# Raymond Quadrangle, Madera and Mariposa Counties, California—Analytic Data

GEOLOGICAL SURVEY PROFESSIONAL PAPER 1214

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*By* PAUL C. BATEMAN *and* WAYNE N. SAWKA

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*Modal and chemical data and isotopic ages of the plutonic rocks of the Raymond quadrangle*

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# CONTENTS

| | Page |
|---|---|
| Abstract | 1 |
| Introduction | 1 |
| General geology | 1 |
| Sampling and analytical methods | 1 |
| Tonalite of Blue Canyon | 2 |
| Granodiorite of Knowles | 2 |
| Isotopic ages | 3 |
| References cited | 3 |

# ILLUSTRATIONS

| | | Page |
|---|---|---|
| FIGURES 1-9. | Simplified geologic map of the Raymond quadrangle showing: | |
| 1. | Locations of analyzed and dated samples | 6 |
| 2. | Volume-percent quartz | 8 |
| 3. | Volume-percent potassium feldspar | 9 |
| 4. | Volume-percent plagioclase | 10 |
| 5. | Volume-percent mafic minerals | 11 |
| 6. | Volume-percent biotite | 12 |
| 7. | Volume-percent hornblende | 13 |
| 8. | 100 hornblende/(biotite + hornblende) | 14 |
| 9. | Bulk specific gravity | 15 |
| 10. | Plots of modes of granitic rocks | 16 |

# TABLES

| | | Page |
|---|---|---|
| TABLE 1. | Chemical analyses, norms, and modes of granitoids | 2 |
| 2. | U-Pb age determinations on zircon from granitoids | 3 |
| 3. | K-Ar age determinations from granodiorite of Knowles | 3 |

# RAYMOND QUADRANGLE, MADERA AND MARIPOSA COUNTIES, CALIFORNIA—ANALYTIC DATA

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ABSTRACT

About 150 samples of the plutonic rocks of the Raymond quadrangle were collected during geologic mapping. Of these, 137 were analyzed modally, 3 were analyzed chemically, and 4 were dated isotopically, 2 by the U-Pb method and 2 by the K-Ar method. In general, the different plutonic rocks show little internal compositional variation, but the hornblende-poor facies of the tonalite of Blue Canyon is zoned from more mafic in the margins to less mafic in the interior. The presence of subhedral to euhedral hornblende prisms and biotite books in the hornblende-rich facies of the tonalite of Blue Canyon is interpreted to indicate abundant $H_2O$ in the melt phase of the magma during crystallization, perhaps about 3 percent. However, a paucity of magnetite indicates low oxygen fugacity ($F_O$).

The plagiogranite of Ward Mountain and locally the tonalite of Blue Canyon, both dated isotopically at about 114 m.y., are deformed, whereas the granodiorite of Knowles, dated at about 111 m.y., is undeformed and intrudes the deformed rocks. These relations are interpreted to indicate a period of deformation sometime during the approximately 3-m.y. interval between the emplacement of the deformed rocks and the granodiorite of Knowles.

## INTRODUCTION

The Raymond quadrangle is mostly in the western foothills of the central Sierra Nevada, but the south and southwest parts extend into the Central Valley of California. California State Highway 140 from Madera, about 7 km southwest or the southwest corner of the quadrangle, extends eastward across the southern margin of the quadrangle, and State Highway 41 crosses the southeast corner. These highways together with county roads provide access to all parts of the quadrangle.

This report supplements the geologic map of the Raymond quadrangle (Bateman and others, 1981) by providing modal and chemical data and isotopic age determinations on the plutonic rocks. These data are presented in maps, diagrams, and tables (figs 1-10; tables 1-3); the brief text is intended as a guide to understanding and interpreting the data. A nontechnical summary of the general geology of the quadrangle accompanies the geologic map.

## GENERAL GEOLOGY

Plutonic and metamorphic rocks underlie most of the quadrangle, but Cenozoic sedimentary deposits overlie the crystalline rocks in the south and southwest parts (fig. 1). Plutonic rocks occupy the part of the quadrangle that lies east of a line drawn from near the northwest corner to near the center of the south border. The south end of the western metamorphic belt lies along the west side of the quadrangle north of the Fresno River, the Adobe Hill roof pendant is in the south-central part, and the west end of the Tick-Tack-Toe roof pendant extends into the southeast corner.

The two largest bodies of granitic rock are the tonalite of Blue Canyon and the granodiorite of Knowles. Two plutons of the plagiogranite of Ward Mountain extend into the east side of the quadrangle from the adjoining Millerton Lake quadrangle where they occupy large areas. Other small bodies of granitoid rocks and hornblende gabbro are present locally. In common with most other granitoids of the western Sierra Nevada, the granitoids of the Raymond quadrangle contain small amounts of potassium feldspar (K-feldspar) (figs. 3 and 10).

## SAMPLING AND ANALYTICAL METHODS

About 150 samples of typical plutonic rocks weighing at least 1 kg were collected. Our objective was to collect samples about 1.6 km apart, but because of poor exposures and deep weathering, especially in the south half of the quadrangle, sample localities are generally somewhat farther apart and are unevenly distributed (fig. 1). Care was taken to collect fresh and representative samples of the rock at each locality. Of the samples collected, 135 were analyzed modally (figs. 2-7); 3 of these were analyzed chemically for their major elements (table 1), 2 were dated isotopically by the U-Pb method (table 2), and 2 were dated by the K-Ar method (table 3).

The modal analyses were made by combining point counts on selectively stained slabs (Norman, 1974) with point counts on thin sections. At least 1,000 regularly spaced points were counted on slabs with areas of 70 $cm^2$ or more to determine the volume percent of quartz, K-feldspar, plagioclase, and total mafic minerals (figs. 2-5). The relative amounts of biotite and hornblende were then determined on thin sections and apportioned to the total content of mafic minerals (figs. 6 and 7). Magnetite and other opaque minerals are present in these granitoids in only trace amounts and were omitted in calculating the amounts of biotite and hornblende. Isopleths were drawn on figures 2-9 to bring out any systematic patterns. However, we made no attempt to contour areas where differences in the values are unsystematic or slight.

TABLE 1.—*Chemical analyses, norms, and modes of granitoids*

[Chemical analyses: sample FD-20 analyzed by Vertie C. Smith under the supervision of Lee C. Peck. Samples RDa-1 and RDb-58 analyzed using the rapid method by H. Smith under the supervision of Floyd Brown. Modal analyses: Felsic mineral and total mafic minerals determined by Oleg Polovtzoff by counting 1000 to 2000 points on selectively stained slabs of at least 70 $cm^2$. Hornblende and biotite determined by Wayne Sawka by apportioning counts on thin sections to total mafic minerals.]

| | Tonalite of Blue Canyon | Granodiorite of Knowles | |
|---|---|---|---|
| | RDa-1 | RDb-58 | FD-20 |
| **Chemical analyses (weight percent)** | | | |
| $SiO_2$ | 65.0 | 72.1 | 72.22 |
| $Al_2O_3$ | 16.7 | 16.0 | 14.98 |
| $Fe_2O_3$ | .97 | .44 | .15 |
| FeO | 3.5 | 1.4 | 1.81 |
| MgO | 2.3 | .62 | .60 |
| CaO | 5.1 | 2.8 | 2.58 |
| $Na_2O$ | 3.5 | 4.0 | 3.96 |
| $K_2O$ | 1.6 | 2.2 | 2.48 |
| $H_2O+$ | .76 | .65 | .47 |
| $H_2O-$ | .07 | .10 | .02 |
| $TiO_2$ | .73 | .25 | .28 |
| $P_2O_2$ | .18 | .12 | .10 |
| MnO | .05 | .03 | .05 |
| $CO_2$ | .02 | .06 | -- |
| F | -- | -- | .04 |
| Sum | 101 | 101 | 99.74 |
| **CIPW Norms (weight percent)** | | | |
| Q | 22.67 | 33.15 | 32.52 |
| C | .42 | 2.37 | 1.35 |
| or | 9.46 | 13.00 | 14.78 |
| ab | 29.61 | 33.84 | 33.77 |
| an | 24.00 | 12.73 | 12.24 |
| di | .00 | .00 | .00 |
| hy | 10.24 | 3.39 | 4.36 |
| mt | 1.41 | .64 | .22 |
| il | 1.39 | .48 | .54 |
| ap | .43 | .28 | .24 |
| cc | .05 | .14 | -- |
| Total | 99.68 | 100.02 | 100.02 |
| **Modes (volume percent)** | | | |
| Quartz | 21 | 33 | 34 |
| Potassium feldspar | 2 | 6 | 14 |
| Plagioclase | 55 | 53 | 44 |
| Biotite | 15 | 8 | 8 |
| Hornblende | 8 | -- | -- |
| Total | 101 | 100 | 100 |
| Bulk specific gravity | 2.75 | 2.67 | 2.64 |

## TONALITE OF BLUE CANYON

The tonalite of Blue Canyon occurs in two bodies, one containing conspicuous hornblende prisms and the other almost devoid of hornblende. These two facies are not in contact within the Raymond quadrangle, but in the adjoining Millerton Lake quadrangle they grade into each other in several places (Bateman and Busacca, in press). The hornblende-bearing facies occurs in the north half of the quadrangle and in the southeast corner, whereas the hornblende-poor facies is confined to the southeast quarter.

The color index (percent of mafic minerals) generally is greater than 15 (fig. 5) and the ratio, 100 hornblende/(biotite + hornblende) (fig. 8), generally is greater than 25 in the hornblende-bearing facies and less than these amounts in the hornblende-poor facies, although a few notable exceptions do exist. Both facies contain only small amounts of K-feldspar. No systematic compositional patterns are evident in the facies containing hornblende prisms, but both the total mafic mineral content (fig. 5) and specific gravity (fig. 9) indicate that the hornblende-poor facies is compositionally zoned with respect to the mafic minerals from a more mafic margin to a more felsic core.

That neither facies contains more than a bare trace of magnetite despite the relatively high color index of the rocks suggests low $f_0$ in the magma. However, the common occurrence of the hydrous minerals, hornblende and biotite, in subhedral to euhedral prisms and books indicates that these minerals crystallized from the melt phase of the magma. Estimates of the amount of water required in the melt phase of the magma for these minerals to precipitate are generally in the range of a few percent. Burnham's (1979) estimate of 3 percent $H_2O$ at 1.2 kb pressure seems well founded. Thus this rock is assumed to have crystallized under conditions of low $f_0$ and relatively abundant $H_2O$.

## GRANODIORITE OF KNOWLES

The granodiorite of Knowles is of special interest because it has been widely used as a building stone in some of the large cities of California, and the Raymond quarry at the north end of the granodiorite is still active. The granodiorite is a light-gray rock of even grain size. In many outcrops, quartz stands out in rounded grains. Individual crystals of both quartz and plagioclase range from 2 to 5 mm across, whereas K-feldspar is generally in thin stringers interstitial to the other minerals. Biotite occurs in tiny, discrete, generally anhedral flakes, and a sprinkling of muscovite also generally is present. Both compositionally and tex-

TABLE 2.—*U-Pb age determinations on zircon from granitoids*

[From Stern and others, 1981]

| | | Age, m.y. | | | Parts per million | | | Atomic ratio | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | $^{206}Pb/^{206}U$ | $^{207}Pb/^{235}U$ | $^{208}Pb/^{232}U$ | Pb | U | Th | $^{208}Pb/^{206}Pb$ | $^{207}Pb/^{206}Pb$ | $^{204}Pb/^{206}Pb$ |
| RDa-1 | Tonalite of Blue Canyon | 111.4 | 107.8 | 102.0 | 5.36 | 295.6 | 69.6 | 0.11631 | 0.06467 | 0.00122 |
| RDb-58 | Granodiorite of Knowles | 111.5 | 109.4 | 87.9 | 25.09 | 489.7 | 74.3 | 0.79070 | 0.33966 | 0.01983 |

TABLE 3.—*K-Ar age determinations from granodiorite of Knowles*

Determinations for sample 220 from Evernden and Kistler (1970). Calculated ages are adjusted to the decay and abundance constants recommended in 1976 by the IUGS Subcommission on geochronology. Potassium measurements on RDa-6 and RDb-68 by Paul Klock. Argon measurements and age calculations on RDa-6 by S. E. Sims and on RDb-68 by B. Myers and J. Von Essen.

$\lambda_\beta = 4.962 \times 10^{-10} yr^{-1}$; $\lambda_\epsilon + \lambda'_\epsilon = 0.581 \times 10^{-10} yr^{-1}$; $^{40}K/K$ - $1.167 \times 10^{-4}$ atom percent. Sample 220 is from same locality as sample RDa-6.

| Sample | Mineral | K (weight percent) | Radiogenic $^{40}Ar$ (moles/gm x $10^{-11}$) | Percentage radiogenic Ar | Age (m.y.) |
|---|---|---|---|---|---|
| 220 (61-041) | Muscovite | 10.34 | 173.26 | 93 | 113 |
| 220 (61-042) | Biotite | 7.53 | 151.10 | 87 | 113 |
| RDa-6 | do. | 7.39 | 114.7 | 95 | 107 |
| RDb-68 | do. | 7.25 | 141.7 | 78 | 109 |

turally, the granodiorite is quite uniform, and the percentages of minerals (figs. 2-7) and specific gravity (fig. 9) vary unsystematically from place to place by small amounts.

## ISOTOPIC AGES

Zircons from one sample each of the tonalite of Blue Canyon and the granodiorite of Knowles have been dated by the U-Pb method (table 2), and biotite from two samples of the granodiorite of Knowles have been dated by the K-Ar method (table 3). Previously published dates on biotite and muscovite from a sample collected at the same locality as one of our samples (RDb-6) are included in table 3. Of the U-Pb ages given, the $^{206}Pb/^{238}U$ is considered the most reliable and is the age used in this discussion. Although the $^{206}Pb/^{238}U$ age on the tonalite of Blue Canyon is 111.4, other ages on this unit from the adjoining quadrangles indicate the probable age to be close to 114 m.y. (Stern and others, 1981). The $^{206}Pb/^{238}U$ age of 111.5 m.y. on sample RDb-58 of the granodiorite of Knowles is somewhat suspect because the sample was collected close to the tonalite of Blue Canyon, and the possibility exists that the dated zircon was picked up from the tonalite of Blue Canyon. However, because this age is close to the average K-Ar ages for the granodiorite of Knowles, we believe that it is approximately correct.

These isotopic ages are important because the plagiogranite of Ward Mountain and, locally, the tonalite of Blue Canyon have been deformed to gneiss, whereas the undeformed granodiorite of Knowles intrudes them and truncates their cataclastic fabric. Isotopic dating of the plagiogranite of Ward Mountain in the adjoining Millerton Lake quadrangle by the U-Pb and K-Ar methods indicates the same age as for the tonalite of Blue Canyon. If the istopic ages are approximately correct, the deformation occurred in a brief interval of probably no more than 3 m.y. between 111 and 114 m.y. ago.

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# FIGURES 1-10

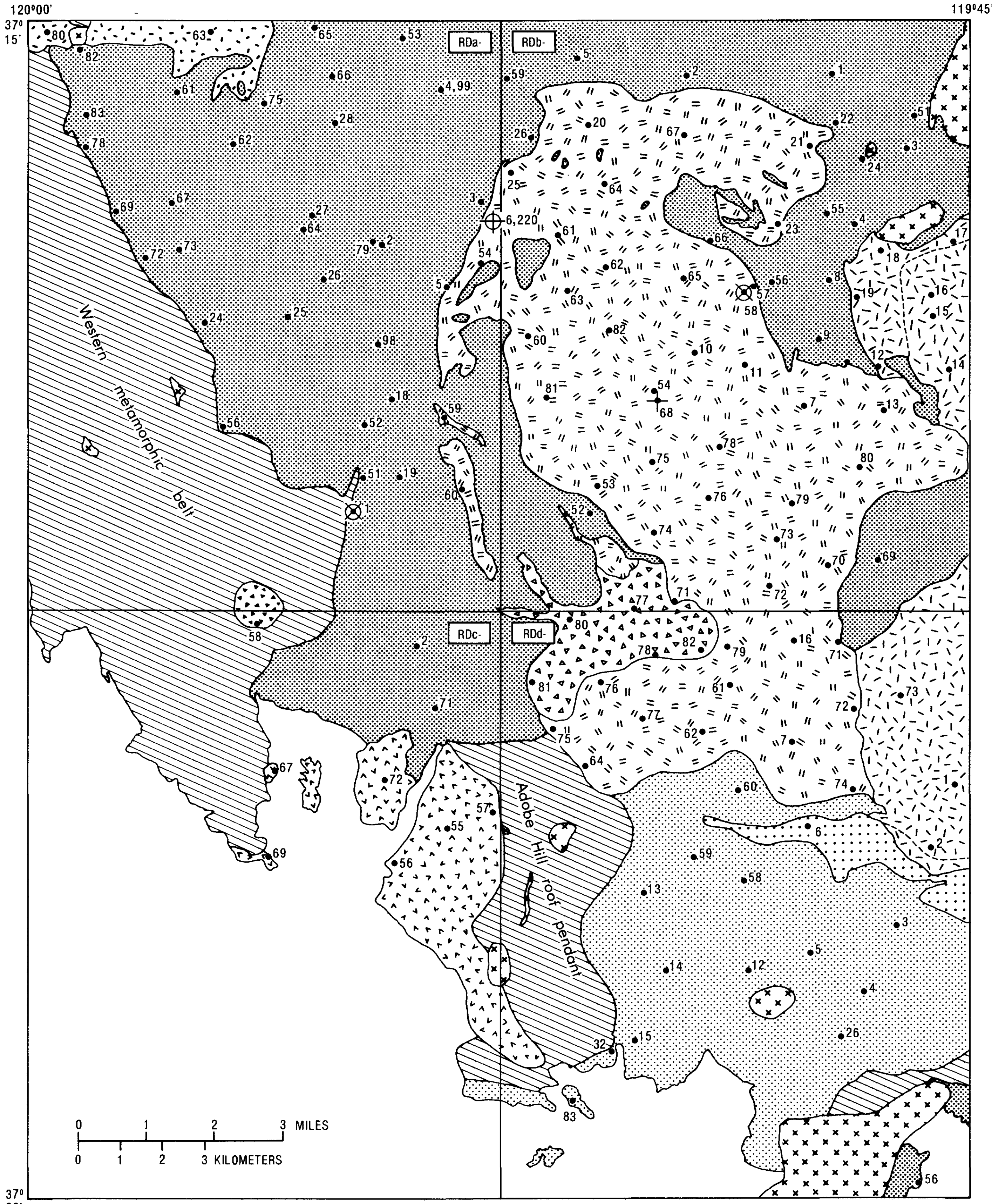


FIGURE 1. Raymond quadrangle showing the principal bedrock units and the locations of modally analyzed, chemically analyzed, and isotopically dated samples. The letters in the upper part of each quadrant (RDa-etc.) prefix the sample numbers in that quadrant.

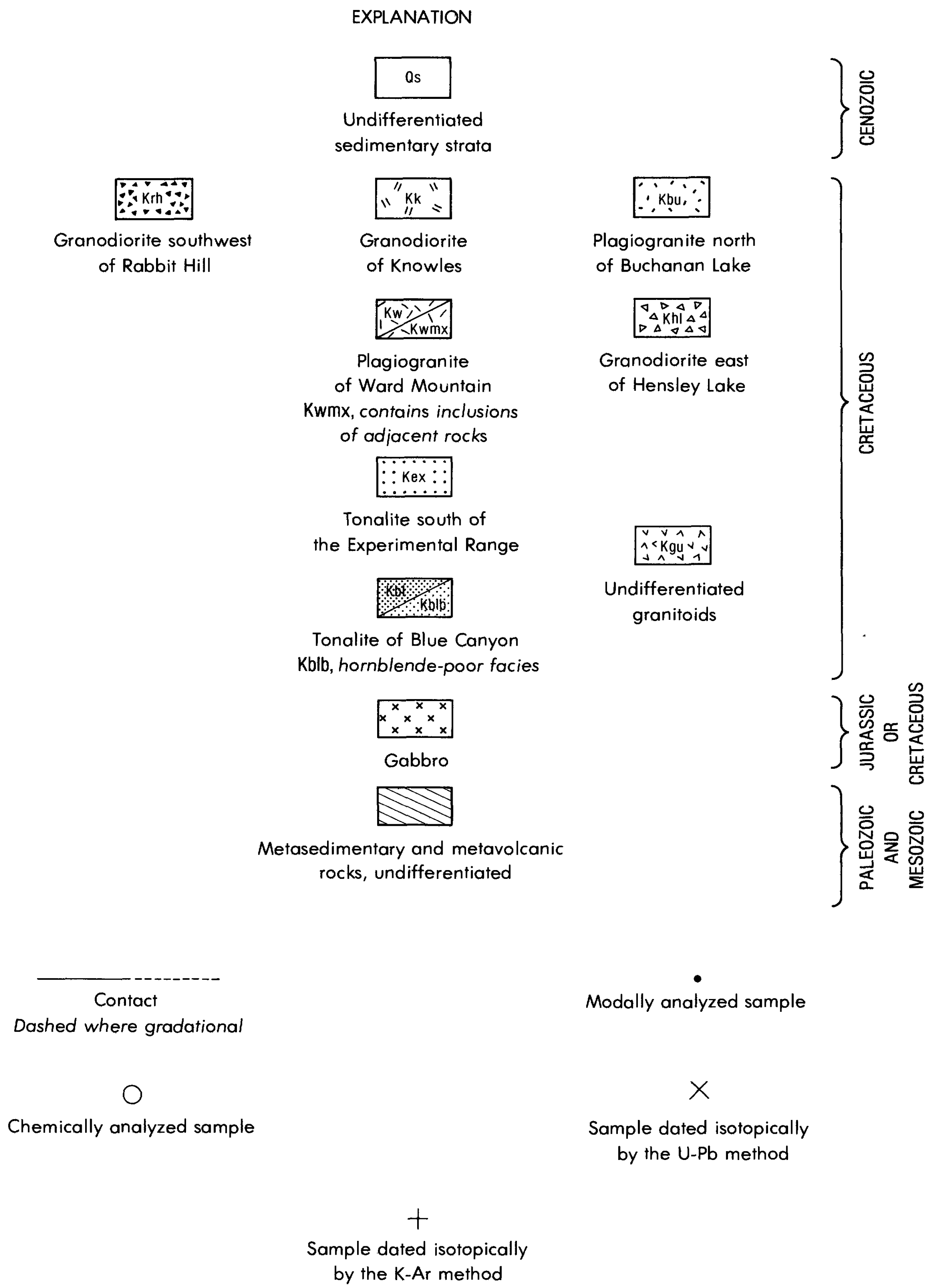


FIGURE 1.—Continued.

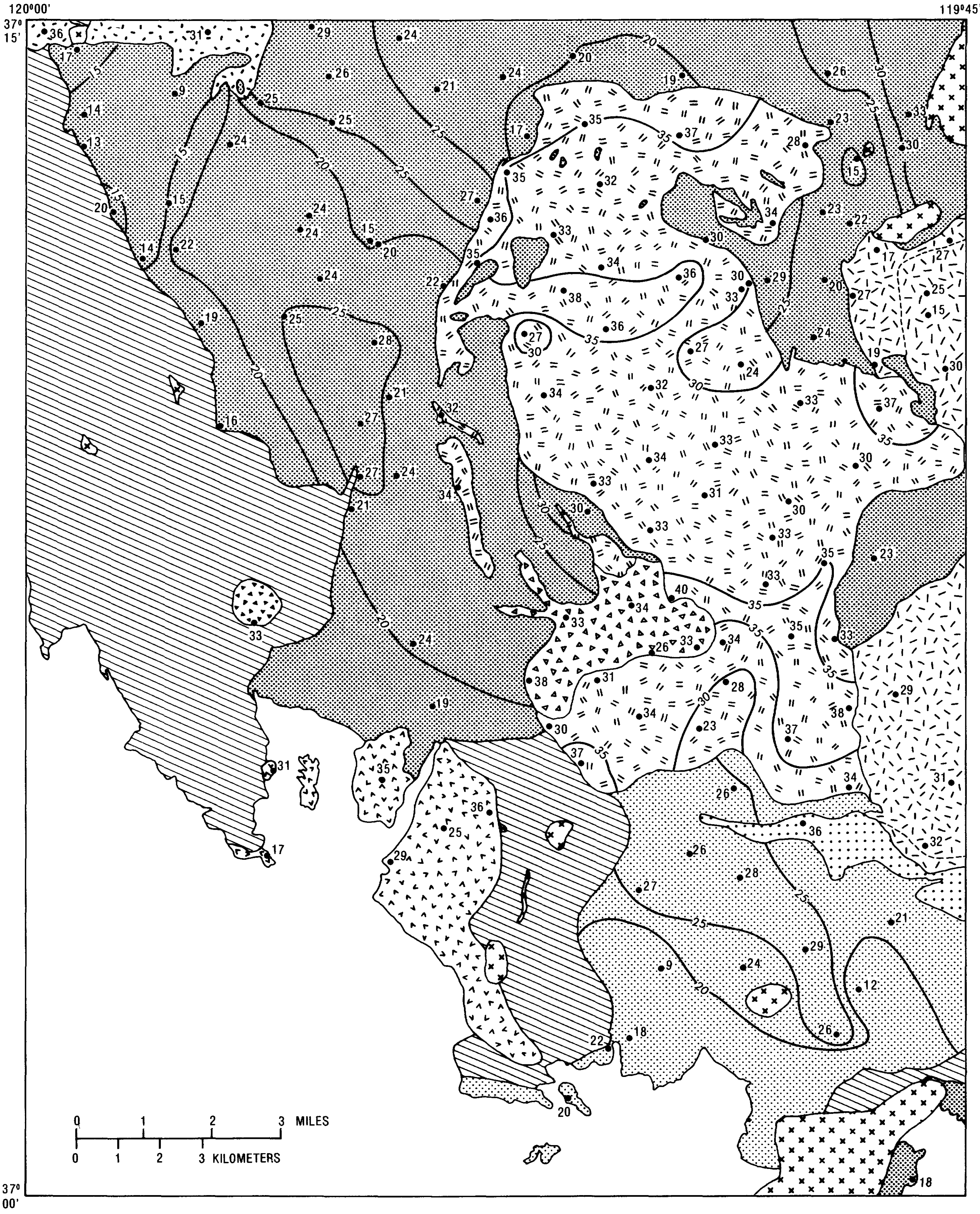


**FIGURE 2.** Raymond quadrangle showing volume-percent quartz. Explanation in figure 1.

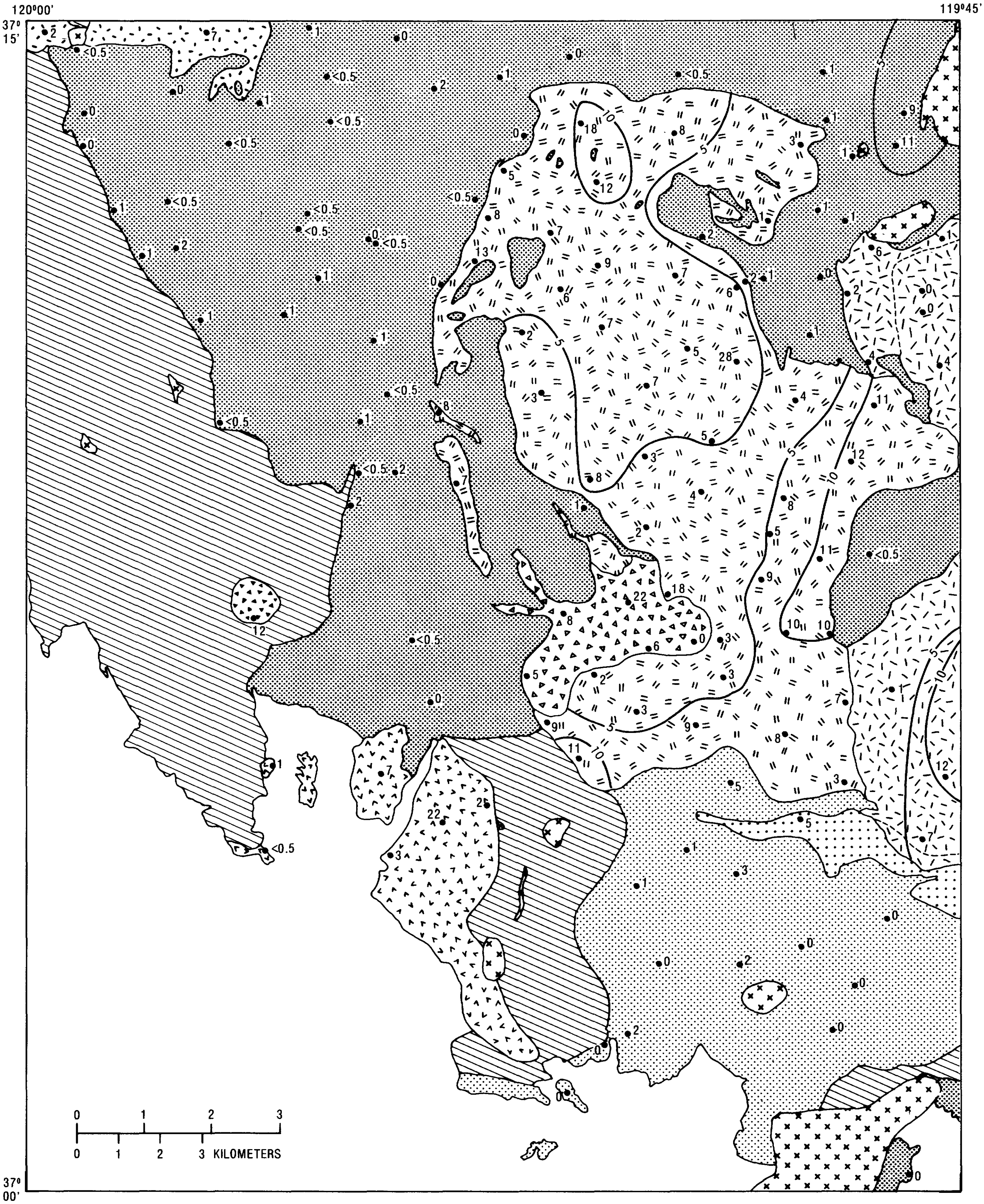


**FIGURE 3.** Raymond quadrangle showing volume-percent potassium feldspar. Explanation in figure 1.

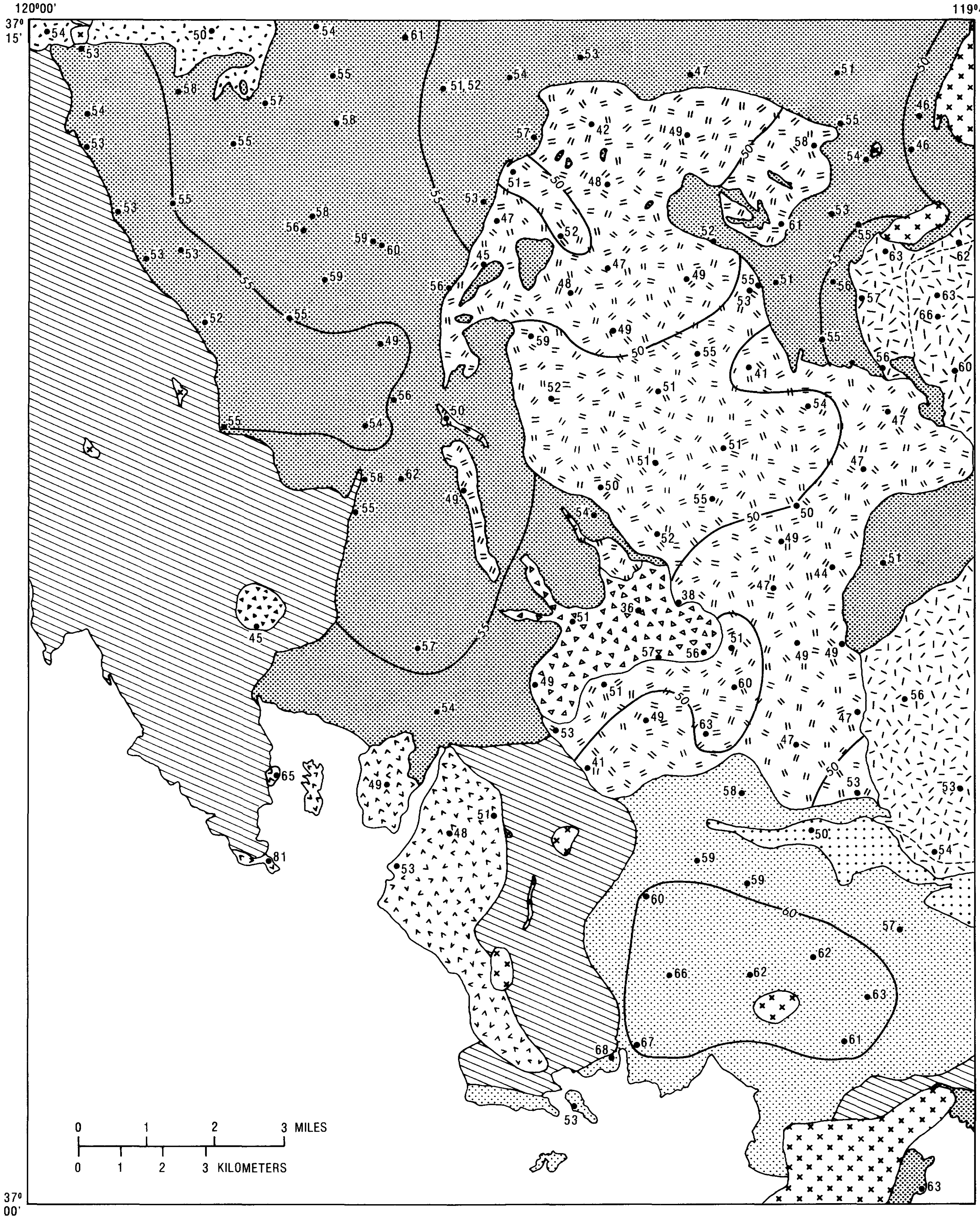


**FIGURE 4.** Raymond quadrangle showing volume-percent plagioclase. Explanation in figure 1.

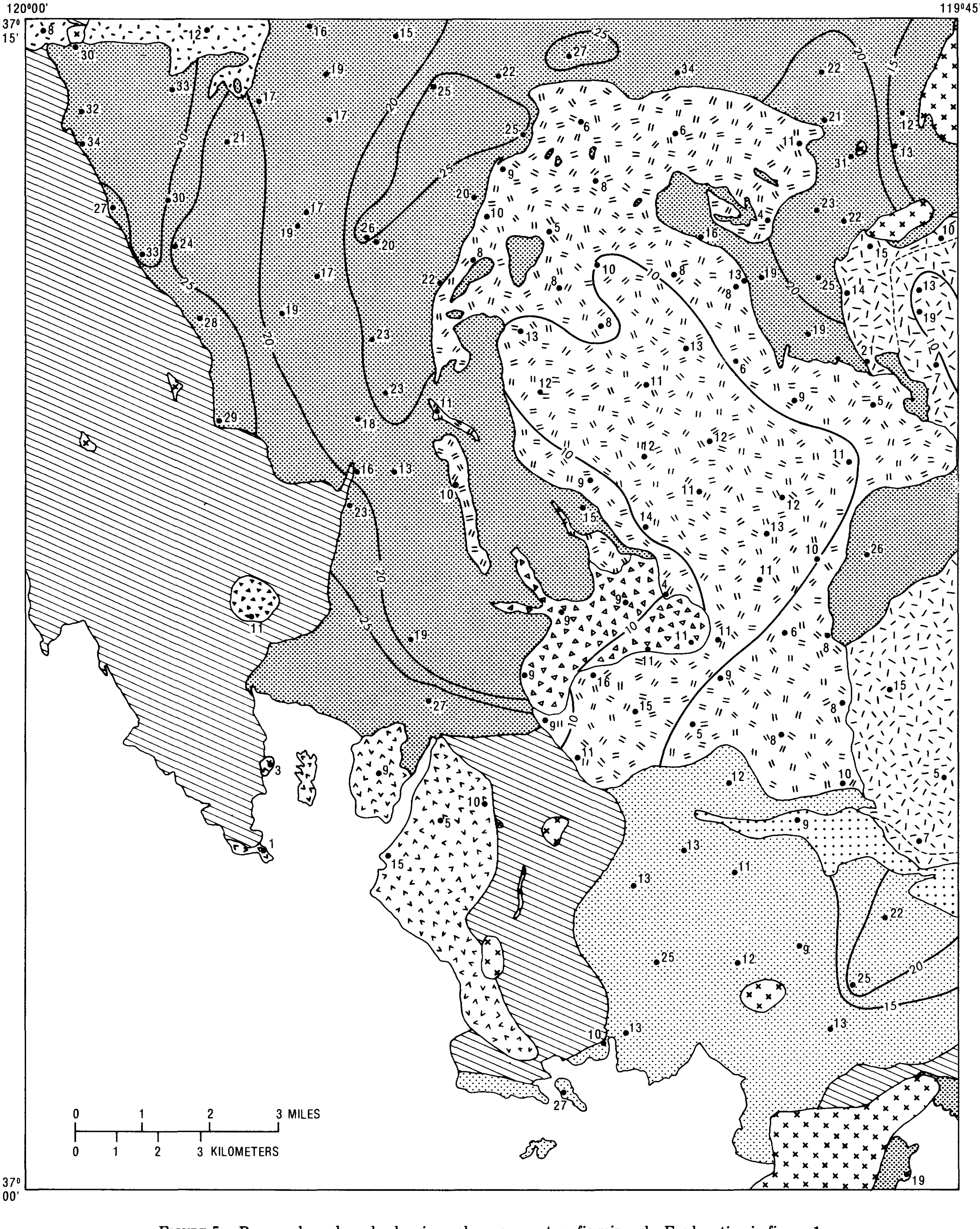


FIGURE 5. Raymond quadrangle showing volume-percent mafic minerals. Explanation in figure 1.

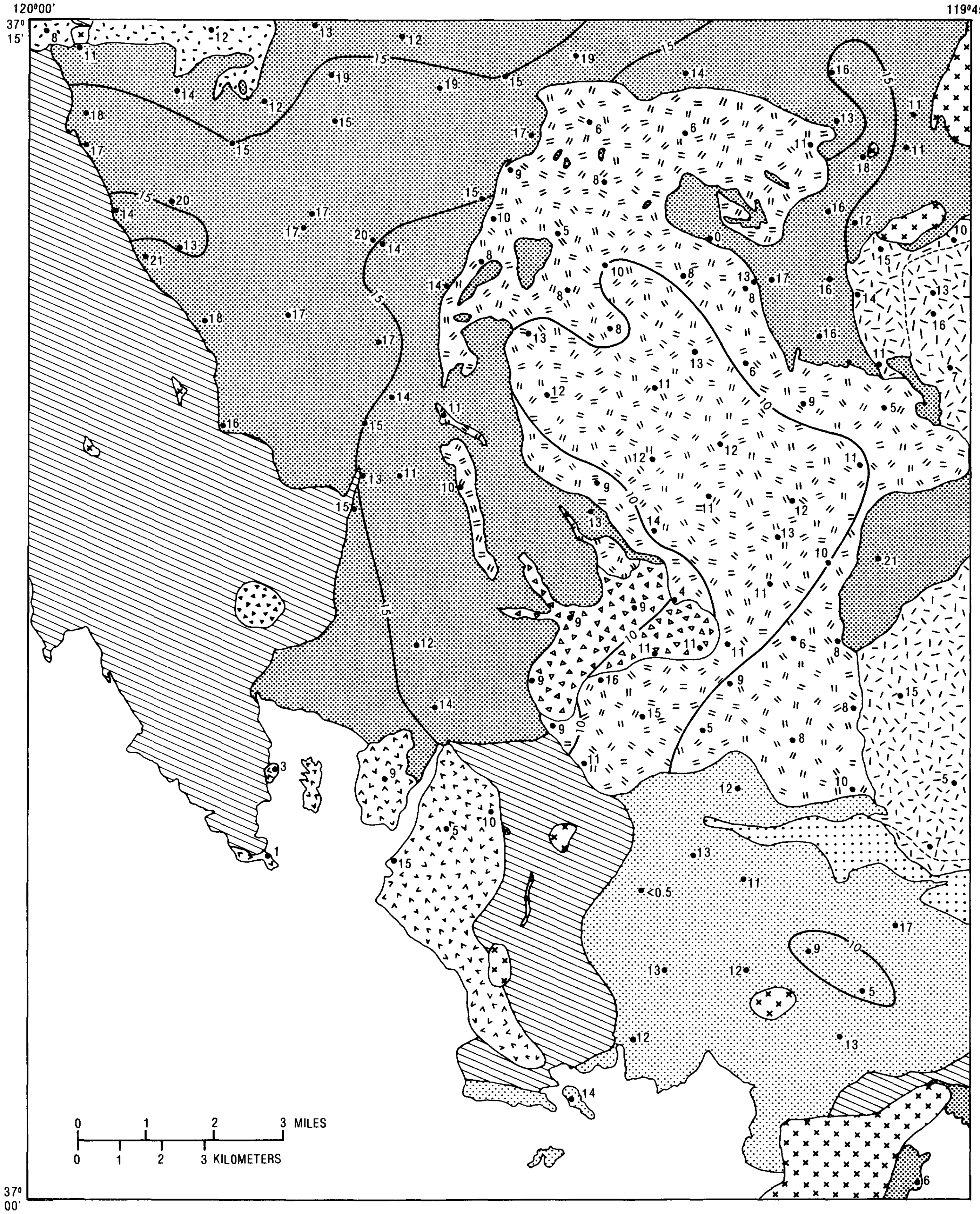


**FIGURE 6.** Raymond quadrangle showing volume-percent biotite. Explanation in figure 1.

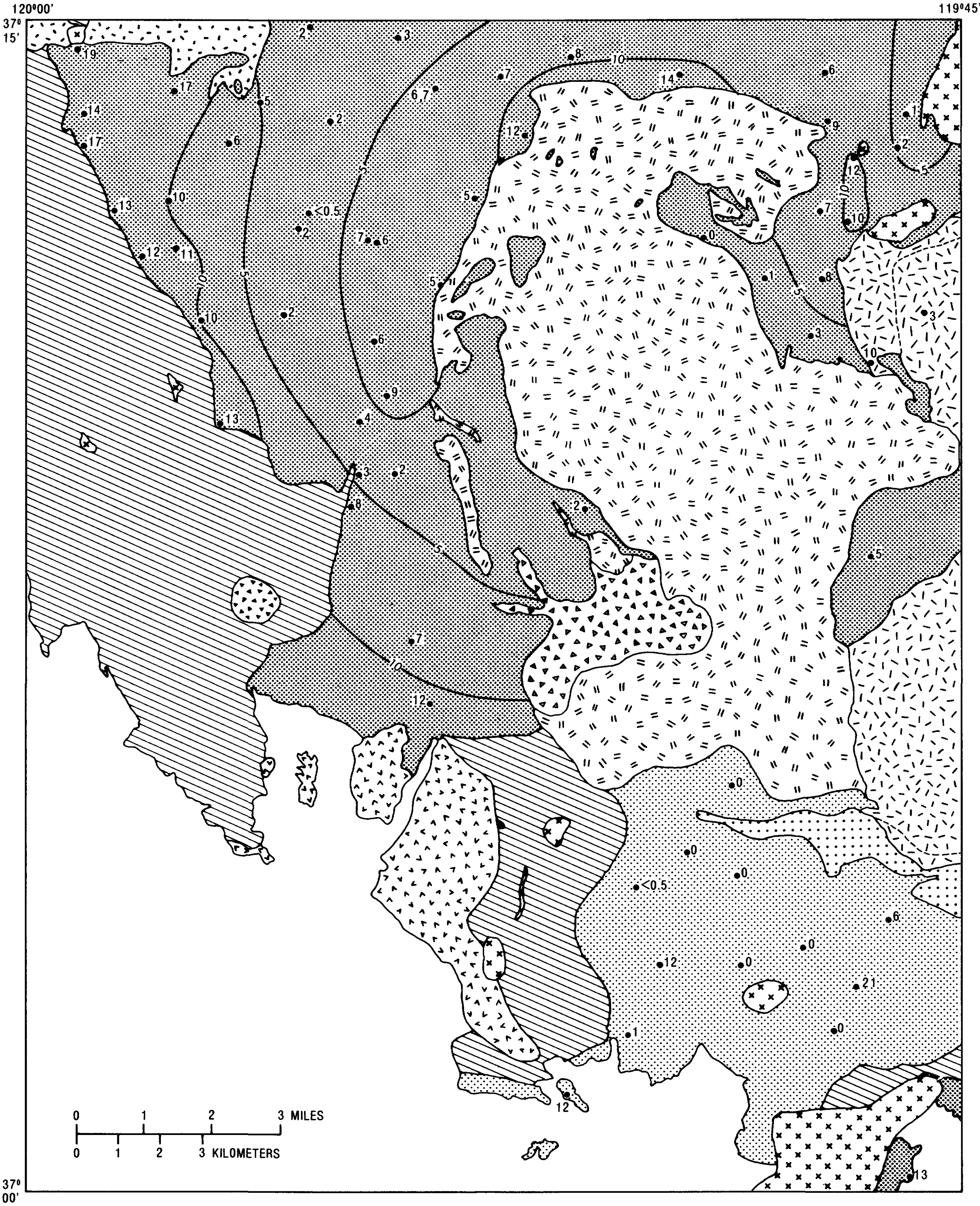


**FIGURE 7.** Raymond quadrangle showing the volume-percent hornblende in the tonalite of Blue Canyon (Kbl and Kblb) and in hybridized samples of the plagiogranite of Ward Mountain. Explanation in figure. 1.

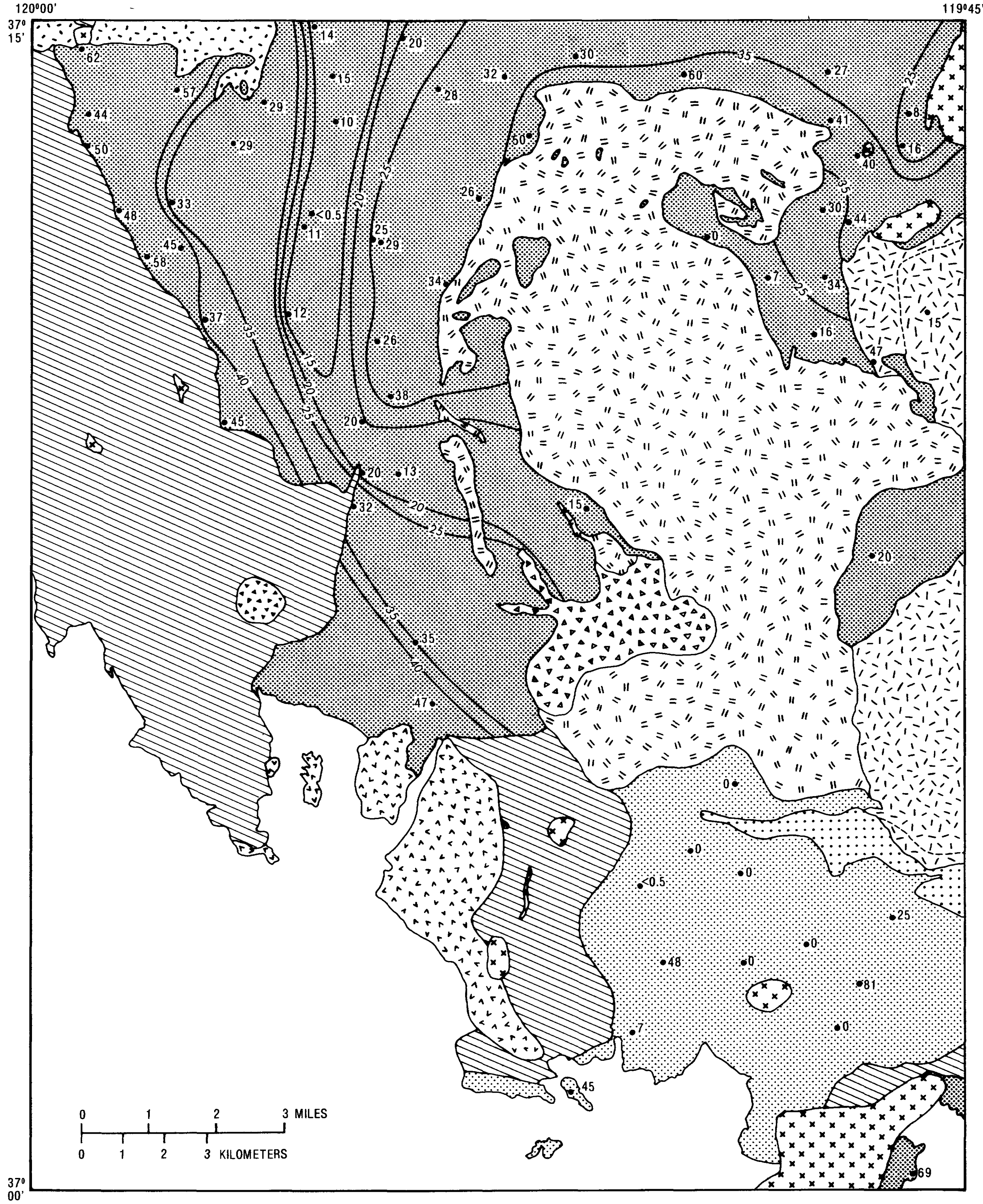


**FIGURE 8.** Raymond quadrangle showing 100 hornblende (biotite + hornblende) in the tonalite of Blue Canyuon and in hybridized samples of the plagiogranite of Ward Mountain. Explanation in figure 1.

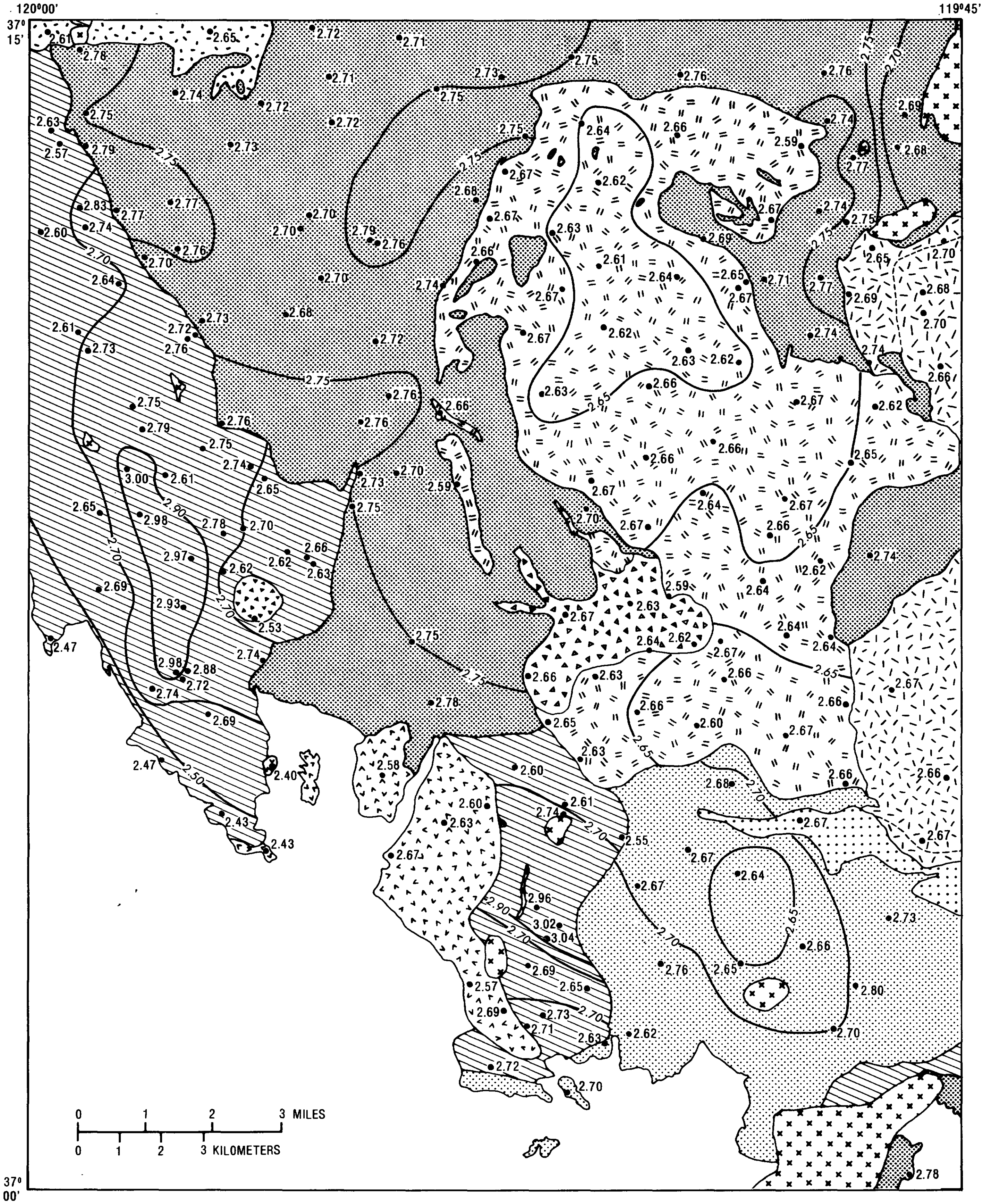


FIGURE 9. Raymond quadrangle showing bulk specific gravity. Explanation in figure 1.

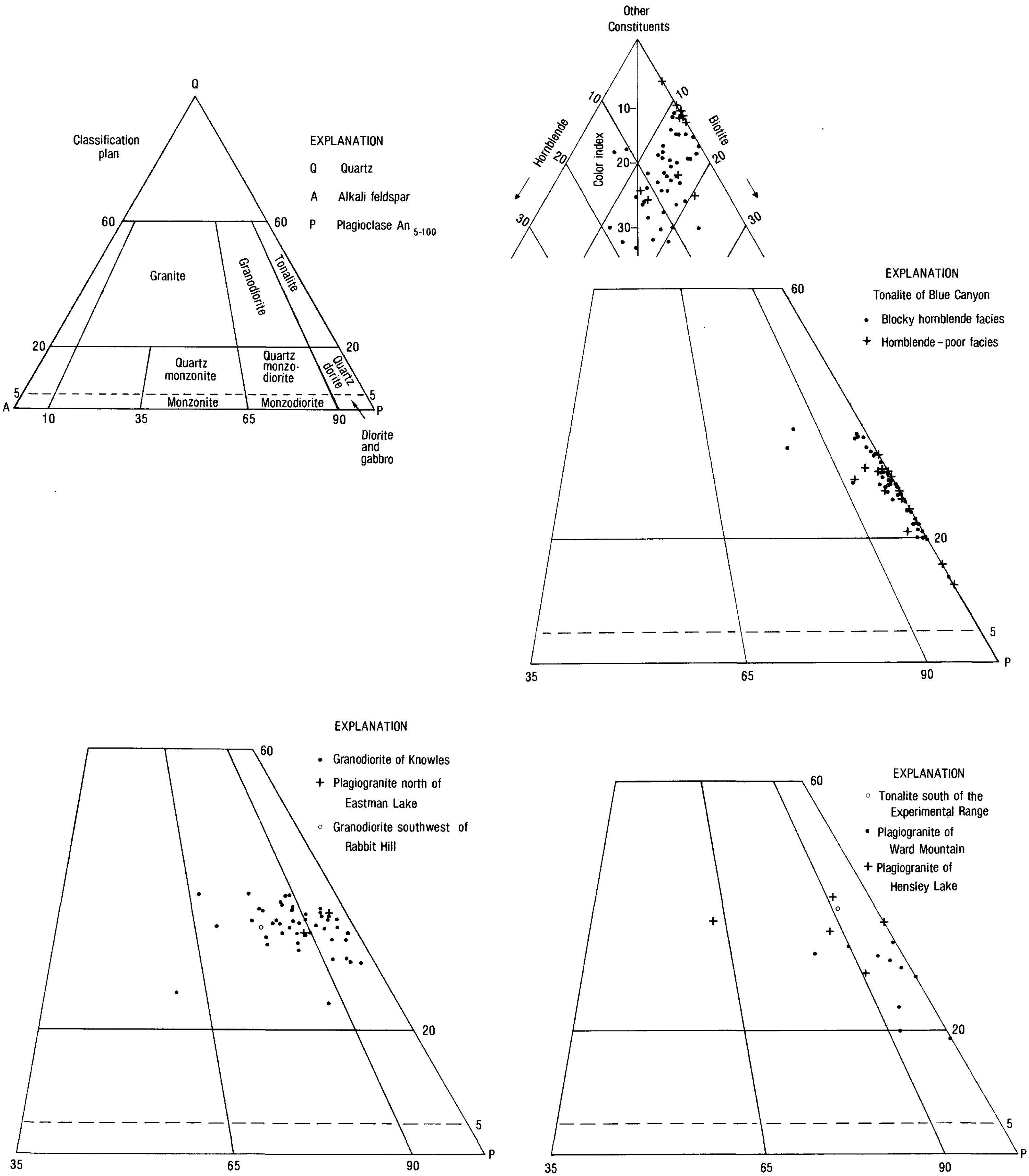


FIGURE 10. Plots of modes of granitic rocks. Classification plan by Streckeisen and others (1973).