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Two-mica granites:

Part A

Their occurrence and petrography

by

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ABSTRACT

Classical European Hercynian two-mica granites host or are genetically related to tin, tungsten and uranium deposits. Similar rocks elsewhere in the world are associated with similar ore deposits, and a knowledge of two-mica granites can be a useful exploration tool.

Two-mica granites occur usually as small plutons late in a plutonic sequence that intrudes high-grade metamorphic rocks of an orogen. In plan they are elongate or eliptical and in three dimensions they are tabular or sheet-like. They are usually leucocratic, massive, hypidiomorphic granular granitoids that consist of about 31 volume percent quartz, 26 percent K-spar, 31 percent plagioclase and about 10 percent mica in which muscovite may exceed biotite. In some, muscovite is absent in which event total mica is about 5 percent, except for a few types that contain abundant biotite. In two-mica granites hornblende is absent, magnetite is sparse, and sphene is rare. Common accessory minerals are apatite, zircon, monazite, garnet, and tourmaline.

Two-mica granitoids are more similar to S-type and ilmenite-series granitoids of Chappell and White (1974) and Ishihara (1977), respectively, than to their I-type and magnetite-series granitoids. Modal plots of two-mica granitoids fall predominantly in the monzogranite subfield of Streckeisen's (1976) modal classification of granitoids. Modal plots, however, do not uniquely define two-mica granites.

INTRODUCTION

This study of two-mica granites will be divided into four parts. Part A deals with their occurrence and petrography. Part B will describe the petrochemistry of the nonmetallic and metallic major oxides of two-mica granites; Part C will be the petrochemistry of the trace elements, isotopes and rare earth elements of two-mica granites; and Part D will discuss other aspects of two-mica granites.

The term "two-mica granite" is used in Europe for a suite of leucocratic, granitic, plutonic rocks that contain both biotite and muscovite. This is not a complete definition, however, because some granites that contain little or no muscovite qualify as "two-mica granites," whereas some granites that contain both biotite and muscovite do not. Our approach will be to describe the characteristics of classical European two-mica granites. We will also discuss similar rocks found in selected areas elsewhere in the world, and will show how two-mica granites are similar to or differ from members of some classification systems for granitic rocks.

European geologists have recognized two-mica granites in the Caledonian-Hercynian orogenic belt in southern England, in the Armorican and Central Massifs of France, in Germany, in the Bohemian Massif of

Czechoslovakia, and in Portugal and Spain, and all the two-mica granites have similar geologic settings and associations. The tin-bearing granites of Czechoslovakia, described by Štemprok and Škvor (1974), are part of the two-mica granite suite as are most other tin-, tungsten-, and lithium-bearing granites of Europe. The uranium-bearing granites, with or without tin, of England, France, Portugal, Spain, Germany, and Czechoslovakia also belong to the two-mica granite suite.

In France uranium deposits in granitic rocks, which are called "intragranitic" deposits, occur in the Armorican and Central Massifs in two-mica granites or in granitic rocks interpreted to be closely related genetically to the two-mica granites. Similar occurrences are known elsewhere in the Hercynian orogen of Europe (fig. A-1).

Plate tectonic reconstructions (fig. A-2) show that the Hercynian orogenic belt extends westward into Newfoundland and the Maritime Provinces of Canada and thence southward into the Appalachian Mountains of the United States. Uranium and tin occurrences and/or deposits have been found in Hercynian two-mica granites in Nova Scotia, and uranium occurrences and/or deposits have been found in two-mica granites in New Hampshire, and in Georgia. The two-mica granites of New Hampshire are part of a sequence of intrusive suites called "binary granite" by Billings (Billings, 1956, p. 61). There seem to be no geologic reasons to believe that the European-Appalachian two-mica granite uranium deposits are unique. Consequently, if a reasonable understanding of these deposits can be developed, it should prove useful for uranium exploration in the United States and elsewhere.

As intragranitic uranium deposits and their habitat have been studied most thoroughly by French geologists, the information to be presented here will draw heavily upon French experience, supplemented by our own studies of such deposits in France and Portugal and in the Appalachians and by studies of similar rocks published in the geologic literature. Because the genesis of these deposits and their host rocks is controversial, our conclusions must be tentative, and we fully expect them to be modified and corrected as a better understanding of these rocks and deposits is developed.

The writers think that the information on two-mica granites presented here is sufficiently abundant and sufficiently characteristic that the accumulation of large amounts of additional similar data will not significantly change the conclusions.

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We also want to thank the personnel of the Commissariat à l'Energie Atomique (CEA), the Compagnie Général Matériel Atomique (COGEMA), and of the Centre de Recherches Pétrographiques et Géochimiques (CRPG) at Nancy for conducted tours of the uranium deposits of France, and for informative discussions of two-mica granites and the uranium deposits associated with them. Deserving of special thanks are Jean-Marc Stussi of CRPG and Jacques

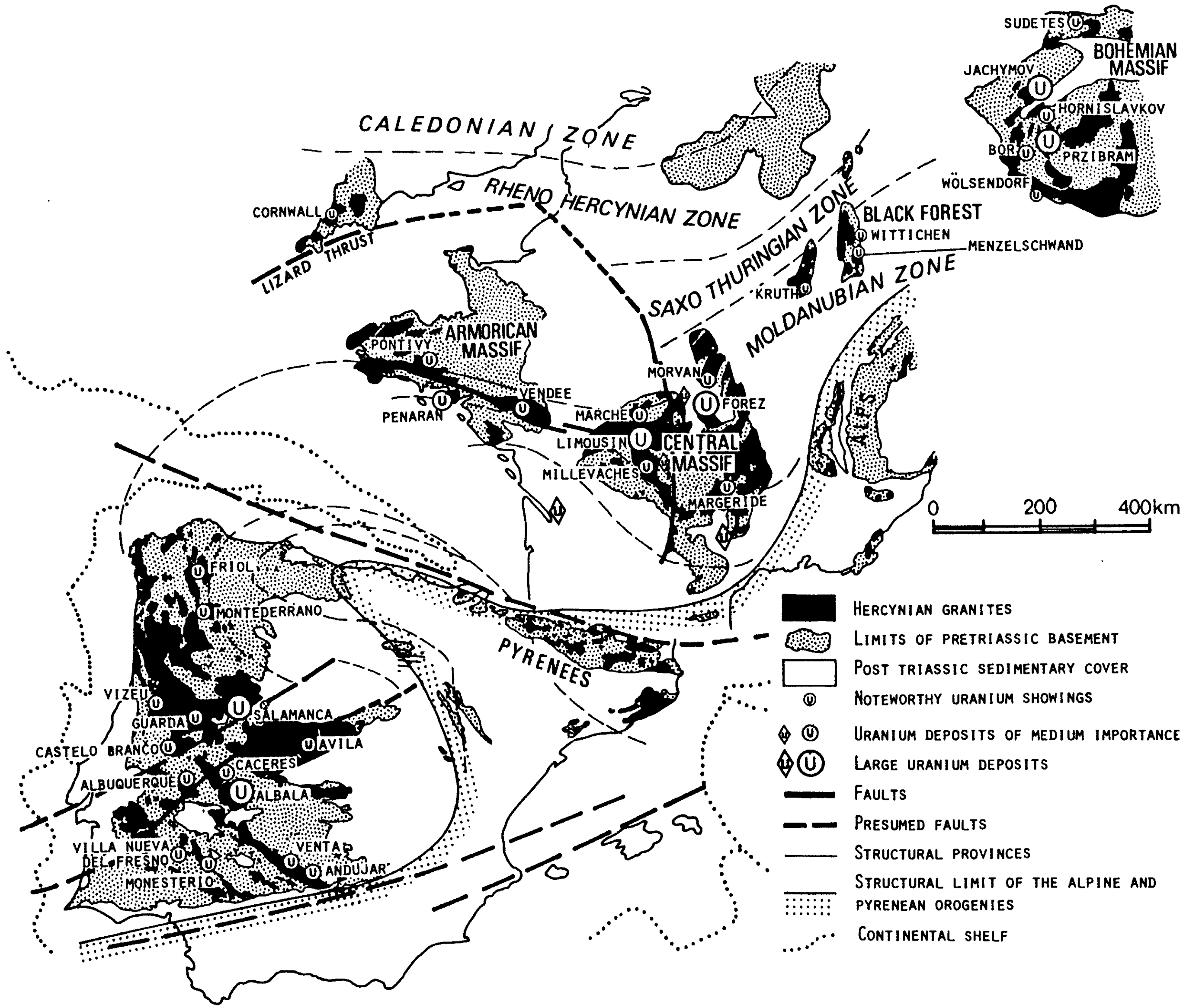

Figure A-1.- Location of the uranium vein deposits in the central Europian Hercynian chain. Tectonic reconstruction after Matte (1974). (Cuney. 1978, fig. 1), (Published with permission.)

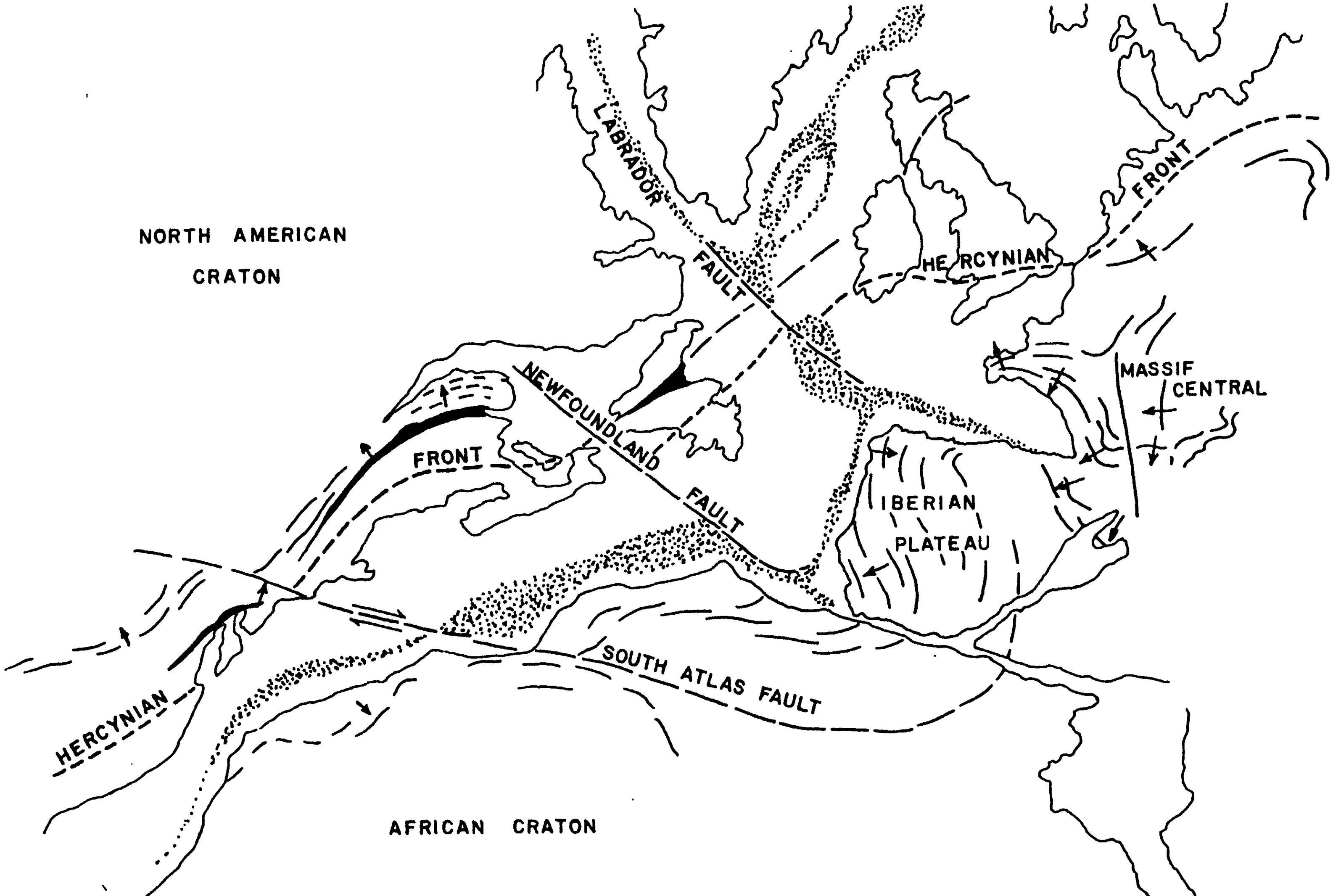

Figure A-2.--Rifting of the Pangean superplate near the end of Triassic time showing the trace of the Hercynian front, vestiges of Iapetus (black), Atlantic Ocean floor (stippled), fold trends and stacking polarity (form lines and arrows), and major transcurrent faults (E. L. Boudette, 1982, unpublished data, modified from Bensaid, 1980)

Grolier of Université d'Orléans. We also thank the personnel of the Junta de Energia Nuclear of Portugal and the Junta de Energia Nuclear of Spain for conducted tours of their uranium deposits and discussions about two-mica granites and associated uranium deposits.
Mistakes in fact and interpretation are solely our responsibility.

CLASSIFICATION OF IGNEOUS ROCKS

"Many and peculiar are the classifications that have been proposed for igneous rocks," and "chacun à son gout" (Johannsen, 1931, v. 1, p. 51); or "For their rock is not as our Rock...(Deuteronomy XXXII:31).

Early classifications of rocks were purely descriptive based solely upon the texture and mineralogy of the rocks. Although this type of classification was useful for coarse-grained rocks, it was of very little use for fine-grained ones. To overcome this deficiency chemical analyses were made of both fine- and coarse-grained rocks, and several systems of rock classification were developed based upon different chemical attributes of the rocks.

Concurrently with the development of chemical rock classifications, classifications based on texture and mineral content were improved and quantified, and evolved into what is known as modal analysis (Chayes, 1956). Modal analysis yields the mode of a rock, that is, the volume percent of the minerals actually present in a rock. The constituent minerals are called modal minerals. Modal analysis is used principally for medium- and coarse-grained rocks and, accordingly, is useful in classifying granitic rocks.

In graphic representations of modal analyses on triangular diagrams, the essential minerals of a rock are depicted rather well, but the varietal minerals are not, which makes modal analyses less useful for rocks in which varietal minerals are important or abundant; and graphic presentations of modal analyses are not meant to deal with the accessory minerals in a rock. These two shortcomings of modal analysis severely restrict its usefulness in petrology.

The granitoid part of the International Union of Geological Sciences' (IUGS), Subcommission on the Systematics of Igneous Rocks (Streckeisen and others, 1976), modal system is shown in figure A-3. IUG's classification of granitoids has not met with universal acceptance, for example Lyons (1976) prefers two-feldspar granite to syenogranite and adamellite to monzogranite, but nevertheless the IUGS System will be used here.

The results of chemical analyses are reported as the weight percent of the major nonmetallic and metallic oxides in a rock, and thus can not be compared directly with modal analyses which are reported as the volume percent of minerals actually present in a rock. Modal analysis gives the mineral composition, and thereby an approximate chemical composition, of a rock and something of its history, whereas chemical analysis gives the chemical composition of a rock and allows inferences to be made about the chemistry and evolution of the magma from which the rock was derived.

A chemico-mineralogical classification system that is widely used is the C.I.P.W. system. In it the results of chemical analyses, that is the weight percents of the major nonmetallic and metallic oxides, are used to calculate "normative" minerals. Normative minerals are in part hypothetical minerals derived mathematically from chemical analyses to give a C.I.P.W. norm.

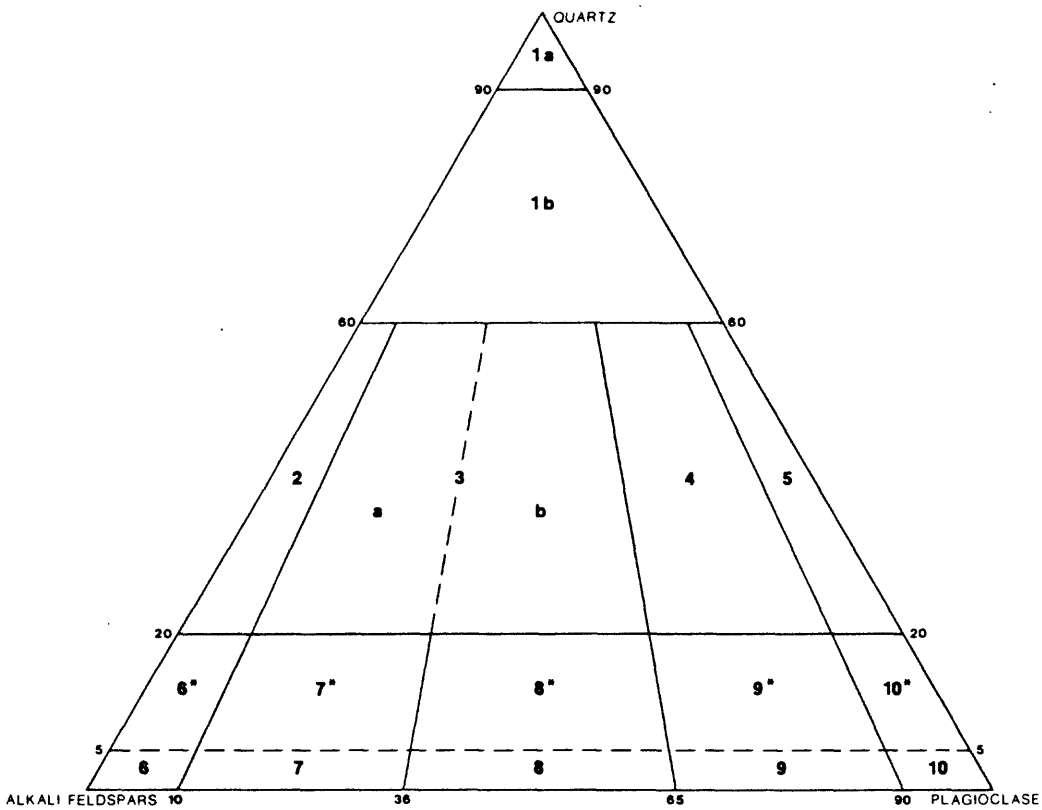

Figure 3.--General classification and nomenclature of granitoid rocks based on mineral content in volume percent as recommended by the International Union of Geological Sciences' (IUGS) Subcommission on the Systematics of Igneous Rocks (Streckeisen, 1976, fig. 1a). 1a, quartzolite; 1b, quartz-rich granitoids; 2, alkali-feldspar granite; 3, granite: a, syenogranite, b, monzogranite; 4, granodiorite; 5, tonalite; 6*, quartz alkali-feldspar syenite; 7*, quartz syenite; 8*, quartz monzonite; 9*, quartz monzodiorite/quartz monzogabbro; 10*, quartz diorite/quartz gabbro/quartz anorthosite; 6, alkali-feldspar syenite; 7, syenite; 8, monzonite; 9, monzodiorite/monzogabbro; 10, diorite/gabbro/anorthosite.

Although many normative minerals may actually be present in the rock being studied, their normative amounts need not be, and seldom are, the same as their modal amounts. And moreover other normative minerals need not be present in the rock at all.

Thus, two basic methods of studying and classifying igneous rocks have evolved; one based on the texture of the rock and its mineral content, the other based on the chemical composition of the rock and a variety of ways for manipulating its chemical components. Although neither system is completely satisfactory both systems are needed, and in many instances parts of several different chemical classifications help to define a rock more precisely.

Chemical classifications which will be used here are those of Shand (1949), Chappell and White (1974) and other papers by them and their colleagues, and Young and Olhoeft (1976). Shand's term "peraluminous" (symbol "p") which is a measure of the degree of aluminum oxide saturation will be used, and fortunately it is also one of the criteria used for distinguishing between the I-type and S-type granitoids of Chappell and White. Young and Olhoeft developed a felsic-mafic index (symbol "F") that they found useful for discriminating among highly felsic leucocratic granitic rocks, a problem very similar to discriminating among potential two-mica granites. Ishihara (1977) and his coworkers have developed a magnetite-series/ilmenite-series classification for Japanese granitoids. The magnetite-series contains magnetite and the ilmenite-series is virtually magnetite-free and may or may not contain ilmenite. This classification is based on minerals in the rocks and is therefore a modal classification. Surprisingly, when the modal Ishihara and chemical Chappell and White classifications are used to classify some granitoids, the magnetite-series appears to correspond to I-type granitoids, and the ilmenite-series, to the S-type granitoids. However, Takahashi and others (1980) have convincingly shown that there is tremendous overlap of the two "types" with the two "series" and that the apparent correspondence is false.

Although none of these classifications alone is capable of uniquely defining highly felsic, highly differentiated rocks such as two-mica granites, it is possible by selecting parts of different systems to show the unique characters of these rocks. Two-mica granites are more similar to S-type and ilmenite-series granitoids than to I-type and magnetite-series granitoids.

The term "granite à deux micas" and its Portuguese and Spanish equivalents are deeply entrenched in European geologic literature and are widely used in Europe. It is unfortunate that "granite à deux micas" and the others translate so easily into English because whereas to most European geologists "granite à deux micas" denotes a particular type of granitoid, its English translation, "two-mica granite," carries no special connotations to most English-speaking geologists, particularly those outside of Europe. The term "two-mica granite" is meant to describe a highly felsic, highly differentiated, leucocratic, peraluminous granitoid poor in calcium, magnesium, titanium, and iron, and that is moderately rich in potash and silica. All systems of rock classification have had difficulty distinguishing among rocks of this type.

Field recognition of two-mica granite is aided by its geologic setting in a metamorphic terrane; by the light color of the rock; its typically medium-grained sugary texture; by the presence of biotite and/or muscovite and sometimes ilmenite; the common appearance of apatite, zircon, monazite, rutile, tourmaline, and garnet, and by the absence of amphibole and sparse, if any, magnetite and sphene.

CHARACTERISTICS OF TWO-MICA GRANITES

Geologic setting and geophysical signature

The typical habitat of two-mica granite plutons is in orogenic belts where in conjunction with other plutonic rocks they intrude high-grade metamorphic terranes of amphibolite to granulite metamorphic facies; some intrude lower grade facies. Two-mica granite plutons penetrate into the upper crust and can have hypabyssal and perhaps even effusive equivalents. The plutons occur in linear belts near the margins of orogens or of microplate boundaires (Klominsky and Sattran, 1980, p. 129; Ranchin, 1971, pl. 15, figs. 1, 8, 11, 16; Renard, 1974, fig. 1; Strong and Hanmer, 1981, fig. 1) and are aligned parallel to the regional tectonic grain; some occur peripherally to orogens. Within orogens two-mica granites occur in the root zones (infracrustal zones) and along thrust planes (Le Fort, 1975, figs. 5, 15; 1978, p. 31; Leroy, 1978, p. 1613) which can pass into the cores of nappes (supracrustal zones) (Boudette, 1977, p. 23).

Moderate to low gravity anomalies occur over many two-mica granite plutons and some have almost no gravity signature at all because they occur in sheets that are relatively thin (Nielson and others, 1976; Lyons and others, 1982). We have no data on the magnetic signature of two-mica granites but because they are composed dominantly of diamagnetic minerals with a few percent of paramagnetic minerals, they should have a low magnetic signature in most terranes.

Color and texture

Two-mica granites are dominantly light colored ranging from a light cream color to light gray; common color variants are pink and salmon.

Typical two-mica granite is massive holocrystalline hypidiomorphic-equigranular and medium- to coarse-grained. If two-mica granites are porphyritic, the phenocrysts are always alkali feldspar. Seriate porphyritic textures are not common.

Inclusions are chemically and structurally similar to the host rocks and are thought by most geologists to be fragments of the protolith from which the two-mica granite formed. Biotite schleiren are oriented approximately parallel to structures in the host rock and to the major structural features controlling the emplacement of the two-mica pluton.

Microgranite and granophyre facies occur locally in small zones within two-mica granite. Dikes of pegmatite and apogranite, many of which extend into the wall rocks, commonly occur along conjugate fracture systems in the granite. In some plutons two-mica granite and pegmatite display mutually crosscutting relations.

Form, size, and internal character

In outcrop pattern two-mica granites are long, thin, and lenticular in shape; some are crescent-shaped; rarely are they round. In three dimensions two-mica granites are thin-tabular or sheet-like, tabular, or lenticular bodies many of which occur in zones of sheet-like plutons; rarely are they cylindrical. Normally these plutons are small and range in areal extent from a few km^2 to several hundred km^2, a few range up to 2,000 km^2 in area. Geophysical evidence has shown the tabular sheet-like bodies to be 1 to 3 km thick (Nielson and others, 1976). Inclusions are more abundant in the borders of plutons than in their centers, and the internal structures of inclusions parallel the structures in the wall rocks. Many two-mica plutons are slightly sheared parallel to the regional tectonic grain. The shearing probably developed late in the formation of the pluton. After emplacement most two-mica plutons have yielded brittely to deformation and some tabular bodies have been gently warped.

Moreau and Ranchin (1973, p. 96) state that there is a direct correlation between the size of uraniferous two-mica granitic plutons and the size of uranium deposits associated with them. Large uranium districts are associated with plutons 600 to 700 km^2 in extent, such as the Mortagne and Saint-Sylvestre plutons in the Vendée and Limousin districts, respectively, whereas only small deposits are associated with plutons 50 km^2 in size, such as the Cognac-le-Froid, Blond and Crozant plutons in the Limousin district. Moreau and Ranchin further state that this relation remains unchanged regardless of the differentiation stage or chemical characteristics of the plutons.

Modal composition

Two mica granite is composed essentially of quartz, orthoclase (with or without microcline perthite), and oligoclase-albite, in which the cores are often more calcic than the rims. Plagioclase compositions of An_{25} to An_5 are usual, and anorthite contents as much as An_{37} and as little as An_0 have been recorded. Typical examples of core-rim compositions are: core An_{28-18}, rim An_{20-10}; core An_{23-22}, rim An_0; core An_{18-15}, rim An_{10}; core An_{32-30}, rim An_{10-0}.

In the two-mica and related biotite granites studied by Štemprok and Škvor (1974, fig. 3), plagioclase appears to be more abundant in later-formed rocks than in the earlier-formed biotite granites. Late enrichment in plagioclase does not normally occur in a mantle-derived crystallization differentiation series, except in ophiolite suites, but it does appear to occur in Štemprok and Škvor's anatectic two-mica granite.

Varietal minerals are biotite and muscovite. Whether muscovite is a primary mineral of the granite or was formed later as a replacement of biotite by deuteric processes has long been discussed, and for some two-mica granites, particularly those with sparse small muscovite flakes, the discussion may not be settled even yet. In other two-mica granites, however, petrographic evidence proves muscovite to be primary and essentially contemporaneous with biotite. For example, as long ago as 1895, Keyes (p. 915) described a two-mica granite, which he called a binary granite, in which abundant, sharply outlined, large, clear flakes of muscovite are intimately associated with feldspar and biotite and in sharp contact with those minerals. He also described masses of muscovite and biotite intergrown parallel to their basal cleavages, as well as muscovite cutting biotite at various angles, and he observed several instances of muscovite completely enveloped by biotite. He stated that where muscovite and biotite are in contact, the contact is sharp and shows no microscopically observable alteration. More recently, Albuquerque (1977, p. 3) using the same type of textural evidence has also described primary muscovite. Euhedral books of muscovite are generally accepted as evidence that the muscovite is primary.

On the other hand, two-mica granites are closely akin to tin granites, and in both deuteric alteration of K-feldspar and biotite to muscovite is common, so it appears that in these rocks some of the muscovite is secondary after K-spar or biotite. Štemprok and Škvor (1974, p. 7) found the tin-bearing granites they studied to have been "strongly influenced.... by post-magmatic alterations," and they concluded that tin-bearing granites have been "influenced by multiple pulses of post magmatic solutions." De La Roche and others (1980, p. 26) recognize albitization, greissenization and tourmalinization as common alteration types in two-mica granites.

The common accessory minerals in two-mica granites, listed in approximate order of frequency of occurrence, are apatite, zircon, monazite, rutile, garnet, allanite and tourmaline. Tourmaline appears to occur more frequently in albitized rocks than in nonalbitized ones. Less common accessories are sillimanite, fluorite and epidote. Sparse accessory minerals are cordierite, andalusite, uraninite, thorite, pyrite, ilmenite and magnetite. Uraninite, however, may be more abundant than is suggested in this listing. Rare accessory minerals in two-mica granitoids are sphene, scheelite, xenotime, anatase, arsenopyrite, pyrrhotite and graphite. Other accessory minerals that have been identified are cassiterite, wolframite, chalcopyrite, molybdenite, topaz, and corundum.

Tables A-1 through A-6 list more than 300 modal analyses from several areas, and another 130 modes from other areas, for which the analyses were not given, are plotted on figures A-6, A-9 and A-11. In table A-1 are modal analyses from the Vendée district and the Massif Central, France, and table A-2 lists modal analyses from the Urgeiriça, S. Pedro do Sul, and Aregos areas of Portugal. Modal plots of these analyses (fig. A-4) fall primarily within the granite field of Streckeisen (1976) and most of them fall in the monzogranite subfield. Samples 362 and 363 are two-mica granodiorites as Albuquerque (1971) recognized, and sample 185 is a two-mica granodiorite that Cuney (1978) included with the Bois Noir biotite granite. Samples 364-366 which Albuquerque (1971) called two-mica granodiorites plot in the monzogranite subfield. As is to be expected the granodiorites are rich in plagioclase and poor in K-spar (see the K-spar/plagioclase ratios). Each of the three samples, 144, 189 and 190, that plot in the syenogranite subfield are from uranium mining districts and are rich in K-spar and low in plagioclase as indicated by their K-spar/plagioclase ratios. The modal analyses of samples 179-185 differ from the others in tables A-1 and A-2 in that the results are given in weight percent rather than in volume percent. Despite this difference, these seven samples do not appear to plot in positions greatly different from the other samples.

Although the total mica content of the rocks listed in tables A-1 and A-2 ranges from 1.7 weight percent to 28.1 volume percent and averages 1/ 10.3 volume percent, this wide-ranging and significant mineralogic characteristic is not considered in the modal plots. The average mica content of the Bois Noir biotite granites is 6.0 weight percent whereas the mica content of the St. Clementin biotite granite is about twice that. The average mica content

1/ All averages given are weighted averages, that is, the analytical values given are multiplied by the number of samples represented by those values.

TABLE A-1.--Modal analyses of two-mica granites from France

	VENDÉE DISTRICT					MASSIF					CENTRAL						
	MORTAGNE		BRESS.	CLÉM.		WESTERN PART					NORTHEASTERN PART						
Sample No.	139	140	141	142	143	144	145	146	147	148	179	180	181	182	183	184	185
No. of Samples	5	35	43	33	21	1	1	1	1	1	1	1	1	1	1	1	1
Quartz	30.4	31.3	33.3	34.0	20.9	25	20	22.5	22.5	24.5	34.0	24.0	27.0	32.0	36.0	33.0	36.0
K-Spar	30.4	28.0	22.6	28.5	26.7	41	42	28.5	28.5	28.5	34.0	38.0	33.0	29.0	31.0	32.0	18.0
Plagioclase	29.1	30.2	31.6	30.5	40.5	20	23	37.0	37.0	32.0	23.0	29.0	28.0	28.0	30.0	26.0	38.0
Micas: Biotite	6.1	3.2	4.7	2.6	11.9	7	8.5	6.5	6.0	15.0	6.5	6.5	9.4	6.1	1.7	5.9	1.9
Micas: Muscovite	4.0	7.3	6.3	4.4	Tr.	7	6.5	4.5	6.0								5.2
Apatite								1.0									
Heavy Minerals											0.72	0.9	0.95	0.15	0.14	0.09	0.23
Other						0	0	0	0	0							
Total	100	100	100	100	100	100	100	100	100	100	98.22	98.4	98.35	95.25	98.84	96.99	99.33
K-spar/Plagioclase ratio	1.0	0.9	0.7	0.9	0.7	2.1	1.8	0.8	0.8	0.9	1.5	1.3	1.2	1.0	1.0	1.2	0.5
Biotite-Muscovite ratio	1.5	0.4	0.7	0.6		1.0	1.3	1.4	1.0								0.4
Total mica	10.1	10.5	11.0	7.0	11.9	14.0	15.0	11.0	12.0	15.0	6.5	6.5	9.4	6.1	1.7	5.9	7.1

Samples 139-143. All drill hole samples. 139 and 140 Massif Mortagne: 139 porphyritic from Cottereau; 140 albitized from Commanderie; 141 Massif Bressuire; 142 and 143 St. Clémentin Granite: 142 two-mica granite, 143 biotite granite. Tr = trace. (Renard, 1974, tbl. 13).

Samples 144-148. From Margnac mine and vicinity. (Moreau and Ranchin, 1973, tbls, 1, 2, 3, and 4).

Samples 179-185. Bois Noir Granite: 179-181 northern facies; 182-184 central facies, some biotite chloritized; 185 fine-grained facies, biotite chloritized. All results reported as weight percent. (Cuney, 1978, tbl. 7).

TABLE A-2.--Modal analyses of two-mica granitoids from Portugal

	URGEIRIÇA		Radioactive Granites		AREGOS REGION						
Sample No.	189	190	220	221	362	363	364	365	366	367	368
No. of Samples	1	1	1	1	1	1	1	1	1	1	1
Quartz	28.39	36.54	27.0	30.1	29.4	26.2	31.0	28.1	31.3	31.8	30.4
K-spar	49.93	37.67	23.4	28.9	10.5	15.1	18.7	27.0	19.0	33.9	31.5
Plagioclase	16.03	16.83	18.5	26.4	36.4	37.5	27.7	31.3	28.6	24.5	27.9
Micas Biotite	3.41	0.71	7.2	6.5	20.5	17.4	14.5	10.9	12.8	6.7	7.6
Micas Muscovite	2.24	8.25	20.9	3.1	2.6	3.4	7.4	1.8	7.2	2.3	2.3
Apatite					0.4	0.3	0.4	0.5	0.7	0.1	0.2
Sillimanite			0.9					0.3		0.4	
Andalusite										0.2	
Ilmenite					0.2	0.1	0.3	0.3	0.4	0.1	0.1
Other			2.1	5.00							
Total	100	100	100	100	100	100	100	100.2	100	100	100
K-spar/Plagioclase ratio	3.1	2.2	1.3	1.1	0.3	0.4	0.7	0.9	0.7	1.4	1.1
Biotite/Muscovite ratio	1.5	0.1	0.3	2.1	7.9	5.1	2.0	6.1	1.8	2.9	3.3
Total mica	5.7	9.0	28.1	9.6	23.1	20.8	21.9	12.7	20.0	9.0	9.9

Samples 189-190. 189 porphyritic granite; 190 fine-grained granite. (Neiva, 1953, p. 49, 52)
Samples 220-221. 220 from S. Pedro do Sul; 221 from Castro Daire. (Fernandes, 1970, p. 55)
Samples 362-368. 362 and 363 biotite granodiorite; 364-366 muscovite-biotite granodiorite; 367 and 368 muscovite-biotite granite (Albuquerque, 1971, p. 2789)

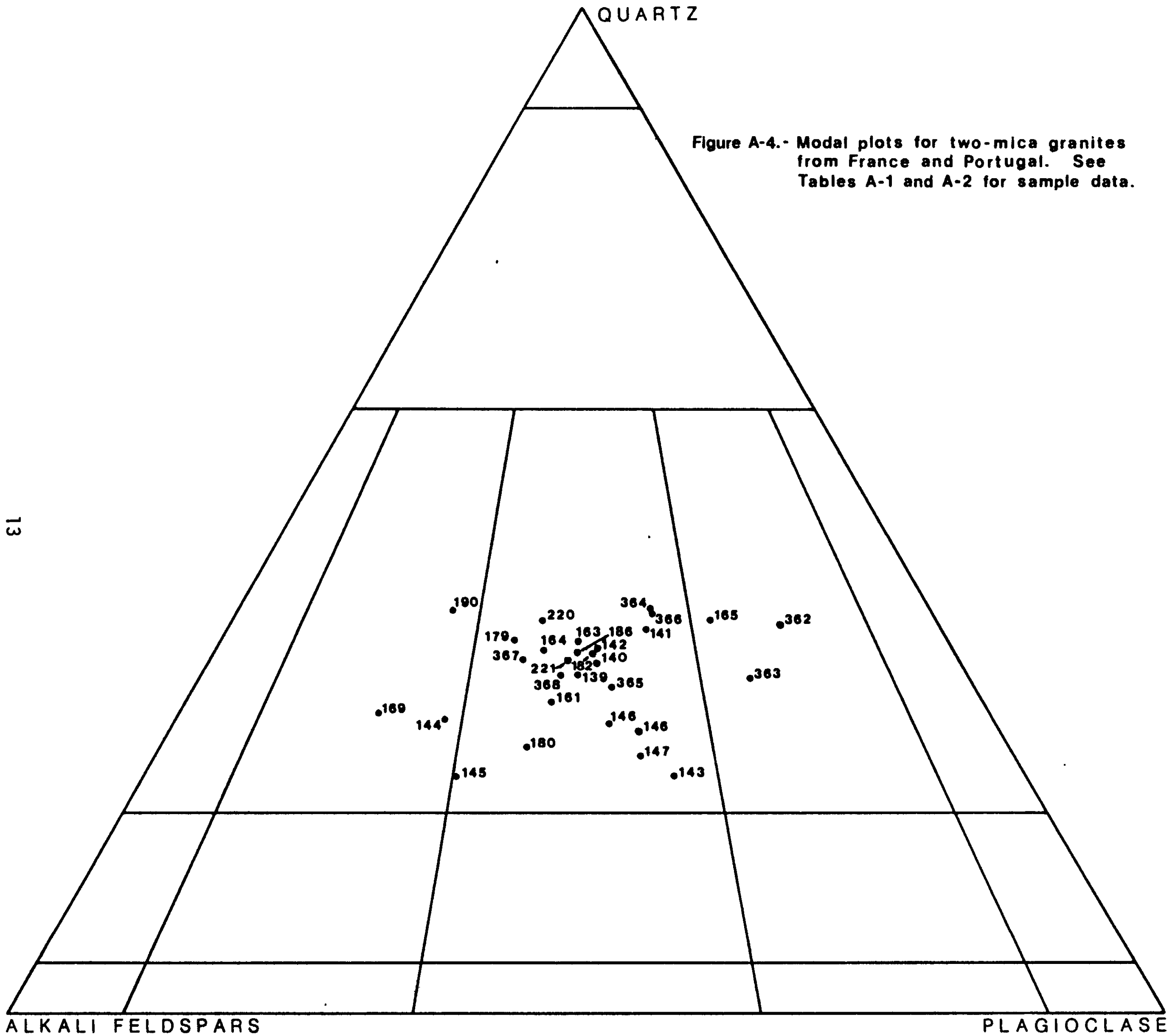

Figure A-4.- Modal plots for two-mica granites from France and Portugal. See Tables A-1 and A-2 for sample data.

of the French two-mica granitoids is 9.8 volume percent, with average biotite and muscovite contents of 3.8 and 6.0 volume percent, respectively, to yield an average biotite/muscovite ratio of 0.6. The average mica content of the Portuguese two-mica granitoids is 15.4 volume percent with biotite and muscovite average contents of 9.8 and 5.6 volume percent, respectively, to yield an average biotite/muscovite ratio of 1.8.

Table A-3 lists modal analyses of two-mica granites from northwestern Spain and figure A-5 shows the modal plots of these analyses. All these rocks fall in Streckeisen's (1976) granite field and all but two fall in the monzogranite subfield. The two are K-spar rich and plagioclase poor and fall in the syenogranite subfield; sample 255 is an anatectic leucogranite. The mica content of these rocks ranges from 5.8 to 20.2 volume percent and averages 12.3; sample 256 contains 3.8 volume percent sillimanite. The biotite content of these granites averages 5.8 volume percent and the muscovite content 6.5, which gives an average biotite/muscovite ratio of 0.9.

In figure A-6 the modal plots of two-mica granites from Krusne hory of the Bohemian Massif also fall in the granite field, most of them in the monzogranite subfield and three in the syenogranite subfield. The Bohemian Massif lies within the Hercynian orogenic belt, which extends eastward from France through Germany to Czechoslovakia (fig. A-1), and it contains two-mica granites similar to those in France, Portugal, Spain and southern England. Stemprok and Skvor (1974) did not publish the modal analyses upon which their figure 3 was based, consequently our figure A-6 is a modified reproduction of their plots for two-mica granites. The plots shown in figure A-6 are very similar to those for other European Hercynian two-mica granitoids.

Twenty-two of the 45 rocks listed by Ishihara (1978) in his description of two-mica granitoids in Japan contain hornblende and no muscovite so they do not qualify as two-mica granites and therefore are excluded here. Of the remaining 23 samples, 8 do not contain hornblende or muscovite (including one with a trace of muscovite) and are included here. Modal analyses of the 23 two-mica granitoids from Japan are given in table A-4 and their modes are plotted on figure A-7. Seventeen plot in the monzogranite subfield and six plot in the granodiorite field. Ishihara (1978, p. 81) divided Japanese two-mica granitoids into, "A) real two-mica monzogranite," that is "one having roughly equal amounts of muscovite and biotite," and "B) muscovite-bearing biotite granodiorite or monzogranite." He stated further that "the real ones are characterized by" being free of "opaque oxides" and by the "presence of accessory garnet and monazite." Samples 101 and 155 are biotite granodiorite. Ishihara called samples 41 and 42 muscovite-bearing biotite granodiorite and considered samples 43 and 44 to be "real two-mica monzogranite." In samples 43 and 44, however, the K-spar/plagioclase ratios are too low for them to plot in the monzogranite subfield. The total mica content in the 23 samples ranges from 1.3 to 11.4 volume percent. The average mica content of the biotite granitoids is 2.8 volume percent. In contrast, the two-mica rocks have an average total mica content of 6.1 volume percent with average biotite and muscovite contents of 4.2 and 1.9 volume percent, respectively, to yield an average biotite/muscovite ratio of 2.2.

The 23 two-mica granitoids and the 22 hornblende-bearing granitoids listed by Ishihara are from the Ryoke and the San-In tectonic belts of Japan (Ishihara, 1978, fig. 1). The Ryoke belt is dominated by ilmenite-series rocks and the San-In belt is dominated by magnetite-series rocks.

TABLE A-3. Modal analyses of two-mica granites from the western part of Salamanca Province, Spain (Martinez, 1974, p. 76 and tbl. 4)

		Microporphyritic							Late monzonitic granite				
Sample No.	255	256	257	258	259	260	261	262	278	279	280	281	282
No. of Samples	1	1	1	1	1	1	1	1	1	1	1	1	1
Quartz	28.01	28.72	26.76	27.87	33.24	31.69	30.55	28.07	39.91	26.38	27.90	26.69	26.82
K-spar	41.81	33.11	39.02	28.37	23.82	41.36	36.09	34.88	26.25	26.26	21.05	27.45	25.51
Plagioclase	20.18	18.42	25.10	29.81	23.82	15.55	19.53	23.68	28.00	32.22	33.50	35.48	38.98
Micas Biotite	3.59	7.01	3.99	5.91	2.77	5.37	8.02	7.44	2.65	8.60	12.71	3.60	5.42
Micas Muscovite	5.45	7.56	3.25	7.68	3.03	5.57	4.14	4.43	3.06	5.96	4.82	6.53	3.77
Apatite		0.65	1.04			0.27							
Cordierite	0.93												
Sillimanite		3.83				0.15	1.63						
Accessories		0.65	0.79	0.33	0.25			1.22	0.12	0.66		0.22	0.07
Total	99.97	99.95	99.99	99.99	99.98	99.96	99.96	99.75	99.98	99.99	99.98	99.97	99.97
K-spar/Plagioclase ratio	2.1	1.8	1.6	1.0	1.0	2.7	1.9	1.5	0.9	0.8	0.6	0.8	0.7
Biotite/Muscovite ratio	0.7	0.9	1.2	0.8	0.9	1.0	1.9	1.7	0.9	1.4	2.6	0.6	1.4
Total mica	9.0	14.6	7.2	13.6	5.8	10.9	12.2	11.9	5.7	14.6	17.5	10.1	9.2

	Medium- and fine-grained														
Sample No.	263	264	265	266	267	268	269	270	271	272	273	274	275	276	277
No. of Samples	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Quartz	29.13	24.71	28.98	27.65	26.83	30.61	39.76	40.47	32.64	29.89	34.12	31.02	33.41	31.68	33.87
K-spar	32.19	33.70	35.13	26.91	32.72	31.53	25.35	16.33	24.57	27.39	23.45	27.84	20.14	22.17	31.51
Plagioclase	23.67	27.31	24.73	29.58	29.20	24.54	20.78	28.80	26.89	28.36	28.53	24.74	34.29	24.30	23.83
Micas Biotite	8.09	8.81	3.54	7.64	4.93	5.65	8.58	4.33	3.05	4.15	5.75	4.09	2.07	7.44	7.39
Micas Muscovite	6.47	4.75	7.30	7.26	5.60	7.65	1.95	9.85	12.34	9.40	7.95	11.37	9.91	12.73	2.83
Apatite															
Cordierite															
Sillimanite															
Accessories	0.42	0.69	0.29	0.93	0.70	0.08	0.55	0.19	0.48	0.78	0.16	0.91	0.15	1.64	0.54
Total	99.97	99.97	99.99	99.99	99.99	99.99	99.96	99.99	99.99	99.97	99.96	99.97	99.97	99.99	99.99
K-spar/Plagioclase ratio	1.4	1.2	1.4	0.9	1.1	1.3	1.2	0.6	0.9	1.0	0.8	1.1	0.6	0.9	1.3
Biotite/Muscovite ratio	1.3	1.9	0.5	1.1	0.9	0.7	4.4	0.4	0.2	0.4	0.7	0.4	0.2	0.6	2.6
Total mica	14.6	13.6	10.8	14.9	10.5	13.3	10.5	14.2	15.4	13.6	13.7	15.5	12.0	20.2	10.2

255. Anatectic leucogranite.

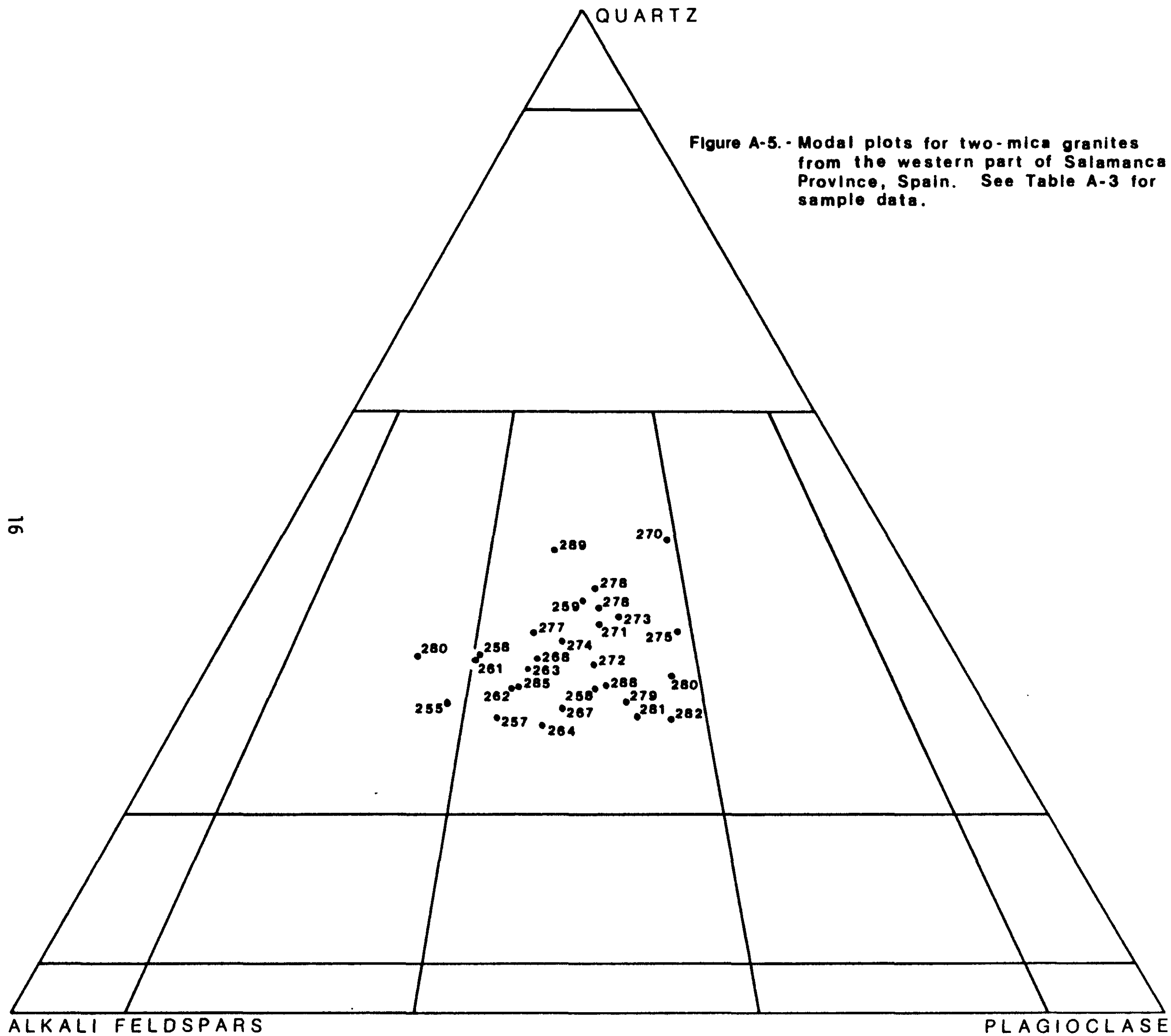

Figure A-5. - Modal plots for two-mica granites from the western part of Salamanca Province, Spain. See Table A-3 for sample data.

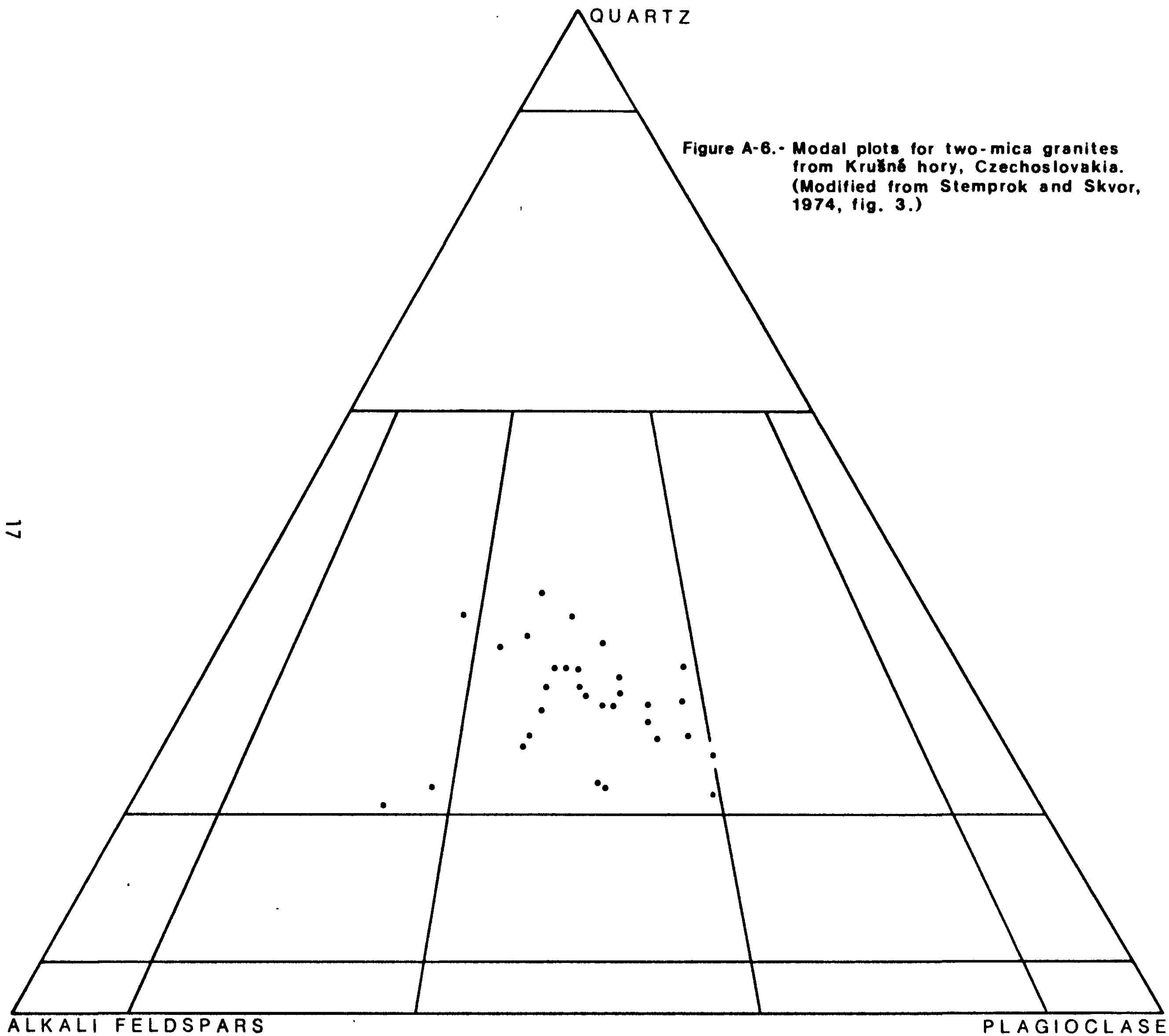

Figure A-6.- Modal plots for two-mica granites from Krušné hory, Czechoslovakia. (Modified from Stemprok and Skvor, 1974, fig. 3.)

TABLE A-4.--Modal analyses of two-mica granitoids from Japan (modified from Ishihara, 1978, tbls. 2 and 3)

	RYOKE BELT																		SAN-IN BELT				
	Toki Granitoids					Ryoke I Granitoids					Ryoke III Granitoids								Komaki Area				
Sample No.	13	14	15	16	17	25	26	28	29	30	41	42	43	44	45	46	47	48	101	155	150	153	169
No. of Samples	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Quartz	32.3	33.6	28.6	33.6	43.8	37.5	30.1	34.4	33.0	36.2	37.1	31.5	33.5	34.1	32.7	33.8	37.6	33.1	29.2	31.1	38.9	36.6	38.7
K-spar	30.7	30.3	29.5	26.3	27.0	29.6	29.0	39.1	27.8	34.2	6.7	14.5	20.0	8.4	33.6	25.6	23.5	26.1	19.0	15.9	24.3	24.8	25.4
Plagioclase	32.3	33.3	37.7	38.3	27.3	31.0	37.2	23.4	37.2	28.0	44.4	46.3	37.3	46.8	26.1	32.3	31.7	33.8	46.7	49.5	32.3	33.1	30.3
Micas: Biotite	4.1	2.6	3.9	1.2	1.3	1.7	3.6	2.6	1.9	1.3	11.2	6.8	6.1	8.3	3.6	3.9	3.7	2.6	4.6	3.1	2.2	1.9	2.6
Micas: Muscovite		Tr	0.1	0.2		0.1		0.1			0.2	0.6	2.8	2.0	3.7	4.1	3.1	4.0			2.1	2.8	2.9
Garnet											0.1		0.2	0.2	0.3			0.1					
Other	0.6	0.2	0.2	0.4	0.6	0.1	0.1	0.4	0.1	0.2	0.3	0.3	0.1	0.2	0.1	0.3	0.4	0.3	0.5	0.4	0.2	0.8	0.1
Total	100	100	100	100	100	100	100	100	100	99.9	100	100	100	100	100.1	100	100	100	100	100	100	100	100
K-spar/Plagioclase ratio	1.0	0.9	0.8	0.7	1.0	1.0	0.8	1.7	0.8	1.2	0.2	0.3	0.5	0.2	1.3	0.8	0.7	0.8	0.4	0.3	0.8	0.8	0.8
Biotite/Muscovite ratio			39.0	6.0		17.0		26.0			56.0	11.3	2.2	4.2	1.0	1.0	1.2	0.7			1.0	0.7	0.9
Total mica	4.1	2.6	4.0	1.4	1.3	1.8	3.6	2.7	1.9	1.3	11.4	7.4	8.9	10.3	7.3	8.0	6.8	6.6	4.6	3.1	4.3	4.7	5.5

Tr = trace. Sample numbers are those of Ishihara.

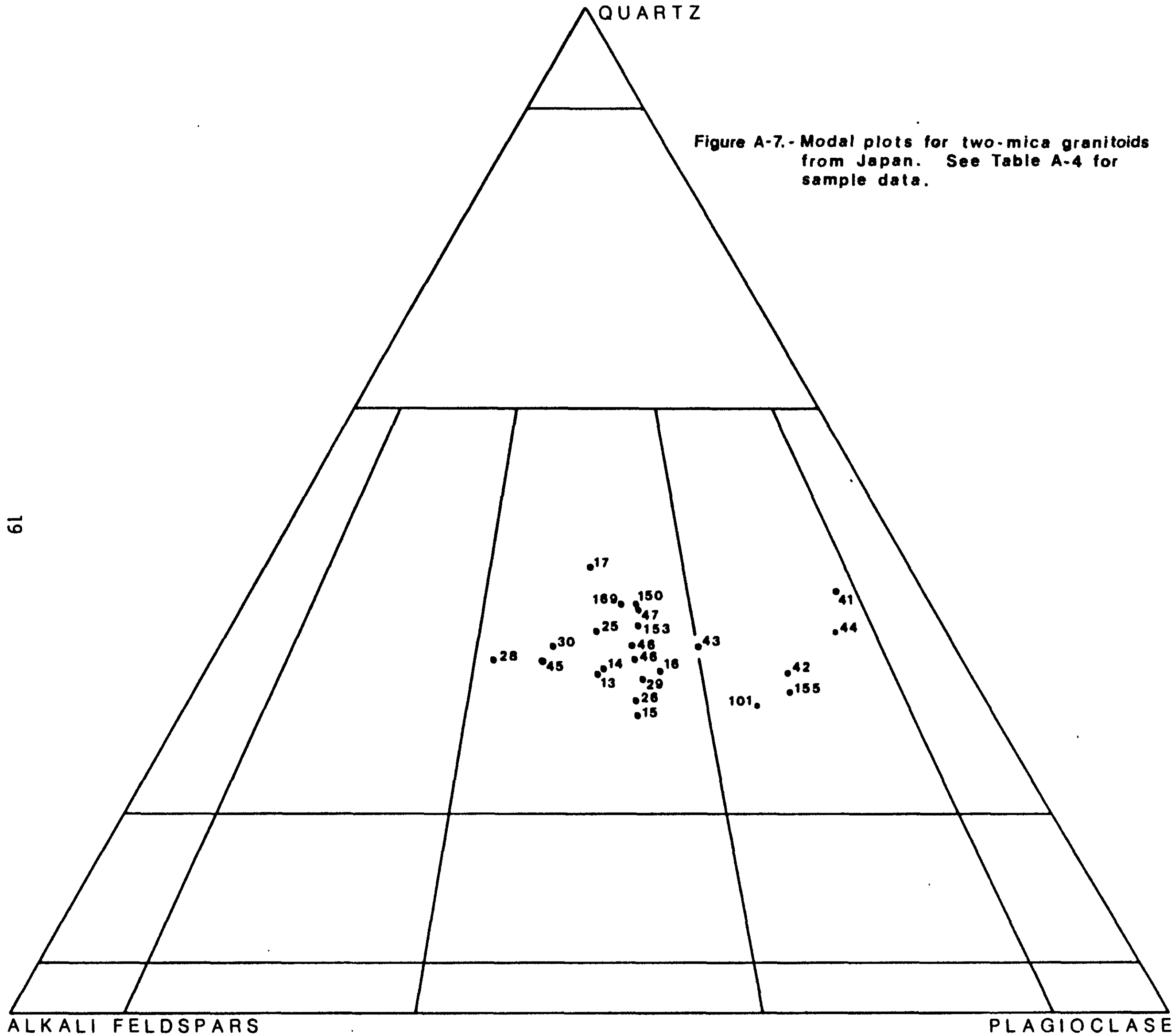

Figure A-7.- Modal plots for two-mica granitoids from Japan. See Table A-4 for sample data.

Modal compositions of some other Asian two-mica and similar granites are given in table A-5 and the modes are plotted in figure A-8. All plot in the monzogranite subfield. Samples 59 and 60 are averages of magnetite-series and ilmenite-series granites, respectively, and both are biotite granites. Samples 64-68 are five different phases of Yanshanian two-mica granites (Yan and others, 1980, tbl. 1) associated with a porphyritic type tungsten deposit. Although samples 59 and 60 are reported in weight percent, they do not seem to plot in positions significantly different from the other samples which are reported in volume percent. The mica content in the biotite granites averages 2.6 weight percent, and in the two-mica granites it averages 5.5 volume percent. Biotite content in the two-mica rocks averages 4.3 and muscovite averages 1.2 volume percent, which yields an average biotite/muscovite ratio of 3.6.

Ishihara and others (1980) studied the granitic rocks associated with tin and tungsten deposits on the southern part of Peninsular Thailand. The rocks are biotite and two-mica granites that contain little or no magnetite and therefore belong to the ilmenite-series. The authors did not publish the modal analyses upon which their figure 2 was based, consequently our figure A-9 is a modified reproduction of their figure 2. About three-quarters of the samples plot in the monzogranite subfield, and the other quarter plots in the syenogranite subfield. Ishihara and others (1980) divided the area studied into east, west, and central zones for which modal plots of 21, 5, and 14, respectively, are shown in figure A-9. Nearly the same percentage of samples from each of the three zones plot in the syenogranite and monzogranite subfields. The central zone contains more quartz than the west zone, and the quartz content of the east zone lies between and overlaps that of the other two zones. These rocks contain more alkali feldspars than any of those discussed above and Ishihara and others (1980, p. 227) consider them good hosts for tin and tungsten because "primary Sn-W deposits are known to occur in and near the syenogranites."

Modal analyses of some two-mica granitoids from the Appalachian Mountains are listed in table A-6 and their modal plots are shown on figure A-10. Three plot in the granodiorite field; one, at the right edge of the syenogranite subfield, and the rest plot in the monzogranite subfield. Albuquerque (1977) identified samples 357 and 358 as muscovite-biotite granodiorite which is confirmed by their low K-spar/plagioclase ratios, and Grant and others (1980) recognized that sample 222, which is the average of 16 modal analyses of stained samples, plots as a granodiorite. Sample 222 is rather surprising because the other samples from Stone Mountain, 101, 102 and 103 which are the averages of 4, 49 and 6 modal analyses, respectively, plot as monzogranites, and megascopically Stone Mountain granite appears to be of uniform composition. It appears that in sample 222 quartz is enriched at the expense of K-spar which throws the sample into the granodiorite field. Sample 224 is included here because it is thought to be the source from which sample 223 was derived (Grant and others, 1980). Sample 223 contains enough magnetite to be classed as a magnetite-series granite; sample 224 is probably an ilmenite-series granitoid. McKenzie and Clarke (1975) reported samples 369 and 370 as biotite granodiorites, they plot, however, as monzogranites in Streckeisen's classification. The same authors called samples 371-380 two-mica adamellites and noted that in these rocks "muscovite [is] an essential mineral" and that "potassic feldspar is generally the predominant feldspar."

TABLE A-5.--Modal analyses of two-mica granites and similar granitoids from Japan and China

	JAPAN		SOUTHEAST CHINA					
	MONZOGRANITE		YANSHANIAN GRANITES					
Sample No	59	60	64	65	66	67	68	69
No. of Samples	7	5	1	1	1	1	1	1
Quartz	34.5	34.6	31	30	29	31	29	38
K-Spar	29.5	28.0	36	33	35	36	34	25
Plagioclase	33.6	33.9	27	29	29	28	28	32
Micas: Biotite	1.6	3.0	3	5	4	5	6	3
Micas: Muscovite			2	1	1	1	1	1
Magnetite or ilmenite	0.8	0.04	0.01 0.01	0.05 0.01	0.04 0.01	0.01 0.01	0.04 0.01	
Other	None	0.5 1/			0.01 2/			
Total	100	100.04	99	98.06	98.06	101.01	98.05	99
K-spar/Plagioclase ratio	0.9	0.8	1.3	1.1	1.2	1.3	1.2	0.8
Biotite/Muscovite ratio			1.5	5.0	4.0	5.0	6.0	3.0
Total mica	1.6	3.0	5	6	5	6	7	4

Samples 59 and 60. Reported as weight percent. 59 = magnetite series; 60 = ilmenite series. 1/ mostly fluorite (Ishihara, 1977, tbl. 1)

Samples 64-69. 64 = ilmenite-series, 65-68 = magnetite-series; 64 and 65 late Yanshanian, 66-68 early Yanshanian(Yanshanian=Jurassic-Cretaceous); 69 Xihaushan granite of Yangchuling complex; 2/ fluorite; magnetite, ilmenite and fluorite contents converted from grams per ton to weight percent (Yan and others, 1980, tbls. 1, 3 and 4).

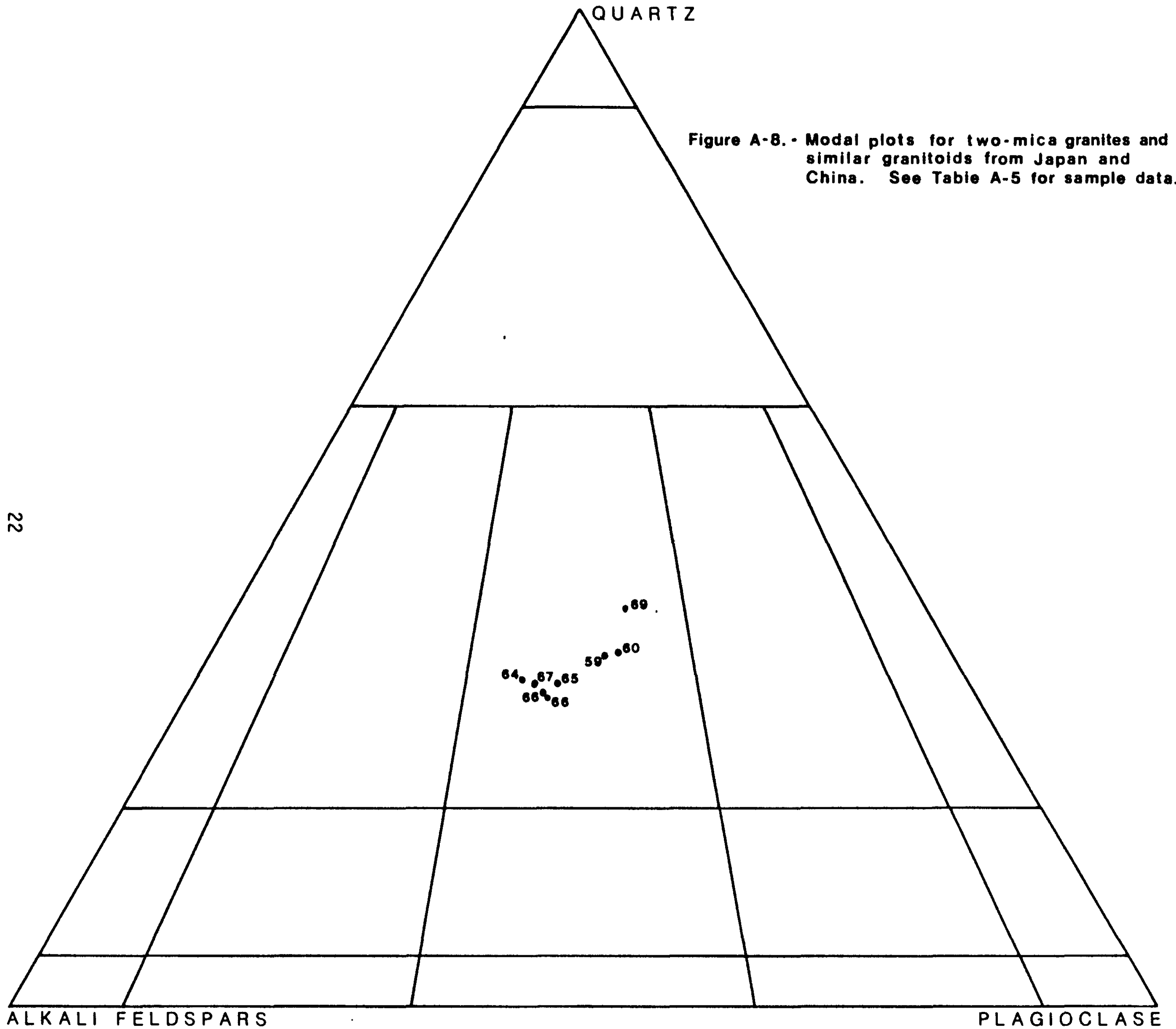

Figure A-8. - Modal plots for two-mica granites and similar granitoids from Japan and China. See Table A-5 for sample data.

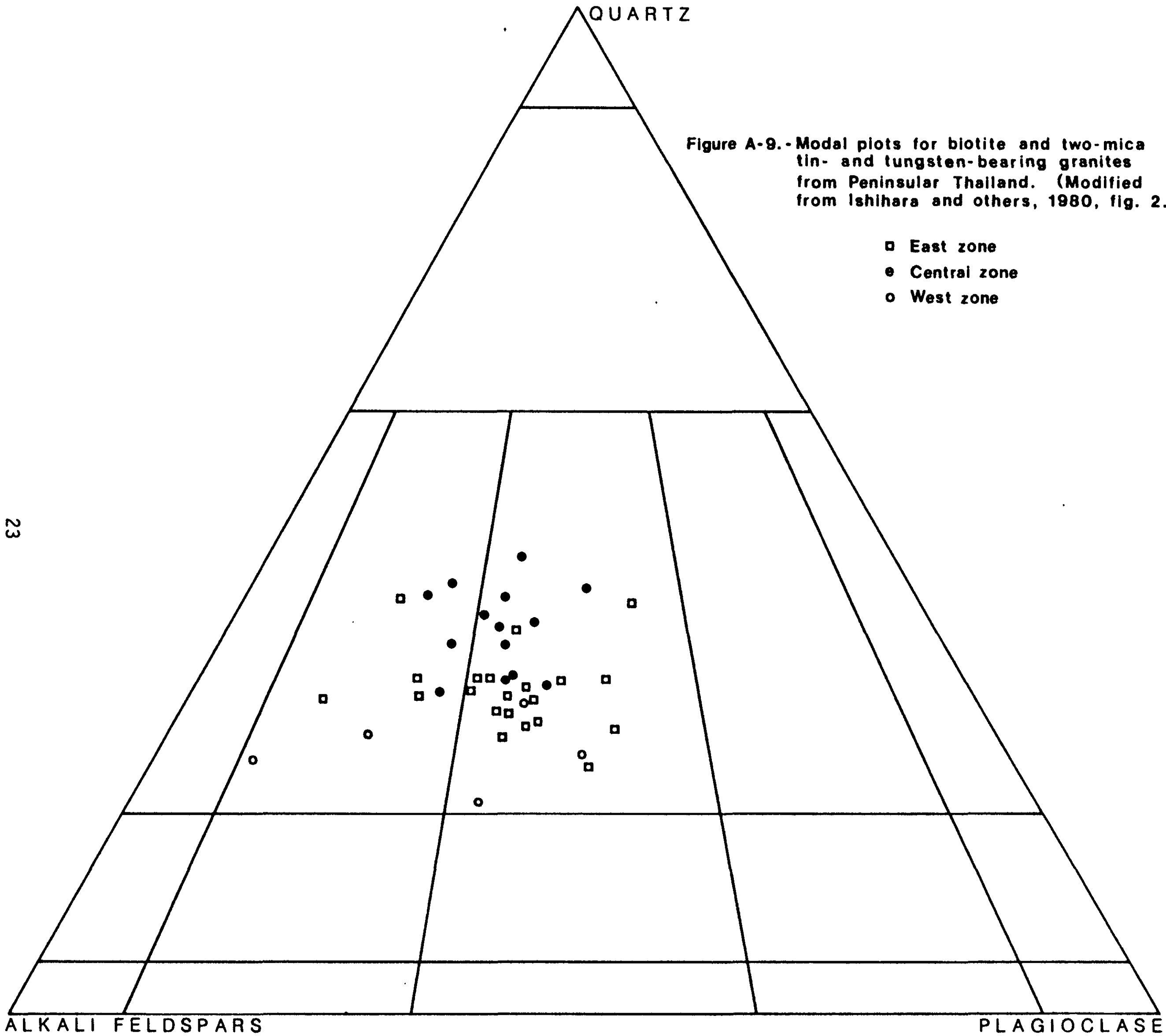

Figure A-9.-Modal plots for biotite and two-mica tin- and tungsten-bearing granites from Peninsular Thailand. (Modified from Ishihara and others, 1980, fig. 2.)

TABLE A-6.--Modal analyses of two-mica granitoids from the Appalachian Mountains

	STONE MOUNTAIN, GA.				ARABIA MTN., GA.		NEW HAMPSHIRE					
					Granite	Gneiss	Milford Granite					
Sample No.	101	102	103	222	223	224	381	382	383	384	385	386
No. of Samples	4	49	6	16	8	4	1	1	1	1	1	1
Quartz	31.9	32.4	30.8	37.2	35.0	34.1	32.5	29.0	28.8	40.0	31.4	32.0
K-spar	22.0	25.7	27.9	16.7	29.3	29.6	28.7	28.2	29.9	30.7	26.4	33.4
Plagioclase	35.7	28.8	31.1	35.6	31.0	31.3	27.9	36.0	33.3	21.4	37.2	29.2
Micas Biotite	1.2	1.2	1.4	1.4	1.6	3.0	9.0	6.4	7.5	7.2	4.8	4.8
Micas Muscovite	8.0	11.5	8.7	9.0	2.2	2.4	2.1	0.4	0.7	0.7	0.2	0.8
Apatite	0.1	Tr	Tr	Tr			Tr	Tr	Tr	Tr	Tr	Tr
Epidote	0.4	0.3	0.1	0.2	Tr	Tr						
Tourmaline		0.3	0.1									
Other				Tr[1]	0.6[2]	0.2[2]	Tr[3]	Tr[3]	Tr[3,4]	Tr[3]	Tr[3]	Tr[3]
Total	100.1	100.2	100.1	100.1	99.7	100.6	100.2	100	100.2	100	100	100.2
K-spar/Plagioclase ratio	0.6	0.9	0.9	0.5	1.0	1.0	1.0	0.8	0.9	1.4	0.7	1.1
Biotite/Muscovite ratio	0.2	0.1	0.2	0.2	0.7	1.3	4.3	16.0	10.7	10.0	24.0	6.0
Total mica	9.2	12.7	10.1	10.4	3.8	5.4	11.1	6.8	8.2	7.9	5.0	5.6

	SOUTHERN NOVA SCOTIA					WESTERN NOVA SCOTIA											
	Port Mouton Pluton				S.P.	South Mountain Batholith											
Sample No.	357	358	359	360	361	369	370	371	372	373	374	375	376	377	378	379	380
No. of Samples	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Quartz	34.8	32.5	30.1	33.6	30.5	32.1	33.1	34.2	25.4	28.6	37.8	33.8	44.8	32.3	32.1	31.6	32.1
K-spar	17.2	19.5	25.2	18.9	28.5	23.0	21.0	34.8	38.6	40.4	30.6	38.4	23.1	36.2	32.0	33.1	35.3
Plagioclase	39.4	37.4	32.8	34.3	27.3	33.0	36.0	23.5	24.8	23.4	22.1	20.6	25.4	26.4	26.3	26.0	29.2
Micas Biotite	3.6	3.4	7.2	8.0	3.9	8.2	9.2	6.6	10.5	2.6	8.9	5.6	3.4	3.7	5.6	6.4	4.4
Micas Muscovite	4.3	6.3	4.0	4.6	9.8	3.4	0.7	0.9	0.7	5.0	0.7	1.5	3.0	1.4	3.8	0.7	1.1
Apatite																	
Epidote																	
Tourmaline																	
Other	0.7	0.9	0.7	0.6	0.3	0.4									0.6		
Total	100	100	100	100	100	100.1	100	100	100	100	100.1	99.9	99.7	100	100.4	97.8	102.1
K-spar/Plagioclase ratio	0.4	0.5	0.8	0.6	1.0	0.7	0.6	1.5	1.6	1.7	1.4	1.9	0.9	1.4	1.2	1.3	1.2
Biotite/Muscovite ratio	0.8	0.6	1.8	1.7	0.4	2.4	13.1	7.3	15.0	0.5	12.7	3.7	1.1	2.6	1.5	9.1	4.0
Total mica	7.9	9.7	11.2	12.6	13.4	11.6	9.9	7.5	11.2	7.6	9.6	7.1	6.4	5.1	9.4	7.1	5.5

Tr = trace
101-103. Two-mica granite (Whitney and others, 1976, tbl. 1)
222-224. Two-mica granitoids; 223 neosome, 224 paleosome; [1] zircon and garnet; [2] magnetite (Grant and others, 1980, tbl. 1)
381-386. [3] zircon, [4] allanite (Aleinikoff, 1978, tbl. 12)
357-361. S.P. = Shelburne pluton; 357 and 358 muscovite-biotite granodiorite; 359 and 360 muscovite-biotite granite; 361 garnet-bearing muscovite-biotite granite (Albuquerque, 1977, tbl. 1)
369-380. 369 and 370 muscovite-biotite granodiorite, 371-380 muscovite-biotite adamellite (McKenzie and Clarke, 1975, tbl. 1)

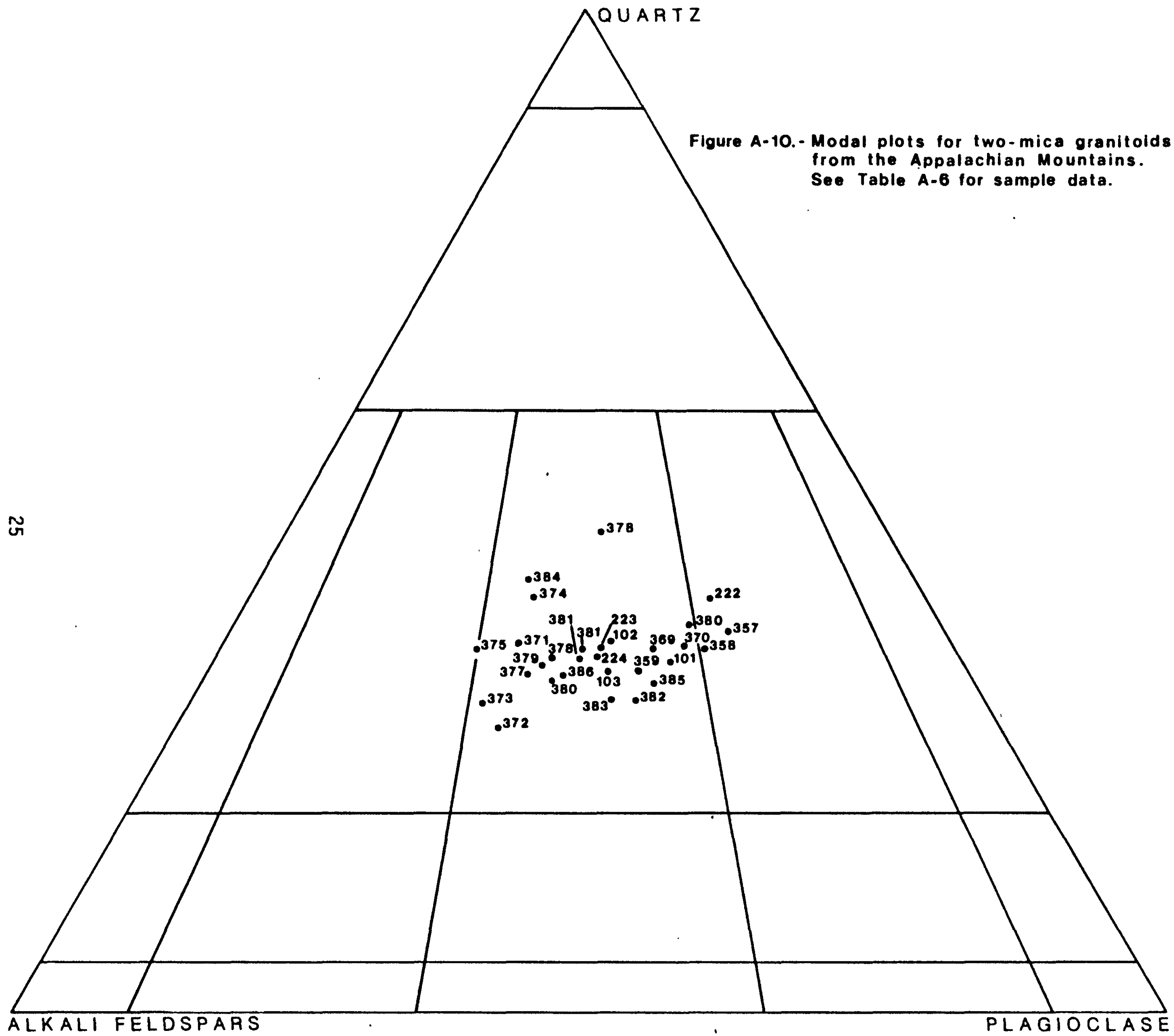

Figure A-10.- Modal plots for two-mica granitoids from the Appalachian Mountains. See Table A-6 for sample data.

The total mica content of the Appalachian two-mica granitoids in Table A-6 ranges from 3.8 to 13.4 volume percent and averages 10.3. The average biotite and muscovite contents are 2.3 and 7.6 volume percent, respectively, and yield an average biotite/muscovite ratio of 0.3.

Modal plots, without modal analyses, for S-type and I-type granitoids from the Kasciusko batholith, southeastern Australia, were given by Hine and others (1978, fig. 2) and are presented here (fig. A-11) for comparison with the preceeding modal plots of two-mica granites. It is evident that the two-mica rocks are more similar to the S-type than to the I-type granitoids. Two-mica rocks contain slightly less quartz than S-type rocks; in addition, they contain more K-spar and plot more in the monzogranite and syenogranite subfields than do the S-type rocks.

In table A-7 are the ranges and average contents of essential minerals of the granitoids listed in tables A-1 through A-6 grouped according to country and European and non-European origin. Also shown are the K-spar/plagioclase ratios for each of the groups. The modal plots of these average essential minerals fall in a restricted area of Streckeisen's monzogranite (fig. A-12) subfield.

From the several foregoing modal plots it is obvious that modal plots of essential minerals do not and can not uniquely define two-mica and related granitoids. Modal analysis, however, is extremely useful because it defines the variety and amount, in volume percent, of minerals present in the rock. The European two-mica granitoids listed contain about 31 percent quartz, 27 percent K-spar and 31 percent plagioclase; the non-European rocks contain about 34 percent quartz, 26 percent K-spar and 32 percent plagioclase. The K-spar/plagioclase ratio in both the European and non-European rocks is about 0.9. There is a suggestion that some two-mica granitoids and related rocks from near uranium deposits contain more K-spar and less plagioclase than the averages given in table A-7, for example, table A-1, samples 144, 145, 179-184 and table A-2, samples 189, 190.

The range and average content of modal biotite and muscovite of the granitoids in tables A-1 through A-6 are listed in table A-8 in groups similar to those in table A-7. The granitoids have been further subdivided into biotite-bearing and two-mica-bearing rocks. For the two-mica rocks the range and average biotite/muscovite ratios as well as the range and average total mica contents are shown. In the European two-mica rocks the total mica content averages about 10.7 volume percent and the biotite/muscovite ratio is about 0.8. The French biotite granites average about 10.6 volume percent biotite because most of the samples are from the St. Clémentin Granite (table A-1) which is unusually rich in biotite. In contrast, the Bois Noir biotite granites (table A-1) average about 6.0 weight percent biotite. Among the non-Eurpoean granitoids, the Appalachian rocks are very like the European in total mica content but contain a larger proportion of muscovite and yield a biotite/muscovite ratio of about 0.3. The Japanese and Chinese two-mica granites differ in that they contain less total mica, about 5.9 volume percent, contain proportionately more biotite and yield a biotite/muscovite ratio as large as 3.6. The non-European biotite granitoids contain about 2.4 volume percent biotite.

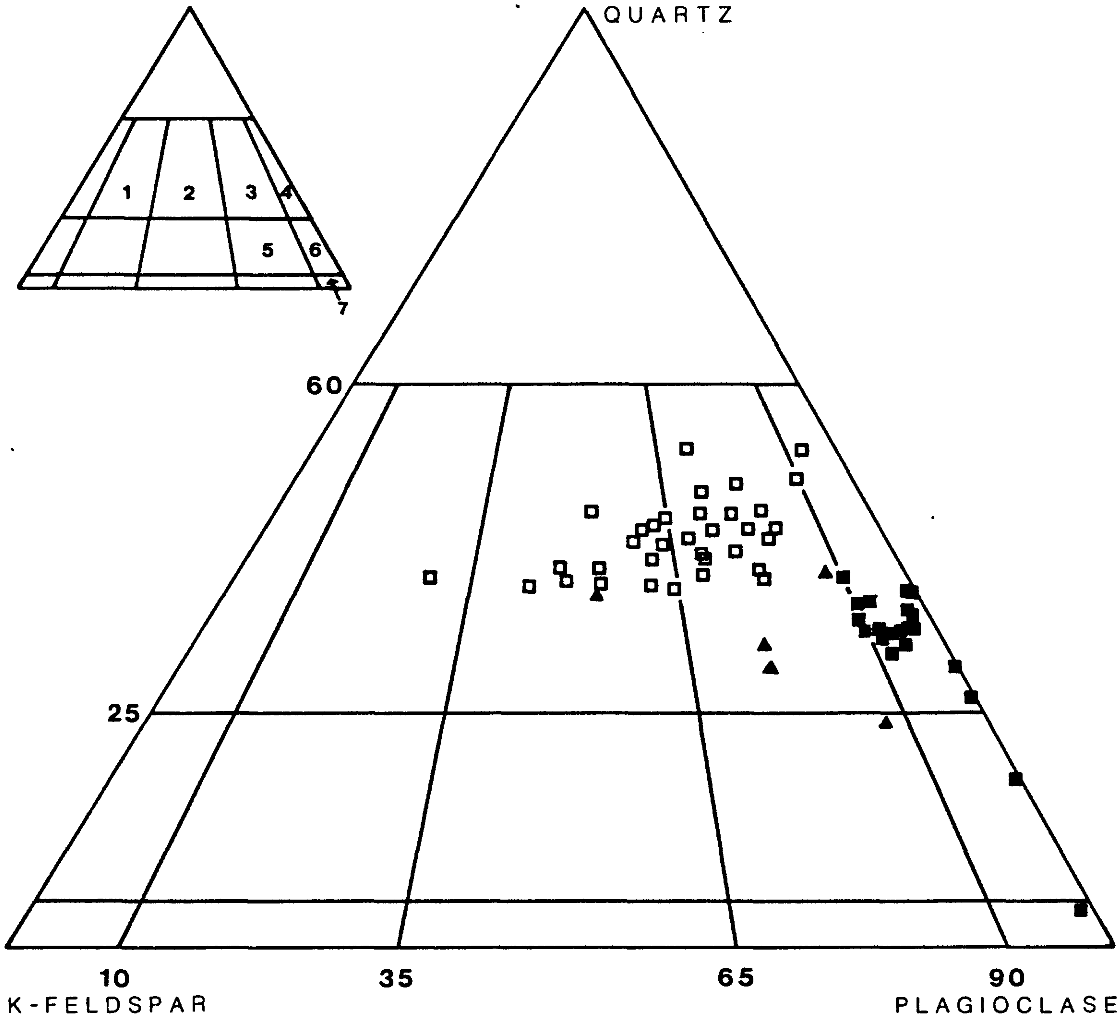

Figure A-11. - Modal compositions (quartz, potassium feldspar, plagioclase) of Kosciusko granitoids. Open squares are S-types and filled squares are I-types of the Jindabyne Suite. Other I-types are plotted as triangles. The classification used is modified slightly from that proposed by the IUGS Subcommission on the Systematics of Igneous Rocks (Streckeisen, 1973): 1, granite; 2, adamellite; 3, granodiorite; 4, tonalite; 5, quartz monzodiorite; 6, quartz diorite and gabbroic diorite; 7, diorite and gabbro. (Hine and others, 1978, fig. 2), (Published with permission.)

TABLE A-7.--Ranges and average modal contents of essential minerals, in volume percent, for granitoids listed in tables A-1 through A-6.

	France	Portugal	Spain	European	Japan	Japan and China	Appalachians	Non-European
No. of Samples	149	11	28	188	23	18	110	151
Quartz								
Range	20.0-36.0	26.2-36.5	24.7-40.5	20.0-40.5	28.6-43.8	29.0-34.6	28.6-44.8	28.6-44.8
Average	30.7	30.0	30.6	30.6	34.4	33.5	33.4	33.6
K-spar								
Range	18.0-42.0	10.5-49.9	16.3-41.8	10.5-49.9	6.7-39.1	25.0-36.0	16.7-40.4	6.7-40.04
Average	26.8	26.9	29.1	27.2	24.8	30.3	25.4	25.9
Plagioclase								
Range	20.0-40.5	16.0-37.5	15.6-39.0	15.6-40.5	23.4-49.5	27.0-33.9	20.6-39.4	20.6-49.5
Average	32.0	26.5	26.6	30.9	35.5	32.1	30.5	31.5
K-spar/Plagioclase ratio								
Range	0.5-2.1	0.3-3.1	0.6-2.7	0.3-3.1	0.2-1.7	0.8-1.3	0.4-1.9	0.2-1.9
Average	0.8	1.2	1.2	0.9	0.8	0.9	0.9	0.8

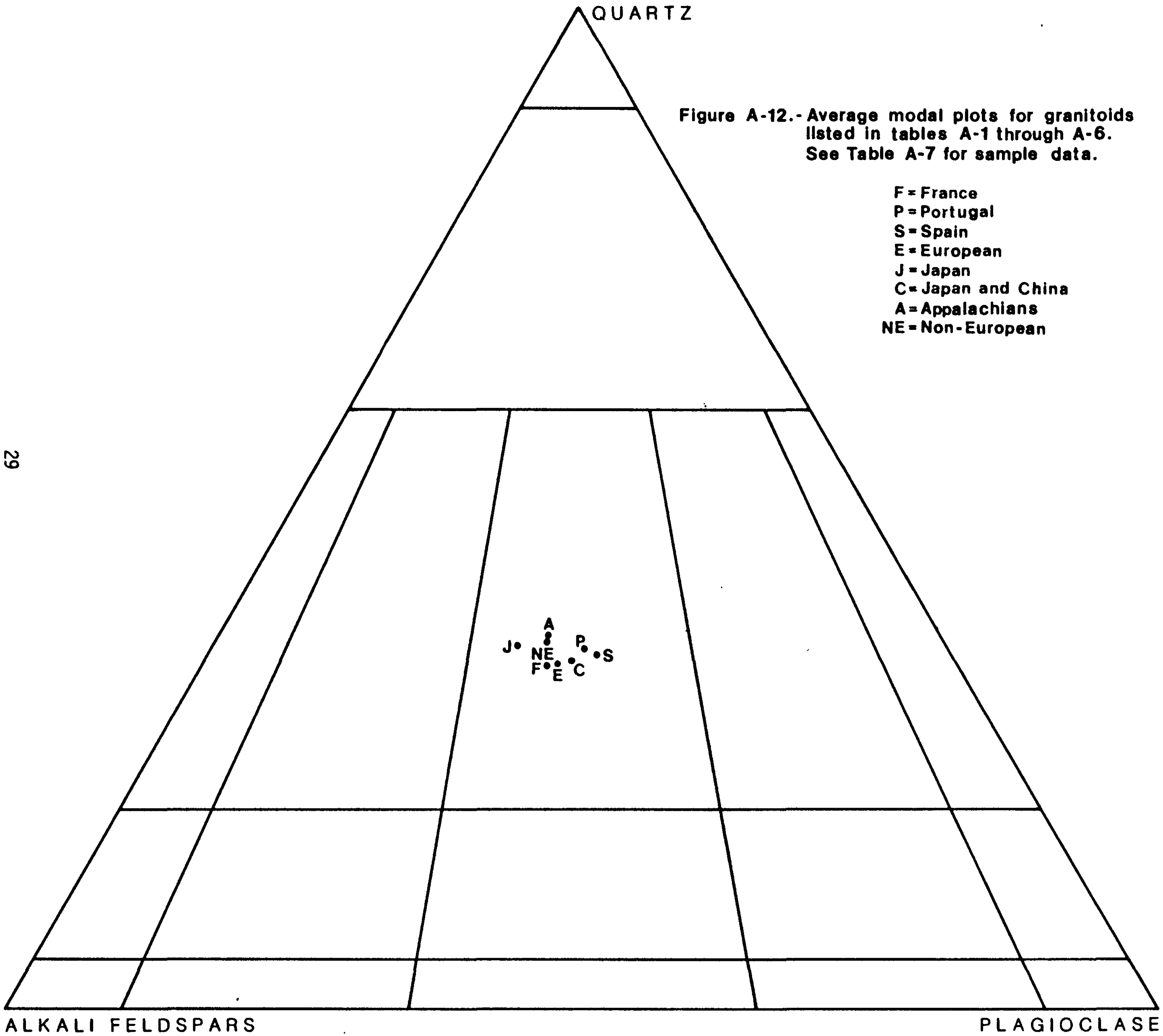

Figure A-12.- Average modal plots for granitoids listed in tables A-1 through A-6. See Table A-7 for sample data.

TABLE A-8.--Range and average content of modal biotite and muscovite, in volume percent, for granitoids listed in tables A-1 through A-6.

	France	Portugal	Spain	European	Japan	Japan and China	Appalachians	Non European
Biotite only								
No. of samples	27			27	8	12		20
Range	1.7-11.9			1.7-11.9	1.3-4.6	1.6-3.0		1.3-4.6
Average	10.6			10.6	2.8	2.2		2.4
Biotite and Muscovite								
No. of samples	121	11	28	161	15	6	109	131
Biotite Range	1.9-8.5	0.7-20.5	2.1-12.7	0.7-20.5	1.2-11.2	3.0-6.0	1.2-10.5	1.2-11.2
Average	3.8	9.8	5.8	4.6	4.2	4.3	2.4	2.7
Muscovite Range	4.0-7.3	1.8-20.9	2.0-12.7	1.8-20.9	0.1-4.1	1.0-2.0	0.2-11.5	0.1-11.5
Average	6.0	5.6	6.5	6.1	1.9	1.2	8.0	7.0
Biotite/Muscovite ratio Range	0.4-1.5	0.1-7.9	0.2-4.4	0.1-7.9	0.7-56.0	1.5-6.0	0.1-24.0	0.1-56.0
Average	0.6	1.8	0.9	0.8	2.2	3.6	0.3	0.4
Total mica Range	1.7-15.0	5.7-28.1	5.7-20.2	1.7-28.1	1.3-11.4	1.6-7.0	3.8-13.4	1.3-13.4
Average	9.8	15.4	12.3	10.7	6.1	5.5	10.4	9.7

If the St. Clēmentin biotite granite is excluded, the figures in the several tables strongly suggest that two-mica rocks contain about twice as much total mica as one-mica rocks. On the other hand, the biotite/muscovite ratio has such a wide range, at least in the data presented, that probably no valid general statement can be made about the relative abundance of the two minerals, except that in the European examples muscovite content seems to slightly exceed biotite content.

SUMMARY

In Europe two-mica granites are associated with or are host to tin, tungsten and uranium deposits. These rocks along with other plutonic rocks intrude high-grade metamorphic terranes, and are usually late in the intrusive sequence. They occur as small plutons that are elongate or eliptical in plan and are sheet-like or tabular in three dimensions. They are leucocratic, massive, hypidiomorphic-granular granitoids that consist of about 32 volume percent quartz, 26 percent K-spar, 31 percent plagioclase, and 10 percent mica in which muscovite may exceed biotite. In Streckeisen's (1976) granitoid modal plot two-mica granites plot predominantly in the monzogranite subfield; some plot in the syenogranite subfield, and others are two-mica granodiorites. There is evidence that suggests that the K-spar-rich, large plutons are the favored hosts for large uranium deposits.

Elsewhere in the world two-mica granites have the same characteristics and are associated with the same types of ore deposits. Two-mica granites are somewhat similar to but different from both S-type granitoids (Chappell and White, 1974) and ilmenite-series granitoids (Ishihara, 1977).

Modal plots are not a sufficiently discriminating technique with which to uniquely identify two-mica granites. In the following chapter (B) it will be seen that major oxide chemistry of two-mica granites can help to define them more accurately.

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