Bulletin de Minéralogie

A cationic classification of common plutonic rocks and their magmatic associations : principles, method, applications

François Debon, Patrick Le Fort

Abstract

This classification is based on cationic calculations from major element data and then applied to simple chemical-mineralogical diagrams. The method follows two sequential steps. The first step is concerned with characterising the individual sample. From the cationic values, the sample is identified by name and its chemical and mineralogical characteristics are determined. The second and most important aim of the chemical-mineralogical diagrams is to define the magmatic association to which the sample or group of samples belong. Based on chemical data, this method can also be used to classify common volcanic rocks. Several applications are presented.

Résumé

Cette classification repose sur le traitement cationique des éléments majeurs dans un ensemble de diagrammes chimico-minéralogiques faciles à mettre en œuvre. La démarche suivie comporte deux étapes complémentaires situées à deux niveaux différents. La première traite de l'échantillon : sa nomenclature et ses particularités chimico-minéralogiques sont définies. La seconde, la plus importante, consiste à déterminer le type d'association magmatique dont relève l'échantillon ou le groupe d'échantillons étudié. Basée sur des données chimiques, cette méthode est également utilisable pour classer les roches volcaniques communes. Plusieurs applications sont présentées.

Bull. Minéral.
(1988), **111**, 493-510

A cationic classification of common plutonic rocks and their magmatic associations : principles, method, applications

by FRANÇOIS DEBON* and PATRICK LE FORT**

* Centre de Recherches Pétrographiques et Géochimiques (C.R.P.G., C.N.R.S.), B.P. 20, 54501 Vandœuvre-lès-Nancy, France
** Géologie alpine (U.A. 69, C.N.R.S.), Institut Dolomieu, 15 rue Maurice Gignoux, 38031 Grenoble, France

Abstract. — This classification is based on cationic calculations from major element data and then applied to simple chemical-mineralogical diagrams. The method follows two sequential steps. The first step is concerned with characterising the individual sample. From the cationic values, the sample is identified by name and its chemical and mineralogical characteristics are determined. The second and most important aim of the chemical-mineralogical diagrams is to define the magmatic association to which the sample or group of samples belong. Based on chemical data, this method can also be used to classify common volcanic rocks. Several applications are presented.

Key-words : chemical-mineralogical diagrams, nomenclature, classification, igneous rocks, magmatic associations.

Une classification cationique des roches plutoniques communes et de leurs associations magmatiques : principes, méthode, applications.

Résumé. — Cette classification repose sur le traitement cationique des éléments majeurs dans un ensemble de diagrammes chimico-minéralogiques faciles à mettre en œuvre. La démarche suivie comporte deux étapes complémentaires situées à deux niveaux différents. La première traite de l'échantillon : sa nomenclature et ses particularités chimico-minéralogiques sont définies. La seconde, la plus importante, consiste à déterminer le type d'association magmatique dont relève l'échantillon ou le groupe d'échantillons étudié. Basée sur des données chimiques, cette méthode est également utilisable pour classer les roches volcaniques communes. Plusieurs applications sont présentées.

Mots-clés : diagrammes chimico-minéralogiques, nomenclature, classification, roches ignées, associations magmatiques.

INTRODUCTION

A rigorous classification of igneous rocks and magmatic associations is a necessary prerequisite for any studies aimed at unravelling geodynamic, petrogenetic or metallogenetic problems involving plutonic or volcanic materials.

The numerous and recent studies devoted to the classification of igneous rocks (*e.g.* La Roche, 1964, 1976, 1980, 1986 ; Chappell and White, 1974 ; Streckeisen, 1976 ; Ishihara, 1977 ; Pitcher, 1979 ; La Roche *et al.*, 1980 *a*, *b* ; Pupin, 1980 ; Lameyre and Bowden, 1982 ; Debon and Le Fort, 1983, 1984 ; White and Chappell, 1983 ; Bowden *et al.*, 1984 ; Dong Shenbao, 1984 ; Stussi and La Roche, 1984 ; Xu Keqin *et al.*, 1984 ; Nachit *et al.*, 1985 ; Le Bas *et al.*, 1986 ; Debon *et al.*, 1988) indicate not only the interest in this typological approach, but also how difficult it is to obtain a satisfactory solution and attain a wide agreement.

Taking into account views recently expressed (*e.g.* La Roche, 1976, 1986 ; Streckeisen, 1976 ; La Roche *et al.*, 1980*a*, *b* ; Debon and Le Fort, 1983), we consider that the following six aspects are important for a rigorous classification of igneous rocks : (1) it should be based on quantitative chemical analyses in preference to modal microscopic data, still longer and more difficult to *accurately* implement ; (2) it should use cationic proportions of major element analyses to reflect the actual mineralogy and permit ready recognition of the mineralogical significance of chemical variations (thus using "*chemical-mineralogical diagrams*" in the same way as La Roche (*ibid.*) ; (3) it should give a rigorous definition both of the type of each individual sample and of their magmatic associations ; (4) it should involve a complete representation of the entire range of common igneous rocks (*e.g.* from gabbros to syenites to leucocratic muscovite granites) and of their magmatic associations (from metaluminous to peraluminous) ; (5) it should use natural and genetic divisions related to established classifications ; (6) it should be able to be modified for use with volcanic rocks as well as plutonic rocks, thereby discarding the use of modal data.

The classification we discuss in this paper was first presented five years ago (Debon and Le Fort, 1983). Unlike other classifications, it takes into account *each* of the six aspects quoted above. Developed and tested on a few hundred plutons of various compositional types from different geodynamic settings (*e.g.* Debon *et al.*, 1986, 1987), it has been shown to be swift and easy to implement, coherent, comprehensive and a good discriminant of igneous associations. In particular, when combined with chronological and isotopic data, it has defined specific constraints on the plutonic and geodynamic history in south central Asia. Based on our experience, we present here an abridged and illustrated version of the classification.

The procedure of Debon and Le Fort's method follows two sequential steps. The first step is concerned with the individual sample. The second one aims at defining the type of magmatic association to which the sample or group of samples belong.

CLASSIFICATION OF INDIVIDUAL SAMPLES

The classification of individual samples is in general agreement with terminology based either on mineralogical (*e.g.* Streckeisen, 1976) or chemical (*e.g.* Shand, 1927) parameters.

Nomenclature

For nomenclature purposes, the "Q-P" diagram (Figure 1) is used. The cationic proportions of quartz, K-feldspar and plagioclase in this diagram are ideally suitable for a classification of common igneous rocks based on these felsic minerals (La Roche, 1964, 1966).

Aluminous balance

The aluminous balance of a sample is defined using the "A-B" diagram (Figure 2). This diagram reflects the nature and proportions of "characteristic minerals", *i.e.* principally muscovite, biotite, amphibole and clinopyroxene. It is divided into six sectors and the number of the sector within which a sample plots should be added to its name (*e.g.* granite I, granite III, syenite V).

Other characteristics

The weight proportions of quartz, feldspars and dark minerals of a given sample are compared to those of its *corresponding* petrographic type. The reference compositions of the twelve petrographic types are listed in table I and shown in the different diagrams. By comparison (Figure 3), the sample studied is designated as being rich, normal or poor in quartz, dark minerals and feldspars.

In order to achieve a rigorous definition of the sample, it is important to include informations concerning its alkali balance (Na and K), its Mg/(Fe + Mg) ratio, as well as any unusual major or trace element characteristics. These are again defined by comparison with the corresponding reference compositions (Table I). In addition, any other mineralogical characteristics can be introduced at this stage (*e.g.* particular minerals determined under the microscope).

We refer to acidic rocks as being leucocratic when they have less than 7 % of dark minerals. Tonalites with a dark mineral content less than 10 % are called trondhjemites.

Table II indicates how to calculate the different parameters, and examples of classification of plutonic samples are given below.

CLASSIFICATION OF MAGMATIC ASSOCIATIONS

This classification comprises two complementary steps. Based on the alumina balance, the first step is to classify a given association as one of three main types (cafemic, alumino-cafemic, aluminous). The second step enhances the first, introducing subdivisions into each of the main types. Applications are given below.

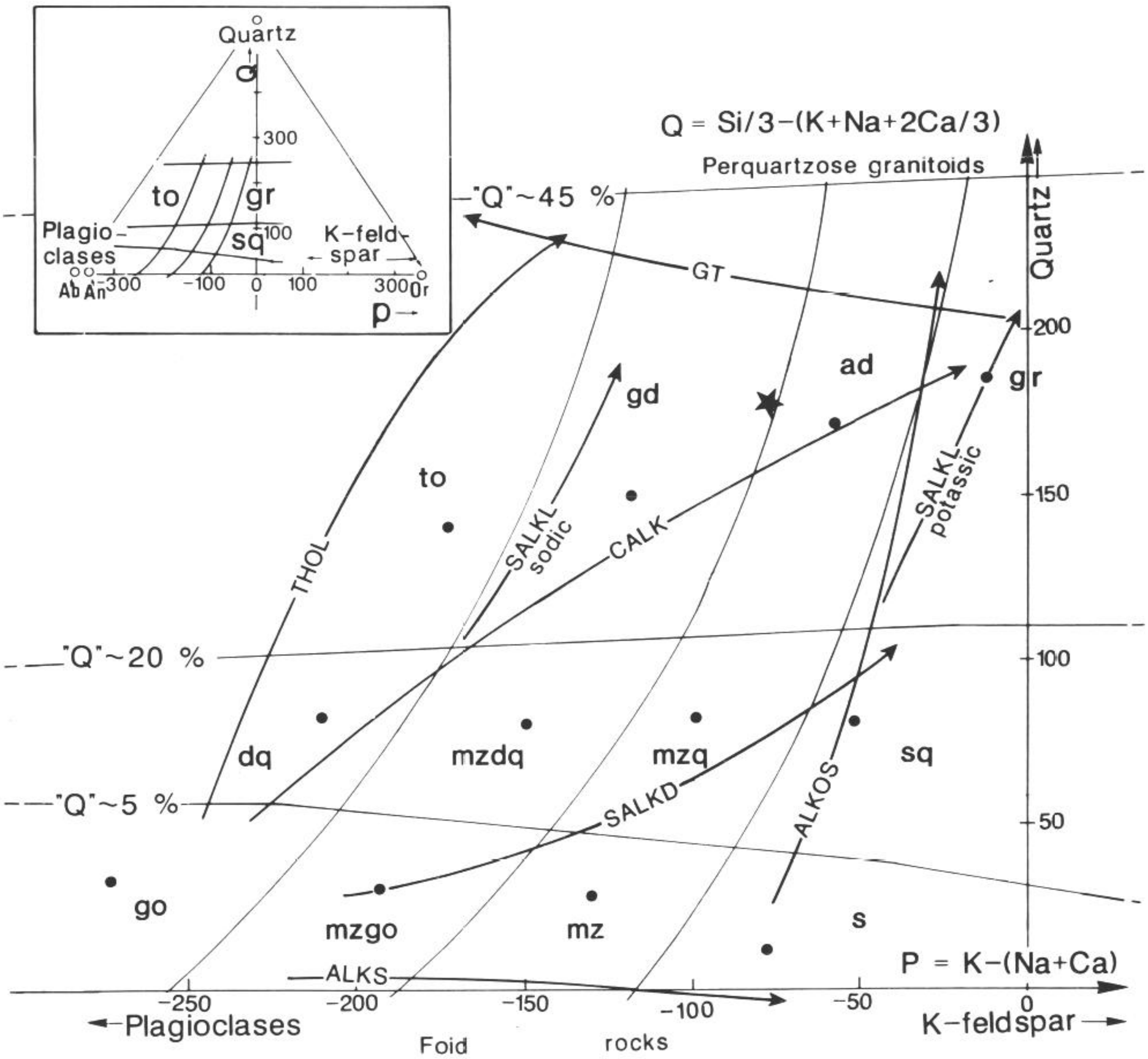

FIG. 1. — *"Q-P" or "nomenclature" diagram* (after La Roche, 1964, 1966 ; modified by Debon and Le Fort, 1983). The two parameters are in millications (10^3 gram-atoms) for 100 g of rock or mineral (see Table II for calculation). In common granitoid rocks, the Q parameter is directly proportional to the weight content of quartz. "Q" = empiric estimate of the quartz / (quartz + feldspars + muscovite) proportions, in volume percentages. Each division of the grid corresponds to a rock type : **ad** *adamellite, (dellenite)*, **dq** *quartz diorite*, quartz gabbro, quartz anorthosite, *(quartz andesite*, quartz basalt), **gd** *granodiorite*, granogabbro, (*rhyodacite*) **go** *gabbro*, diorite, anorthosite, (*basalt*, andesite ; kenningite, Eckermann, 1938, p. 277), **gr** *granite, (rhyolite)*, **mz** *monzonite, (latite)*, **mzdq** *quartz monzodiorite*, quartz monzogabbro, *(quartz latiandesite*, quartz latibasalt), **mzgo** *monzogabbro*, monzodiorite, (*latibasalt*, latiandesite), **mzq** *quartz monzonite, (quartz latite)*, **s** *syenite, (trachyte)*, **sq** *quartz syenite, (quartz trachyte)*, **to** *tonalite*, trondhjemite, *(dacite)*. Ab, An, Or stand for albite, anorthite, orthoclase respectively. The twelve model compositions adopted for a reference system (Table I) are shown as black points. The black star corresponds to the example given in table II. Combined with the "Q-B-F" triangle (Figure 3*a*) the "Q-P" diagram enables us to distinguish different subtypes among the magmatic associations of cafemic and alumino-cafemic types (Figure 2) ; for comparison, a reference system of typical trends corresponding to most of these subtypes is shown : THOL tholeiitic ; CALK calc-alkaline ; SALKD, SALKL dark- and light- coloured subalkaline (*i.e.* monzonitic) respectively ; ALKS dark-coloured alkaline saturated ; ALKOS light-coloured alkaline oversaturated ; GT granitic-trondhjemitic. Other explanations in Appendix.

Diagramme "Q-P" ou "de nomenclature".

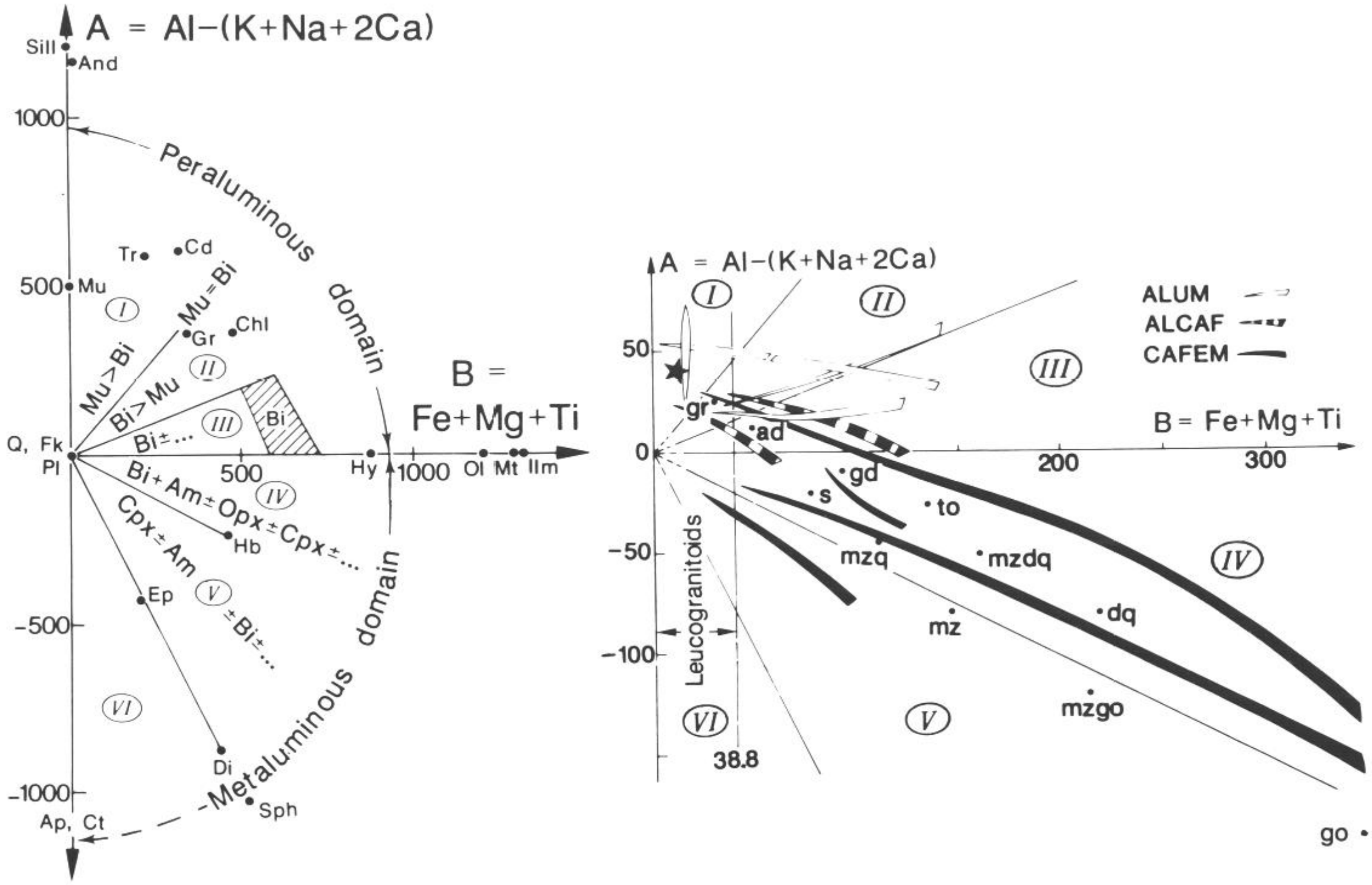

FIG. 2. — *"A-B" or "characteristic minerals" diagram* (Debon and Le Fort, 1983). The two parameters are in millications (10^3 gram-atoms) for 100 g of rock or mineral (see table II for calculation ; Fe = total iron). A is a classical "alumina index" (Schand, 1927) and B is directly proportional to the weight content of dark minerals in common granitic rocks (La Roche, 1964). This diagram separates the peraluminous rocks or minerals (*i.e.* those with a positive A value ; *e.g.* And andalusite, Bi biotite, Cd cordierite, Chl chlorite, Gr garnet, Mu muscovite, Sill sillimanite, Tr tourmaline) from the metaluminous ones (*i.e.* those with a negative A value ; *e.g.* Ap apatite, Cpx clinopyroxene, Ct calcite, Di diopside, Ep epidote, Hb hornblende, Sph sphene). Each of its six sectors, numbered from *I* to *VI*, corresponds to a specific mineralogical composition. *I, II, III* = sectors of peraluminous rocks with, respectively : *I* muscovite > biotite (by volume) ; *II*, biotite > muscovite ; *III*, biotite (usually alone, at times with a few amphibole) ; *IV, V, VI* = sectors of metaluminous rocks with, respectively : *IV*, biotite + amphibole ± pyroxene ; *V*, clinopyroxene ± amphibole ± biotite ; *VI*, unusual rocks (*e.g.* carbonatites). This diagram allows us to distinguish three main types of magmatic associations : ALUM aluminous, ALCAF alumino-cafemic, CAFEM cafemic. For comparison, typical trends corresponding to each of these three types are shown. Other explanations as in figure 1.

Diagramme "A-B" ou "des minéraux caractéristiques".

Distinction between the three main types of associations

For this purpose, only the "A-B" diagram (Figure 2) has to be used, taking into consideration : firstly, the location of the association being studied in the peraluminous or the metaluminous domain, and, secondly, the slope of its evolutionary trend. Thus we can distinguish the following types (see Glossary) : cafemic, alumino-cafemic, aluminous.

From a descriptive point of view, the cafemic and aluminous associations are approximately equivalent to the I- and S-types, respectively, of Chappell and White (1974).

Subdivisions among the cafemic associations

The processing of a cafemic association both in the "Q-P" (Figure 1) and "Q-B-F" (Figure 3*a*) diagrams and the comparison of its location

Rock type	gr	ad	gd	to	sq	mzq	mzdq	dq	s	mz	mzgo	go
n	94	194	208	60	5	10	27	36	2	8	6	20
SiO_2	73.67	71.58	67.02	62.98	66.34	62.89	59.13	55.22	60.40	57.48	53.83	47.02
Al_2O_3	13.79	14.39	15.38	16.20	15.98	15.64	16.76	16.97	18.49	16.92	16.09	16.12
Fe_2O_3t	1.54	2.31	4.01	5.55	3.66	5.07	6.91	8.16	4.31	6.16	8.67	10.04
MnO	0.03	0.05	0.08	0.10	0.07	0.09	0.13	0.15	0.12	0.12	0.16	0.16
MgO	0.32	0.60	1.43	2.34	0.37	1.55	2.56	4.17	0.70	2.34	3.52	8.15
CaO	0.84	1.80	3.77	5.65	1.12	3.57	5.56	7.98	2.48	5.10	6.99	11.89
Na_2O	3.27	3.58	3.54	3.32	4.75	4.00	3.61	3.08	5.10	4.15	3.93	2.30
K_2O	5.13	4.23	2.99	1.67	5.73	4.44	3.04	1.39	6.10	4.49	2.74	0.60
TiO_2	0.21	0.29	0.50	0.57	0.46	0.75	0.83	0.94	0.46	0.86	1.26	1.26
L.I.	0.77	0.78	0.98	1.17	0.95	1.32	1.04	1.55	1.40	1.72	1.97	2.12
TOTAL	99.57	99.61	99.70	99.55	99.43	99.32	99.57	99.61	99.56	99.34	99.16	99.66
Ba	414	552	579	378	229	481	639	335	718	700	850	175
Cr	2-11	7-13	19-21	37	0-10	15-20	28-30	65	0-10	37-41	55	299
Cu	3-12	3-12	10-16	10-17	11-15	14-17	22-25	38-40	0-10	60-63	21-24	61-62
Ni	2-10	6-12	17-19	32	0-10	10-14	23-25	50	0-10	21-25	42	125
Rb	235	171	103	48	236	163	108	39	157	142	65	25-29
Sr	126	195	322	303	92	299	417	358	284	650	848	417
V	17-21	33-34	79	118	19-21	71	121	200	7-12	115	205	274
CHEMICAL-MINERALOGICAL PARAMETERS												
Q	185	171	150	141	80	83	81	82	11	29	31	33
P	-11	-57	-118	-173	-51	-99	-150	-211	-79	-130	-194	-273
A	27	13	-9	-26	-1	-44	-50	-80	-20	-79	-119	-195
B	30	48	91	134	61	110	159	217	77	146	211	344
F	340	336	314	280	414	362	315	256	467	380	313	178
Na+K	214	205	177	142	275	223	181	129	295	229	185	87
K/(Na+K)	0.51	0.44	0.36	0.25	0.44	0.42	0.36	0.23	0.44	0.41	0.31	0.15
Mg/(Fe+Mg)	0.30	0.34	0.41	0.46	0.16	0.38	0.42	0.50	0.24	0.43	0.45	0.62
Quartz (Weight % 100 %)	33.3	30.8	27.0	25.4	14.4	15.0	14.6	14.8	2.0	5.2	5.6	5.9
Dark minerals (Weight % 100 %)	5.4	8.6	16.4	24.1	11.0	19.8	28.6	39.1	13.9	26.3	38.0	62.0
Feldspars + muscovite (Weight % 100 %)	61.3	60.6	56.6	50.5	74.6	65.2	56.8	46.1	84.1	68.5	56.4	32.1

TABLE I. — *The twelve chemical and mineralogical compositions used as a reference system for the classification of common igneous rocks*. These compositions are average values obtained from 670 plutonic samples from Afghanistan (K. Govindaraju, emission spectrometry, C.R.P.G., Nancy ; Debon and Le Fort, 1983 ; Debon *et al.*, 1987). The classification of these samples into twelve petrographical groups is based on their partition in the "Q-P" or "nomenclature" diagram (Figure 1). Abbreviations : ad adamellite, dq quartz diorite, gd granodiorite, go gabbro, gr granite, mz monzonite, mzdq quartz monzodiorite, mzgo monzogabbro, mzq quartz monzonite, s syenite, sq quartz syenite, to tonalite ; n number of analysed samples ; Fe_2O_3t total iron as ferric oxide ; L.I. loss on ignition. Trace element abundances in p.p.m. Parameters and mineralogical compositions calculated from chemical analyses (see table II for signification and calculation).

Les douze compositions chimiques et minéralogiques utilisées comme système de référence pour la classification des roches ignées communes.

and slope with those of a reference system of typical associations enable it to be classified as one of the following classic subtypes (see Glossary) :

- tholeiitic (or gabbroic-trondhjemitic)
- calc-alkaline (or granodioritic)
- subalkaline (or monzonitic): dark-coloured / light-coloured / composite
- alkaline (and peralkaline): dark-coloured saturated / light-coloured oversaturated / composite

Remarks : (1) Except for the tholeiitic and granitic-trondhjemitic (see below) subtypes, the "Q-B-F" triangle is usually a better guide than the "Q-P" diagram in discriminating between the different subtypes of the cafemic and alumino-cafemic (see below) associations ; in particular, it allows ambiguities between the

	1 Oxide %	2 Molecular weight	3 Factor	4 Millications	5 Parameters	
SiO_2	74.16	60.06	60.06	Si = 1235	Q = Si/3 - (K + Na + 2 Ca/3)	= 178
Al_2O_3	14.89	101.94	50.97	Al = 292	P = K - (Na + Ca)	= - 78
Fe_2O_3t	0.59	159.70	79.85	Fe^{3+} = 7	A = Al - (K + Na + 2 Ca)	= 41
FeO	-	71.85	71.85	Fe^{2+} = -	B = Fe + Mg + Ti	= 12
MnO	0.10	70.93	70.93	Mn = 1	F = 555 - (Q + B)	= 365
MgO	0.16	40.32	40.32	Mg = 4	Na + K	= 225
CaO	0.75	56.08	56.08	Ca = 13	K/(Na + K)	= 0.36
Na_2O	4.49	62.00	31.00	Na = 145	Mg/(Fe + Mg)	= 0.36
K_2O	3.75	94.19	47.10	K = 80		
TiO_2	0.06	79.90	79.90	Ti = 1	Weight % — Quartz (% 100)	= 32.1
L.I.	0.59				Weight % — Dark minerals (% 100)	= 2.2
TOTAL	99.54				Weight % — Feldspars + muscovite (% 100)	= 65.7

Trace elements (p.p.m.): Ba 29, Cr < 10, Cu < 10, Ni < 10, Rb 287, Sr 12, V < 10

TABLE II. — *Example of calculation of the different parameters.* Column 1 : chemical analysis, in weight per cent of metallic oxides, of an aplitic sample (K. Govindaraju, emission spectrometry, C.R.P.G., Nancy). Fe_2O_3t, total iron as ferric oxide ; L.I., loss on ignition. Column 2 : molecular weight of the different oxides. Column 3 : factor obtained by dividing the molecular weight by the number of metallic atoms (cations) in the oxide formula. Column 4 : number of millications (10^3 gram-atoms) per 100 grams, obtained by dividing values from column 1 by the corresponding factor of column 3, and then multiplying by 10^3. The different parameters (column 5) are calculated from the millicationic values. In the B and Mg/(Fe + Mg) parameters, Fe represents Fe^{2+} + Fe^{3+}. The Q, B and F parameters are directly proportional to the weight contents of quartz, dark minerals and feldspars + muscovite in common granitic rocks (La Roche, 1964). These contents, expressed in weight percentages, are obtained by dividing Q, B and F by 5.55. The sample studied here is shown as a black star on figures 1 to 5.

Exemple de calcul des différents paramètres.

calc-alkaline and the subalkaline subtypes at times observed in the "Q-P" diagram to be removed. (2) Associations may fall between two subtypes ; they are classified as transitional between those subtypes.

Subdivisions among the alumino-cafemic associations

Using the same diagrams (Figures 1, 3*a*), similar subdivisions to those adopted for the cafemic associations can be defined. The dark-coloured associations are generally lacking here however. On the other hand, a "granitic-trondhjemitic" subtype may be added (see Glossary).

Subdivisions among the aluminous associations

These subdivisions are completely different from those proposed for the cafemic and alumino-cafemic associations. Having no genuine equivalent among previous classifications, they are designated using a new terminology. They are based on a set of complementary criteria that have to be considered in order to achieve a rigorous definition. Thus the aluminous associations are classified according to their :

- *quartz content*. Three subtypes are distinguished : quartz-rich, quartz-normal, and quartz-poor (see Figure 3*b* and Glossary) ;

- *colour index*. According to the dark mineral content expressed as weight percentage, *i.e.* B = (Fe + Mg + Ti)/5.55 (Table II), three subtypes are distinguished : leucocratic ($B < 7$ %), subleucocratic ($7 \% \leqslant B \leqslant 10 \%$), mesocratic ($B > 10$ %) (Figure 3*b* or 4) ;

- *alkali ratio*. Three subtypes are distinguished : potassic [$K/(Na + K) \geqslant 0.50$, in millications, *i.e. in 10^3 gram-atoms*], sodi-potassic [$0.50 > K/(Na + K) \geqslant 0.45$], sodic [$K/(Na + K) < 0.45$] (Figure 4) ;

- *quartz - dark minerals - alkalies relationships*. The trend of an association is studied from the darkest to the most leucocratic samples. At least six subtypes may be distinguished : silico-potassic trend showing a parallel increase in the

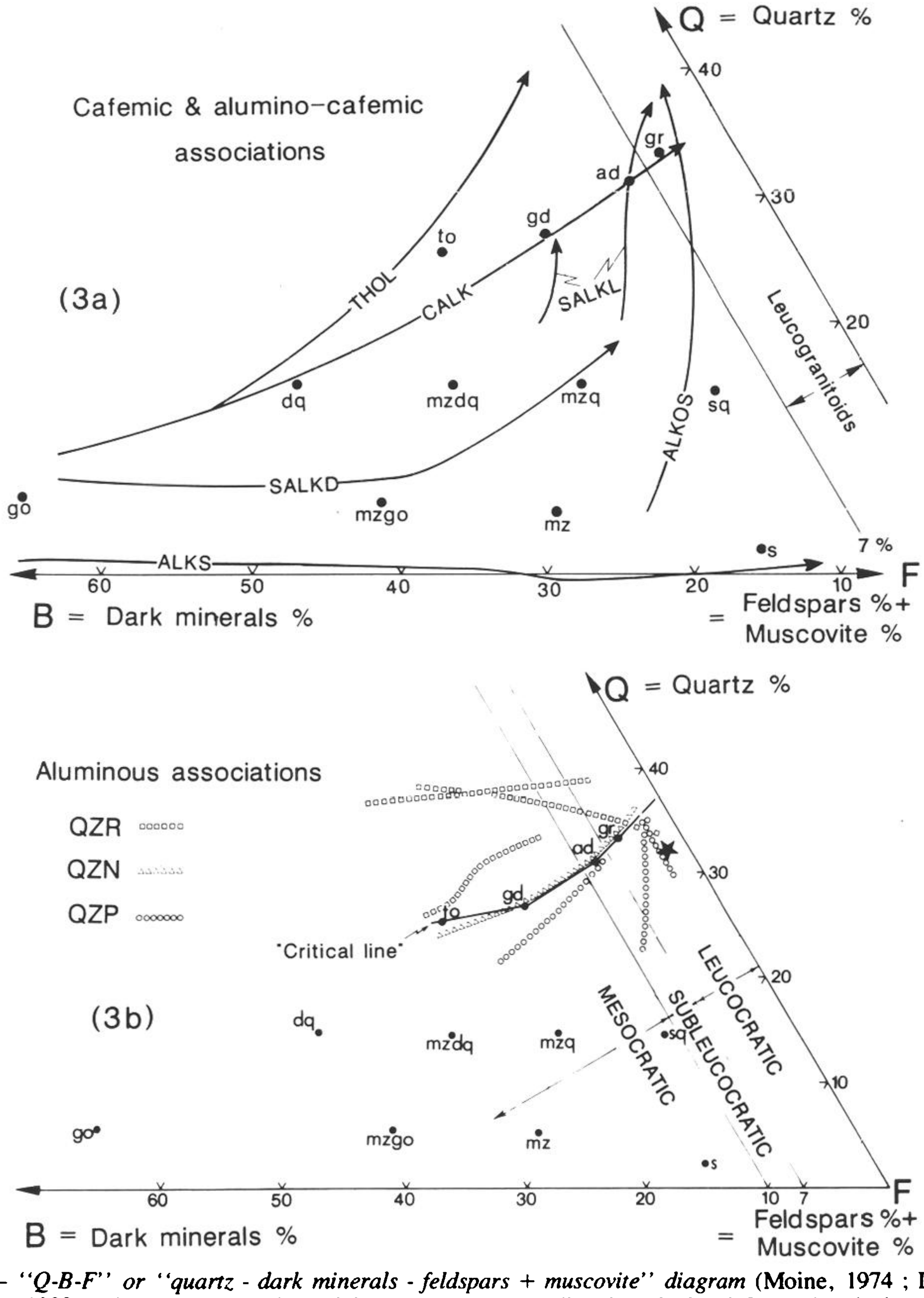

FIG. 3. — *"Q-B-F" or "quartz - dark minerals - feldspars + muscovite" diagram* (Moine, 1974 ; Debon and Le Fort, 1983). The parameters, in weight percentages, are directly calculated from chemical analyses (La Roche, 1964 ; see table II for calculation). (a) Combined with the "Q-P" diagram (Figure 1), this triangle enables us to distinguish different subtypes among the magmatic associations of cafemic and alumino-cafemic types : THOL, tholeiitic ; CALK, calc-alkaline ; SALKD, SALKL dark- and light -coloured subalkaline (*i.e.* monzonitic) respectively ; ALKS dark-coloured alkaline saturated ; ALKOS light-coloured alkaline oversaturated ; a reference system of typical trends is shown for comparison. (b) Among the associations of aluminous type, this triangle allows us to distinguish the following subtypes : QZR quartz-rich, QZN quartz-normal and QZP quartz-poor (according to the positions of their plots above, on and below the "critical line" respectively) ; leucocratic, subleucocratic, mesocratic (depending upon their dark minerals content). Other explanations as in figure 1.

Diagramme "Q-B-F" ou "quartz - minéraux colorés - feldspaths + muscovite".

quartz content, *i.e.* in the Q = Si/3 - (K + Na + 2Ca/3) parameter (Table II), and the K/(Na + K) ratio ; silico-sodic trend exhibiting an increase of Q but a decrease of K/(Na + K) ; exclusively siliceous trend with an increase of Q but no variation in K/(Na + K) ; exclusively potassic or exclusively sodic trend, with a constant Q ; decreasing Q trend with or without variation in K/(Na + K) ; no trend : Q and K/(Na + K) remain constant (Figure 4) ;

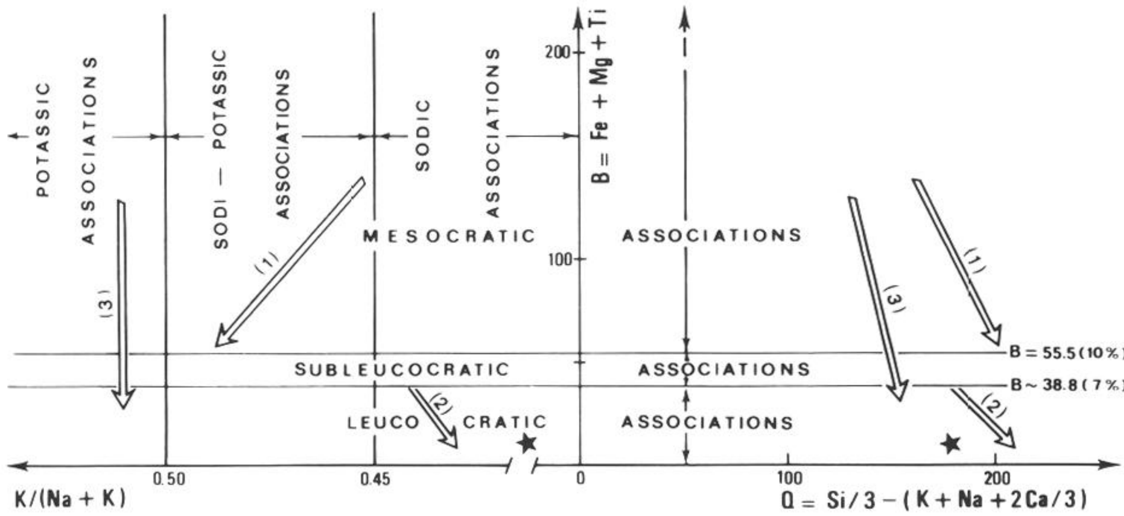

FIG. 4. — *Classification of aluminous associations using B = Fe + Mg + Ti as a function of Q = Si/3 - (K + Na + 2Ca/3) and K/(Na + K)* expressed as millications (10^3 gram-atoms) of each element in 100 g of material. Fe = total iron. The three theoretical associations correspond respectively to a mesocratic and sodi-potassic association with a silico-potassic trend (1), a leucocratic and sodic association with a silico-sodic trend (2) and a meso- to leucocratic and potassic association with a siliceous trend (3) (Debon and Le Fort, 1983). Other explanations as in figures 1 and 2.

Classification des associations alumineuses au travers des diagrammes B = Fe + Mg + Ti fonction de Q = Si/3 - (K + Na + 2Ca/3) et K/(Na + K).

- *alumina index.* Five subtypes are distinguished, with (A = Al - (K + Na + 2Ca) expressed in millications, *i.e.* 10 × 10^3 gram-atoms :

very low aluminous	$A < 10$
low aluminous	$10 \leqslant A < 20$
moderately aluminous	$20 \leqslant A < 40$
high aluminous	$40 \leqslant A < 60$
very high aluminous	$A \geqslant 60$

- *location and slope in the "A-B" diagram* (Figure 2). The location is defined by the number(s) of the sector(s) in which the studied association falls. The slope may be either vertical or positive or horizontal or slightly negative or indeterminate.

Association overlapping several subtypes may exist.

CONCLUDING REMARKS

Based on major element chemistry, the classification we have presented here applies to confident analyses of fresh samples. In particular, a perfect coherence must exist between the actual mineralogical composition and that deduced from the location in the "A-B" diagram (Figure 2).

In the same way that there are "granites and granites", it can be said that there are calc-alkaline and calc-alkaline associations, or subalkaline and subalkaline associations. In practice, it means that the definition of an association may be made more precise by taking into account additional criteria. In particular, a distinction between *magnesian* and *ferriferous* associations is necessary (Figure 5).

There is no reason why this classification cannot be directly applied to volcanic rocks. In this transposition, only the plutonic names have to be replaced by their volcanic equivalents (Figure 1).

For more details, the reader is referred to the paper of Debon and Le Fort (1983).

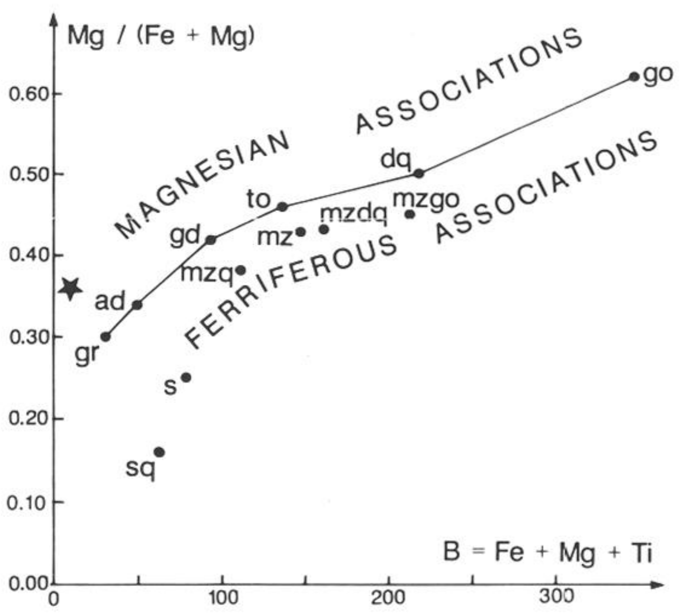

FIG. 5. — *Mg/(Fe + Mg) against B = Fe + Mg + Ti diagram.* The two parameters are in millications (10^{-3} gram-atoms) (see table II for calculation ; Fe = total iron). The line passing through the granite, adamellite, granodiorite, tonalite, quartz diorite and gabbro reference points is used to distinguish between magnesian, common, and ferriferous associations (according to the positions of their plots above, on, and below this line, respectively). Other explanations as in figures 1 and 2.

Diagramme Mg/(Fe + Mg) fonction de B = Fe + Mg + Ti.

GLOSSARY

- **Alkaline (and peralkaline) association :** subtype of the cafemic and alumino-cafemic types ; rare ; three variants are distinguished : (1) *dark-coloured saturated variant :* predominantly made up of dark-coloured rocks that may include gabbros, diorites, monzogabbros, monzodiorites, (syenites) ; it lies towards the base of the "Q-P" and "Q-B-F" diagrams, more or less parallel to it (Figures 1, 3*a*) ; (2) *light-coloured oversaturated variant :* may include felsic monzonites, syenites, quartz monzonites, quartz syenites, adamellites and granites ; specific alkali-rich minerals allow possible ambiguities with light-coloured subalkaline associations to be removed ; its trend displays a very steep slope in the "Q-P" diagram and is more or less close and parallel to the Q-F edge of the "Q-B-F" triangle (Figures 1, 3*a*) ; sodic and potassic varieties may be distinguished. Peralkaline associations are a particular case of the alkaline ones ; at least part of their rock members exhibit peralkaline characteristics (*i.e.* (Na + K) > Al, in cations or gram-atoms) ; (3) *Composite variant :* it has the features of both saturated and oversaturated associations.

- **Alumino-cafemic association :** type of magmatic association mainly or totally composed of peraluminous rocks ; usually, its trend shows a typical negative slope in the "A-B" diagram (Figure 2) ; it is mainly made up of light-coloured rocks.

- **Aluminous association :** type of magmatic association entirely composed of peraluminous rocks ; its trend may show various slopes (vertical, positive, horizontal, slightly negative) in the "A-B" diagram (Figure 2).

- **Association :** a group of igneous samples originating from the same body or from a related set of bodies and showing a community of characteristics.

- **Cafemic association :** type of magmatic association mainly or totally composed of metaluminous rocks ; its trend shows a negative slope in the "A-B" diagram (Figure 2) ; its felsic rock members often enter the peraluminous domain.

- **Calc-alkaline (or granodioritic) association :** subtype of the cafemic and alumino-cafemic types ; very frequent ; made up of common rocks that may include : (gabbros), diorites, quartz diorites, (tonalites), *granodiorites*, adamellites, (granites) ; atypical monzogabbros and quartz monzodiorites (*e.g.* feldspar-poor but dark mineral-rich) may also occur ; typical monzonites or syenites, whether these are quartz-bearing or not, are always lacking ; it lies close to the gabbro-granite line in the "Q-P" and "Q-B-F" diagrams (Figures 1,3*a*).

- **Common plutonic rock :** silica-oversaturated or saturated granular igneous rock. It includes the granitoids and related plutonic rocks that commonly occur in the plutonic belts.

- **Critical line :** in the "Q-B-F" diagram (Figure 3*b*), it is the line passing through the tonalite, granodiorite, adamellite and granite reference points (Table I). It is used to discriminate among the three main subtypes of aluminous associations, namely the quartz-rich, quartz-normal and quartz-poor subtypes.

- **Ferriferous association :** variety of magmatic association ; in an Mg/(Fe + Mg) *vs.* Fe + Mg + Ti diagram (Figure 5), it lies below the line passing through the granite, adamellite, granodiorite, tonalite, quartz diorite and gabbro reference points.

- **Granitic-trondhjemitic association :** subtype of the alumino-cafemic type ; very rare ; typically made up of quartz-rich and leucocratic granites, adamellites, granodiorites and tonalites (*i.e.* trondhjemites) (Figure 1) ; in the "Q-B-F" diagram, its rock members cluster together in the same leucocratic and quartz-rich domain (see Debon *et al.*, 1987, p. 38).

- **Magnesian association :** variety of magmatic association ; in an Mg/(Fe + Mg) *vs.* Fe + Mg + Ti diagram (Figure 5), it lies above the line passing through the granite, adamellite, granodiorite, tonalite, quartz diorite and gabbro reference points.

- **Metaluminous rock :** rock with Al ⩽ (K + Na + 2Ca) (in cations or gram-atoms), *i.e.* a zero or negative value for the A parameter (Figure 2).

- **Peraluminous rock :** as for Shand (1927), rock with Al > (K + Na + 2Ca), *i.e.* a positive value for the A parameter (Figure 2).

- **Quartz-normal association :** subtype of the aluminous type ; not very frequent ; may include (trondhjemites, exceptionnally), (granodiorites), adamellites and granites ; it typically lies close to the "critical line" of the "Q-B-F" diagram (Figure 3*b*) and displays normal quartz, feldspar (± muscovite) and alkali contents.

- **Quartz-poor association :** subtype of the aluminous type ; rather frequent ; may include (trondhjemites, uncommonly), (granodiorites), adamellites (often predominant) and granites ; it typically lies below the "critical line" of the

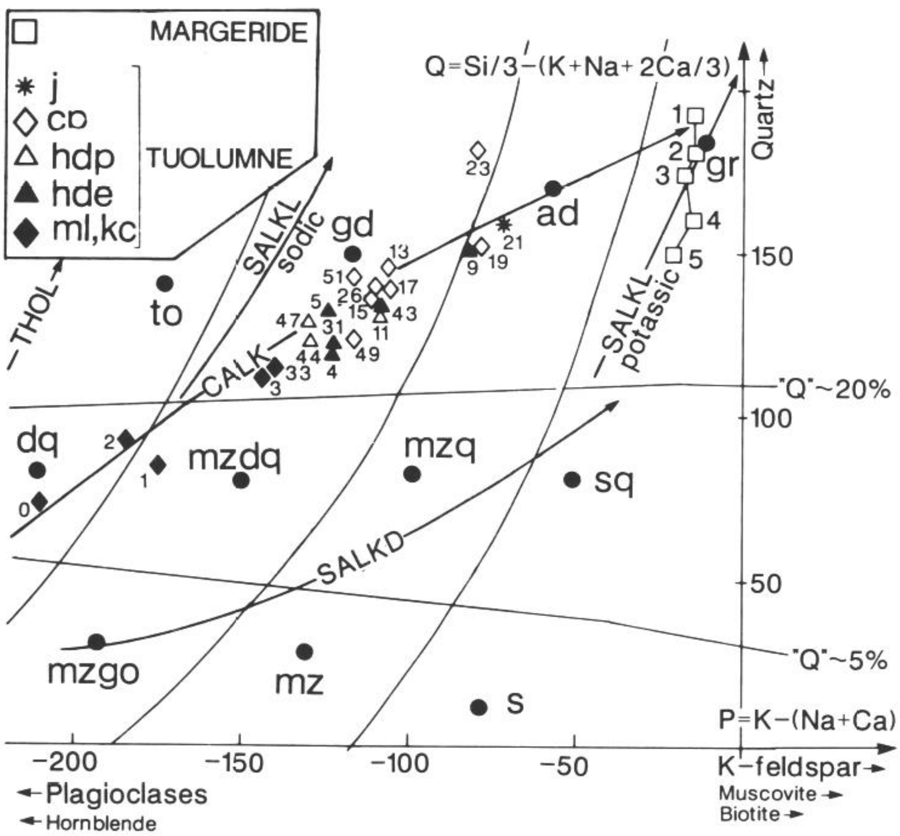

FIG. 6. — *Plots of the Tuolumne and Margeride plutons in the "Q-P" diagram.* Data and numbering from Bateman and Chappell (1979) and Couturié (1977, adjusted in 1979) (Table III). The Tuolumne pluton is represented by individual samples classified into five units : "May Lake Quartz Diorite" and "Kuna Crest Granodiorite" (ml, kc) ; "Half Dome Granodiorite", either equigranular (hde) or porphyritic (hdp) ; "Cathedral Peak Granodiorite" (cp) ; "Johnson Granite Porphyry" (j). Average compositions are used for representing the five facies of the Margeride pluton. Other explanations as in figure 1.

Distribution des plutons de Tuolumne et de la Margeride dans le diagramme "Q-P".

"Q-B-F" diagram (Figure 3*b*) and is (relatively) poor in quartz but feldspar-(± muscovite) and alkali-rich.

- **Quartz-rich association :** subtype of the aluminous type ; frequent ; may include (trondhjemites, exceptionnally), (granodiorites), adamellites and/or often only granites ; it typically lies above the "critical line" of the "Q-B-F" diagram (Figure 3*b*) and is rich in quartz but feldspar-(± muscovite) poor and alkali-deficient (sodic deficit, usually).

- **Subalkaline (or monzonitic) association :** subtype of the cafemic and alumino-cafemic types ; intermediate between the calc-alkaline and the alkaline associations ; frequent ; three variants are distinguished : (1) *dark-coloured variant :* may include feldspar- and alkali-rich gabbros and diorites, monzogabbros, monzodiorites, (monzonites, uncommonly), quartz monzodiorites, quartz monzonites, (quartz syenites) ; it lies below the gabbro-granite line in the "Q-P" and "Q-B-F" diagrams (Figures 1, 3*a*) ; (2) *light-coloured variant* : may include (quartz monzodiorites), quartz monzonites, quartz syenites, feldspar- and alkali-rich (leuco-tonalites, exceptionnally), granodiorites, adamellites and granites ; in the "Q-B-F" diagram (Figure 3*a*), its trend starts below the gabbro-granite line and shows a very steep slope, at times parallel to the Q-B or Q-F edges of the triangle ; sodic and potassic varieties may be distinguished (Figure 1) ; (3) *composite variant* : it has the features of both dark- and light-coloured associations.

- **Tholeiitic (or gabbroic-trondhjemitic) association :** subtype of the cafemic and alumino-cafemic types ; any oversaturated association exclusively made up of low-K rocks (*i.e.* gabbros, diorites, quartz diorites, tonalites, trondhjemites, sometimes very quartz-rich), whatever its "iron trend" and the proportion of its different rock members ; it may be unambiguously identified in the "Q-P" diagram (Figure 1) ; a feldspar-deficiency is frequent and thus it often lies above the gabbro-granite line in the "Q-B-F" diagram (Figure 3*a*).

The illustration of these different concepts through practical examples may be found *in* Debon and Le Fort (1983, 1984) and Debon *et al.* (1986, 1987, 1988), as also hereafter.

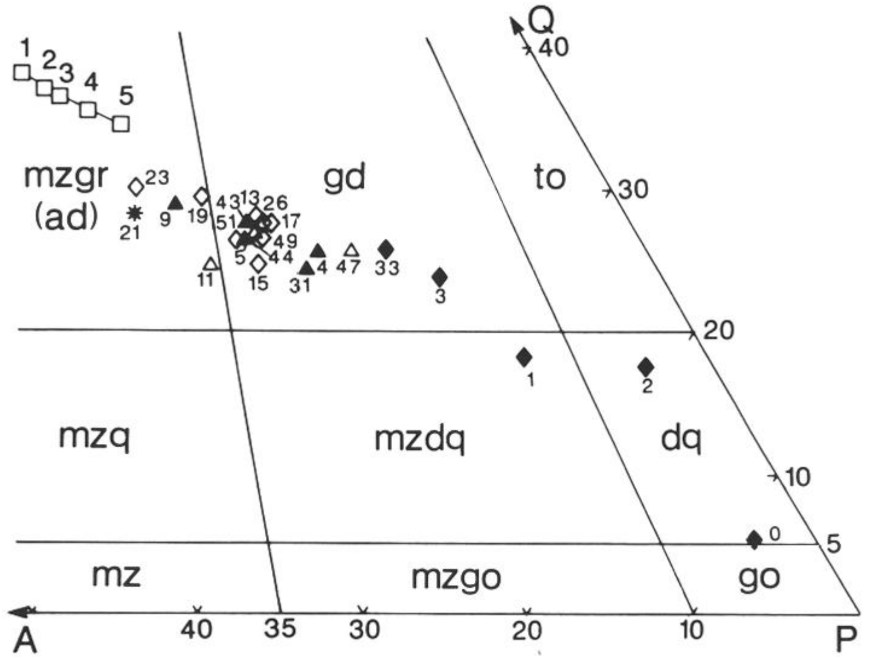

FIG. 7. — *Plots of modes of the Tuolumne and Margeride plutons in the QAP Streckeisen (1976) diagram.* Modal data from Bateman and Chappell (1979) and Couturié (1977). Q quartz, A alkali-feldspar, P plagioclase, mzgr monzogranite. Other explanations as in figures 1 and 6.

Distribution modale des plutons de Tuolumne et de la Margeride dans le diagramme QAP de Streckeisen (1976).

APPLICATIONS

Three applications of the classification are presented. They deal with an isolated sample (Himalayan dyke) and with two groups of samples (Tuolumne and Margeride plutons).

North-Himalayan dyke

The sample we classify here represents a Caenozoic aplitic dyke of the North-Himalaya plutonic belt (southern Tibet). Its chemical composition is given in table II and it is shown as a black star on figures 1 to 5. According to the classification, it is a peraluminous (I) (Figure 2) leucocratic (Figure 3*b*) granodiorite (Figure 1). Compared to the reference granodiorite composition (Table I), it is very poor in dark minerals but rich in quartz, feldspars + muscovite (Figure 3*b*) and alkalies (Na and K excesses), very deficient in Ca, Ba, Cr, Cu, Ni, Sr and V but Rb-rich, with a rather low Mg/(Fe + Mg) ratio (Figure 5). Its location in sector I of the "A-B" diagram (Figure 2) suggests that it is a two mica rock with more muscovite than biotite. The microscopic examination corroborates these informations and specifies that it is a garnet-bearing rock (Debon and Le Fort, 1984). It is not possible to confidently define the type of magmatic association to which such an isolated leucocratic peraluminous sample belongs. Notice only that, though defined as quartz-rich and rather ferriferous, such a sample yet could belong to a quartz-poor (Figure 3*b*) and magnesian (Figure 5) aluminous (Figure 2) association.

Tuolumne pluton

The Tuolumne pluton (Sierra Nevada batholith, California), or Tuolumne Intrusive Series (Bateman and Chappell, 1979), is a Cretaceous concentrically-zoned body. From the margins inwards, five units have been distinguished : "May Lake Quartz Diorite and Kuna Crest Granodiorite,..." (ml, kc), "Half Dome equigranular Granodiorite" (hde), "Half Dome porphyritic Granodiorite" (hdp), "Cathedral Peak granodiorite" (cp), and "Johnson Granite Porphyry" (j). The compositions, both chemical and modal, of twenty-two samples are available (Bateman and Chappell, *ibid.* ; table III).

Following our classification :

- the *May Lake, Kuna Crest unit* (ml, kc ; five samples) is composed of quartz diorites, quartz monzodiorites and granodiorites (Figure 6), the average composition of which is a quartz monzodiorite. According to the positions of their plots in sector IV of the "A-B" diagram (Figure 8), they are metaluminous rocks with biotite + amphibole ± pyroxene. The microscopic examination and modal data (Table III, figure 7) corroborate these informations and specify that magnetite, sphene, apatite and, at ti-

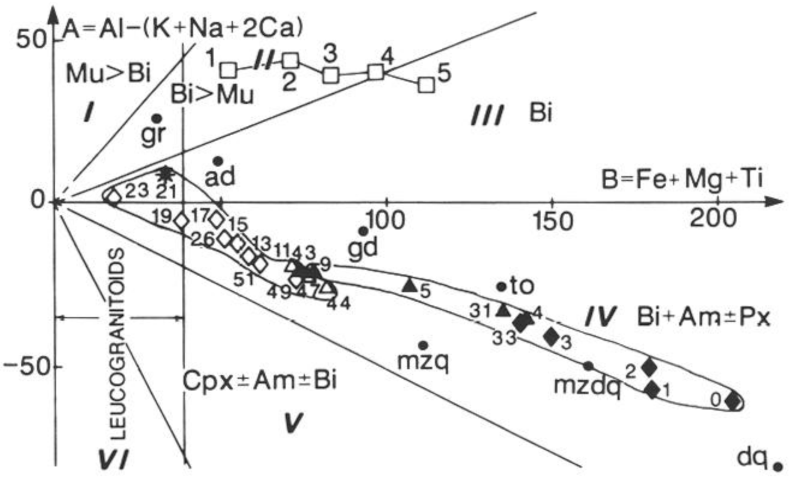

FIG. 8. — *Plots of the Tuolumne and Margeride plutons in the "A-B" diagram.* Other explanations as in figures 1, 2 and 6.

Distribution des plutons de Tuolumne et de la Margeride dans le diagramme "A-B".

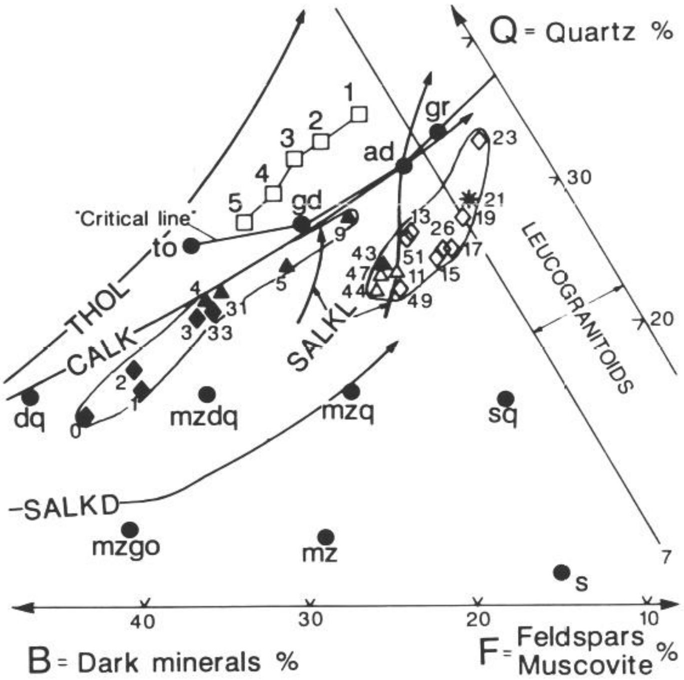

FIG. 9. — *Plots of the Tuolumne and Margeride plutons in the "Q-B-F" diagram.* Other explanations as in figures 1, 3 and 6.

Distribution des plutons de Tuolumne et de la Margeride dans le diagramme "Q-B-F".

mes, pyroxene are present as accessory minerals. Compared to the quartz monzodiorite reference composition (Tables I, III ; figures 8-10), these rocks are, on average, rather quartz-, Cu- and Sr-rich but more or less depleted in feldspars, alkalies (K deficiency), Cr and Ni ; the Mg/(Fe + Mg) ratio is not very high ;

- according to Bateman and Chappell (1979), five out of the twenty-two analysed samples belong to the *Half Dome equigranular unit* (hde). However, we have discarded sample 43 from calculations because, judging from its composition (Figure 9), it is most likely a representative of the hdp unit rather than of the hde one. The hde unit comprises granodiorites as dominant type and very few adamellites (sample 9) (Figure 6), both of them metaluminous (sector IV of figure 8). These features again agree with modal data (Table III ; figure 7). Compared to the granodiorite reference composition (Tables I, III ; figures 8-10), these rocks are, on average, rather rich in dark minerals, (Mg, Fe, K, Ba, Rb) and Sr but more or less depleted in quartz, (Si), Cr and Ni ; the Mg/(Fe + Mg) ratio is slightly high ;

- the *Half Dome porphyritic unit* (hdp ; three samples) is exclusively made up of metaluminous (IV ; figure 8) granodiorites (Figure 6). Such a typology once again agrees with modal data (Table III), except sample 11 classified as monzogranite (adamellite) in figure 7. Compared to the granodiorite reference composition (Tables I, III ; figures 8-10), these rocks are, on average, rather rich in feldspars, alkalies (Na and K excesses), Ba and Sr but more or less depleted in quartz, (dark minerals, Fe, Mg), Cr, Cu, Ni and V ; the Mg/(Fe + Mg) ratio is common ;

- the *Cathedral Peak unit* (cp ; eight samples) comprises granodiorites as dominant type and very few adamellites (sample 19 ; figure 6). They are metaluminous rocks (sector IV ; figure 8), except the leucocratic and slightly peraluminous sample 23 which falls in sector III, *i.e.* in the sector of rocks with biotite alone. Such a typology once more agrees with microscopic and modal data (Table III), except sample 23 classified as monzogranite (adamellite) in figure 7. Compared to the granodiorite reference composition (Tables I, III ; figures 8-10), these rocks are, on average, rich in feldspars, alkalies (excess Na and K), Si, Ba, (Rb) and Sr, depleted in dark minerals, Fe, Mn, Mg, Ca, Ti, Cr, Cu, Ni and V, and rather common in quartz ; the Mg/(Fe + Mg) ratio is not very low ;

- the *Johnson Porphyry unit* (j ; one sample) is a leucocratic and slightly peraluminous (Table III ; figure 8) adamellite (Figure 6). Such a typology once more agrees with microscopic and modal data (Table III ; figure 7) though the occurrence of 0.3 % muscovite implies, if primary, that the sample should plot in sector II of figure 8. Compared to the adamellite reference composition (Tables I, III ; figures 8-10), this rock is rich in feldspars, (alkalies, by slight Na excess), Ba and Sr but depleted in dark minerals, (quartz, Fe), Mg, Cr, Ni and V ; the Mg/(Fe + Mg) ratio is rather low.

Bateman and Chappell (1979, p. 477) implicitly consider the Tuolumne pluton to be calc-alkaline and assert (p. 479) that : "No chemical discontinuities are apparent at any of the contacts between the mapped units except at the contact between the Cathedral Peak Granodiorite and the Johnson Granite Porphyry". As already emphasized by La Roche *et al.* (1980*b*) through a cationic treatment, different from ours, of the

PLUTON	TUOLUMNE					MARGERIDE					
Unit, facies	ml,kc	hde	hdp	cp	j	1	2	3	4	5	Weighted average
n	5	4	3	8	1	22	32	37	22	20	133
SiO_2	59.49	65.27	67.27	70.15	71.65	72.69	70.71	69.61	67.81	66.28	69.59
Al_2O_3	16.67	15.39	15.62	15.10	14.87	14.05	14.51	14.60	14.97	15.21	14.64
Fe_2O_3	2.32	1.91	1.72	1.23	0.84	0.92	1.02	1.04	1.23	1.31	1.09
FeO	3.93	2.54	1.50	0.99	0.81	0.87	1.28	1.66	1.98	2.42	1.61
MnO	0.11	0.09	0.06	0.05	0.04	0.04	0.05	0.05	0.05	0.05	0.05
MgO	3.06	1.95	1.12	0.69	0.38	0.97	1.41	1.61	1.85	2.19	1.58
CaO	5.96	4.16	3.48	2.62	1.87	0.96	1.24	1.46	1.59	1.84	1.40
Na_2O	3.53	3.43	4.11	4.18	3.98	3.06	2.92	2.89	2.87	2.84	2.91
K_2O	2.33	3.39	3.38	3.70	4.19	4.75	4.81	4.78	4.95	4.89	4.83
TiO_2	0.85	0.60	0.52	0.37	0.24	0.41	0.49	0.55	0.65	0.65	0.54
P_2O_5	0.20	0.16	0.18	0.13	0.08	0.17	0.19	0.20	0.21	0.25	0.20
H_2O^+	1.15	0.80	0.56	0.46	0.58	0.93	0.94	0.89	1.04	0.89	0.93
H_2O^-	0.17	0.16	0.10	0.14	0.17	0.17	0.13	0.15	0.12	0.13	0.14
TOTAL	99.77	99.85	99.62	99.81	99.70	99.99	99.70	99.49	99.32	98.95	99.51
Ba	608	683	920	721	1170	356	558	533	869	1015	690
Cr	18	8	6	3	< 1	32	45	53	76	84	60
Cu	39	14	8	6	8	13	15	13	13	30	18
Ni	11	6	3	2	2	14	22	17	28	28	22
Rb	111	137	115	137	158	283	273	255	246	239	260
Sr	546	460	667	593	484	153	173	203	253	275	207
V	147	91	54	34	18	24	46	33	59	56	42
CHEMICAL-MINERALOGICAL PARAMETERS											
Q	96	130	127	144	159	192	181	175	159	150	172
P	-171	-113	-123	-103	-72	-15	-14	-18	-16	-21	-16
A	-48	-29	-23	-12	9	42	45	40	40	36	40
B	171	115	77	51	34	53	72	83	97	112	82
F	288	310	351	360	362	310	302	297	299	293	301
Na + K	163	183	205	214	217	200	196	194	198	196	197
K/(Na + K)	0.30	0.39	0.35	0.37	0.41	0.505	0.520	0.521	0.530	0.531	0.52
Mg/(Fe + Mg)	0.48	0.45	0.40	0.37	0.29	0.50	0.53	0.53	0.52	0.52	0.52
Quartz (Weight %, 100 %)	17.3	23.4	22.9	25.9	28.7	34.6	32.6	31.5	28.6	27.0	31.0
Dark minerals (Weight %, 100 %)	30.8	20.7	13.9	9.2	6.1	9.5	13.0	15.0	17.5	20.2	14.8
Feldspars + muscovite (Weight %, 100 %)	51.9	55.9	63.2	64.9	65.2	55.9	54.4	53.5	53.9	52.8	54.2
MODAL DATA (volume %)											
n	5	4	3	8	1	22	33	35	22	21	133
Quartz (100 %)	13.5	22.2	23.4	26.0	27.6	35.1	33.2	32.0	30.3	28.2	31.9
K-feldspar (100 %)	7.3	19.5	20.6	22.7	29.0	28.9	27.4	26.1	24.5	22.5	26.1
Plagioclase (100 %)	51.8	42.5	47.0	45.9	41.1	28.2	28.8	29.2	30.3	31.3	29.4
Biotite (Bi) (100 %)	11.8	8.3	5.1	3.3	1.5	5.1	9.2	12.3	14.9	18.0	11.7
Hornblende (Hb) (100 %)	14.2	6.1	2.2	0.8	-	-	-	-	-	-	-
Pyroxene (100 %)	0.1	-	-	-	-	-	-	-	-	-	-
Cordierite (Cd) (100 %)	-	-	-	-	-	1.8	0.8	0.3	-	-	0.6
Muscovite (Mu) (100 %)	-	-	-	-	0.3	0.9	0.6	0.1	-	-	0.3
Miscellaneous (100 %)	1.3	1.4	1.7	1.3	0.5						
Quartz (100 %)	13.5	22.2	23.4	26.0	27.6	35.1	33.2	32.0	30.3	28.2	31.9
Dark minerals (100 %)	27.2	15.6	8.8	5.2	1.9	6.9	10.0	12.6	14.9	18.0	12.3
Feldspars + muscovite (100 %)	59.3	62.2	67.8	68.8	70.5	58.0	56.8	55.3	54.8	53.8	55.8
Bi/(Bi + Hb)	0.45	0.58	0.70	0.80	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Bi/(Bi + Cd + Mu)	1.00	1.00	1.00	1.00	0.83	0.65	0.87	0.97	1.00	1.00	0.93

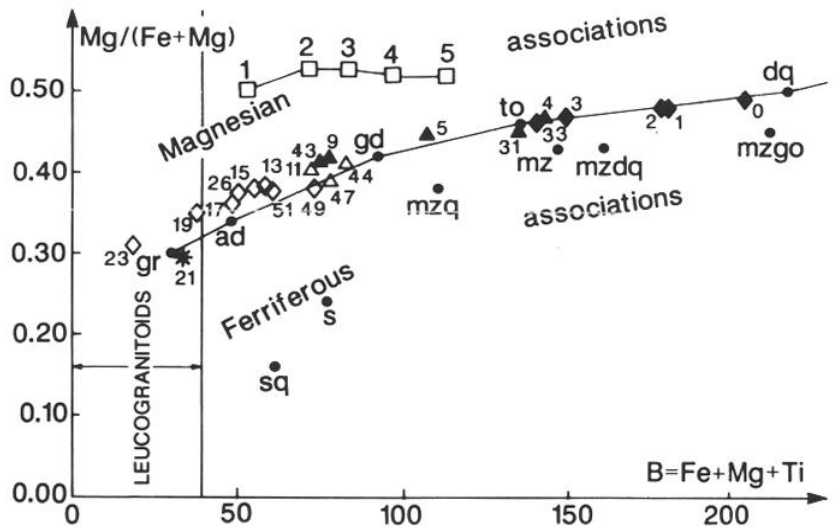

FIG. 10. — *Plots of the Tuolumne and Margeride plutons in the Mg/(Fe + Mg) vs. B = Fe + Mg + Ti diagram.* Other explanations as in figures 1, 5 and 6.

Distribution des plutons de Tuolumne et de la Margeride dans le diagramme Mg/(Fe + Mg) vs. B = Fe + Mg + Ti.

Tuolumne chemical data, such an assertion is unsuitable. In agreement with the interpretations of the isotopic data by Kistler *et al.* (1986), figure 9 shows that the Tuolumne pluton is a composite association comprising two quite different magmatic groups : (1) a dark-coloured group including the May Lake, Kuna Crest and Half Dome equigranular units (*i.e.* the two outermost zones of the pluton). It corresponds to a cafemic (Figure 8) and calc-alkaline (Figure 9) series ; (2) a light-coloured group comprising the Half Dome porphyritic, Cathedral Peak and, perhaps, Johnson Porphyry units. It corresponds to a series of cafemic type (Figure 8), transitional between the light-coloured and rather sodic subalkaline (monzonite) subtype and the calc-alkaline subtype (Figures 6, 9). Its strong subalkaline affinity is supported also by : (a) the abundance of feldspars, alkalies, Ba and Sr (see above) ; (b) proportions of sphene (*ca.* 0.5 % on average) and amphibole (see the Bi/(Bi + Hb) ratio in Table III) unusually high in such light-coloured rocks and reflecting their relatively marked metaluminous character (Figure 8). In addition, such a division of the main plutonic units of an intrusive body into two quite distinct groups, dark- and light-coloured respectively, is a frequent feature in subalkaline complexes (Debon and Le Fort, 1983 ; *e.g.* Ballons massif in the Vosges, Pagel and Leterrier, 1980). As regards the magnesian or ferriferous aspect, both series of the Tuolumne pluton are common (Figure 10).

TABLE III. — *Mean chemical and mineralogical compositions of the Tuolumne and Margeride plutons.* Data from Bateman and Chappell (1979) and Couturié (1977 ; chemical data adjusted in 1979). n = number of analysed samples. Trace element abundances in p.p.m. Chemical-mineralogical parameters : see table II for signification and calculation. Tuolumne pluton : five units are distinguished : "May Lake Quartz Diorite" and "Kuna Crest Granodiorite" (ml, kc) ; "Half Dome Granodiorite", either equigranular (hde) or porphyritic (hdp) ; "Cathedral Peak Granodiorite" (cp) ; "Johnson Granite Porphyry" (j). Sample 43 discarded from calculation of the hde average composition. Hornblende is respectively quite scarce (traces) and non-existent in samples 19 and 23 of the cp unit. Miscellaneous minerals = magnetite + sphene + 0.1 − 0.3 % of apatite. Margeride pluton : for Ba, Cr, Cu and Ni, n = 10 samples (facies 1), 4 (2), 9 (3), 6 (4) and 13 (5) ; for V, n = 5 (1), 1 (2), 6 (3), 2 (4) and 7 (5). Dark minerals = biotite + cordierite.

The mineral contents obtained through chemical and modal analyses are expressed as weight and volume percentages respectively. This difference must be taken into account when comparing the two groups of data. It accounts, in particular, for dark minerals contents always significantly higher when expressed as weight percentages. Consequently, due to the calculation method (F = 555 - Q - B ; table II), the feldspars + muscovite weight contents are systematically lower than the modal contents.

Compositions chimiques et minéralogiques moyennes des plutons de Tuolumne et de la Margeride.

Margeride pluton

Based on the dark minerals content, five facies have been distinguished within the Hercynian porphyritic Margeride Granite (French Massif Central) through a study supported by 133 chemical and modal analyses (Couturié, 1977 ; table III).

On average, each of the five facies, numbered from 1 to 5, is made up of granites *sensu stricto* according to the "Q-P" diagram (Figure 6) and by monzogranites (adamellites) following the Streckeisen classification (Figure 7). This distorsion may result from : (a) the widening of the granite division at the expense of the adamellite division introduced by Debon and Le Fort (1983) in the classification grid of the "Q-P" diagram ; (b) the usual shift of rocks rich in mica with a high mica/amphibole ratio toward the right-side of the "Q-P" diagram.

The five granite facies are peraluminous (Figure 8). Their location in the "A-B" diagram well reflects their respective contents in "characteristic minerals" (Table III) : sector III and boundary between II and III for facies 5 and 4 with biotite alone ; sector II for the other three facies with biotite + cordierite + muscovite, the modal biotite/(biotite + cordierite + muscovite) ratio of which decreasing from 0.97 (facies 3) to 0.65 (facies 1).

In the scope of this paper, it would be useless to describe successively the five facies. Following our classification and compared to the granite reference composition (Table I ; figures 8-10), the Margeride granites taken as a whole are, on average (see column "Weighted average" in Table III), rich in dark minerals, (Al), Fe, (Mn), Mg, Ca, Ti, (Ba), Cr, Cu, Ni, (Rb), Sr and V but depleted in (quartz), feldspars, alkalies (Na and K deficiencies) and Si ; the Mg/(Fe + Mg) ratio is very high. Thus, they are quite unusual granites.

According to Couturié (1977, p. 82, 273), the Margeride Granite is calc-alkaline. Using the classification leads us to a different conclusion. The five facies define a typical aluminous magmatic association (Figure 8). This association is quartz-rich (Figure 9), dominantly mesocratic, exclusively potassic with a silico-(sodic) evolutionary trend (Figure 11) and (moderately) to high-aluminous (A = 40 millications on average ; Table III) ; in the "A-B" diagram (Figure 8), it lies in sectors II and III and displays a subhorizontal trend. Finally, it is a strongly magnesian association (Figure 10).

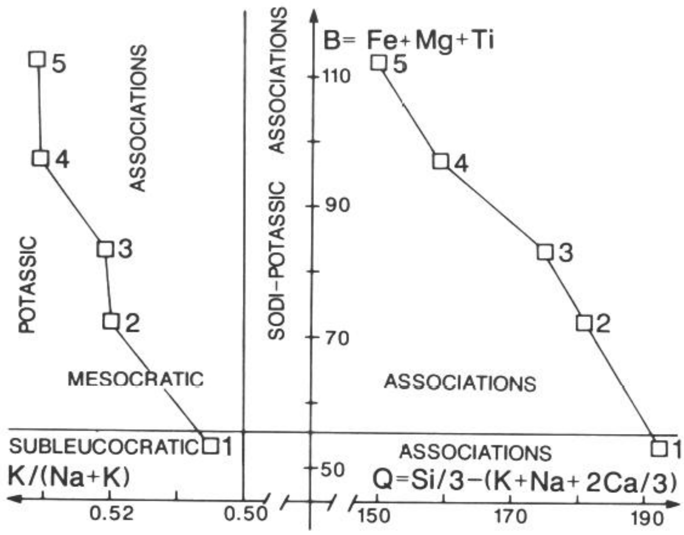

FIG. 11. — *Plots of the Margeride aluminous pluton in the B = Fe + Mg + Ti vs. K/(Na + K) and Q = Si/3 - (K + Na + 2Ca/3) diagram.* Other explanations as in figures 1, 4 and 6.

Distribution du pluton alumineux de la Margeride dans le diagramme B = Fe + Mg + Ti vs. K/(Na + K) et Q = Si/3 - (K + Na + 2Ca/3).

ACKNOWLEDGEMENTS

Our classification owes much to H. de La Roche who brought into focus many of the ideas presented here. It benefitted by the excellence of the spectrochemical method of analysis developed by K. Govindaraju (C.R.P.G., Nancy). Early drafts of the manuscript were greatly improved by critical reviews or comments from P. Bowden, J. Fabriès, J. Lameyre, S.M.F. Sheppard and P.C. Bateman. The judicious advice from J. Touret, the cooperation of the E.D.T.A. department of the C.R.P.G., and the help of C. Devey with the initial English manuscript are gratefully acknowledged.

Reçu le 4 janvier 1988
Accepté le 31 mars 1988

REFERENCES

BATEMAN, P.C. and CHAPPELL, B.W. (1979). — Crystallisation, fractionation, and solidification of the Tuolumne Intrusive Series, Yosemite National Park, California. *Geol. Soc. Amer. Bull.*, *90*, 465-482.

BOWDEN, P., BATCHELOR, R.A., CHAPPELL, B.W., DIDIER, J. and LAMEYRE, J. (1984). — Petrological, geochemical and source criteria for the classification of granitic rocks : a discussion. *Physics Earth Planet. Inter.*, *35*, 1-11.

CHAPPELL, B.W. and WHITE, A.J.R. (1974). — Two contrasting granite types. *Pacific Geol.*, *8*, 173-174.

COUTURIÉ, J.-P. (1977) — Le massif granitique de La Margeride (Massif Central français). Etude pétrographique, géochimique et structurale. Exemples de différenciation par gravité dans les roches granitiques. Evolution régionale de la croûte au cour de l'orogenèse hercynienne. *Ann. Sci. Univ. Clermont, Géol.-Minéral.*, *29*, *62*, 319 p.

DEBON, F. and LE FORT, P. (1983). — A chemical-mineralogical classification of common plutonic rocks and associations. *Trans. R. Soc. Edin. : Earth Sci.*, *73*, 135-149.

DEBON, F. and LE FORT, P. (1984). — Chemical-mineralogical classification of plutonic rocks and associations - Examples from southern Asia belts. *In* : "Geology of granites and their metallogenctic relations", Xu Keqin and Tu Guangchi eds., Science Press, Beijing, 293-311. (Equally in Chinese).

DEBON, F., AFZALI, H., LE FORT, P., SONET, J. and ZIMMERMANN, J.L. (1987). — Plutonic rocks and associations in Afghanistan : typology, age and geodynamic setting. *Mém. Sci. Terre*, *49*, 132 p.

DEBON, F., LE FORT, P. and SABATÉ, P. (1988). — Uma classificação químico-mineralógica das rochas plutonicas comuns e de suas associações magmáticas : método e applicações. *Rev. Brasil. Geoci.*, *18*, 1, in press.

DEBON, F., LE FORT, P., SHEPPARD, S.M.F. and SONET, J. (1986). — The four plutonic belts of the Transhimalaya-Himalaya : a chemical, mineralogical, isotopic and chronological synthesis along a Tibet-Nepal section. *J. Petrol.*, *27*, 219-250.

DONG SHENBAO (1984). — A discussion on the classification of genetic types of granites. *In* : "Geology of granites and their metallogenetic relations", Xu Keqin and Tu Guangchi eds., Science Press, Beijing, 71-86.

ECKERMANN, H. von (1938). — The anorthosite and kenningite of the Nordingra-Rödö region. A contribution to the problem of the anorthosites. *Geol. Fören. Förhandl.*, *60*, 2, 243-284.

ISHIHARA, S. (1977). — The magmetite-series and ilmenite-series granitic rocks. *Mining Geol.*, *27*, 293-305.

KISTLER, R.W., CHAPPELL, B.W., PECK, D.L. and BATEMAN, P.C. (1986). — Isotopic variation in the Tuolumne Intrusive Suite, central Sierra Nevada, California. *Contrib. Mineral. Petrol.*, *94*, 205-220

LAMEYRE, J. and BOWDEN, P. (1982). — Plutonic rock type series : discrimination of various granitoid series and related rocks. *J. Volc. Geoth. Res.*, *14*, 169-186.

LA ROCHE, H., de (1964). — Sur l'expression graphique des relations entre la composition chimique et la composition minéralogique quantitative des roches cristallines. Présentation d'un diagramme destiné à l'étude chimico-minéralogique des massifs granitiques ou grano-dioritiques. Application aux Vosges cristallines. *Sci. Terre*, *9*, (1962-1963), 3, 293-337.

LA ROCHE, H., de (1966). — Sur l'usage du concept d'association minérale dans l'étude chimique des roches : modèles chimiques, statistiques, représentations graphiques, classification chimico-minéralogique. *C.R. Acad. Sci. Paris, D*, *262*, 1665-1668.

LA ROCHE, H., de (1976). — Sur la contribution des données chimiques à une systématique générale des roches ignées. Avec, en appendice, "A diagram for a chemical classification of igneous rocks referred to their mineral content". *Sci. Terre*, *21*, 17-35.

LA ROCHE, H., de (1980). — Granites' chemistry through multicationic diagrams. *Sci. Terre, Informat. géol.*, *13*, 65-88.

LA ROCHE, H., de (1986). — Classification et nomenclature des roches ignées : un essai de restauration de la convergence entre systématique quantitative, typologie d'usage et modélisation génétique. *Bull. Soc. géol. Fr.*, *8*, *II*, *2*, 337-353.

LA ROCHE, H., de, LETERRIER, J., GRANDCLAUDE, P. and MARCHAL, M. (1980*a*). — A classification of volcanic and plutonic rocks using R1R2 diagram and major element analyses. Its relationships with current nomenclature. *Chem. Geol.*, *29*, 183-210.

LA ROCHE, H., de, STUSSI, J.-M. and CHAURIS, L. (1980*b*). — Les granites à deux micas hercyniens français. Essais de cartographie et de corrélations géochimiques appuyés sur une banque de données. Implications pétrologiques et métallogéniques. *Sci. Terre*, *24*, 5-121.

LE BAS, M.J., LE MAITRE, R.W., STRECKEISEN, A. and ZANETTIN, B. (1986). — A chemical classification of volcanic rocks based on the total alkali-silica diagram. *J. Petrol.*, *27*, 745-750.

MOINE, B. (1974). — Caractères de sédimentation et de métamorphisme des séries précambriennes épizonales à catazonales du centre de Madagascar (région d'Ambatofinandrahana). Approche structurale, pétrographique et spécialement géochimique. *Mém. Sci. Terre*, *31*, 293 p.

NACHIT, H., RAZAFIMAHEFA, N., STUSSI, J.-M. and

CARRON, J.-P. (1985). — Composition chimique des biotites et typologie magmatique des granitoïdes. *C. R. Acad. Sci. Paris, II, 301*, 813-818.

PAGEL, M. and LETERRIER, J. (1980). — The subalkaline potassic magmatism of the Ballons massif (Southern Vosges, France) : shoshonitic affinity. *Lithos, 13*, 1-10.

PITCHER, W. (1979). — Comments on the geological environments of granites. *In* : "Origin of granite batholiths, geochemical evidence", M.P. Atherton and J. Tarney eds., Shiva, Orpington, 1-8.

PUPIN, J.P. (1980). — Zircon and granite petrology. *Contrib. Mineral. Petrol., 73*, 207-220.

SHAND, S.J. (1927). — Eruptive rocks. Their genesis, composition, classification and their relation to ore-deposits. Murby, London.

STRECKEISEN, A.L. (1976). — To each plutonic rock its proper name. *Earth Sci. Rev., 12*, 1-33.

STUSSI, J.-M. and LA ROCHE, H. de (1984). — Le magmatisme orogénique de la chaîne varisque française. Typologie chimique et répartition spatiale. *C.R. Acad. Sci. Paris, II, 298*, 43-48.

WHITE, A.J.R. and CHAPPELL, B.W. (1983). — Granitoid types and their distribution in the Lachlan fold belt, Southeastern Australia. *In* : "Circum-Pacific plutonic terranes", J.C. Roddick edit., *Geol. Soc. Amer. Mem., 159*, 21-34.

XU KEQIN, SUN NAI, WANG DEZI, HU SHOUXI, LIU YINGJUN and JI SHOUYUAN (1984). — Petrogenesis of the granitoids and their metallogenetic relations in South China. *In* : "Geology of granites and their metallogenetic relations", Xu Keqin and Tu Guangchi eds., Science Press, Beijing, 1-31.

APPENDIX

In order to reproduce accurately the classification grid of the "Q-P" diagram (Figure 1), the following coordinates are given. The first one corresponds to the P parameter and the second to the Q parameter ; values without brackets correspond to the intersection points of the grid lines ; values in brackets correspond to other points of the grid lines : (-216, 238) ; -119, 242 ; -59, 244 ; -17, 245 ; (100, 249 ; -134, 190 ; -71, 190 ; -29, 190 ; -156, 136 ; -89, 137 ; -44, 140 ; -274, 100) ; -172, 104 ; -103, 107 ; -55, 109 ; (-30, 110 ; 75, 110 ; -187, 79 ; -125, 70 ; -69, 77 ; -300, 57 ; -224, 57) ; -205, 55 ; -143, 48 ; -88, 43 ; (-40, 38 ; 50, 23 ; -400, 0) ; -257, 0 ; -188, 0 ; -117, 0 ; (50, 0).

C.R.P.G. contribution n° 759.