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Petrographic and Chemical Data for the Quien Sabe Volcanic Rocks in the Mariposa Peak Quadrangle, Central Diablo Range, California

by

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INTRODUCTION

This preliminary report contains petrographic and chemical data for Late Miocene volcanic rocks collected from the Quien Sabe volcanic field located along the crest of the central Diablo Range approximately 10 miles (16 km) east of Hollister, in west central California, (fig. 1). The volcanic rocks are partially within Merced, San Benito, and Santa Clara counties, and are largely on private ranch lands. Limited access to the northwestern part of the volcanic field can be gained via Comstock and Lone Tree roads which originate east of Hollister. The purpose of this report is to provide background information for other reports in progress and to supplement future investigations or related work.

Fieldwork and sampling were done during 1981 and 1982, (Drinkwater 1983), with additional mapping and sampling done during 1984, 1985, and 1986, (Drinkwater and others, unpublished data, 1988). Most of the rock samples were collected within the Mariposa Peak 1:24,000 quadrangle outlined in figure 2 and include representatives of all map units.

The petrographic data consist of descriptive summaries of rock samples and volcanic units. The chemical data are presented in tables as major-element chemical analysis of 40 whole-rock samples that range from basalt to rhyolite in composition. Binary and ternary variation diagrams are presented to show the petrologic affinities and rock classification of the volcanic rocks.

The regional geologic setting of the volcanic rocks is shown in fig. 2 and more detailed descriptions of the regional geology can be found in Nilsen and Dibble (1981), Ernst (1981), and Page (1966). Only a brief description of the volcanic geology is presented here. Detailed mapping and descriptions of the volcanic rocks were done by Bailey and Myers (1942), Leith (1949), Osuch (1970), Guimaraes (1972), Prowell (1974), and Drinkwater (1983).

The volcanic rocks have been dated by K-Ar methods as Late Miocene in age (Prowell, 1974; and Drinkwater, 1983).

Current research in progress, (Drinkwater, Sorg, and Russell, unpublished data, 1988) includes detailed studies of the geochronologic and tectonic evolution of the volcanic field, and the mineralogy and age of the hydrothermal alteration and associated epithermal antimony and mercury mineralization in the volcanic rocks.

Geologic Setting

Late Miocene volcanic rocks of the Quien Sabe volcanic field cover an area of approximately 100 square miles (259 km^2) along the crest of the central Diablo Range 10 miles (16 km) east of Hollister in west central California.

Within the Mariposa Peak Quadrangle, which encloses a 45-square-mile area of volcanic rocks in the northern part of the volcanic field, is an estimated 4000-foot (1220 m) section of volcanic breccias and flows, three major intrusive and vent centers, and a northwest-trending system of steeply dipping normal and reverse faults along which extensive hydrothermal alteration and epithermal antimony-mercury mineralization has occurred.

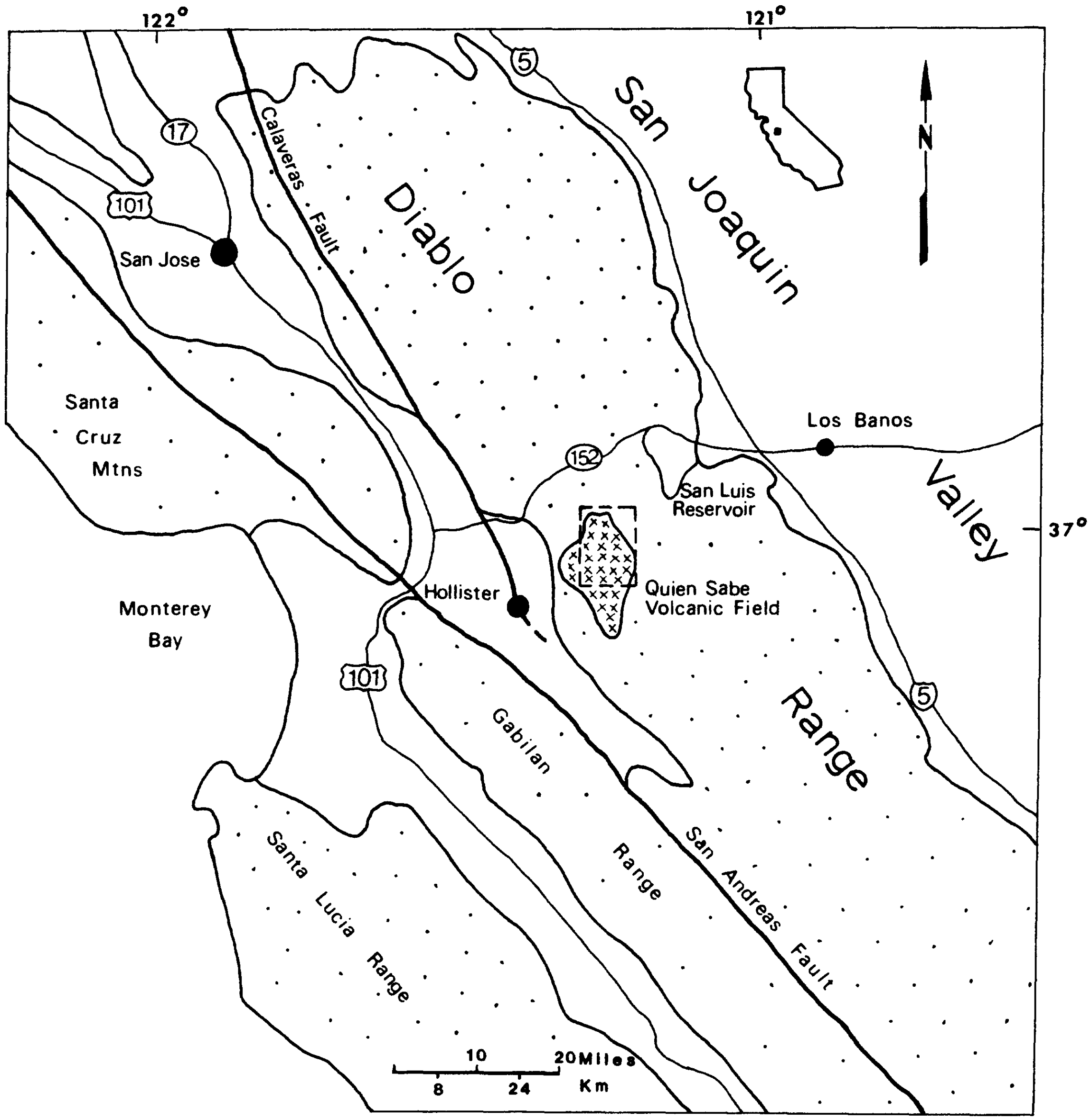

Figure 1.--Index map showing location of Quien Sabe volcanic field and the primary area under investigation in this study (dashed area).

The flat-lying to broadly folded Quien Sabe volcanic rocks unconformably overlie penetratively deformed and stratally disrupted basement rocks of the Mesozoic Franciscan Complex, uptilted, but otherwise relatively undeformed, Mesozoic marine sedimentary rocks of the Great Valley Sequence, and a relatively thin sequence of gently folded middle Miocene marine sandstones and shales of the Lone Tree formation (Osuch, 1970).

Several major northwest-trending faults transect the region; the San Andreas fault to the west, the Calaveras and Quien Sabe faults to the northwest and west, and the Ortigalita fault to the east (fig. 2).

The volcanic rocks, which range from basalt to rhyolite in composition, consist of a thick series of flows and volcanic breccias with minor interbeds of tuff and volcanic sediments. Andesites and dacites are most abundant in volume and occurrence while basalts and basaltic andesites are less abundant in volume but are laterally extensive. Rhyolite is present as small domes and vent bodies, and as minor tuff layers and breccia clasts in the volcanic rocks of the uppermost units.

Flow rocks prevail in the lower and upper parts of the volcanic sequence, while the middle part of the sequence consists predominantly of volcaniclastic rocks. Massive bouldery breccias are the most abundant volcaniclastic rock and they form rugged, resistant ridges and cliffs. Field evidence indicates that the volcanic breccias are mostly epiclastic, lahar-type, debris and mud flows, are largely nonbedded, unsorted, poorly graded, and poorly jointed deposits and contain interbeds of conglomerate and pebbly sandstone. Pyroclastic breccias are less abundant and are matrix supported tuff-breccias which contain pumice and vesicular volcanic fragments in an abundant ash-rich matrix, and are typically interbedded with tuff. Tuff layers are widespread but thin, (up to several cm), although several meters of tuff can be found locally at the base of the volcanics. Most of the tuffs consist of massive to graded lithic tuff, lithic lapilli tuff and minor crystal tuff. Welded tuffs are not present in the volcanic field. Interbedded volcanic sediments are chiefly pebble conglomerate and coarse sandstone that are locally as much as 12 meters (40 ft) thick, and locally contain minor quantities of detritus from Franciscan assemblage rock sources.

Multiple vent sources are indicated by numerous dacitic and rhyolitic intrusive plugs that are present within the volcanic field. Field evidence suggests that most of the extrusive rocks were derived from 3 main vent complexes (Drinkwater, 1983), which are located in the northern half of the volcanic field.

The stratigraphic sequences and lithologic variations of the volcanic rocks derived from the major vent areas are similar. With the exception of a localized basal dacite flow unit (Tld), basalt and basaltic andesite flows occupy the base of the volcanic sequence, followed by andesites and dacites. Dacitic and rhyolitic intrusions (plugs, pipes, and domes) were emplaced from 10.0 to 9.0 m.y. (unpublished K/Ar dates) ago and followed the cessation of basaltic and andesitic volcanism. The rhyolitic intrusives of Mariposa and Cathedral Peaks are the youngest recognized volcanic activity in the field.

A brief outline of rock sequences and lithologies are shown in figure 3 and table 1. The data in figure 3 represent a composite interpretation, because the stratigraphic relationships tend to be somewhat obscured due to

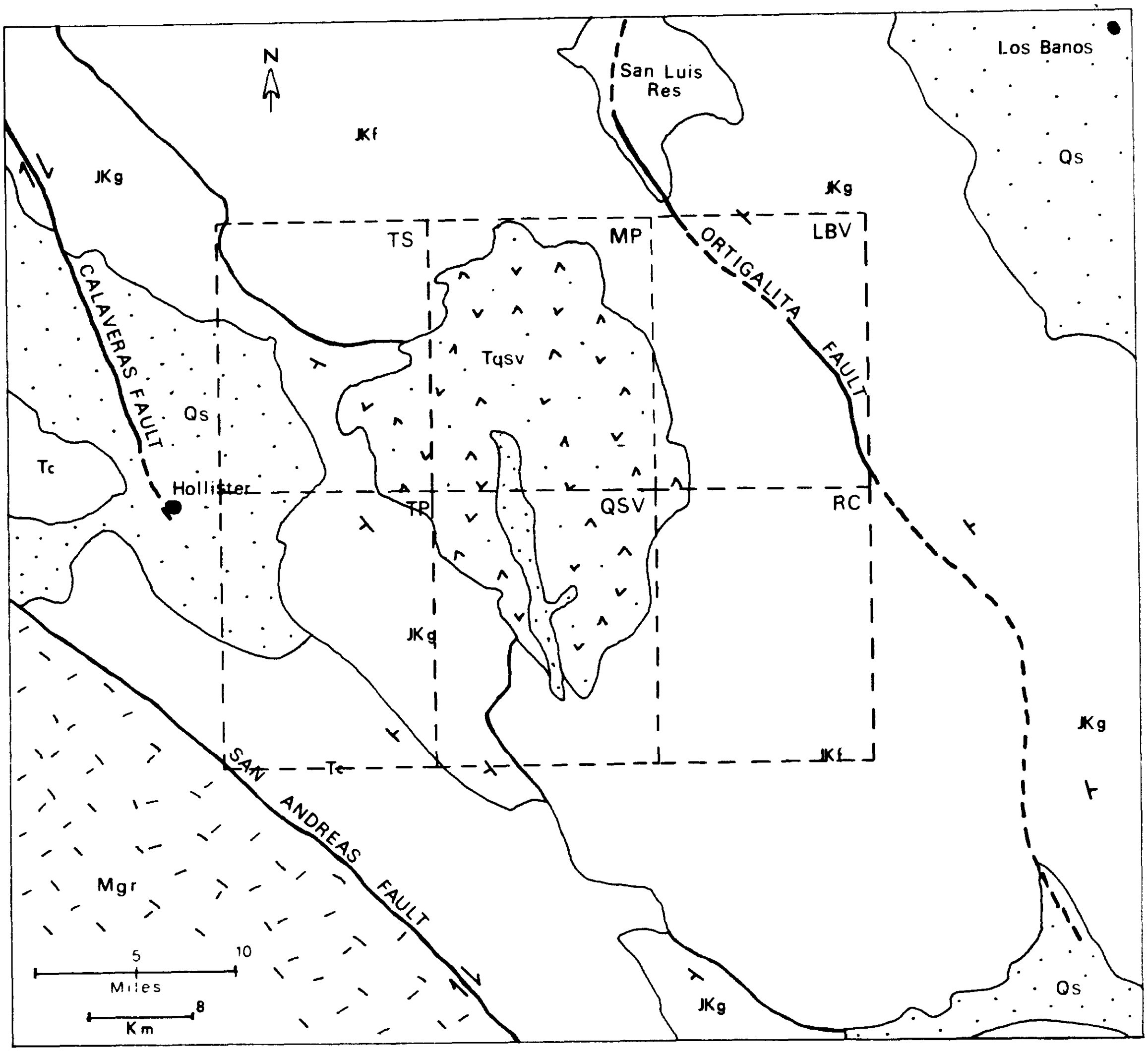

Figure 2. -- Generalized regional geologic map of the Quien Sabe volcanic field, and location of 7½ min quadrangles which include the volcanics. Modified from Geologic Map of California, Santa Cruz Sheet, 1959. Map sympols: Qs-Quaternary surficial deposits, Tqsv-Quien Sabe volcanics (upper Miocene), Tc-Tertiary clastics, JKg-Great Valley sequence, JKf-Franciscan Complex (Jurassic-Cret.), Mgr-granitic rocks (Mesozoic). Quadrangle names; TS-Three Sisters, MP-Mariposa Peak, LBV-Los Banos Valley, TP-Tres Pinos, QSV-Quien Sabe Valley, and RC- Ruby Canyon

the presence of overlapping flows from multiple vent sources. Only a brief summary of the characteristic features of the volcanic rocks is given here; more detailed information on the stratigraphy, petrography and chemistry of Quien Sabe volcanic rocks can be found in Drinkwater (1983), Prowell (1974), and Osuch (1970). Volcanic units of table 1 are composite map units each composed of numerous or several flows and/or volcaniclastic beds of similar lithology.

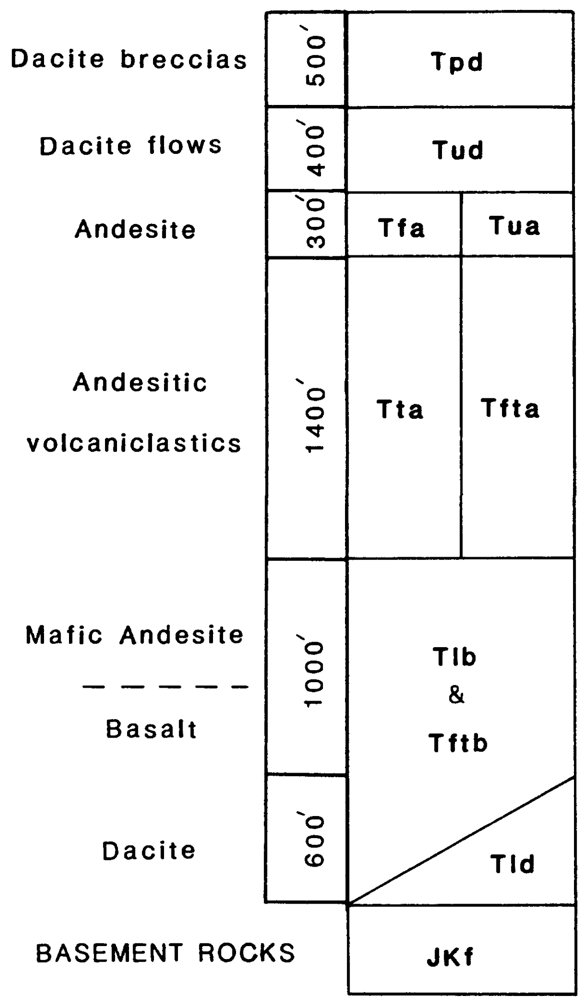

Figure 3.--Generalized stratigraphic column and maximum thickness of mapped units from the Quien Sabe volcanics. Refer to table 1 for description of unit abbreviations.

Table 1. Description of volcanic units

MAP UNIT	SYMBOL	LITHOLOGY
Intrusive Rhyolite-Rhyodacite	Tir	biotite-hornblende-pyroxene rhyodacite and hornblende-biotite rhyolite
Intrusive Dacite	Tid	biotite-hornblende-orthopyroxene dacite and hornblende-biotite dacite
Intrusive Andesite	Tia	hornblende-pyroxene andesite
Felsic Breccia	Trd	biotite-hornblende rhyolite and rhyodacite
Upper pyroxene Dacite	Tpd	biotite bearing oxyhornblende-two pyroxene dacite
Upper Dacite	Tud	hornblende-biotite dacite
Andesite Flow-Breccia	Tfta Tua	biotite-hornblende-pyroxene andesite, hornblende-pyroxene andesite, and dacite
Andesite Flows	Tfa	biotite-bearing hornblende-pyroxene andesite
Andesite Breccias	Tta	biotite-hornblende-pyroxene andesite, hornblende andesite, and dacite
Basalt and Andesite Flow-Breccia	Tftb	basalt, olivine andesite and hornblende-pyroxene andesite
Lower Basalt and Mafic Andesite	Tlb	basalt, olivine andesite and hornblende-bearing pyroxene andesite
Lower Dacite	Tld	biotite-hornblende dacite

SUMMARY OF PETROGRAPHIC CHARACTERISTICS - The rocks of the Quien Sabe volcanic field exhibit a range of lithologies from basalt to rhyolite. Most of the rocks are porphyritic, and only the basal basalts are megascopicly aphanitic. Plagioclase, clinopyroxene, orthopyroxene, oxyhornblende, hornblende, biotite, and olivine occur as phenocrysts. Groundmass textures are mostly pilotaxitic and hyalopilitic, but range from intersertal in basaltic rocks to microgranular in dacites, and glassy or cryptofelsitic in some rhyolites.

Quartz phenocrysts are uncommon and are only apparent in the upper dacites and felsitic intrusions. The lack of sanidine or potash feldspar phenocrysts is characteristic of these volcanic rocks. Orthoclase and quartz, however, are major constituates in the groundmass of the dacites and rhyolitic rocks. Embayed quartz megacrysts commonly occur in the andesites and dacites, and typically exhibit thin rims of pyroxene; they are considered to be xenocrystic.

Plagioclase is the most abundant mineral as both phenocryst and groundmass component. It displays complex zoning as well as various resorption and alteration features. Clinopyroxene is the common mafic mineral of the basalts and andesites and usually occurs as microphenocrysts (< .5 mm) or small phenocrysts. Orthopyroxene is sporadic in occurrence and is common as phenocrysts only in the intrusive dacites and rhyodacites, and in rocks of the upper pyroxene dacite unit. Olivine is restricted to the lower basalts and basaltic andesites where it occurs as phenocrysts only. The olivine is fresh in some flows and partly altered to chlorite or iddingsite in others. Oxyhornblende and brown hornblende are common mafic minerals in the dacites, rhyolites, and most andesites, and often show partial or complete alteration to granular opaque oxides and chlorite. Biotite occurs only as phenocrysts in the dacites, rhyolites, and some andesites, although never in abundance. It also shows some alteration to chlorite and granular opaque oxides.

Table 2. Petrographic Data for Quien Sabe Volcanic Rock Samples

Field no.	Map Unit	Main Texture +	Phenocryst & (microphenocryst) o	Groundmass o	Groundmass Texture □	Rock Type *
81JD003	Tlb?	Por	Plg, Px, hbl, bio	plg, ox, chl, crp	hyp	And
81JD005	Tlb	Por	Plg, Px, oxhb, bio	plg, cpx, chl, chl, ox	pil	And
81JD008	Tlb	wPo	Plg, oxhb, cpx	plg, ox, crp, chl	pil	And
85JD009	Tta	Por	Plg, px, oxhb, bio	plg, px, gl, crp	hyp	And
81JD010	Tlb	Aph	plg, ol	plg, px, ox, gl, crp	int-pil	B-And
81JD013a	Tlb	Aph	plg, ol	plg, Px, ox	mpo-ig	B-And
81JD019	Tfa	Por	Plg, px, oxhb	plg, Px, ox, chl	pil	And
81JD020	Tfa	wPo	Plg, px, oxhb, bio	plg, crp, ox, chl	pil	And
81JD023	Tir	sPo	Plg, px, qtz, hbl, bio	qtz, k-f, crp	hyp	Rhd
81JD029	Tld	Por	Plg, hbl, bio	plg, qtz k-f, ox	fel	Dct
81JD037	Tpd	Por	plg, px, oxhb, bio	plg, gl, ox, crp	hyp	Dct
81JD052	Tld	sPo	Plg, oxhg, bio	plg, qtz, k-f, ox	fel	Dct
81JD057b	Tta	Pyr	px, plg, qtz, Ltf	crp	pyr	Tuff-And
81JD064	Tir	sPo	Plg, px, qtz, bio, hbl	plg, k-f, qtz, crp	hyp	Rhd
81JD068	Tir	sPo	Plg, px, qtz, bio, hbl	plg, k-f, qtz, crp, ox	hyp	Rhd
81JD070	Tlb	Aph	ol, px, oxhb	plg, px, crp	Mpo-int	B-And

Table 2, continued. Petrographic Data for Quien Sabe Volcanic Rock Samples

Field no.	Map Unit	Main Texture +	Phenocryst (microphenocryst) o	Groundmass o	Groundmass Texture □	Rock Type *
81JD071	Tld	sPo	plg, hbl, bio	plg, qtz, k-f	mcg	Dct
81JD072	Tlb	Aph	plg, ol, Px	plg, gl, px, crp	mpo-pil	B-And
81JD075	Tld	Por	Plg, oxhb, bio	plg, k-f, ox, crp	fel	Dct
81JD078	Tlb	wPo	plg, oxhb, px, bio	plg, px, ox, crp, gl	pil	And
81JD086	Tir	Por	plg, qtz, oxhb, px	plg, crp, ox, k-f	fel	Rhd
81JD097	Tlb	wPo	plg, cpx, oxhb	plg, px, ox, chl, crp	int	And
81JD102b	Tld	Por	Plg, cpx, oxhb, qtz	plg, crp	fel	Dct
81JD128	Tld	Por	plg, hbl, bio	plg, k-f, qtz	mcg	Dct
81JD141a	Tid	Por	Plg, bio, hbl, opx	plg, qtz	mcg	Dct
81JD150	Tftb	Aph	ol, cpx	plg, px, gl, crp	mpo-int	B-And
81JD153	Tid	Por	Plg, bio, hbl, qtz	plg, crp, gl	hyp	Dct
81JD172	Tid	sPo	Plg, opx, bio, oxhb	plg, k-f, qtz ox	fel	Dct
81JD198	Tta	wPo	Plg, oxhb, Px	plg, px, ox	pil	And
81JD202	Tfta	wPo	plg, px, oxhb	plg, px, gl, crp, ox	hyp	And
81JD206	Tftb	wPo	ol, px	plg, px, ox, chl	ig	B-And
81JD209	Tftb	Por	Plg, oxhb, px	plg, crp, ox, chl	hyp	And
81JD214	Tir	Vph	Plg, bio, hbl	plg, k-f, qtz	gly-fel	Rhy

Table 2, continued. Petrographic Data for Quien Sabe Volcanic Rock Samples

Field no.	Map Unit	Main Texture +	Phenocryst (microphenocryst)	Groundmass o	Groundmass Texture □	Rock Type *
81JD217	Tud	Por	Plg, hbl, bio, opx	plg, qtz, k-f, crp, ox	hyp	Dct
81JD218	Tir	Vph	plg, bio, hbl, qtz, k-f	gl, crp	gly	Rhy
81JD226	base	Pyr	Ltf	qtz, k-f, px, plg, crp	pyr	Tuff
81JD238	Tid	sPo	Plg, opx, hbl, bio	k-f, qtz, plg	mcg	Dct
81JD252	Tia	Por	Plg, bio, oxhb, cpx	plg, px, crp	pil	And
81JD253	Tia	wPo	plg, oxhb, cpx	plg, px, crp	pil	And
82JD269	Tta	Por	plg, oxhb, bio, cpx	plg, px, crp	hyp	And
82JD274	Tftb	Por	Ol, px	plg, px, ox, cpr	pil	B-And
82JD278	Tftb	Por	Px, plg, ol	plg, px, ox	pil-ig	Bsl
82JD279	Tua	Por	Plg, px, oxhb, bio	plg, px, gl cpr	hyp	And
82JD290	Tid	sPo	Plg, oxhb, opx, bio	plg, qtz, ox	mcg	Dct
84JD003	Tpd	Por	Plg, oxhb, bio	plg, qtz, ox, k-f	mcg	Dct
85JD003	Tpd	Por	Plg, opx, oxhb, bio	plg, cpx, ox, crp	hyp	Dct
85JD005	Tta	Por	Plg, hbl, bio	opx, plg, crp	hyp	Dct
85JD011	Tta	Por	Plg, opx, hbl, bio	plg, px, crp	hyp	And
84Sg-03	Tid	sPo	Plg, oxhb, bio	plg, qtz, ox	mcg	Dct
84Sg-06	Tid	Por	Plg, hbl, bio, opx	plg, px, ox	pil	Dct
84Sg-12	Tld	Por	plg, qtz, opx	plg, px	pil	Dct

Table 2, continued. Petrographic Data for Quien Sabe Volcanic Rock Samples

Field no.	Map Unit	Main Texture +	Phenocryst (microphenocryst) o	Groundmass o	Groundmass Texture □	Rock Type *
85Sg-06	Tir	Vph	plg, bio	gl, crp	gly	Rhy
84JD007	Tftb	Aph	ol	cpx, ol, Plg	mpo-pil	B-And
84JD008	Tid	Por	Plg, oxhb, bio, opx	plg, px, ox, qtz	fel	Dct
85JD013	Tid	Por	Plg, oxhb, bio	plg, k-f, qtz	mcg	Dct
86JD005	Tid	Por	plg, oxhb, bio	plg, k-f, qtz	mcg	Dct
86JD006	Tid	sPo	Plg, oxhb, opx, bio	plg, k-f, crp, px	fel-hyp	Dct

+ -- Por- Porphyritic; wPo - weakly Porphyritic (< 5%); sPo - strongly Porphyritic (> 40%); Aph - Aphanitic to Aphyric (< 1%); Vph - vitrophyric; Pyr - Pyroclastic

O -- plg - plagioclase; px - pyroxene; opx - orthopyroxene; cpx - clinopyroxene; hbl - hornblende; oxhb - oxyhornblende; bio - biotite; ol - olivine; qtz - quartz; k-f - potash feldspar; gl- glass; ox - opaque oxides; chl - chlorite; crp - cryptocrystalline material; ltf - lithic fragments

□ -- mpo- microporphyritic; pil - pilotaxitic; hyp - hyalopilitic; int - intersertal; ig - intergranular; fel - felsitic; mcg - microgranular; gly - glassy; pyr - pyroclastic

* -- Bsl - Basalt; And - Andesite; Dct - Dacite; Rhy - Rhyolite; Rhd - Rhyodacite; B-And - Basaltic Andesite

-- most common major phase in "Higher Case letters"

Table 3.--Petrographic Summary of Volcanic Units

Volcanic Unit	Principal Texture	Percent Phenocryst	Phenocryst Mineralogy	Avg Size Range mm.	Groundmass Texture	Remarks
Lower dacite Tld	felsophyric	25-40%	plagioclase (An_{34-51}) oxyhornblende biotite	.5 to 3 1 to 2 1 to 2	felsitic to microgranular	xenoliths, minor clinopx
Lower basalt & mafic andesites Tlb	aphanitic to slightly porphyritic	1-10%	plagioclase (An_{44-70}) olivine pyroxene oxyhornblende	.5 to 2 .5 to 1 <1 1 to 2	intersertal to pilotaxitic	bio bearing in upper part, mostly clinopx
Andesite breccias Tta	porphyritic & microlitic	5-25%	plagioclase (An_{39-51}) hornblende biotite pyroxene	1 to 3 .5 to 2 .5 to 1 .25 to 1	hyalopilitic to pilotaxitic	qtz megacryst, clino & ortho pyroxene
Andesite flows Tfa Tua	aphanitic to slighlty porphyritic	1-10%	plagioclase (An_{40-52}) clinopyroxene oxyhornblende	.5 to 2 <1 1 to 2	pilotaxitic	minor bio, qtz megacryst
Basalt & andesite flow-breccias Tftb	aphyric to slighlty porphyritic	1-5%	olivine pyroxene plagioclase oxyhornblende	.5 to 2 $\leq$.5 $\leq$.5 .5 to 1	intersertal to intergranular and hyalopilitic	clino & ortho pyroxene
Andesite flow-breccias Tfta	porphyritic	5-25%	plagioclase (An_{39-54}) pyroxene oxyhornblende biotite	1 to 3 .5 to 1 1 to 2 1 to	hyalopilitic	qtz megacryst, clino & ortho pyroxene

Table 3, continued. Petrographic Summary of Volcanic Units

Volcanic Unit	Principal Texture	Percent Phenocryst	Phenocryst Mineralogy	Avg Size Range mm.	Groundmass Texture	Remarks
Upper biotite dacite Tud	porphyritic	30-40%	plagioclase (An_{37-39}) biotite hornblende	2 to 4 .5 to 2 1 to 3	hyalopilitic	quartz as microphenocrst, minor Pyroxene
Upper Pyroxene dacite Tpd	porphyritic	20-30%	plagioclase (An_{40-47}) orthopyroxene clinopyroxene oxyhornblende	1 to 3 1 to 2 .5 to 1 1 to 2	hyalopilitic	ss xenoliths abundant, biotite bearing
Rhyolite + Rhyodacite Tir	porphyritic to vitrophyric	20-45%	plagioclase (An_{26-38}) Hornblende Biotite Quartz	1 to 4 1 to 3 1 to 2 1 to 2	felsitic to cryptofelsitic to glassy	Lithic inclusions, k-feld in groundmass only. locally coarse grain mafic phenocryst (up to 1 cm)
Intrusive Dacite Tid	porphyritic glomerophyric	30-60%	plagioclase (An_{30-40}) oxyhornblende biotite ±orthopyroxene	2 to 4 1 to 3 1 to 2 .5 to 2	microgranular to felty and microfelsitic	Lithic inclusions common. K-feld & quartz in groundmass. clinopyroxene in groundmass and as microphenocryst
Intrusive andesite Tia	slightly porphyritic	10-20%	plagioclase (An_{50-52}) clinopyroxene oxyhornblende	1 to 3 <1 1 to 2	microporphyritic and pilotaxitic	Biotite bearing

CHEMICAL CHARACTERISTICS -- Major-element whole-rock chemical analysis for Quien Sabe volcanic rocks are listed in table 4. Table 4 is divided into two parts; part A includes samples whose oxide abundances that are plotted on the variation diagrams (figures 4 through 9), and table 4B list analysis of samples not plotted on the variation diagrams. Samples are listed, in general, by increasing SiO_2 values. General chemical and physical characterics of major rock types are depicted in table 6 and 7, and tabulation of average chemistry by volcanic units is shown in table 8.

The Quien Sabe volcanic rocks are a highly differentiated andesitic suite as indicated by their mineralogy, petrography and chemistry. The presence of orthopyroxene, olivine as a phenocryst phase only, and lack of sanidine phenocrysts in the Quien Sabe volcanic rocks is considered distinctive of calc-alkaline volcanics (McBirney, 1969; and Ewart, 1979). The quartz and diopside normative composition (table 4), trends in the variation diagrams (figs. 5-9), and alkali-lime index of 61 (fig. 10) also illustrate their calc-alkaline affinity. Most of the rocks can be classified as andesite or dacite although the total range in composition is from basalt to rhyolite (range of SiO_2 from 51% to 72%). True basalts (SiO_2 less than 53%) are relatively rare, and are confined to the base of the volcanic sequence. Most of the olivine bearing rocks are actually olivine andesites or basaltic andesites (SiO_2 of 53%-56%). True rhyolites (SiO_2>70%) are also relatively uncommon and only occur as a few small intrusive bodies and as tuffs and clasts in the uppermost volcanic breccia units. We use 63% SiO_2 as a dividing point between dacite and andesite. Using SiO_2 values as a classification basis, 19 of the 40 analyzed samples are dacites, 13 are andesites, 4 are basalts or basaltic andesites, and (4) are rhyolites or rhyodacites.

The Al_2O_3 content, in which high values are considered distinctive of calc-alkaline rocks, ranges between 14% and 19% in Quien Sabe volcanic rocks, and cover the range of typical calc-alkaline andesites (16% to 18% Al_2O_3) according to McBirney (1969). Values of K_2O from intermediate rocks of the Quien Sabe volcanic field range from 1.84% to 2.94% and are considered average for calc-alkaline rocks or intermediate between island arc (low K) andesites and continental margin (high K) andesites (Williams and McBirney, 1979), although on the SiO_2 vs. K_2O diagram (fig. 5) they overlap the boundary between medium and high-K series rocks.

The trend in the extrusive sequence of the Quien Sabe volcanic rocks is from basic to more siliceous rocks followed by more siliceous intrusives. The rocks become progressively richer in SiO_2 and K_2O and more depleted in MgO and total iron. Na_2O and CaO show significant enrichment and depletion respectively only between the more mafic and felsic rocks but show more uniform values throughout the intermediate rocks (andesites and dacites). TiO_2 also decreases upward in the volcanic sequence and in the more felsic rocks.

The chemical differences between the lower and upper dacites are less discernable (table 8). The higher levels of MgO, and slightly higher total iron content in the upper extrusive and intrusive dacites probably correspond to the presence of orthopyroxene in these rocks, which is absent or rare in the lower dacites, which contain only oxyhornblende and biotite as the major mafics. The intrusive dacites typically contain higher SiO_2 values and lower Al_2O_3 and CaO values than the extrusive dacites.

Table 4a. - Major-element chemical analyses and CIPW norms for Quien Sabe volcanic rocks.

Field no. unit	81JD278 Tftb	82JD274 Tftb	81JD013 Tlb	81JD010 Tlb	81JD150 Tftb	81JD020 Tfa	81JD078 Tlb	81JD202 Tfta
oxide	Whole-rock analyses (weight percent)							
SiO_2	51.39	56.26	56.73	59.80	58.70	59.61	61.80	60.04
Al_2O_3	17.54	13.66	14.30	16.05	14.96	15.89	16.51	16.80
Fe_2O_3	2.78	3.50	2.99	2.72	3.24	2.49	1.90	1.89
FeO	3.76	4.73	4.04	3.67	4.37	3.36	2.57	2.56
MgO	8.03	8.86	8.34	4.69	4.48	4.39	4.13	4.58
CaO	11.17	7.28	7.53	6.85	6.60	7.25	5.35	7.52
Na_2O	3.20	2.52	2.94	3.97	3.94	3.57	3.27	4.16
K_2O	.77	1.84	2.42	2.14	2.31	2.30	2.28	2.09
TiO_2	.80	.90	.88	.94	.88	.99	.79	.74
P_2O_5	.25	.31	.39	.25	.38	.35	.29	.24
MnO	.12	.13	.12	.17	.23	.12	.08	.08
Total	99.82	100.00	100.68	101.25	100.09	100.32	98.97	100.7
FeO*	6.16	7.76	6.63	6.02	7.17	5.51	4.21	4.19
mineral	CIPW norms							
QZ	--	7.48	4.66	8.70	8.22	10.52	16.73	7.77
CO	--	--	--	--	--	--	--	--
OR	4.56	10.88	14.21	12.49	13.64	13.55	13.62	12.27
AB	27.13	21.32	24.71	33.18	33.31	30.11	27.96	34.96
AN	31.28	20.53	18.51	19.41	16.30	20.47	23.88	20.85
DI	17.90	10.77	12.69	10.01	11.21	10.43	.81	11.60
HY	7.81	21.52	18.32	9.98	10.09	8.63	12.02	7.89
OL	5.19	--	--	--	--	--	--	--
MT	4.04	5.08	4.30	3.89	4.69	3.59	2.78	2.72
IL	1.52	1.71	1.66	1.76	1.67	1.87	1.52	1.40
AP	.59	.73	.92	.58	.90	.83	.69	.56

*FeO = Total iron [FeO + (Fe_2O_3 x .8998)]
note - chemistry by XRF analysis of whole-rock samples fused with lithium metaborate

Table 4a, continued. -- Major-element chemical analyses and CIPW norms for Quien Sabe volcanic rocks.

Field no. unit	81JD253 Tia	84Sg6 Tid	82JD279 Tua	85JD003 Tfta	81JD029 Tld	81JD071 Tld	81JD075 Tld	81JD217 Tud
oxide				Whole-rock analyses (weight percent)				
SiO_2	63.38	61.54	62.38	59.90	64.61	63.75	66.56	65.52
Al_2O_3	16.10	17.38	15.57	17.02	18.88	18.02	17.65	17.35
Fe_2O_3	1.83	1.97	2.36	2.20	1.14	1.66	1.30	1.43
FeO	2.48	2.66	3.19	2.97	1.54	2.24	1.76	1.94
MgO	3.83	2.64	3.81	2.99	.88	1.87	.82	1.76
CaO	5.16	5.48	6.23	5.03	5.08	5.28	4.00	4.65
Na_2O	3.50	4.45	3.25	5.09	5.45	4.84	5.24	4.93
K_2O	2.54	2.08	2.27	2.40	2.38	2.36	2.68	2.67
TiO_2	.62	.75	.72	.72	.72	.66	.61	.64
P_2O_5	.22	.18	.20	.17	.24	.20	.16	.17
MnO	.08	.08	.09	.07	.04	.05	.03	.04
Total	99.74	99.22	100.07	98.56	100.95	100.92	100.81	101.10
FeO*	4.06	4.36	5.23	4.87	2.53	3.68	2.88	3.18
mineral				CIPW norms				
QZ	16.95	12.65	16.81	6.86	12.59	13.06	16.25	14.72
CO	--	--	--	--	--	--	--	--
OR	15.05	12.39	13.41	14.39	13.93	13.82	15.71	15.61
AB	29.69	37.95	27.48	43.70	45.68	40.58	43.98	41.26
AN	20.77	21.47	21.17	16.74	19.83	20.28	16.59	17.14
DI	2.75	3.80	6.72	5.97	2.87	3.52	1.68	3.67
HY	10.43	7.00	9.16	7.31	1.55	4.65	2.40	3.96
OL	--	--	--	--	--	--	--	--
MT	2.67	2.88	3.42	3.23	1.63	2.38	1.87	2.06
IL	1.18	1.44	1.37	1.39	1.35	1.24	1.15	1.20
AP	.52	.43	.47	.41	.56	.47	.38	.40

*FeO = total iron [FeO + (Fe_2O_3 x .8998)]
note - chemistry by XRF analysis of whole-rock samples fused with lithium metaborate

Table 4a, continued. -- Major-element chemical analyses and CIPW norms for Quien Sabe volcanic rocks.

Field no. unit	81JD086 Tir/Tid	81JD009 Tta	81JD023 Tid	81JD238 Tid	81JD172 Tid	84Sg8 Tir	84Sg3 Tid	81JD218 Tir
oxide	Whole-rock analyses (weight percent)							
SiO_2	65.03	63.67	63.45	64.45	64.50	65.90	67.68	73.71
Al_2O_3	16.86	16.82	16.46	17.33	17.05	17.16	17.22	14.55
Fe_2O_3	1.31	1.77	1.70	1.66	1.68	1.55	1.05	.66
FeO	1.76	2.39	2.30	2.24	2.27	2.09	1.42	.89
MgO	2.40	2.52	3.23	2.01	1.60	1.84	1.50	.82
CaO	5.37	4.55	4.85	4.45	4.15	4.14	3.26	1.54
Na_2O	4.84	3.95	4.55	4.95	5.33	3.92	4.56	3.57
K_2O	2.13	2.61	2.22	2.32	2.48	2.62	2.94	4.48
TiO_2	.54	.72	.65	.62	.66	.65	.51	.28
P_2O_5	.17	.22	.17	.18	.26	.18	.14	.05
MnO	.05	.08	.07	.06	.07	.06	.03	.03
Total	100.46	99.30	99.65	100.26	100.05	100.11	100.30	100.58
FeO*	2.89	3.92	3.77	3.68	3.72	3.43	2.33	1.46
mineral	CIPW norms							
QZ	15.06	17.22	14.04	14.46	13.40	21.21	20.58	30.92
CO	--	--	--	--	--	.78	.94	1.14
OR	12.53	15.54	13.17	13.68	14.65	15.47	17.32	26.33
AB	40.77	33.66	38.64	41.77	45.08	33.13	38.47	30.03
AN	17.90	20.60	17.99	18.17	15.26	19.34	15.21	7.27
DI	5.97	.55	4.01	2.15	2.92	--	--	--
HY	4.47	7.96	8.05	5.78	4.29	6.18	4.67	2.71
OL	--	--	--	--	--	--	--	--
MT	1.88	2.58	2.47	2.39	2.43	2.24	1.51	.95
IL	1.12	1.38	1.24	1.17	1.25	1.23	.97	.53
AP	.40	.52	.40	.43	.62	.43	.33	.12

*FeO = Total iron [Fe + (Fe_2O_3 x .8998)]
note - chemistry by XRF analysis of whole-rock samples fused with lithium metaborate

Table 4b. -- Additional major-element chemical analysis, and CIPW norms for Quien Sabe volcanic rocks that are not plotted in Figs. 4-9.

Field no. unit	81JD072 Tlb	84JD007 Tfta	86JD001c Tta	86SG01 Tpd	81JD037 Tpd	8SG007 Tta	81JD008 Tlb	86SG004 Tpd
oxides	Whole-rock chemistry (volatile free in weight percent)							
SiO_2	54.30	56.30	60.50	61.10	62.20	62.30	62.40	62.60
Al_2O_3	15.10	14.30	15.20	17.40	16.40	15.60	15.70	16.10
Fe_2O_3	1.75	2.00	1.22	2.34	1.83	2.14	1.87	1.69
FeO	4.50	4.50	3.50	2.50	2.50	2.50	2.50	2.50
MgO	6.30	7.20	4.40	2.50	2.40	3.30	4.00	3.00
CaO	9.24	7.60	7.22	4.10	4.94	5.46	5.56	5.34
Na_2O	2.30	3.00	3.20	3.30	3.10	3.20	3.30	3.60
K_2O	1.06	1.46	1.84	2.32	2.40	1.98	1.92	2.06
TiO_2	0.92	0.84	0.74	0.74	0.72	0.72	0.72	0.64
P_2O_5	0.22	0.24	0.20	0.16	0.20	0.24	0.26	0.18
MnO	0.12	0.12	0.08	0.07	0.08	0.09	0.08	0.06
LoI	3.25	1.37	.75	2.75	2.75	1.37	1.25	1.50
Total	99.06	98.93	98.85	99.28	99.52	98.90	99.56	99.27
FeO*	6.34	6.46	4.69	4.77	4.29	4.54	4.25	4.11
mineral	CIPW norms							
QZ	9.76	7.82	14.42	20.99	21.18	20.55	18.86	18.53
OR	6.56	8.86	11.11	14.18	14.65	11.99	11.52	12.47
AB	20.30	26.05	27.58	28.93	27.08	25.75	28.43	31.14
AN	28.94	21.74	22.08	19.98	23.94	22.94	22.73	22.19
DI				2.48	0.23			
WO	7.26	6.38	5.49			1.35	1.53	1.56
HY	22.16	23.95	15.62	8.06	8.28	10.25	12.17	9.95
MT	2.65	2.97	1.80	3.51	2.74	3.17	2.75	2.51
IL	1.82	1.63	1.42	1.46	1.41	1.41	1.39	1.23
AP	0.54	0.59	0.47	0.40	0.50	0.59	0.62	0.43

Analyses done at USGS laboratories in Menlo Park
LoI = Lost on Ignition (H_2O, CO_2, etc.)

Table 4b, continued. -- Additional major-element chemical analysis, and CIPW norms for Quien Sabe volcanic rocks that are not plotted on Figs. 4-9.

Field no. unit	86JD002c Tpd	81JD052 Tld	86SG006 Tid	82JD290 Tid	81JD068 Tir	86SG003 Tid	81JD214 Tir	86JD006 Tir
oxides			Whole-rock chemistry (volatile free and in weight percent)					
SiO_2	63.50	64.49	65.10	65.40	66.30	66.30	69.40	72.20
Al_2O_3	16.60	17.58	16.10	15.60	16.20	16.40	14.70	13.90
Fe_2O_3	2.05	1.89	1.05	1.26	0.00	1.23	0.03	0.36
FeO	2.50	2.55	2.50	2.00	2.04	2.00	2.00	0.50
MgO	2.20	1.37	2.00	1.60	1.30	0.25	0.70	0.20
CaO	4.16	4.30	4.38	3.68	3.96	3.68	2.22	1.27
Na_2O	3.90	5.39	3.90	3.70	3.60	4.00	3.80	3.00
K_2O	2.24	2.35	2.36	2.30	2.08	2.36	3.26	4.10
TiO_2	0.72	.67	0.62	0.48	0.68	0.70	0.40	0.18
P_2O_5	0.16	.22	0.18	0.20	0.20	0.24	0.12	0.02
MnO	0.06	.06	0.06	0.05	0.03	0.06	0.03	0.03
LoI	1.63	--	1.50	2.75	2.50	2.00	2.25	3.56
Total	99.72	100.87	99.75	99.02	100.93	99.22	98.91	99.32
FeO*	4.43	4.18	3.51	3.26	2.08	3.20	2.10	0.86
mineral				CIPW norms				
QZ	20.04	13.08	20.84	25.46	27.32	26.42	28.94	37.53
OR	13.47	13.77	14.18	14.12	12.76	14.35	19.91	25.29
AB	33.68	45.22	33.59	32.49	31.64	34.76	33.26	26.48
AN	20.00	16.69	19.81	17.59	19.03	17.18	10.63	6.47
DI	0.58	2.47		0.85	1.34	1.18	1.20	2.37
WO			0.48					
HY	7.44	4.29	7.93	6.14	6.06	2.30	4.95	0.91
MT	3.03	2.71	1.55	1.90	0.00	1.84	0.04	0.55
IL	1.39	1.26	1.20	0.95	1.35	1.37	0.78	0.36
AP	0.38	.52	0.43	0.50	0.50	0.59	0.28	0.05

Note -- Analyses done at USGS laboratories in Menlo Park. FeO approximated from average composition of orogenic andesite types (See Gill, 1981). FeO* = total iron = [FeO + (Fe_2O_3 x .8998)]

LoI = Lost on Ignition (H_2O, CO_2, etc.)

Table 5. Fused Bead Data and SiO_2 analysis

Sample no.	Map Unit	R.I.	Inferred SiO_2%	analyzed SiO_2 (wt. %)
Qs-023	Tir	1.515	66.7	63.45
Qs-101	Tlb	1.562	55.5	59.80
Qs-013	Tlb	1.559	56.2	56.73
Qs-020	Tfa	1.543	59.8	59.61
Qs-029	Tld	1.523	64.8	64.61
Qs-052	Tld	1.523	64.8	64.49
Qs-068	Tir	1.512	67.6	66.30
Qs-072	Tlb	1.560	56.0	54.30
Qs-078	Tlb	1.531	62.5	61.80
Qs-071	Tld	1.527	64.0	63.75
Qs-075	Tld	1.517	66.2	66.56
Qs-086	Tir	1.516	66.4	65.03
Qs-095	Tir	1.514	67.0	
Qs-150	Tftb	1.550	58.5	58.70
Qs-172	Tid	1.518	66.0	64.50
Qs-202	Tfta	1.538	61.0	60.04
Qs-209	Tftb	1.537	61.2	
Qs-214	Tir	1.503	70.2	69.40
Qs-217	Tud	1.516	66.4	65.52
Qs-218	dike	1.495	72.0	73.71
Qs-238	Tid	1.516	66.4	64.45
Qs-253	dike	1.531	62.5	63.38
Qs-274	Tftb	1.563	55.4	56.26
Qs-278	Tftb	1.574	53.2	51.40
Qs-279	Tfta	1.534	62.0	62.38
Qs-290	Tid	1.516	66.4	65.40

Note: R.I. = Refractive Index
Numbers in parenthesis are chemical analysis of SiO_2 in weight %.

Table 6. General characteristic of major volcanic rock types of the Quien Sabe Volcanic field.

Characteristic Feature	Basalt & Basaltic Andesite	Andesite	Dacite	Rhyolite
wt.% SiO_2	51-57	57-63	63-69	70-74
wt% K_2O	.78-2.4	1.9-2.4	2.0-2.9	2.4-4.5
wt% MgO	6.6-8.7	3.8-4.7	.88-3.4	.21-.82
wt% FeO*	6.3-8.2	4.4-5.8	2.7-4.8	.86-2.1
Textures	microporphyritic intersertal intergranular pilotaxitic	porphyritic pilotaxitic hyalopilitic aphanitic	porphyritic microgranular felsitic hyalopilitic	porphyritic vitrophyritic felsitic hyalopilitic
phenocryst	olivine clinopyroxene plagioclase(±)	plagioclase clinopyroxene oxyhornblende biotite(±)	plagioclase hornblende/oxyhb biotite orthopyroxene(±) clinopyroxene(±)	plagioclase biotite hornblende quartz pyroxene(±)
Type of deposit	flows tuff breccias laharic breccias	flows pyroclastics laharic breccias dikes and sills	flows pyroclastics laharic breccias intrusives	intrusives tuffs breccia fragments
no. of volcanic units	2	5	4	1

Table 7. -- Summary of selected chemical components for major dacite units

Component	Lower Dacite range	Upper Dacite range	Intrusive Dacite range
% SiO_2	63.7-66.6	63.6-65.5	64.5-68.2
% K_2O	2.4-2.7	2.1-2.7	2.3-2.5
% MgO	.9-1.9	1.8-3.1	1.6-2.0
% FeO*	2.5-4.2	3.2-4.7	3.2-3.7
% Al_2O_3	17.6-18.9	16.5-18.0	16.2-17.3
% CaO	4.0-5.3	4.2-5.5	3.8-4.5
ab	40.6-45.7	27.1-33.7	32.5-45.1
an	16.6-20.3	20.0-23.9	15.3-19.8
Range Norm An	27-33	37-47	25-37
no. of samples	4	5	8

[FeO* = total iron, FeO + (Fe_2O_3 x .8998)]

Table 8. -- Average chemical composition of rocks from volcanic units of the Quièn Sabe volcanic field (units are arranged in stratigraphic sequence from base to top)

Volcanic Unit (n)*	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	TiO_2
Tir (4)	72.43	15.27	.36	1.39	.78	2.32	3.59	3.57	.40
Tid (8)	65.81	16.95	1.45	2.17	1.69	4.19	4.39	2.46	.63
Tud (1)	65.52	17.35	1.43	1.94	1.76	4.65	4.93	2.67	.64
Tpd (4)	64.09	17.09	2.03	2.57	2.60	4.76	3.57	2.32	.72
Tua (Tfa) (2)	61.00	15.73	2.43	3.28	4.10	6.74	3.41	2.29	.86
Tta (3)	63.07	16.10	1.73	2.84	3.46	5.84	3.50	2.17	.74
Tfta (2)	60.00	16.91	2.05	2.77	3.79	6.25	4.63	2.25	.73
Tlb upper subunit (3)	61.69	16.18	2.17	2.93	4.30	5.95	3.53	2.12	.82
Tlb lower subunit (2)	56.70	15.03	2.41	4.37	7.46	8.59	2.67	1.77	.92
Tftb (4)	56.02	15.14	2.89	4.37	7.19	8.21	3.19	1.61	.86
TLd (4)	64.85	18.03	1.50	2.02	1.24	4.67	5.23	2.44	.67

*(n) = number of samples used in averages

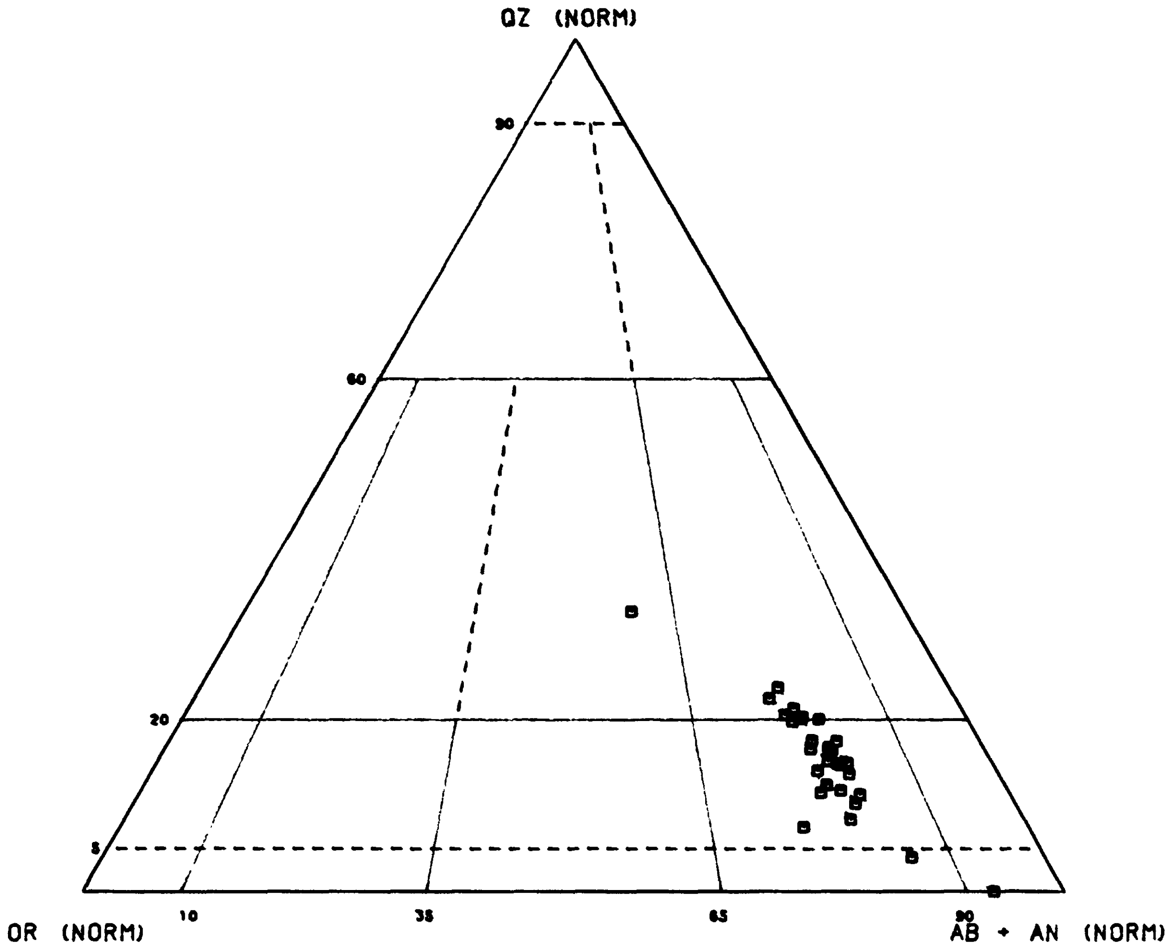

Figure 4. -- CIPW normative composition of Quien Sabe volcanic rocks plotted on the quartz (Qz), potash feldspar (Or), plagioclase (AB+AN) diagram of Streckeisen (1979)

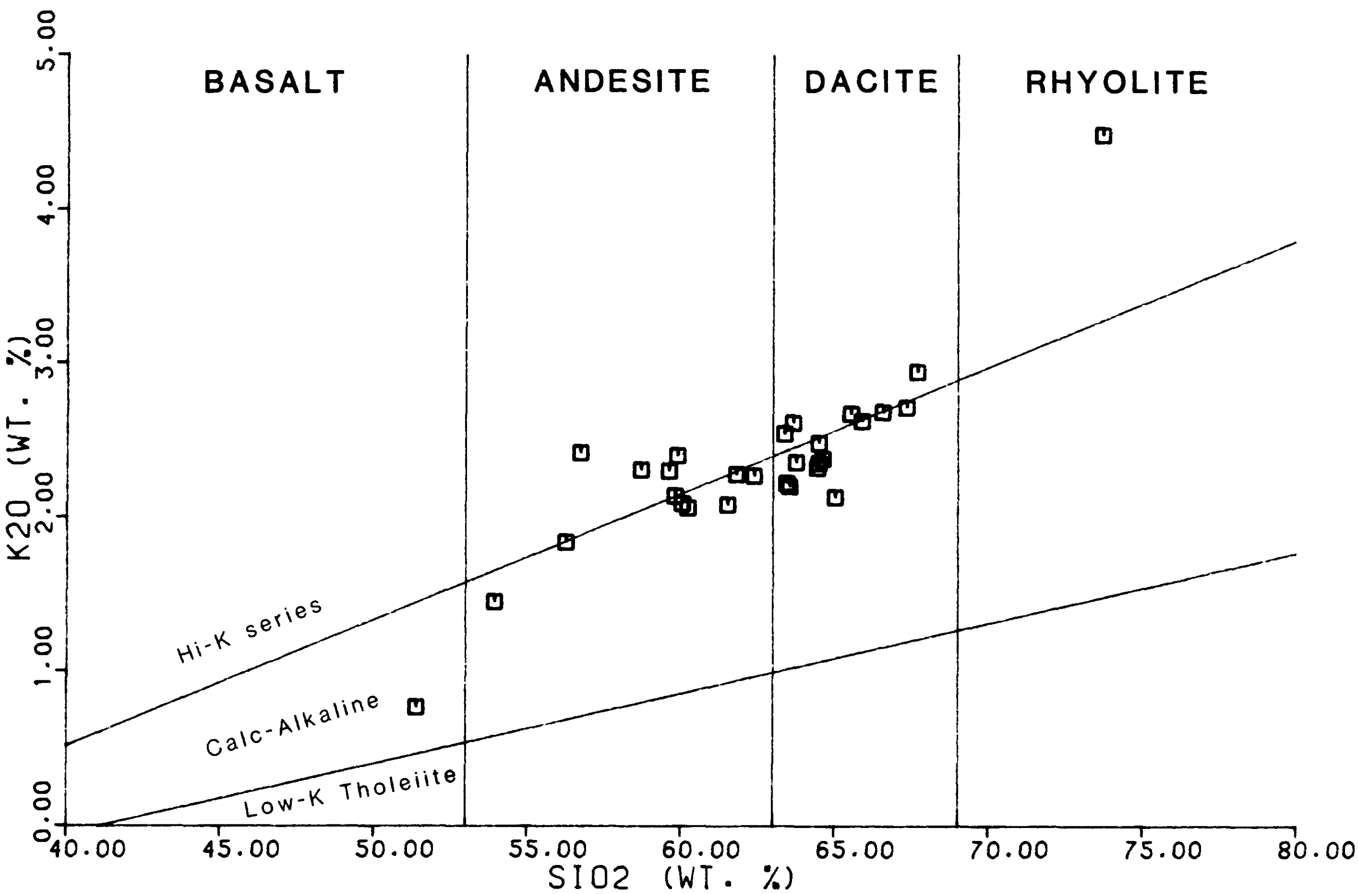

Figure 5. Variations between K_2O and SiO_2 contents of Quien Sabe volcanic rocks, field boundaries from Gill (1981).

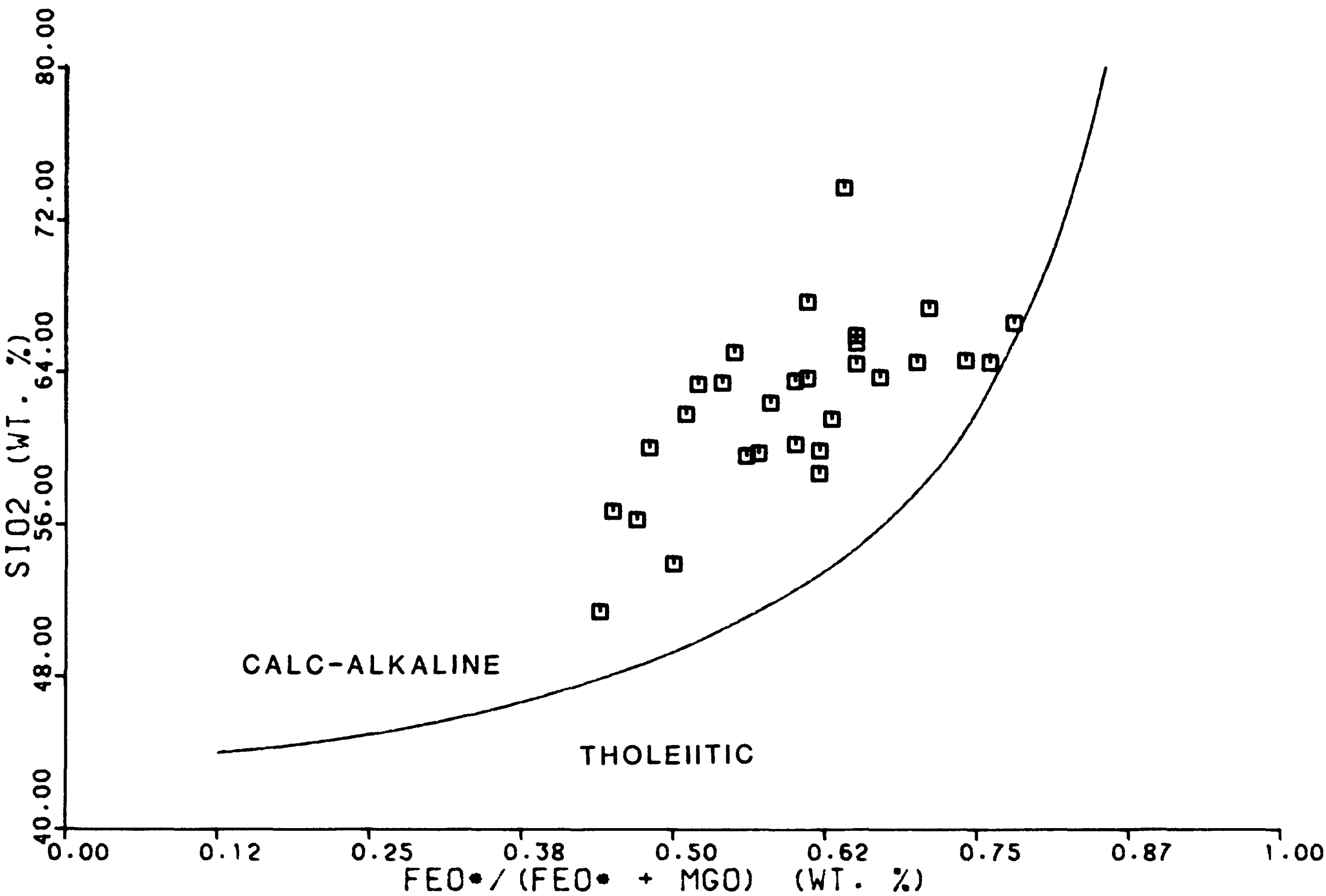

Figure 6.--Variations between SiO_2 content and mafic index (FeO + .9 Fe_2O_3/MgO + Feo + .9 Fe_2O_3) of Quien Sabe volcanic rocks.

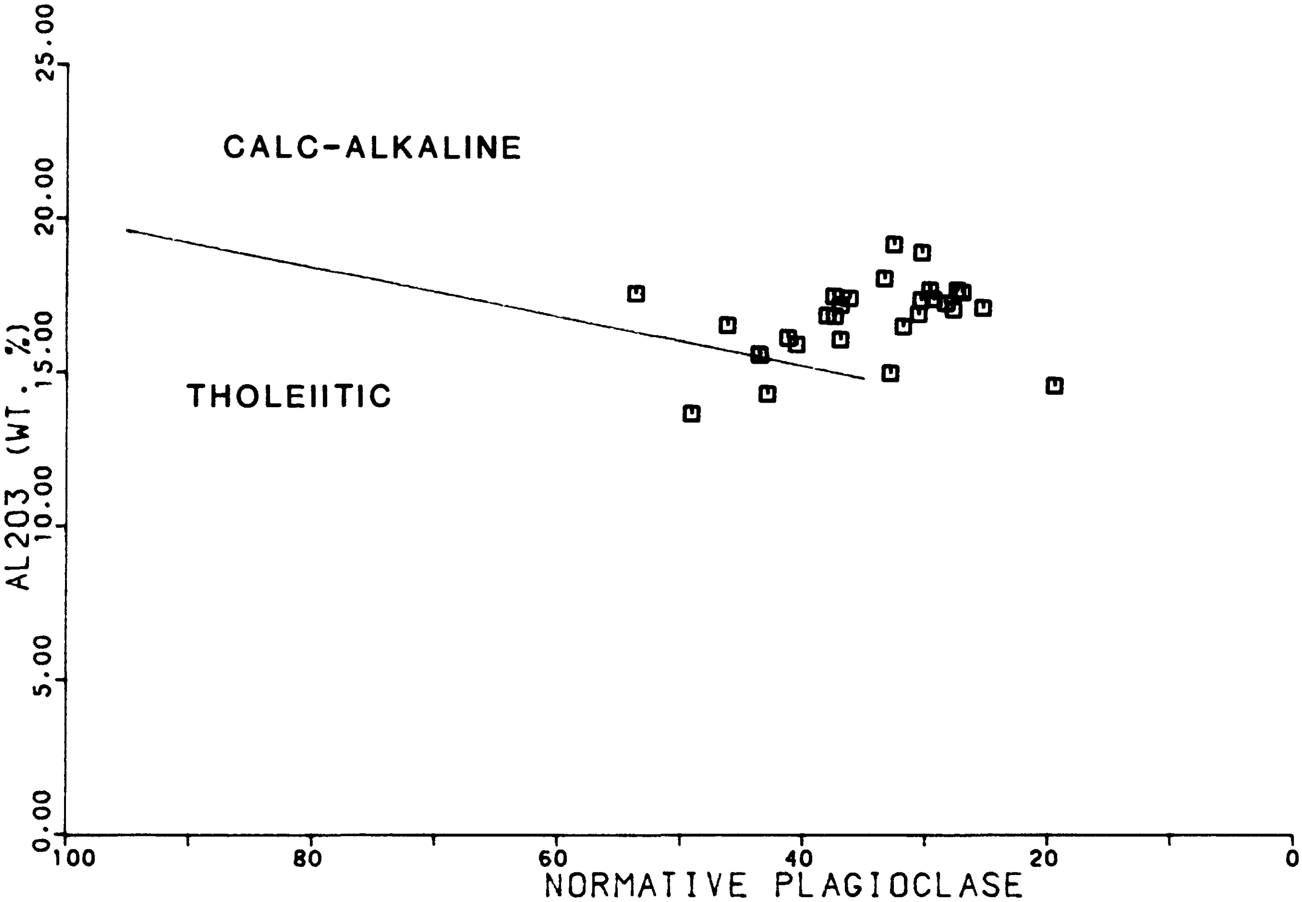

Figure 7.--Variation between normative plagioclase An composition (An x 100/An + Ab) and Al_2O_3 content of Quien Sabe volcanic rocks. Field boundary from Irvine and Barager (1971).

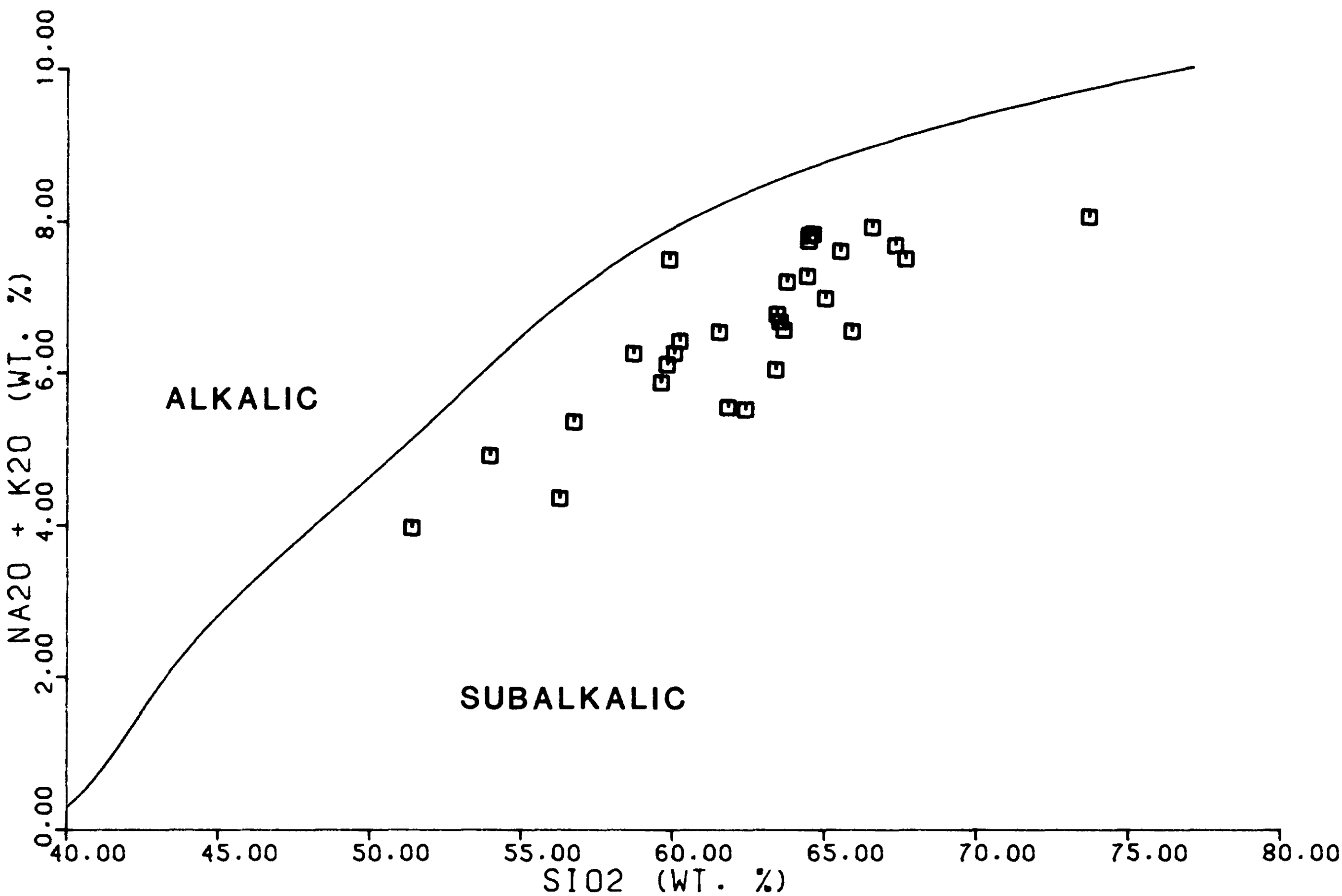

Figure 8.--Variation in SiO_2 content and total alkalies ($Na_2O + K_2O$) content of Quien Sabe volcanic rocks. Field boundary from Baragar (1971).

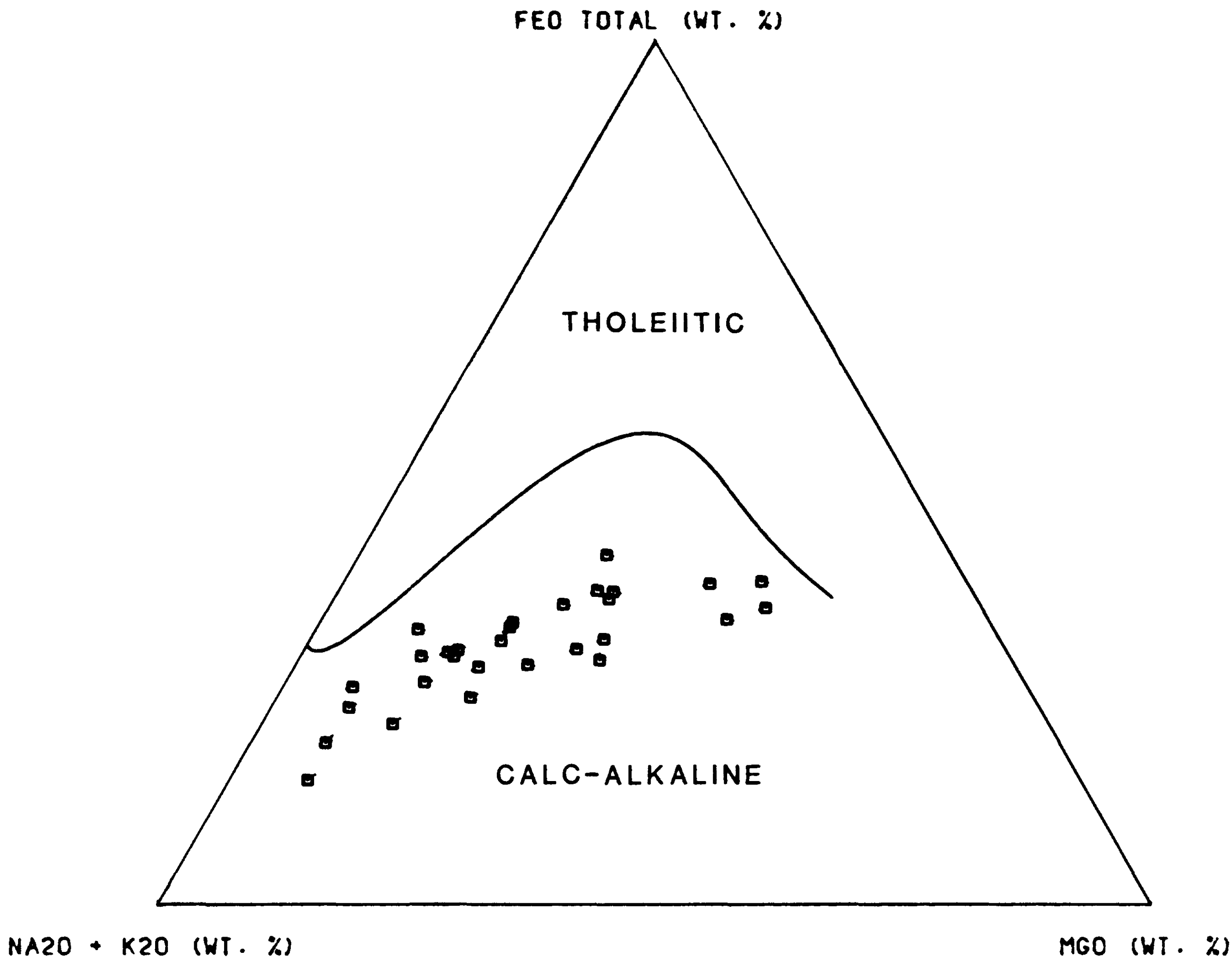

Figure 9.--AMF Diagram with plots of Quien Sabe volcanic rock samples. Dividing line between tholeiitic and calc-alkaline fields from Irvine and Baragar (1971).

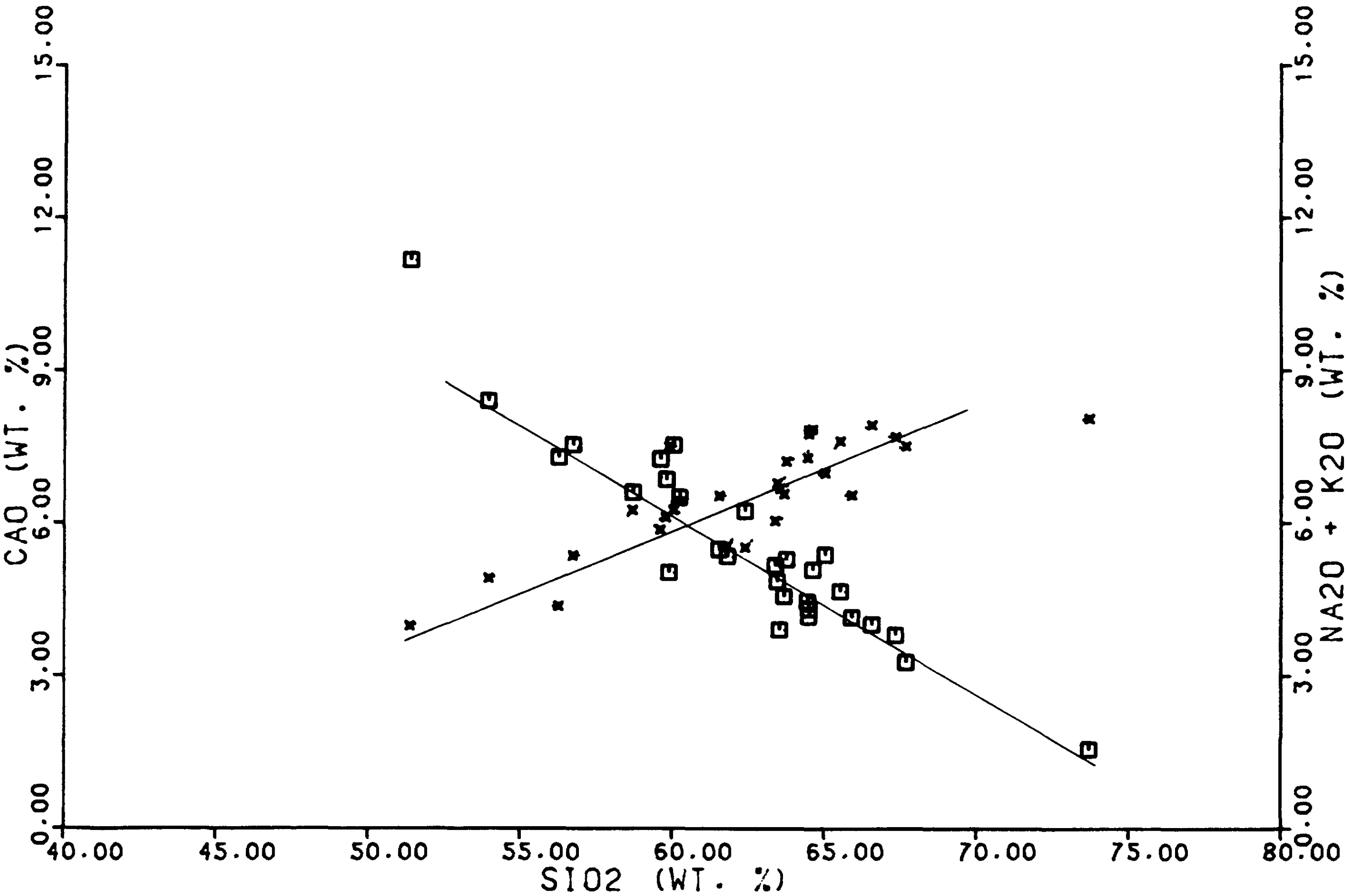

Figure 10.--Variations between CaO (squares), and Na2O + K2O (crosses) with SiO_2 for Quien Sabe volcanic rocks. Crossing point of CaO and Na2O + K2O trend lines gives an approximate alkali-lime index of 61, indicating a calc-alkaline affinity.

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