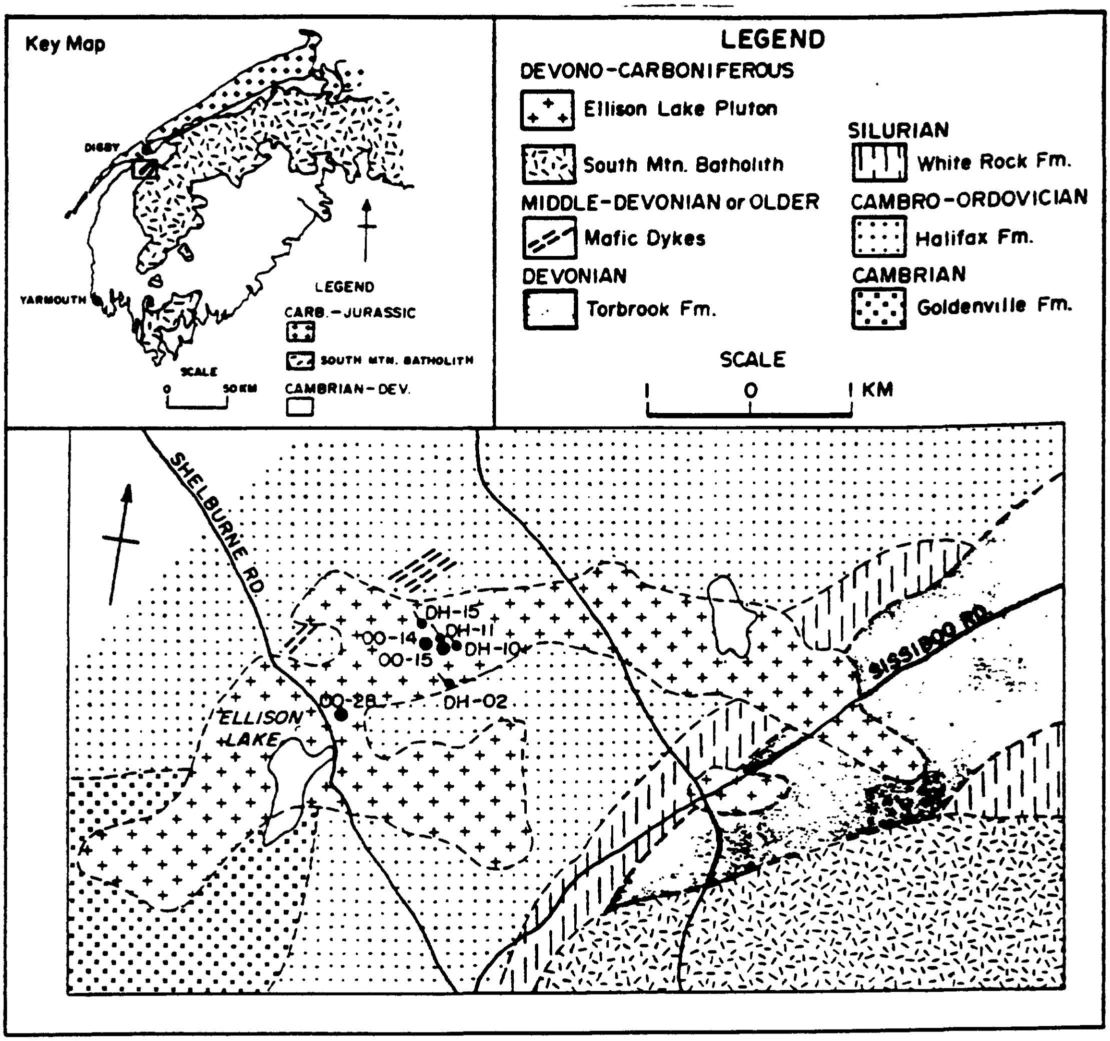


Figure 7. Ellison Lake pluton, southwestern Nova Scotia (taken from Allen and Barr, 1983).

granodiorite and adamellite constitute the bulk of the plutons; they have been dated by Cormier (1972) at 410 ± 50 m.y.

A biotite analysis from a granitic dike within one of the plutons is given. When MgO, Fe_2O_3 + TiO_2, and FeO + MnO are summed to 100 percent the following results obtain (analyzed amounts in parenthesis):

MgO	Fe_2O_3 + TiO_2	FeO + MnO
(8.03) 23.2	(7.32) 21.1	(19.31) 55.7

On figure 4 the data for this biotite plot in the metamorphic-metasomatic field.

Corroborating evidence that the three plutons are metamorphic-metasomatic in origin is obtained with the F-S method. Wiebe (1975) gives the average chemical composition of nine samples from points throughout the three plutons and a calculated chemical analysis based on an average of 48 modal analyses (table 9). Data from the nine samples translate to F = 19.6 (compositional equivalent of a granite) and S = 2.61; from the 48 modal analyses F = 22.0 (compositional equivalent of a granite) and S = 2.66. Both of these data points plot left of the oversaturation trend line on figure 1, which is indicative of metamorphic-metasomatic rocks.

Further corroborating evidence is provided by the $\Sigma Al_2O_3 + Na_2O + K_2O$ method. This Σ for the nine samples is 23.29 and 23.49 for the 48 samples, both indicative of metamorphic-metasomatic rocks. Thus, all three methods point to a metamorphic-metasomatic origin for the three plutons.

A closing comment is relevant here. Barr and Pride (1986) recently drew attention to two constrasting Devonian granitic plutons on Cape Breton Island, Nova Scotia. No biotite analyses were made, but it is interesting to note that conclusions reached using the F-S method and the $\Sigma Al_2O_3 + Na_2O + K_2O$ method agree with the conclusions reached by Barr and Pride (1986). Furthermore, one of the plutons, the White Point, is the same one studied by Wiebe (1975) and already classified as metamorphic-metasomatic in this paper on the basis of his data.

Figure 9, taken from Barr and Pride (1986), shows the location of the two plutons and table 10 from the same authors gives the main geologic features of the two plutons. I would draw attention to the well-developed contact aureole of hornblende-hornfels facies and the "sanidine transitional to orthoclase" of the Gillis Mountain pluton and the no apparent contact aureole and microcline of the White Mountain pluton, namely, a magmatic versus metamorphic-metasomatic signature on the basis of field geology and petrography. From chemical analyses of the two plutons given by the authors the following data are derived:

	Gillis Mountain pluton	White Point pluton
F (average)	10.8 (compositional equivalent of adamellite)	21.7 (compositional equivalent of granite)
S (average)	2.29	2.47
$\Sigma Al_2O_3 + Na_2O + K_2O$ = (average)	22.09	23.69

Using figure 1 for the F-S method the White Point pluton plots in the metamorphic-metasomatic field and the Gillis Mountain pluton plots close to the magmatic field. The $\Sigma Al_2O_3 + Na_2O + K_2O$ method indicates similar conclusions.

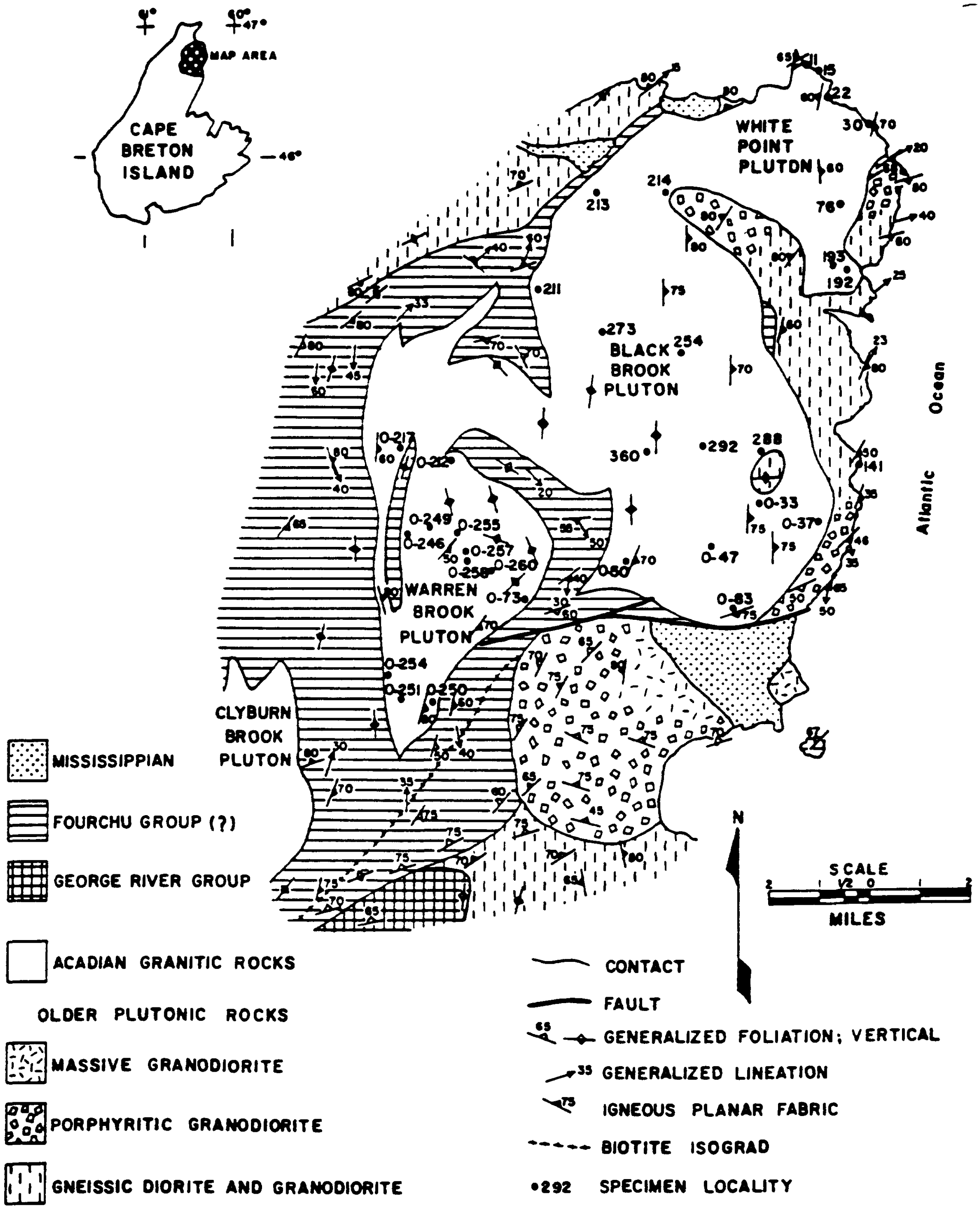


Figure 8. Plutons in northern Cape Breton Island, Nova Scotia (taken from Wiebe, 1975).

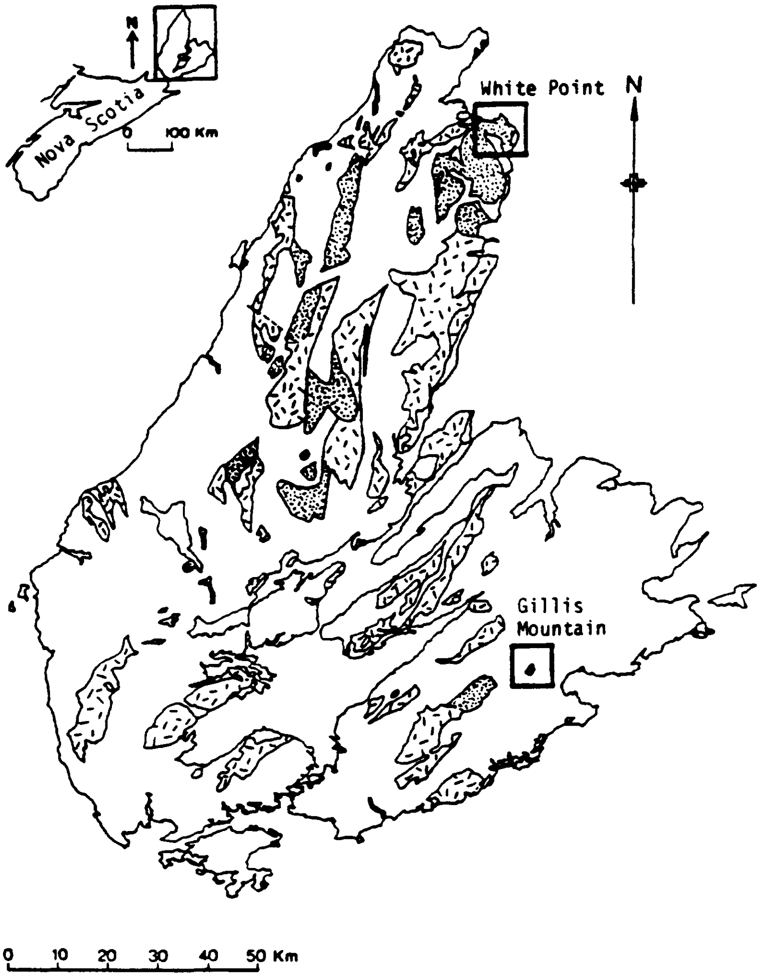


Figure 9. Gillis Mountain and White Point plutons, Cape Breton Island, Nova Scotia (taken from Barr and Pride, 1986).

DISCUSSION

In no way should the F-S method be construed as a valid competitor with the Johannsen or Streckeisen igneous rock classifications, which are much more comprehensive and detailed. Those classifications are based on mineralogy, whereas the F-S method is based on chemistry. As a legitimate aid, however, the F-S method will lead to name/composition integrity. Furthermore, petrologic inferences, peculiar to the F-S method, coupled with geologic field data may lead to more realistic conclusions. The geologic examples, cited in this report, appear to be clear-cut, but other cases may be more ambiguous. Only many more applications will show whether the F-S method can, indeed, validly discriminate between igneous and metamorphic-metasomatic rocks.

REFERENCES CITED

Allen, P.L., and Barr, S.M., 1983, The Ellison Lake pluton--a cordierite-bearing monzogranitic body in southwestern Nova Scotia: Canadian Mineralogist, v. 21, p. 583-590.

Barr, S.M., and Pride, C.R., 1986, Petrogenesis of two contrasting Devonian granitic plutons, Cape Breton Island, Nova Scotia: Canadian Mineralogist, v. 24, p. 137-146.

Cormier, R.F., 1972, Radiometric ages of granitic rocks, Cape Breton Island, Nova Scotia: Canadian Journal Earth Science, v. 9, p. 1074-1086.

Deer, W.A., Howie, R.A., and Zussman, J., 1962, Sheet silicates, v. 3 of rock-forming minerals: John Wiley and Sons, New York, N.Y., 270 p.

Ernst, W.G., 1960, Diabase-Granophyre relations in the Endion sill, Duluth, Minnesota: Journal of Petrology, v. 1, pt. 3, p. 286-303.

Gable, D.J., 1980, The Boulder Creek Batholith, Front Range, Colorado: U.S. Geological Survey Professional Paper 1101, 88 p.

Gokhale, N.W., 1967, Alakali-poor biotites from the Velence Mountain granites, Hungary: Current Science, v. 36, no. 21, p. 578-579.

______1968, Chemical composition of biotites as a guide to ascertain the origin of granites: Bulletin Geological Society of Finland, v. 40, p. 107-111.

Hawley, C.C., and Wobus, R.A., 1977, General geology and petrology of the Precambrian crystalline rocks, Park and Jefferson Counties, Colorado: U.S. Geological Survey Professional Paper 608-B, 77 p.

Johannsen, Albert, 1939, A descriptive petrography of the igneous rocks: 4 volumes, University Chicago Press, 1629 p.

Kabesh, M.L., and Aly, M.M., 1982, The chemistry of biotites as a guide to the petrogenesis of some Precambrian granitic rocks, Yemen Arab Republic: Chem. Erde, v. 41, p. 313-324.

Kopf, Manfred, 1966, Die Untersuchung physikalischer Eigenschaften von granitoiden Gesteinen als neue Methode der Granitforschung: Geologie, no. 53, p. 1-135.

______1967, The petrophysical character of the "granites" of Bornholm: Geol. Fören. Förh., v. 89, p. 3-14.

Leighton, M.W., 1954, Petrogenesis of a gabbro-granophyre complex in northern Wisconsin: Geological Society of America Bulletin, v. 65, p. 401-442.

LeMaitre, R.W., 1965, Comments on "A method of classifying analyses with any number of terms": American Mineralogist, v. 50, p. 1131-1133.

Machigad, B.S., 1967, Some aspects of garnet-biotite equilibria in enderbites from Pallavarum, Madras, India: Journal of Karnatak University, v. XII, p. 25-40.

McIntyre, D.B., Welday, E.E., and Baird, A.K., 1965, Geologic application of the air pycnometer: A study of the precision of measurement: Geological Society of America Bulletin, v. 76, p. 1306-1320.

Mertie, J.B., Jr., 1964, A method of classifying analyses with any number of terms: American Mineralogist, v. 49, p. 1306-1320.

______1965, Reply to comments on "A method of classifying analyses with any number of terms": American Mineralogist, v. 50, p. 1133.

Naik, M.S., 1965, The Molakalmuru granites of Chitradurga District, Mysore State, India: Unpublished Ph.D. thesis, Karnatak University, Dharwar, India.

Nockolds, S.R., 1947, The relation between chemical composition and paragenesis in the biotite micas of igneous rocks: American Journal of Science, v. 245, p. 401-420.

______1954, Average chemical compositions of some igneous rocks: Geological Society of America Bulletin, v. 65, p. 1007-1032.

Peikert, E.W., 1963, Biotite variation as a guide to petrogenesis of granitic rocks in the Precambrian of northeastern Alberta: Journal of Petrology, v. 4, p. 432-459.

Platou, S.W., 1968, On the petrophysical properties of granitic rocks: Geol. Foren, Forh., v. 90, p. 427-433.

Saxov, Svend, and Abrahamsen, Niels, 1964, Some rock densities in Bornholm: Geol. Foren. Forh., v. 86, p. 83-95.

Segerstrom Kenneth, and Young, E.J., 1972, General geology of the Hahn Peak and Farewell Mountain quadrangles, Routt County, Colorado, with a chapter on Triassic and Jurassic rocks by G.N. Pipiringos: U.S. Geological Survey Bulletin 1349, 63 p.

Simpson, E.S.W., 1954, On the graphical representation of differentiation trends in igneous rocks: Geologic Magazine, v. 91, p. 238-244.

Streckeisen, A.L., 1976, To each plutonic rock its proper name: Earth Science Reviews, v. 12, p. 1-33.

Taylor, R.B., 1964, Geology of the Duluth Gabbro Complex near Duluth, Minnesota: Minnesota Geological Survey Bulletin 44, 63 p.

Wager, L.R., and Deer, W.A., 1939, Geological investigations in East Greenland, pt. III, The petrology of the Skaergaard intrusion, Kangerdlugssuag, East Greenland: Medd. Gronland, v. 105, no. 4.

Whitney, J.A., Jones, L.M., and Walker, R.L., 1976, Age and origin of the Stone Mountain Granite, Lithonia district, Georgia: Geological Society of America Bulletin, v. 87, p. 1067-1077.

Wiebe, R.A., 1975, Origin and emplacement of Acadian granitic rocks, northern Cape Breton Island: Canadian Journal Earth Sciences, v. 12, p. 252-262.

Wright, N.P., 1966, Mineralogic variation in the Stone Mountain Granite, Georgia: Geological Society of America Bulletin, v. 77, p., 207-210.

Young, E.J., 1984, Chemical methods for distinguishing between metamorphic-metasomatic and magmatic granitic rocks: Geological Society of America, Abstracts with Programs, v. 16, p. 703.

Young, E.J., and Olhoeft, G.R., 1976, Relations between specific gravity and chemical composition for a suite of igneous and metamorphic rocks: U.S. Geological Survey Open-File Report 76-809, 12 p.

Table 1. Felsic-mafic ratios (F) calculated from rock analyses compiled by Nockolds (1954)

$$F = \frac{SiO_2 + Na_2O + K_2O}{FeO + Fe_2O_3 + MgO + CaO} \text{ in weight percent}$$

Plutonic rock (Volcanic equivalent)	Number of Nockolds' samples contributing to average felsic-mafic ratio (F)		F	Weighted F for compositional pair	Boundary values of F
					33.7
Felsic granite	48	69	28.5	28.2	
(Felsic rhyolite)	21		27.4		
					23.6
Granite	72	94	18.4	19.7	
(Rhyolite)	22		23.8		
					15.2
Adamellite	121	179	11.1	11.7	
(Quartz latite)	58		13.0		
					9.62
Granodiorite	137	252	8.15	7.91	
(Rhyodacite)	115		7.63		
					6.80
Tonalite	58	108	6.29	5.85	
(Dacite)	50		5.35		
					4.52
Monzonite	46	88	3.61	3.49	
(Latite)	42		3.35		
					2.98
Diorite	50	99	2.33	2.55	
(Andesite)	49		2.78		
					2.14
Gabbro	160	297	1.73	1.80	
(Basalt)	137		1.88		
					1.51

Note: I have made the following synonymous changes in Nockolds' terminology: Felsic granite and Felsic rhyolite for Alkali granite and Alkali rhyolite; Quartz latite for Dellenite

Table 2. Silica saturation ratios (S) calculated from rock analyses compiled by Nockolds (1954)

$$S = \frac{SiO_2}{Al_2O_3 + Na_2O + K_2O + MgO + CaO + FeO + Fe_2O_3} \text{ in weight percent}$$

Plutonic rock (Volcanic equivalent)	Number of Nockolds' samples contributing to average silica saturation ratio (S)		S	Weighted S for compositional pair	Normative % qz or ol
Felsic granite	48	69	2.92	2.96	32.2 qz
(Felsic rhyolite)	21		3.05		31.1 qz
Granite	72	94	2.69	2.74	29.2 qz
(Rhyolite)	22		2.92		33.2 qz
Adamellite	121	179	2.35	2.39	24.8 qz
(Quartz latite)	58		2.46		26.1 qz
Granodiorite	137	252	2.12	2.09	21.9 qz
(Rhyodacite)	115		2.06		20.6 qz
Tonalite	58	108	2.05	1.94	24.1 qz
(Dacite)	50		1.82		19.6 qz
Monzonite	46	88	1.31	1.28	1.2 ol
(Latite)	42		1.24		0.5 qz
Diorite	50	99	1.15	1.20	0.3 qz
(Andesite)	49		1.26		5.7 qz
Gabbro	160	297	0.982	1.04	6.8 ol
(Basalt)	137		1.11		3.5 qz

Note: I have made the following synonymous changes in Nockolds' terminology: Felsic granite and Felsic rhyolite for Alkali granite and Alkali rhyolite; Quartz latite for Dellenite

Table 3. Values of F and ρ

Rock	F	ρ
Ultrafelsic granite (Ultrafelsic rhyolite)	>33.7	<2.643
Felsic granite (Felsic rhyolite)	23.6 - 33.7	2.644 - 2.643
Granite (rhyolite)	15.2 - 23.6	2.653 - 2.644
Adamellite (quartz latite)	9.62 - 15.2	2.683 - 2.653
Granodiorite (rhyodacite)	6.80 - 9.62	2.724 - 2.683
Tonalite (dacite)	4.52 - 6.80	2.786 - 2.724
Monzonite (latite)	2.98 - 4.52	2.854 - 2.786
Diorite (andesite)	2.14 - 2.98	2.903 - 2.854
Gabbro (basalt)	1.51 - 2.14	2.947 - 2.903
Ultramafic	<1.51	>2.947

Table 4.--The F-S Method
Example 1. Stone Mountain Granite, Georgia

Chemical analysis - average of 5 (Whitney, Jones, and Walker, 1976)

SiO_2	73.74
TiO_2	0.13
Al_2O_3	15.33
FeO[1]	0.70
MnO	0.03
MgO	0.12
CaO	1.00
Na_2O	3.82
K_2O	4.52
P_2O_5	0.15
H_2O^+	0.46
	100.00

$$F = \frac{SiO_2 + Na_2O + K_2O}{FeO + Fe_2O_3 + MgO + CaO} = 45.10$$

(Compositional-equivalent name: Ultrafelsic granite)

$$S = \frac{SiO_2}{Al_2O_3 + Na_2O + K_2O + MgO + CaO + FeO + Fe_2O_3} = 2.893$$

Specific gravity (measured) - 2.633 (Johannsen, 1939, Vol II, p. 122)

from Table 3 F>33.7 (Compositional-equivalent name: Ultrafelsic granite)

Modal analysis - average of 49 modal analyses (Wright, 1966)

Mineral	Volume %		Specific gravity	Weight factor
Quartz	32.4	x	2.648	85.80
Oligoclase(An_{15})	28.8	x	2.625	75.60
Microcline	25.7	x	2.57	66.05
Muscovite	11.5	x	2.8	32.20
Biotite	1.2	x	2.86	3.43
Epidote & clinozoisite	0.3	x	3.4	0.62
Tourmaline	0.2	x	3.1	0.62
	100.1			264.38

Calculated specific gravity of rock

$$\frac{264.38}{100.1} = 2.641$$[2]

from Table 3 F>33.7
(Compositional-equivalent name: Ultrafelsic granite)

Names from other classifications-Streckeisen (1976) method:
based on QAP (corrected to 100%)

Q 32.4	37.3
A 25.7	29.6
P 28.8	33.1
	100.0

Name - Granite
The rock plots near the center of the 3b field (Monzogranite-formerly called Adamellite)

Johannsen (1939) method:

Name - Leucoadamellite 127"P

Remarks: This is a good example to show how differently granitic rocks of this type are classified according to the F-S method as contrasted with the classifications of Streckeisen and Johannsen, both of which point to adamellite, or its equivalent. According to the F-S method the Stone Mountain Granite is hardly an adamellite by composition, but a special kind of granite, namely an ultrafelsic granite, separated from adamellite by 2 compositional grade classifications. The determination, ultrafelsic granite, is indicated in three dissimilar ways: chemistry, mineralogy (modal), and an important physical property (p). Moreover, its silica-saturation ratio indicates that it is definitely less oversaturated in silica than "normal" silica-oversaturated rocks for this particular F ratio. The potential of the F-S method remains to be investigated, especially in regard to granitic rocks.

[1] Total Fe expressed as FeO

[2] 2.64 is too close to the borderline between felsic granite and ultrafelsic granite to have much reliability

Table 5. The F-S Method
Example 2. Boulder Creek Granodiorite
from the NW/4 Sec 16 T1N,
R75W, south of Lake Granby, Colorado

Chemical analysis -SL-51 (D-220053) by N. Skinner, D. Kobilis

SiO_2	58.1
TiO_2	0.84
Al_2O_3	16.5
Fe_2O_3	2.0
FeO	4.3
MnO	0.11
MgO	3.7
CaO	5.3
Na_2O	3.2
K_2O	3.2
P_2O_5	0.41
H_2O^+	1.0
H_2O^-	0.21
CO_2	0.01
	99.88

F = 4.22 (Compositional-equivalent name: Monzonite, close to Tonalite)

S = 1.521

Specific gravity (measured) - 2.83

from equation 2 F = 3.46 (Compositional-equivalent name: Monzonite)

Modal analysis - 826 points

Mineral	Volume %		Specific gravity	Weight factor
Andesine (An_{43})	37.5	x	2.673	100.24
Quartz	20.7	x	2.648	54.81
Hornblende	13.7	x	3.2	43.84
Biotite	11.3	x	2.86	32.32
Microcline	9.4	x	2.57	24.16
Sericite	4.0	x	2.8	11.20
Epidote	1.6	x	3.46	5.44
Sphene	1.2	x	3.5	4.20
Apatite	0.5	x	3.2	1.60
Magnetite	0.1	x	5.2	0.52
Zircon	tr		---	---
	100.0			278.33

Calculated specific gravity of rock = 2.7833 from equation 2 F = 4.61 (Compositional-equivalent name: Tonalite, close to Monzonite)

Names from other classifications-Streckeisen (1976) method:
based on QAP (corrected to 100%)

Q	20.7	30.6
A	9.4	13.9
P	37.5	55.5
		100.0

Name - Granodiorite

Johannsen (1939) method:

Name - Granodiorite 227P

Remarks: According to the F-S method, this rock is compositionally closer to monzonite than a tonalite. The silica-saturation ratio indicates that the rock is halfway between the oversaturated and saturated trend lines. The presence of about 20% quartz suggests that mafic tonalite is a more appropriate name, but, at any rate, the rock is far too mafic to be called granodiorite (Streckeisen and Johannsen methods).

Table 6.--Evaluation of accuracy of calculating F from modal analyusis and specific gravity

Case 1. Boulder Creek Granodiorite (from unpublished work of the author)

	A		B		C		D	
	F from chemical analysis	Compositional name	F from modal analysis	Compositional name	F from specific gravity	Compositional name	F from average of F's from modal analysis and specific gravity	Compositional name
SL-35	4.60	Tonalite	5.22	Tonalite	5.01	Tonalite	5.12	Tonalite
SL-51	4.22	Monzonite	4.61	Tonalite	3.46	Monzonite	4.04	Monzonite
SL-57	4.63	Tonalite	5.62	Tonalite	3.82	Monzonite	4.72	Tonalite
SL-66	5.04	Tonalite	6.78	Tonalite	4.29	Monzonite	5.54	Tonalite
SL-67	5.94	Tonalite	7.41	Granodiorite	5.88	Tonalite	6.65	Tonalite
SL-70	6.45	Tonalite	6.68	Tonalite	5.69	Tonalite	6.19	Tonalite
Average	5.15	Tonalite	6.05	Tonalite	4.69	Tonalite	5.39	Tonalite

Table 7.--Evaluation of calculating F from modal analysis and specific gravity

Case 2. Silver Plume Granite (from Part I of this bulletin)

	A		B		C		D	
	F from chemical analysis	Compositional name	F from modal analysis	Compositional name	F from specific gravity	Compositional name	F from average of F's from modal analysis and specific gravity	Compositional name
SM-3	25.2	Felsic granite	10.6	Adamellite	>33.7	Ultrafelsic granite	>22.2	Granite or more felsic
SM-4	19.7	Granite	15.0	Adamellite	11.5	Adamellite	13.3	Adamellite
SM-43A	22.3	Granite	>33.7	Ultrafelsic granite	12.6	Adamellite	>23.2	Granite or more felsic
SL-34	16.5	Granite	12.4	Adamellite	13.1	Adamellite	12.8	Adamellite
SL-40	28.6	Felsic granite	>33.7	Ultrafelsic granite	33.7	Felsic granite	>33.7	Ultrafelsic granite
SL-64	30.2	Felsic granite	>33.7	Ultrafelsic granite	18.9	Granite	>26.3	Felsic granite or more felsic
SL-65	24.2	Felsic granite	20.6	Granite	12.2	Adamellite	16.4	Granite
Average	23.8	Felsic granite	>22.8	Granite or more felsic	>19.4	Granite or more felsic	>21.1	Granite or more felsic

Table 8. The mean composition of 14 analyzed samples of the Ellison Lake pluton (taken from Allen and Barr, 1983)

SiO_2	67.31 ±	1.14	Q	29.57
TiO_2	0.61	0.01	C	2.64
Al_2O_3	14.94	0.04	Or	25.19
Fe_2O_3**	4.72	0.01	Ab	24.68
MnO	0.09	0.01	An	8.64
MgO	1.32	0.06	Hy	3.36
CaO	1.97	0.26	Ru	0.51
Na_2O	2.87	0.06	Il	0.19
K_2O	4.18	0.18	Hm	4.80
P_2O_5	0.19	0.01	Ap	0.45
LOI	1.3	0.6		
			D.I.***	79.4 ± 0.9
Total	99.5			
			A/CNK****	1.17 ± 0.05

*Analyses done by atomic absorption spectrometry at Acadia University. Analysts P. Allen and J. Cabilio

**Total Fe as Fe_2O_3

***Differentiation Index (Thornton and Tuttle, 1960)

****Molecular Proportion $Al_2O_3/(CaO + Na_2O = K_2O)$

Table 9. Chemical analyses of Acadian granites (taken from Wiebe, 1975)

	214	141B†	0-47B	213	141A^{-}	0-258	0-50	11A	193	A-1**	A-2**
SiO_2	69.84	69.19	71.10	71.57	71.97	71.27	72.85	72.68	73.35	71.54	72.28
TiO_2	0.33	0.30	0.29	0.16	0.28	0.13	0.19	0.15	0.19	0.22	0.20
Al_2O_3	15.82	16.49	14.82	15.39	14.71	15.27	14.74	15.11	14.42	15.20	15.15
Fe_2O_3	1.21	0.88	1.02	0.91	0.91	0.85	0.72	0.66	1.42	0.95	0.25
FeO	1.10	1.03	0.98	1.02	0.94	0.90	0.65	0.78	0.34	0.86	1.14
MnO	0.01	0.02	0.03	0.03	0.04	0.02	0.01	0.02	0.02	0.02	0.04
MgO	0.86	0.80	0.79	0.57	0.71	0.49	0.63	0.44	0.37	0.63	0.49
CaO	2.20	2.03	2.06	1.76	1.43	1.52	1.43	1.29	0.97	1.63	1.77
Na_2O	4.01	4.76	3.74	4.41	3.52	4.12	3.54	4.42	3.64	4.02	4.40
K_2O	3.20	3.10	3.71	3.94	4.78	4.57	4.60	4.07	4.69	4.07	3.94
P_2O_5	0.08	0.09	0.08	0.07	0.07	0.07	0.06	0.05	0.03	0.07	--
H_2O+	0.60	0.72	0.71	0.59	0.58	0.51	0.72	0.41	0.48	0.59	0.27
H_2O^-	0.34	0.34	0.62	0.36	0.37	0.29	0.26	0.30	0.35	0.36	--
Total	99.60	99.75	100.42	100.31	100.31	100.01	100.40	100.38	100.27	100.16	99.93
DI	81.11	82.63	83.58	86.13	87.04	87.54	87.82	89.26	90.26	87.0	86.9
						Weight norms					
Q	28.27	24.03	30.01	25.53	29.01	25.67	30.68	27.80	31.68	28.0	26.4
Or	18.91	18.32	21.93	23.28	28.25	27.01	27.18	24.05	27.72	23.9	23.3
Ab	33.93	40.28	31.65	37.32	29.79	34.86	29.96	37.40	30.80	34.1	37.2
An	10.39	9.48	9.70	8.27	6.64	7.08	6.70	6.07	4.62	8.1	8.8
Hy	2.64	2.70	2.50	2.33	2.35	1.99	1.87	1.77	0.92	2.0	2.8
He									1.00		
Mt	1.75	1.28	1.48	1.32	1.32	1.23	1.04	0.96	0.61	1.4	0.4
Il	0.63	0.57	0.55	0.30	0.53	0.25	0.36	0.28	0.36	0.5	0.4
Ap	0.19	0.21	0.19	0.16	0.16	0.16	0.14	0.12	0.07	0.2	--
C	1.95	1.83	1.10	0.84	1.31	0.95	1.48	1.21	1.66	1.2	0.4

*Analyst: Japan Analytical Chemistry Research Institute, T. Asari, Director.

**A-1 is average of 9 analyses. A-2 is calculated analyses based on the averge of 48 modes and analyses of alkali feldspar (15A) and biotite (141A) in table 1.

†Dikes.

Table 10. Comparative geologic features of the Gillis Mountain and White Point plutons (taken from Barr and Pride, 1986)

FEATURE	GILLIS MOUNTAIN	WHITE POINT
Size	6 km^2 (isolated stock)	30 km^2 (part of much larger intrusion)
Shape	Subelliptical	Irregular lobate
Country rocks	Cambrian clastic sedimentary rocks	Precambrian orthogneisses
Contact aurole	Hornblend-hornfels facies	None apparent. Spectacular injection complex of dykes from the pluton extends several km from contacts
Main rock types	Composite intrusion: quartz monzodiorite, porphyritic granite, and fine-grained granite	Essentially one lithology: granite gradational to granodiorite
Dykes	Scattered aplite and porphyry dykes in pluton	Very abundant pegmatite and aplite dykes in pluton and country rocks
Structures	Unfoliated Post-tectonic	Foliated (weak to moderate) Syntectonic
Mineralization	"Porphyry-type" Cu-Mo	None known
Major minerals	Plagioclase (andesine)	Plagioclase (albite-oligoclase)
	Sanidine/orthoclase	Microcline
	Quartz	Quartz
	Biotite	Biotite
	Hornblende	No hornblende
	No muscovite	Muscovite
Age**	384+10 Ma	386+1 Ma

*Additional details in Wiebe (1975), Barr & O'Beirne (1981), and Barr *et al.* (1982)

**From Cormier (1979 and written communication, 1981)