# Potassium-Argon Geochronology of the Eastern Transverse Ranges and Southern Mojave Desert, Southern California

GEOLOGICAL SURVEY PROFESSIONAL PAPER 1152

# Potassium-Argon Geochronology of the Eastern Transverse Ranges and Southern Mojave Desert, Southern California

*By* FRED K. MILLER *and* DOUGLAS M. MORTON

GEOLOGICAL SURVEY PROFESSIONAL PAPER 1152

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1980

**UNITED STATES DEPARTMENT OF THE INTERIOR**

**CECIL D. ANDRUS,** *Secretary*

**GEOLOGICAL SURVEY**

**H. William Menard,** *Director*

**Library of Congress Cataloging in Publication Data**

Miller, Fred K

Potassium-argon geochronology of the eastern Transverse Ranges and southern Mojave Desert, southern California.

Bibliography: p. 24

Supt. of Docs. no.: I 19.16:1152

1. Potassium-argon dating. 2. Geology--California --Transverse Ranges. 3. Geology--California--Mohave Desert. I. Morton, Douglas M., joint author. II. Title. III. Series: United States. Geological Survey, Professional paper ; 1152.

QE508.M5 551.7'09794 80-607097

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402

# CONTENTS



# ILLUSTRATIONS



# TABLE

# POTASSIUM-ARGON GEOCHRONOLOGY OF THE EASTERN TRANSVERSE RANGES AND SOUTHERN MOJAVE DESERT, SOUTHERN CALIFORNIA

By FRED K. MILLER and DOUGLAS M. MORTON


## ABSTRACT

More than 200 potassium-argon apparent ages on minerals from crystalline rocks, chiefly from the San Bernardino and eastern San Gabriel Mountains and the southern Mojave Desert, define an area greater than 10,000 km$^2$ in which the potassium-argon isotopic systematics have been highly disturbed. The disturbance or disturbances appear to have culminated at different times in different parts of the region, ranging from 57 m.y. ago in the eastern San Gabriel Mountains to about 70 m.y. ago in the southern Mojave Desert.

The region can be subdivided into three parts on the basis of potassium-argon dating: (1) An inner area of anomalous ages in which the rocks yield apparent potassium-argon ages that indicate complete or nearly complete resetting of the isotopic system. (2) An outer area in which the rocks yield apparent ages that are, or approach, emplacement ages. (3) A zone separating these two areas from which rocks yield discordant apparent ages on coexisting mineral pairs. This discordant zone varies in width from about 6 to 12 km and grades inward to rocks reset to the degree that they yield concordant potassium-argon apparent ages on coexisting mineral pairs and outward toward rocks that yield near-concordant apparent ages. Rocks from the center and the inner parts of the discordant zone yield the most discordant apparent ages.

Contouring of the apparent ages defines the extent of the reset region that occurs on both sides of the San Andreas fault. The apparent ages can be contoured across the fault, although the position of the fault is well defined by abrupt deflection of the contours parallel to the fault. The reverse fault bounding the north side of the San Bernardino Mountains may or may not be reflected by offset contours; correlation of possible offset features across the fault is uncertain. Several northwest-trending faults on the Mojave Desert strongly disrupt the contours but do not show the right-lateral displacements that have been attributed to them on the basis of apparent offsets of geologic features. These faults may have a component of vertical movement, and it is not known what effect this might have on the contours; even a small amount could be profound.

The cause of the isotopic disturbance is not well understood, as the area of most complete resetting does not appear to be coincident with any single batholithic mass. The apparent-age contours cross the boundaries of individual plutons, and the configuration of the contours shows no apparent relation to the shapes of plutons or groups of plutons. Even though there does appear to be a lack of correlation between individual plutons or batholith-size collections of plutons, this lack of correlation may be more apparent than real. It is possible that some of the plutons within the area of anomalous ages are part of an extensive batholithic mass of which only the uppermost part is exposed.

An alternative interpretation of the anomalous ages is that a continuing postemplacement heat source generated by continued underthrusting of the Pacific plate beneath North America caused the region to remain at elevated temperatures such that argon retention by minerals datable by potassium-argon methods was not possible for some time after pluton emplacement. As suggested by Coney and Reynolds (1977), possibly the angle of underthrusting was shallower than when the Transverse Range plutons were emplaced.

Locally, the youngest ages show a spatial relation to the Vincent thrust fault and its correlatives. If this fault is the cause of the region-wide resetting, it has to have extended under most of the western part of southern California.

The configuration of the anomalous-age zone is roughly coincident with the position of the Transverse Ranges, the recently discovered southern California uplift, a relatively shallow high-velocity zone in southern California, and the projection of the Murray fracture zone. The eastward extent coincides roughly with the eastern limit of high seismicity in southern California.


## INTRODUCTION

Potassium-argon apparent ages were determined on mineral separates from 158 granitic and gneissic rocks from an area of about 14,000 km$^2$ of the eastern Transverse Ranges and southwestern Mojave Desert (fig. 1). Most potassium-argon-datable granitic rock bodies from the San Bernardino, San Gabriel, and Santa Monica Mountains were sampled and "dated." Biotite was analyzed from most samples, and coexisting hornblende and biotite were analyzed from about 30 percent of the samples. The granitic rocks range in composition from alkali quartz monzonite to mafic quartz diorite; gneissic rocks include amphibolite and Precambrian quartzofeldspathic gneiss.

All rocks yield Mesozoic or early Tertiary potassium-argon apparent ages, even the known Precambrian gneiss. The apparent ages range from 57 m.y. to 199 m.y.; they vary in a regular and systematic way such that it is possible to contour them throughout most of the region. Contouring the apparent or anomalous ages was done both for the entire region sampled (pl. 1*C*) and within individual fault-bounded blocks (pl. 1*D*). On plate 1*C*, even though faults were ignored for the purpose of contouring, the location of most major faults is expressed as a linear trend or

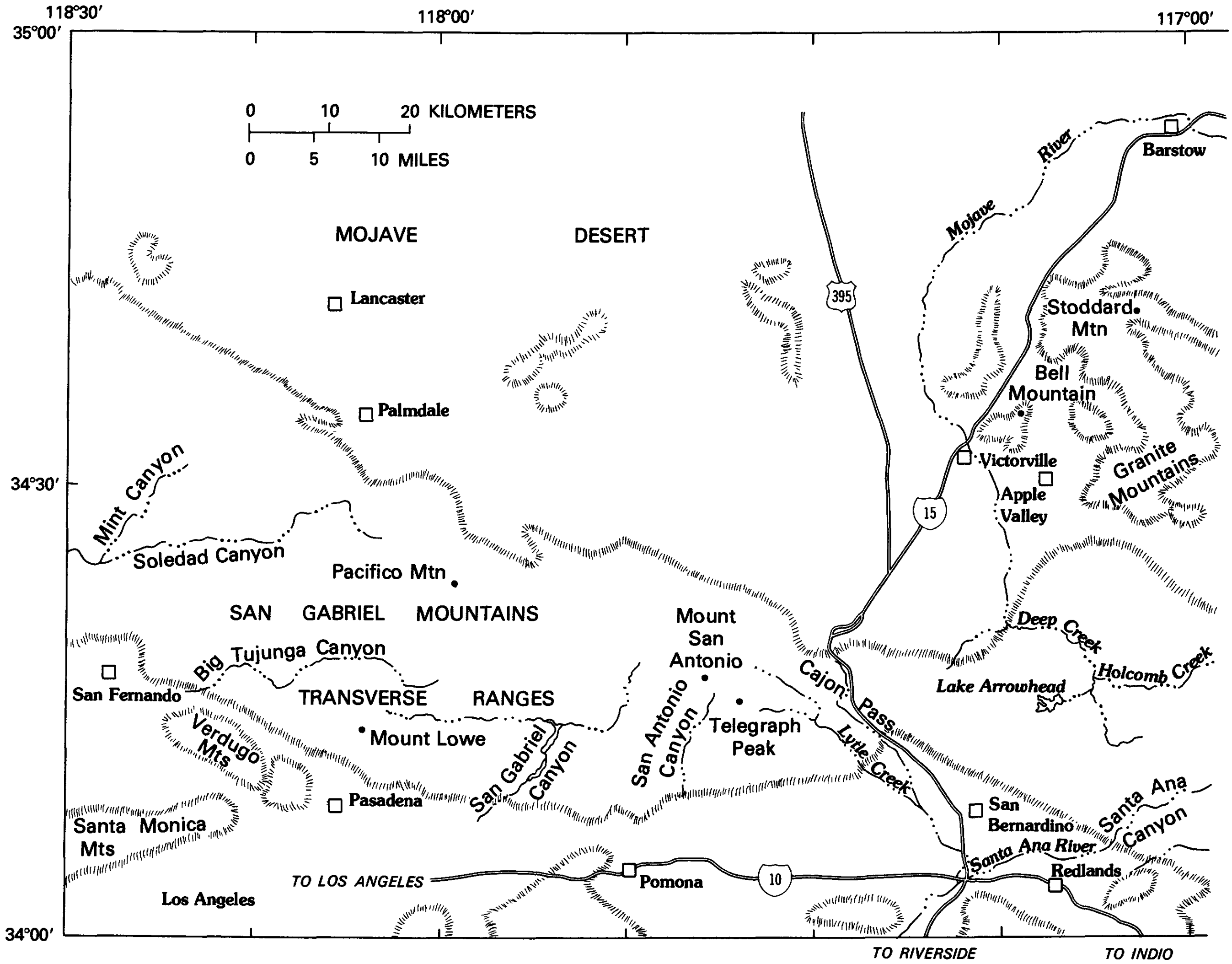


FIGURE 1.—Selected geographic features of the eastern Transverse Ranges and southern Mojave Desert.

anomalous, strongly divergent disruption in the trends of contours. Within major structural blocks (for example, the San Gabriel Mountains between the San Andreas fault and the frontal fault system of the range), the contours have an internally consistent pattern, markedly different from the pattern of the contours in adjacent blocks.

Only a few of the potassium-argon ages obtained may approach emplacement ages; most reflect a complex postintrusive thermal history that affected the entire region sampled. The area yielding apparent and (or) reset ages is surrounded by a zone of discordant ages, outside which granitic rocks yield concordant[1] or near-concordant ages from coexisting mineral pairs and are considered to approach closely the age of emplacement of the sampled plutons (fig. 2). All the rocks in the thoroughly reset area surrounded by the zone of discordant ages yield anomalous potassium-argon cooling ages, even though most mineral pairs from this anomalous area are concordant or nearly concordant.

Although the style of the contours on either side of the San Andreas fault is somewhat different, the difference in the range of apparent ages is small and there are no striking contrasts across the fault. This lack of isotopic contrast across the fault is not significant in itself because granitic rocks yielding potassium-argon apparent ages in this age range are common throughout the Western United States and Baja California (Evernden and Kistler, 1970; Armstrong and Suppe, 1973; and Krummenacher and others, 1975). It is significant, however, that granitic and gneissic rocks on both sides of the fault representing a wide range in emplacement and metamorphic ages yield reset

[1]The age of a rock is considered concordant if a mineral pair (hornblende and biotite or muscovite and biotite) from a single sample of that rock yields dates that differ by no more than 6 percent (± 3 percent for each mineral).

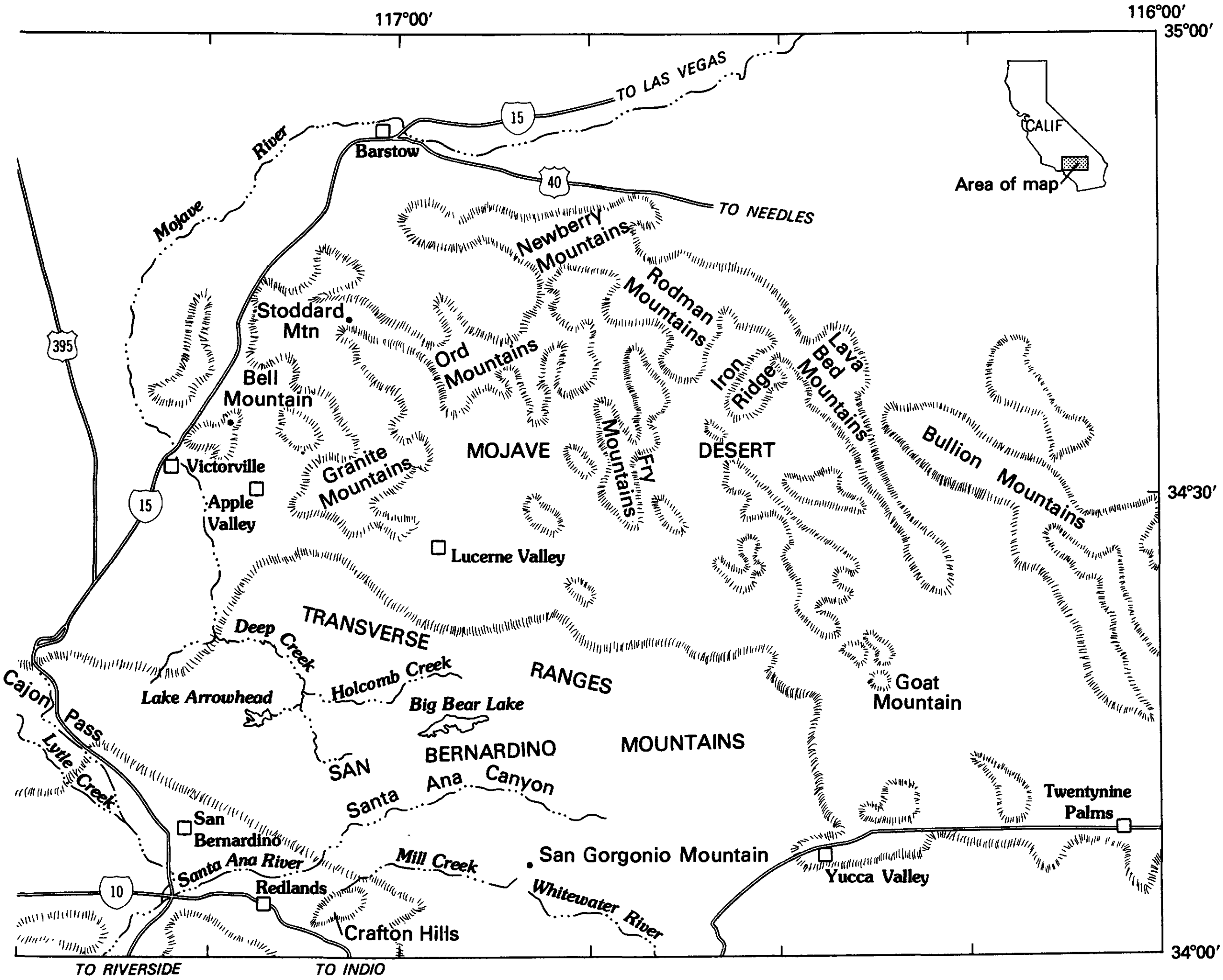


FIGURE 1.—Continued.

potassium-argon ages that fall almost exclusively in about the same age span and lie in a continuous zone that straddles a fault that may have more than 240 km of right-lateral slip along it (Crowell, 1962; Ehlert and Ehlig, 1977).

To refer to this area of reset ages as a zone may be misleading, because the anomalous ages occur over an extremely large area, the bounds of which are known incompletely. West of the San Andreas fault, there appears to be a marked change in the configuration of apparent age patterns across the frontal fault system of the Transverse Ranges, which separates this province from the Peninsular Ranges province to the south. East of the San Andreas fault, the area of reset ages grades into only partially reset and possibly emplacement ages. The boundary between these two isotopically different areas east of the San Andreas has a sinuous, though roughly east-west, trend that passes just north of lat 34°30'N, turning to a south-southeast trend about 20 km northeast of the San Bernardino Mountains (see fig. 2 and pl. 1*C*). The west and southeast extension of this boundary is unknown but under investigation. On the west side of the San Andreas, no such potassium-argon isotopic boundaries have yet been recognized; it is not known if plutonic rocks west of the San Andreas and north of the San Gabriel Mountains yield potassium-argon ages that approach emplacement ages.

The apparent ages and the interpretations reported here constitute a progress report on a continuing potassium-argon isotopic study that will eventually cover most of southern California north of lat 33°N. Interpretations presented here may be modified or changed as more information becomes available.

## ACKNOWLEDGMENTS

We are indebted to E. A. Rodriguez and P. N. Castle for their help in collecting the samples; to D. H. Sorg,

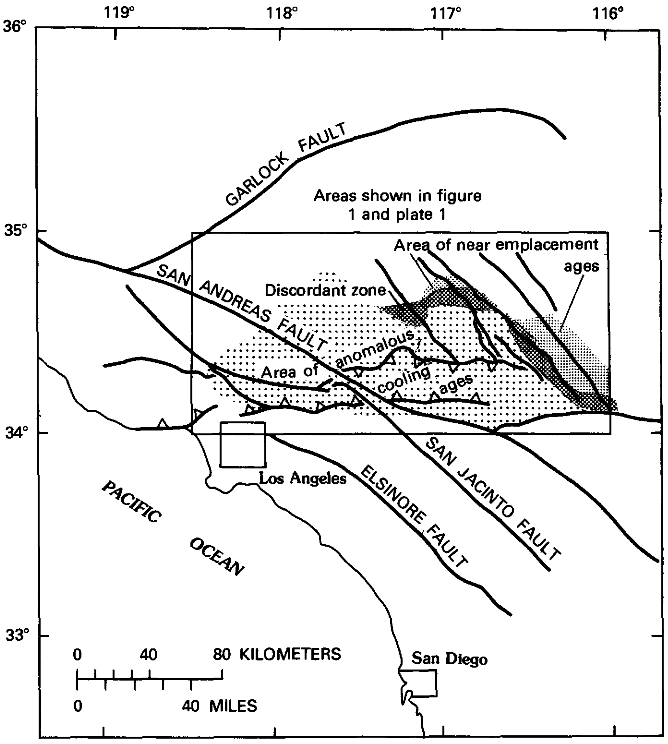


FIGURE 2.—Sketch map showing the relation of the three apparent-age subdivisions to large faults in southern California. The discordant zone is shown dark stippled.

for performing all mineral separations, and to Brent Fabbi and Joe Christy for the $K_2O$ analyses. C. C. Smith did the argon extractions and mass spectrometry on many of the samples, for which we thank him. We are particularly indebted to R. O. Castle for many discussions on all aspects of southern California geology relating to this study.

## GEOLOGIC SETTING

With the exception of the Uinta Mountains, the Transverse Ranges of southern California are the only major east-trending mountain ranges in the western conterminous United States. They constitute a major physiographic province that disrupts the northwest-oriented Cordilleran trends of the Peninsular Ranges to the south and the Coast Ranges to the north (fig. 1 and pl. 1*A*). The San Andreas fault passes through the province but appears to displace the overall eastward trend of the mountains only slightly if at all. From east to west, the major ranges of the province are the San Bernardino Mountains, San Gabriel Mountains, Santa Monica Mountains, and Santa Ynez Mountains. Granitic rocks of Mesozoic age occur mainly in the San Bernardino and San Gabriel Mountains and the east end of the Santa Monica Mountains; in the western ranges, except in the Ridge Basin and Frazier Mountain areas, the crystalline rocks are covered by thick sections of Tertiary sedimentary rocks.

### SAN BERNARDINO MOUNTAINS

The San Bernardino Mountains are 95 km long and average about 2,000 m in height except for the mass centered on San Gorgonio Mountain in the southern part of the range, which rises to about 3,350 m. Most of the range is underlain by intermediate composition granitic rock of Mesozoic age. Precambrian schist and gneiss make up about 20 percent of the basement rock; they occur chiefly in the southern part of the range and to a lesser extent, in the central and north parts. Unconformably overlying the gneiss is relatively unmetamorphosed younger Precambrian quartzite, phyllite, and dolomite that is overlain by Paleozoic limestone and dolomite, part of which is Mississippian in age (Richmond, 1960; Stewart and Poole, 1975). Other than the granitic plutons, no rocks of Mesozoic or early Tertiary age are present. The other rocks in the range consist of several patches of Pliocene basalt, and, in structural depressions, Pliocene and (or) Pleistocene rocks ranging from conglomerate to shale. Discontinuous Quaternary gravels and alluvial deposits are widespread, particularly around the flanks of the range.

The San Bernardino Mountains are bounded on the north by a relatively narrow, irregularly trending zone of south-dipping reverse faults that dip under the range. This zone of faults appears to die out eastward as the mountains gradually decrease in elevation almost to the desert floor near Yucca Valley. No historic earthquakes have occurred along this fault zone, but youthful-appearing scarps as high as 30 m occur in all but the youngest alluvial gravels. The various branches of the San Andreas fault bound and occur within the southwest part of the San Bernardino Mountains. The north-dipping Banning reverse fault zone forms the south boundary, and the Pinto Mountain fault roughly coincides with the ill-defined southeast margin of the range. Just southeast of San Gorgonio Mountain, the Pinto Mountain fault, which has components of left-lateral and possibly reverse slip along it, trends northeastward, then eastward from its intersection with the north branch of the San Andreas fault.

### SAN GABRIEL MOUNTAINS

The San Gabriel Mountains are one of the most rugged mountain ranges in southern California with steep-sloped peaks rising to more than 2,700 m, and one to 3,050 m. Petrologically, the range is more diverse than the San Bernardino Mountains. A large Precambrian (Silver and others, 1963) anorthosite complex intrudes Precambrian gneiss and schist at the west end of the range. These rocks are in turn intruded by the Late Permian to Early Triassic Mount Lowe Granodiorite of Miller (1926), which underlies a large part of the west half of the range. Cretaceous granitic rocks (Silver, 1971) ranging in composition from quartz diorite to granodiorite intrude the older rocks.

In the eastern part of the mountains, several zones of mixed metamorphic and cataclastic rocks occur along the south front, including an unusually thick zone of north-dipping mylonite and ultramylonite. The mylonite and less cataclastically deformed rocks along the mountain front were derived from a variety of high-grade metamorphic rocks. North of these cataclasites is a second zone of cataclasites that appear to have been derived chiefly from mafic granitic rocks that range in composition from granodiorite to quartz diorite. Many of these granitic rocks are still preserved and are uncataclasized in the interior of the range, especially in the southeastern part. They intrude gneiss and schist of probable Precambrian age and schist, quartzite, and carbonate rock that may be Paleozoic and (or) Mesozoic.

In the northeastern part of the range, gneissic rocks and plutonic rocks are thrust over the Cretaceous or older Pelona Schist, a low-grade but pervasively metamorphosed assemblage of schist, greenstone, quartzite, and carbonate rock. The Pelona Schist and the structurally overlying gneiss are everywhere separated from one another by a thick zone of mylonite and cataclastic rock developed along the Vincent thrust fault. The rocks in this zone differ from the mylonite and cataclastic rock near the front of the range. Intruding the schist and the Vincent thrust is a medium-grained relatively leucocratic granodiorite that yields an early or mid-Miocene potassium-argon age (19 m.y. or 14 m.y., see Miller and Morton, 1977) and establishes an isotopically determined upper limit on the age of thrusting (Hsü and others, 1963, Miller and Morton, 1977). No pre-Tertiary plutonic rocks are known to intrude the Pelona Schist in the Transverse Ranges.

The San Gabriel Mountains are bounded on the south by a zone of north-dipping reverse faults that separate the Transverse Ranges province from the Peninsular Ranges province. From east to west, this zone is composed of the Cucamonga fault and Sierra Madre fault. The east end of the Santa Susana thrust fault bounds the southwest edge of the San Gabriel Mountains but is completely within the Transverse Ranges province. The Raymond Hill, Hollywood, Santa Monica, and Malibu Coast faults branch southwestward off of the Sierra Madre fault in a continuation of the boundary between the two provinces, forming the southern boundary of the Verdugo Mountains and the Santa Monica Mountains (see fig. 1 and pl. 1*A*). Historic earthquakes on the Malibu Coast fault and a branch of the Santa Susana fault indicate that the west end of this reverse fault system is active. Large (6 ± m) scarps in the youngest alluvial fans at the east end of the fault system (Cucamonga fault) suggest that this part of the zone is active, although no historic seismicity of significant magnitude has been recorded.

The north edge of the range is bounded by the San Andreas fault and probably includes the southeast end of the zone of surface rupture that occurred during the 1857 Fort Tejon earthquake.

Within the range there are several large faults, but the magnitude, sense, and recency of latest movement are not well understood for any of them. The San Gabriel fault forms an arcuate trace that cuts through the western and southern parts of the range. Continuity at either end of the fault is not well understood; at the east end, the fault is covered by alluvium and either dies out, merges with faults in upper San Antonio Canyon, or is terminated by these faults. At the west end, the fault either dies out or is concealed beneath the late Tertiary rocks or the thrust complex near Frazier Mountain.

### MOJAVE DESERT

The area from which samples were collected in the southern Mojave Desert is largely underlain by Mesozoic plutons and lesser amounts of Paleozoic and Mesozoic metamorphic rock. These rocks are exposed in low mountain ranges separated by large areas of Quaternary alluvium; bedrock is exposed over only about 40 percent of the area.

Most of the granitic rocks in the southern Mojave Desert fall within the same general compositional range as those in the San Bernardino Mountains, from alkalic quartz monzonite to mafic quartz diorite. The Paleozoic rocks, marble, quartzite, and schist, are slightly to highly metamorphosed and strongly deformed. The Mesozoic metamorphic rocks are part of the Sidewinder Volcanic Series of Bowen (1954); they consist of metamorphosed flows and breccia of intermediate composition (Bowen, 1954). Small areas underlain by gneiss that have been mapped as Precambrian are found at various places throughout the region; the largest is in the west half of the Ord Mountains (Dibblee, 1964a).

The San Andreas fault bounds the Mojave on the southwest, the reverse fault system at the base of the San Bernardino Mountains on the south. On the southeast side, the boundary between the Mojave and Colorado Deserts is ill defined but it is usually considered to be the eastward projection of the San Bernardino

Mountains. The most prominent structures within the southern Mojave block are a series of northwest-striking right-lateral strike-slip faults. Total offset across individual faults is poorly established on the basis of displaced lithologic units but it is thought to range from a few kilometers to about 40 km (Garfunkle, 1974). All of these northwest-trending strike-slip faults have youthful-appearing primary fault features along them developed in young alluvium, and several have had historic seismic activity (Hill and Beeby,1977).

## ROCK TYPES DATED

### SAN BERNARDINO MOUNTAINS

Within the San Bernardino Mountains, the rocks dated fall into five general groups:

1. The oldest rock is the Baldwin Gneiss and several unnamed gneiss bodies that are probably related to or directly correlative with the Baldwin Gneiss of Guillou (1953). Two samples taken from exposures of known Baldwin Gneiss are fairly well layered biotite- and muscovite-rich quartzofeldspathic gneiss. The highly porphyroblastic part of the gneiss that is thought to be metaplutonic in origin (Guillou, 1953) was not sampled. Silver (1971) obtained a zircon uranium-lead age of 1750 m.y. for the gneiss that locally is overlain by younger Precambrian and fossiliferous Paleozoic rock.

2. Mafic plutonic rock, which ranges in composition from monzonite to quartz monzonite and is chemically and petrologically distinct from most other granitic rocks in the San Bernardino Mountains, crops out on the north flank of the range, north of Big Bear Lake. Hornblende is the primary characterizing mineral and makes up more than 15 percent of the rock in most of the body. Much of the hornblende has partly altered cores of clinopyroxene. Biotite, present locally is completely absent at most places. The rock, medium to fine grained and commonly lineated and (or) foliated, contrasts with most of the relatively structureless younger Mesozoic rocks that intrude it. Miller (oral commun., 1977) obtained an age of 220 m.y. for this rock on the basis of uranium-lead data.

3. A wide east-trending zone of porphyritic foliated hornblende-biotite quartz monzonite occurs in the south half of the range and extends nearly from one end of the mountains to the other. The rock is ubiquitously foliated and (or) lineated and contains phenocrysts of pink microcline as long as 8 cm (average length 3–4 cm). On the basis of its internal structure, we consider this rock to be older than most of the granitic rocks in the range even though the potassium-argon apparent ages have been completely reset.

4. Several large plutons, at least one larger than 125 $km^2$, make up the bulk of the plutonic rocks in the range. Rocks of these plutons range in composition from granodiorite to quartz monzonite; the quartz monzonite is much more common. Several plutons contain both hornblende and biotite; a few plutons have muscovite and biotite and two of the largest bodies have biotite only. Most of these rocks are massive; the only exception is foliated rock found locally along the margins of some bodies. Several of the plutons are made up of porphyritic rock or are at least porphyritic in part. Because of petrologic similarities, all plutons of this group may be approximately the same age or close to the same age, but it was not possible to determine this with potassium-argon methods.

5. Diverse plutonic rock types form small bodies at several places in the range. These rocks make up a miscellaneous group that ranges in composition from alaskite to hornblende quartz diorite. Most of these rock bodies are less than 3 or 4 $km^2$ in areal extent. Many are internally inhomogeneous and may be hybrids. All dated samples from these small bodies reflect the same cooling history in the potassium-argon apparent ages as the plutonic rocks that surround them.

### SAN GABRIEL MOUNTAINS

Sampling in the San Gabriel Mountains was restricted to rocks of known or presumed Mesozoic age. None of the known Precambrian gneiss and (or) anorthosite complex in the western part of the range were sampled. Most dated rocks of the San Gabriel Mountains do not fall into relatively well defined petrogenetic groups, as do rocks in the San Bernardino Mountains. In addition, the mafic nonporphyritic dioritic to granodioritic Cretaceous plutonic rocks of the San Gabriel Mountains markedly contrast with the relatively leucocratic, porphyritic granodioritic to quartz monzonitic rocks typical of the San Bernardino Mountains. In the descriptions that follow, the rocks are grouped in order of decreasing suspected age.

The Mount Lowe Granodiorite of Miller (1926) is a porphyritic highly lineated and (or) foliated rock, one of the few porphyritic rocks in the San Gabriel Mountains. It is leucocratic, with streaked-out hornblende crystals accounting for less than 10 percent of most samples collected. Biotite and minor amounts of muscovite are present in a highly porphyritic specimen taken from near the top of Pacifico Mountain (sample 13, pl. 1*B*). In general, the groundmass of this rock is highly cataclastic, and the phenocrysts commonly have a milled appearance. Silver (1971) obtained an age on zircons from the Mount Lowe Granodiorite of $220\pm10$ m.y. using uranium-lead methods.

Mafic hornblende-biotite granodiorite, quartz diorite, and diorite plutons make up a large part of the plutonic rocks in the range; proportionately the largest number of samples from the San Gabriel Mountains were taken from these bodies. Many of these rocks have a pronounced secondary cataclastic fabric developed in them. Most have a relatively high color index, and in these, hornblende is more abundant than biotite. Small irregularly shaped bodies of amphibolite or hornblendite near the front of the range may be related to these mafic plutons. Potassium-argon dating does not yield emplacement ages for any of these rocks, but Hsü, Edwards, and McLaughlin (1963) report a rubidium-strontium age of 105±10 m.y. for a sample collected at the east end of the range. Silver (1968), on the basis of uranium-lead ages, indicates emplacement of batholithic rocks in the San Gabriel Mountains between 100 m.y. and 160 m.y., and in a later paper (1971) he notes conspicuous episodes at 160–170 m.y. and 75–90 m.y.

Cataclastically deformed plutonic rocks are common throughout the eastern part and near the south front of the range and in the crystalline complex just above the Vincent thrust fault. They range from sheared plutonic rocks in which the granitic texture is still relatively well preserved to ultramylonite in which any vestige of the primary rock is lacking. Potassium-argon determinations on hornblende and on whole rocks from the ultramylonite yield ages that fall into the general contour pattern of the other plutonic rocks (Miller and Morton, unpub. data 1979); their range implies that the cataclastic rocks underwent the same final cooling history as the other rocks.

## SOUTHERN MOJAVE DESERT

The variety in plutonic rocks of the southern Mojave Desert is greater than in either the San Bernardino or San Gabriel Mountains. Many of the same general rock types found in the San Bernardino Mountains are present in the Mojave, but no plutons were mapped that crossed the boundary between the two provinces. There may be exceptions to this generalization at the east end of the San Bernardino Mountains, however, where the fault system on the north side of the range appears to die out. No detailed mapping of the plutonic rocks has been done in this area.

Most of the crystalline rocks dated can be roughly grouped into six categories.

1. Probably the oldest rock unit sampled in the Mojave Desert is hornblende gneiss shown as Precambrian on the San Bernardino sheet of the State geologic map series (Rogers, 1969). A sample from this unit (No. 79 on pl. 1*B*) yielded an apparent Mesozoic potassium-argon age (96 m.y.) on hornblende but was collected within the area of anomalous cooling ages. The gneiss ranges from well-layered quartzofeldspathic gneiss to highly contorted hornblende-rich quartzofeldspathic gneiss. Small smeared-out pods of highly recrystallized carbonate rock and calcsilicate rock are locally present.

2. Lineated and foliated hornblende monzonite makes up most of the Granite Mountains west of Lucerne Valley (Ross, 1972). This body was studied by C. F. Miller (1976), who established the emplacement age of these rocks at 220 m.y. using the uranium-lead method on zircons. Miller suggested that the monzonite is probably related to the mafic monzonite to quartz monzonite in the San Bernardino Mountains on the basis of chemical, petrological, and age similarities. The Granite Mountains plutonic rock is medium to coarse grained and contains about 10 percent hornblende that commonly forms highly lineate crystal aggregates streaked out in the plane of foliation. Many hornblende crystals have cores of clinopyroxene. At several places, the foliation is clearly cut by younger, massive granodiorite (sample 68) and quartz monzonite plutons.

3. A few plutons of nonporphyritic medium-grained hornblende-biotite granodiorite have yielded discordant Jurassic potassium-argon ages and may be as old as Triassic. These rocks lack any secondary fabric, such as that developed in the monzonite in the Granite Mountains, and have relatively high color indexes that generally range from 20 to 30. A pluton exposed along the south flank of Bell Mountain, northeast of Victorville (sample 72), is a good example of this group. With the possible exception of two characteristics, we detected no consistent differences in appearance between these rocks and those of any other group that would allow us to reliably give an age assignment in the field. These two characteristics, neither of which is totally reliable, are high color index and a hornblende-biotite ratio equal to, or greater than, one. Most plutons of known or suspected Cretaceous age have a lower color index and a hornblende-biotite ratio considerably less than one. The mafic granodiorite plutons are grouped here only on the basis of their older potassium-argon apparent ages, consistently high color index, and high hornblende-biotite ratio. Some of the mafic granodiorite and quartz monzonite plutons within the area of anomalous cooling ages in the San Bernardino Mountains that yield relatively young apparent potassium-argon ages may or may not belong to this group.

4. A distinctive porphyritic hornblende-biotite granodiorite makes up an estimated 20–30 percent of all exposed plutonic rocks from east of the Lenwood fault to the limits of the area sampled. The granodi-

orite contains 2- to 4-cm phenocrysts of gray to purple-gray orthoclase. The phenocryst content is highly variable, ranging from almost none to about 40 percent. The groundmass is medium to coarse grained; the color index ranges from 15 to 20; and the ratio of hornblende to biotite is in most cases less than one. Sphene is abundant in all samples collected. The rock is massive at all sample localities and only locally has poorly developed foliation. Outside the area of anomalous cooling ages, this rock yielded an apparently concordant potassium-argon hornblende-biotite age slightly greater than 160 m.y., although there is some question as to the reproducibility of the hornblende age. Another sample (79A) gave a hornblende apparent age of 185 m.y.; this age may be close to the emplacement age of the rock.

5. Both porphyritic and nonporphyritic plutons of quartz monzonite to granodiorite yielding concordant Cretaceous potassium-argon apparent ages are found throughout the southern Mojave Desert both within and outside the area of anomalous cooling ages. Some of these plutons may be completely reset older bodies, but none show clear signs of recrystallization with respect to either mineralogy or texture. Most of these bodies are made up of rock with a relatively low color index, generally less than 15. The rock ranges from fine to coarse grained, but it is typically homogeneous with regard to grain size within any individual pluton. Almost none display any distinct fabric.

6. A collection of small bodies is considered here as a miscellaneous group. These rock types are found at places throughout the Mojave Desert, but they cannot be demonstrated to be consistently associated with one or another of the more voluminous plutonic rock types. Many are probably equivalent to similar rocks in category (5) or to rocks described from the San Bernardino Mountains.

The most common rock type in this group is hornblende-biotite quartz-diorite or diorite. Most samples have a color index between 35 and 40 and are medium to fine grained. Locally, the rock approaches a hornblendite in composition. Quartz content is variable from body to body and is near zero in some. A slight but noticeable foliation and (or) lineation is common. In many occurrences, this rock forms small pods or dissociated bodies, each up to several hundred meters in length, around a larger pluton. Three samples of this rock type (Nos. 133, 73D, and 78C) yielded strongly discordant apparent ages ranging from Late Triassic to Late Cretaceous (199 m.y. on hornblende to 77 m.y. on biotite) suggesting that all of the highly mafic bodies may be relatively old.

Mafic inhomogeneous rock, probably a hybrid of Jurassic and Cretaceous plutonic rocks and older metamorphic and plutonic rocks, is common throughout the southern Mojave, but it does not make up a significant proportion of exposed rocks. These bodies are generally made up of finely mixed metamorphic and plutonic rocks and are rarely more than 1 $km^2$ in outcrop area. Most are foliated or lineated in whole or in part. They are highly variable in texture and composition within a given body. Samples 107 and 120 both are from within the area of anomalous ages.

## SAMPLING AND ANALYTICAL PROCEDURES

Early in the dating of the plutonic crystalline rocks of southern California, it became evident that most concordant potassium-argon ages did not represent emplacement ages and that the area yielding the concordant ages was bounded on the north and east by areas yielding discordant potassium-argon ages. It also became evident that these apparent ages varied in a systematic way that could be contoured, presumably to reflect the cooling history of the area. We assumed that within the area of concordant but anomalously young ages, any crystalline rock, regardless of its age based on other dating methods, would yield a potassium-argon age that would fit the contouring. This assumption appears to be justified, as known Precambrian and Permian to Triassic rocks yielded Cretaceous potassium-argon apparent ages that fall exactly on the contours of granitic rocks of probable Cretaceous age. Since this thorough resetting was documented fairly early in our dating program, subsequent sampling, with few exceptions, was done to obtain an even distribution of samples for contour control.

In addition to the distribution criteria for sampling, samples were collected from as many individual plutons as possible, and more than one sample was collected from the larger plutons. Most plutons in the San Bernardino Mountains north of Santa Ana Canyon, more than half of the plutons in the San Gabriel Mountains, and probably between 50 and 75 percent of those in the Mojave Desert were sampled. Because many of the individual plutons in the Mojave are combined into larger plutonic units on published maps, it is not known for certain how many plutons are present. Gneissic or schistose metamorphic rocks known or suspected of being older than the Mesozoic plutonic rocks were sampled at various places in the area to test the degree to which the ages of the rocks have been reset.

About 10 kg of rock was taken at each sample site. At all sites, the most representative, least altered, and least weathered rock present was collected. In some areas, all exposed rock was too altered or weathered in a place where a sample was needed for contouring control. At those places, no sample was taken. Most of the areas where altered rock was a problem were in the Mojave Desert. Weathering or alteration did not prevent sampling at relatively regular intervals in the Transverse Ranges except in the Santa Monica Mountains and the northwestern San Gabriel Mountains.

The most serious impediment to a regular sampling interval was absence of datable rock over large alluviated areas in some parts of the region, particularly in the southwestern part of the Mojave Desert. In the western San Gabriel Mountains, the Precambrian anorthosite complex occupies a large area where no samples were taken, as does the Pelona Schist in the eastern San Gabriel Mountains. Relatively unmetamorphosed Precambrian and Paleozoic sedimentary rocks that underlie two large areas in the central San Bernardino Mountains were not sampled.

All mineral separates were checked for impurities in oil with a petrographic microscope. With few exceptions, mica separates were more than 99 percent pure, and most hornblende separates were nearly 100 percent free of foreign material, especially mica. Hornblende from sample 85 contained pyroxene cores that could not be completely separated from the hornblende. That separate, which has an anomalous age, is discussed in the section on anomalous features of the apparent ages.

Argon analyses were made using standard isotope-dilution techniques in a 6-in. 60° Nier-type mass spectrometer, except for sample 126, which was analyzed on a 9-in. 90° multicollector mass spectrometer.

Constants used to calculate the ages are $\lambda\beta = 4.962 \times 10^{-10}$ $yr^{-1}$; $\lambda\epsilon = 0.581 \times 10^{10}$ $yr^{-1}$ (Beckinsale and Gale, 1969); and $^{40}K/K = 1.167 \times 10^{-4}$ (Garner and others, 1975). Since these constants were recently adopted by the IUGS Subcommittee on Geochronology (Steiger and Jager, 1977), previously determined dates using the old constants must be recalculated before they are compared with our data.

At least two potassium analyses were made on each sample using a flame photometer with a lithium internal standard. If a pair of analyses differed by more than 2 percent, replicate analyses were made. The values used in the age calculations are averages.

Errors (± values for the ages) have been assigned on the basis of experience with duplicate analyses; they represent the additive effects of uncertainties in the argon and potassium analyses, in the isotopic composition of the $^{38}Ar$ tracers, and in the concentration of the flame-photometer standards. Replicate argon analyses were made for many of the samples as a check on reproducibility; none differed from the initial analysis by more than 1.5 percent.

# DISCUSSION AND INTERPRETATION OF APPARENT AGES

## GENERAL CHARACTERISTICS AND DISTRIBUTION OF APPARENT AGES

Potassium-argon age determinations were made on 216 mineral separates of plutonic and metamorphic rocks from the Transverse Ranges and Mojave Desert—155 on biotite, 56 on hornblende, and 5 on muscovite (table 1). From 45 of the samples, separate ages on coexisting hornblende and biotite were obtained, and from 5 samples apparent ages on coexisting muscovite-biotite pairs. The apparent ages, which range from 57 m.y. to 199 m.y., represent discordant, concordant, and possible emplacement ages. The latter two are not necessarily synonymous in this region.

The potassium-argon apparent ages fall into three well-defined groups that in the following discussion will be referred to as (1) areas of anomalous cooling ages, (2) discordant zone, and (3) emplacement or near-emplacement ages. The majority of these apparent ages fall within and define the zone of anomalous cooling ages, a region that appears to have undergone a long and perhaps complex thermal history. The area most completely affected by this complex thermal history covers the eastern San Gabriel Mountains, the entire San Bernardino Mountains, and the southernmost Mojave Desert. This area is surrounded by a zone of discordant ages constituting the discordant zone; outside of this zone, the third group occurs (fig. 2 and pl. 1*C*). In this outer group, coexisting mineral pairs give concordant or near concordant potassium-argon ages that are probably close to the emplacement age of the individual plutons.

All the following comments on the contoured apparent ages refer to the contours using all biotite ages, plate 1*C*, and only when specifically noted, to contours for individual blocks, plate 1*D*. Before discussing what we interpret the contour map to show, however, a few comments should be made regarding the control for the contours, the contour interval, and the relative significance of trends defined by the contours.

Control for the contours is good throughout the area shown on plate 1*C* and 1*D* except for the large alluviated area between Cajon Pass and Victorville, and an area in the northeastern San Gabriel Mountains that is underlain by the Pelona Schist. Granitic rock samples from the western two-thirds of the Santa Monica Mountains and the San Fernando Valley would be desirable in order to extend contouring in that direction, but owing to the Tertiary and Quaternary sedimentary cover, none are exposed. For this reason, the few dates from the eastern Santa Monica Mountains are not contoured.

TABLE 1.—*Analytical data and calculated potassium-argon ages of plutonic and metamorphic rocks from the San Bernardino and San Gabriel Mountains and the eastern Mojave Desert*

[Constants (Steiger and Jager, 1977): $\lambda_\beta=4.962 \times 10^{-10}\ yr^{-1}$; $\lambda_\epsilon=0.581 \times 10^{-10}\ yr^{-1}$; $^{40}K/K=1.167 \times 10^{-4}$. BIO=biotite, HBL=hornblende, MUS=muscovite]

| Sample localities (pl. 1*B*) | Mineral | $K_2O$ (in percent) | $^{40}Ar_{rad}$ ($10^{-10}$ mol/gm) | $^{40}Ar_{rad}$ (in percent) | Calculated age (m.y.) | Field No. |
|---|---|---|---|---|---|---|
| 1 | BIO | 8.69 | 12.68 | 92 | 98.6±3.0 | T2–5 |
| | HBL | .893 | 1.385 | 73 | 105±3.2 | |
| | HBL[1] | .893 | 1.364 | 62 | 103±3.1 | |
| 1A | BIO | 9.63 | 12.48 | 89 | 87.8±2.6 | WT–2 |
| | HBL | .947 | 1.309 | 78 | 93.5±2.7 | |
| 2 | BIO | 9.05 | 9.452 | 75 | 71.1±2.1 | T1–5 |
| 3 | BIO | 8.92 | 9.303 | 91 | 71.0±2.1 | T76–4 |
| 4 | BIO | 9.16 | 9.145 | 93 | 68.0±2.0 | T77–4 |
| 5 | BIO | 8.69 | 8.966 | 92 | 70.3±2.1 | T50–4 |
| 6 | BIO | 8.76 | 9.180 | 93 | 71.4±2.1 | T49–4 |
| | HBL | .695 | .7191 | 53 | 70.5±2.1 | |
| 7 | HBL | 1.284 | 1.223 | 87 | 65.0±2.6 | T33–4 |
| 8 | BIO | 9.03 | 8.793 | 90 | 66.4±2.0 | T80–4 |
| | HBL | 1.052 | 1.158 | 70 | 74.8±2.2 | |
| 9 | BIO | 9.09 | 8.672 | 93 | 65.1±2.0 | T34–4 |
| 10 | BIO | 6.82 | 6.453 | 89 | 64.6±1.9 | T79–4 |
| 11 | BIO | 9.13 | 8.654 | 92 | 64.7±1.9 | T78–4 |
| 12 | BIO | 8.66 | 7.707 | 90 | 60.8±1.8 | T48–4 |
| 13 | BIO | 9.37 | 10.91 | 93 | 79.1±2.4 | T38–4 |
| | MUS | 10.31 | 12.99 | 92 | 85.5±2.6 | |
| 14 | BIO | 9.17 | 8.950 | 84 | 66.6±2.0 | T82–4 |
| 15 | BIO | 8.99 | 8.507 | 83 | 64.6±1.9 | T83–4 |
| 16 | BIO | 9.36 | 8.966 | 82 | 65.3±2.0 | T36–4 |
| 17 | HBL | 1.392 | 2.299 | 84 | 113±3.4 | T35–4 |
| 18 | BIO | 7.76 | 6.426 | 77 | 56.6±1.7 | T67–4 |
| | BIO[2] | 8.93 | 7.550 | 86 | 57.8±1.7 | T2–6 |
| 19 | BIO | 8.68 | 9.144 | 93 | 71.7±2.9 | T47–4 |
| | HBL | 1.259 | 1.356 | 65 | 73.3±2.2 | |
| 20 | BIO | 8.78 | 9.122 | 95 | 70.8±2.8 | T46–4 |
| 21 | BIO | 8.33 | 7.835 | 88 | 64.2±1.9 | T68–4 |
| 22 | BIO | 7.63 | 8.049 | 91 | 71.8±2.2 | T105–4 |
| | HBL | .288 | .5059 | 43 | 118±3.5 | |
| 22A | BIO | 8.23 | 7.828 | 93 | 64.9±1.9 | T1–6 |
| | BIO[3] | 8.23 | 7.841 | 79 | 65.0±2.0 | |
| | HBL | .357 | .7851 | 79 | 147±4.4 | |
| 23 | BIO | 9.10 | 7.967 | 89 | 59.8±1.8 | T41–4 |
| | HBL | 1.655 | 1.531 | 86 | 63.1±1.9 | |
| 24 | BIO | 8.95 | 7.655 | 92 | 58.5±1.8 | T37–4 |
| 25 | BIO | 9.11 | 9.808 | 94 | 73.3±2.2 | T102–4 |
| | HBL | 1.276 | 1.324 | 70 | 70.6±2.1 | |
| 26 | BIO | 8.42 | 9.246 | 92 | 74.7±2.2 | M26–4 |
| 27 | BIO | 9.53 | 10.41 | 85 | 74.3±2.2 | M27–4 |
| 28 | BIO | 9.35 | 10.30 | 92 | 74.9±2.2 | M30–4 |
| 29 | BIO | 9.27 | 9.142 | 85 | 67.2±2.0 | M31–4 |
| 30 | BIO | 9.43 | 10.75 | 93 | 77.5±2.3 | M32–4 |
| 31 | BIO | 9.50 | 10.94 | 79 | 78.3±2.3 | M33–4 |
| | HBL | .579 | .6402 | 58 | 75.2±2.3 | |
| 31A | BIO | 8.79 | 9.986 | 86 | 77.2±2.3 | M52–7 |
| 32 | BIO | 9.25 | 10.44 | 88 | 76.2±2.3 | M34–4 |
| 33 | BIO | 9.56 | 11.57 | 81 | 82.2±2.5 | M28–4 |
| | HBL | .635 | .7890 | 70 | 84.3±2.5 | |
| 34 | BIO | 8.55 | 9.313 | 72 | 74.1±2.2 | M35–4 |
| 35 | BIO | 8.70 | 10.67 | 91 | 83.2±2.5 | M29–4 |
| 36 | BIO | 9.06 | 9.223 | 80 | 69.4±2.1 | T100–4 |
| 37 | BIO | 8.97 | 9.454 | 92 | 71.8±2.2 | T101–4 |
| 38 | BIO | 9.22 | 8.509 | 88 | 63.0±1.9 | T84–4 |
| 39 | BIO | 9.14 | 9.498 | 90 | 70.8±2.1 | T99–4 |
| 40 | BIO | 8.90 | 9.098 | 92 | 69.6±2.1 | T98–4 |
| | HBL | 1.542 | 1.718 | 73 | 75.8±2.3 | |
| 41 | HBL | 1.490 | 1.457 | 80 | 66.7±2.0 | T106–4 |
| | HBL[3] | 1.490 | 1.450 | 75 | 66.3±2.0 | |
| 42 | BIO | 8.29 | 7.560 | 87 | 62.3±1.9 | T70–4 |
| | HBL | 1.250 | 1.202 | 79 | 65.6±2.0 | |
| 43 | BIO | 9.18 | 8.067 | 87 | 60.0±1.8 | T71–4 |
| 44 | BIO | 9.26 | 9.907 | 93 | 72.8±2.2 | T72–4 |
| 45 | BIO | 9.07 | 9.727 | 89 | 73.0±2.2 | T103–4 |
| 46 | BIO | 9.22 | 10.20 | 92 | 75.3±2.3 | T104–4 |
| | HBL | 1.267 | 1.383 | 68 | 74.2±2.2 | |
| 47 | BIO | 8.21 | 8.228 | 88 | 68.3±2.0 | T73–4 |
| 48 | BIO | 9.21 | 9.530 | 87 | 70.5±2.1 | T74–4 |
| 49 | BIO | 9.32 | 10.21 | 93 | 74.5±2.2 | T75–4 |
| 50 | BIO | 9.43 | 9.891 | 94 | 71.4±2.1 | T19–3 |
| | HBL | 1.810 | 1.782 | 77 | 67.1±3.4 | |
| 51 | BIO | 9.06 | 9.295 | 85 | 69.9±2.1 | T86–4 |

TABLE 1.—*Analytical data and calculated potassium-argon ages of plutonic and metamorphic rocks from the San Bernardino and San Gabriel Mountains and the eastern Mojave Desert*—Continued

| Sample localities (pl. 1*B*) | Mineral | $K_2O$ (in percent) | $^{40}Ar_{rad}$ ($10^{-10}$ mol/gm) | $^{40}Ar_{rad}$ (in percent) | Calculated age (m.y.) | Field No. |
|---|---|---|---|---|---|---|
| 52 | BIO | 9.16 | 9.544 | 93 | 71.0±2.1 | T4–3 |
| | HBL | 1.07 | 1.083 | 81 | 69.0±3.1 | |
| 53 | BIO | 9.08 | 9.485 | 91 | 71.1±2.1 | T85–4 |
| 54 | BIO | 9.20 | 9.453 | 85 | 70.0±2.1 | T1–4 |
| | HBL | .880 | .8577 | 73 | 66.5±2.0 | |
| | HBL[3] | .880 | .8432 | 74 | 65.4±2.0 | |
| 55 | BIO | 8.05 | 8.337 | 94 | 70.5±2.8 | T2–4 |
| | BIO[3] | 8.05 | 8.361 | 93 | 70.7±2.8 | |
| 56 | BIO | 8.41 | 8.558 | 92 | 69.3±2.8 | T3–4 |
| 57 | BIO | 9.25 | 9.526 | 94 | 70.1±2.1 | T53–4 |
| 57A | HBL | 1.312 | 1.257 | 70 | 65.3±2.0 | 416 |
| 58 | BIO | 9.50 | 9.284 | 88 | 66.6±2.0 | T18–4 |
| 59 | BIO | 9.16 | 9.030 | 90 | 67.2±2.0 | T66–4 |
| | HBL | 1.222 | 1.328 | 78 | 73.9±2.2 | |
| 59A | BIO | 8.31 | 8.093 | 87 | 66.4±2.0 | M17–7 |
| 60 | BIO | 8.62 | 8.352 | 87 | 66.1±2.0 | T12–4 |
| 61 | BIO | 9.25 | 9.005 | 88 | 69.4±2.0 | T15–4 |
| | BIO[3] | 9.25 | 9.453 | 94 | 69.6±2.1 | |
| | HBL | .984 | 1.062 | 87 | 73.4±2.9 | |
| 62 | BIO | 8.88 | 9.057 | 90 | 69.5±2.1 | T16–4 |
| 63 | BIO | 9.24 | 9.408 | 86 | 69.4±2.1 | T65–4 |
| 64 | BIO | 9.33 | 11.17 | 90 | 81.3±2.4 | T21–3 |
| 65 | BIO | 9.25 | 10.88 | 93 | 79.9±2.4 | T43–4 |
| 66 | BIO | 9.40 | 10.00 | 92 | 72.4±2.9 | T44–4 |
| 67 | HBL | 1.436 | 3.003 | 81 | 140±5.6 | M1–3 |
| 68 | BIO | 9.51 | 10.31 | 92 | 73.8±2.2 | M2–4 |
| 69 | BIO | 8.85 | 9.384 | 80 | 72.2±2.2 | M14–4 |
| 70 | BIO | 9.50 | 9.970 | 92 | 71.5±3.6 | M1–4 |
| 71 | BIO | 8.95 | 9.516 | 94 | 72.4±2.2 | M9–4 |
| 72 | BIO | 8.71 | 10.71 | 90 | 83.4±2.5 | M8–4 |
| | HBL | .521 | 1.328 | 68 | 169±11.8 | |
| 73 | BIO | 8.92 | 11.31 | 91 | 86.0±2.6 | M7–4 |
| 73A | BIO | 9.19 | 10.28 | 88 | 76.1±2.3 | M3–6 |
| 73B | BIO | 8.86 | 9.742 | 88 | 74.8±2.2 | M1–7 |
| | HBL | .632 | .6434 | 49 | 69.4±2.1 | |
| | HBL | .632 | .6597 | 10 | 71.8±2.2 | |
| 73C | BIO | 8.88 | 13.31 | 82 | 99.2±3.0 | M2–7 |
| 73D | BIO | 9.22 | 15.88 | 55 | 116±3.5 | M3–7 |
| | HBL | .459 | 1.391 | 71 | 199±6.0 | |
| 74 | BIO | 8.74 | 9.472 | 92 | 73.7±2.2 | M6–4 |
| 75 | BIO | 9.25 | 11.91 | 92 | 87.3±2.6 | T90–4 |
| 76 | BIO | 9.35 | 14.68 | 92 | 106±3.2 | T91–4 |
| | HBL | .704 | 1.985 | 77 | 186±5.6 | |
| 76A | BIO | 9.04 | 9.660 | 74 | 74.9±2.3 | M20–7 |
| 77 | BIO | 8.89 | 9.803 | 79 | 75.0±2.3 | T92–4 |
| 78 | BIO | 9.25 | 10.58 | 78 | 77.7±2.3 | T93–4 |
| 78A | BIO | 9.34 | 20.26 | 94 | 145±4.3 | M5–7 |
| | HBL | .430 | 1.105 | 47 | 170±5.1 | |
| 78B | BIO | 9.11 | 18.18 | 95 | 134±4.0 | M6–7 |
| 78C | BIO | 9.00 | 13.27 | 39 | 99.6±4.0 | M7–7 |
| | HBL | .855 | 2.152 | 87 | 167±5.0 | |
| 79 | HBL | 1.200 | 1.705 | 79 | 96.1±4.8 | T94–4 |
| 79A | BIO | 9.21 | 10.57 | 85 | 78.0±2.3 | M10–7 |
| | HBL | .898 | 2.524 | 87 | 185±5.6 | |
| 79B | BIO | 9.19 | 9.605 | 57 | 71.2±2.1 | M11–7 |
| 80 | BIO | 9.21 | 9.468 | 89 | 70.0±2.1 | M13–4 |
| 81 | BIO | 9.04 | 9.825 | 86 | 74.0±2.2 | T95–4 |
| 82 | BIO | 9.51 | 9.800 | 91 | 70.2±2.1 | T97–4 |
| | HBL | 1.089 | 1.155 | 64 | 72.2±2.2 | |
| 83 | BIO | 9.26 | 9.660 | 92 | 71.0±2.1 | T89–4 |
| 84 | BIO | 8.70 | 9.040 | 89 | 70.8±2.1 | T96–4 |
| 85 | BIO | 9.16 | 11.07 | 90 | 82.0±2.5 | T31A–4 |
| | HBL[4] | .644 | 1.211 | 82 | 126±3.8 | |
| | HBL[5] | .550 | 1.651 | 55 | 197±15.8 | |
| 86 | BIO | 9.08 | 9.484 | 88 | 71.1±2.1 | T54–4 |
| 87 | BIO | 8.73 | 9.037 | 96 | 70.5±2.1 | T13–4 |
| 88 | BIO | 9.24 | 10.03 | 90 | 73.9±2.2 | T14–4 |
| | MUS | 10.64 | 11.37 | 89 | 72.7±2.2 | |
| 89 | BIO | 9.16 | 9.369 | 95 | 69.7±2.1 | T11–4 |
| | HBL | 1.209 | 1.332 | 85 | 74.9±2.2 | |
| 90 | BIO | 9.16 | 9.708 | 96 | 72.2±2.2 | T10–4 |
| | HBL | .960 | 1.003 | 76 | 71.1±3.6 | |
| 91 | BIO | 9.35 | 9.603 | 94 | 70.0±2.1 | T55–4 |
| 92 | BIO | 9.42 | 9.890 | 89 | 71.5±2.1 | T32–4 |
| | HBL | .763 | .7901 | 64 | 70.5±3.5 | |
| 93 | BIO | 9.30 | 9.333 | 87 | 68.4±2.1 | T64–4 |

TABLE 1.—*Analytical data and calculated potassium-argon ages of plutonic and metamorphic rocks from the San Bernardino and San Gabriel Mountains and the eastern Mojave Desert*—Continued

| Sample localities (pl. 1*B*) | Mineral | $K_2O$ (in percent) | $^{40}Ar_{rad}$ ($10^{-10}$ mol/gm) | $^{40}Ar_{rad}$ (in percent) | Calculated age (m.y.) | Field No. |
|---|---|---|---|---|---|---|
| 94 | BIO | 9.83 | 10.20 | 92 | 70.7±2.1 | T30–4 |
| | MUS | 10.75 | 10.97 | 93 | 69.5±2.1 | |
| 95 | HBL | 1.156 | 1.250 | 73 | 73.6±3.2 | T87–4 |
| 96 | BIO | 9.48 | 9.534 | 92 | 68.5±2.1 | T5–4 |
| 97 | BIO | 9.27 | 9.301 | 89 | 68.4±2.1 | M3–4 |
| 98 | BIO | 8.75 | 8.768 | 90 | 68.3±2.1 | M10–4 |
| 99 | BIO | 9.52 | 10.39 | 88 | 74.3±3.0 | M36–4 |
| 100 | BIO | 9.44 | 21.10 | 97 | 149±4.5 | M38–4 |
| 100A | BIO | 8.95 | 9.389 | 79 | 71.4±2.1 | M44–7 |
| 101 | BIO | 8.87 | 9.969 | 93 | 76.4±2.3 | M39–4 |
| | HBL | .568 | .6146 | 59 | 73.6±5.9 | |
| 102 | BIO | 9.31 | 10.97 | 93 | 80.0±2.4 | M40–4 |
| 102A | BIO | 9.48 | 11.28 | 90 | 80.4±2.4 | M22–7 |
| | HBL | 1.061 | 2.608 | 60 | 163±4.9 | |
| 103 | BIO | 9.17 | 9.994 | 87 | 74.2±2.2 | M41–4 |
| 104 | BIO | 9.34 | 10.30 | 91 | 75.0±2.3 | M19–4 |
| 105 | BIO | 8.91 | 9.143 | 94 | 69.9±2.1 | M15–4 |
| | HBL | .725 | .7707 | 20 | 72.4±2.9 | |
| 106 | BIO | 9.22 | 9.327 | 91 | 68.9±2.1 | M11–4 |
| 107 | BIO | 8.87 | 8.792 | 89 | 67.6±2.0 | M12–4 |
| | HBL | 1.061 | 1.007 | 69 | 69.2±2.1 | |
| 108 | BIO | 8.96 | 9.215 | 92 | 70.1±2.1 | T45–4 |
| | HBL | .926 | .9916 | 48 | 72.9±2.9 | |
| 109 | BIO | 9.26 | 8.817 | 85 | 65.0±2.0 | T61–4 |
| 110 | BIO | 9.64 | 9.354 | 90 | 66.2±2.0 | T63–4 |
| 111 | BIO | 9.01 | 9.187 | 94 | 69.5±2.8 | T62–4 |
| | MUS | 10.69 | 11.14 | 89 | 71.0±2.1 | |
| 112 | BIO | 9.07 | 9.601 | 93 | 72.1±2.2 | T9–4 |
| | HBL | 1.059 | 1.145 | 85 | 73.6±2.2 | |
| 112A | BIO | 8.92 | 7.716 | 94 | 59.1±1.8 | TA–6 |
| 113 | BIO | 9.48 | 9.451 | 54 | 68.0±2.0 | T60–4 |
| 114 | BIO | 9.62 | 10.12 | 96 | 71.6±2.1 | T8–4 |
| 115 | BIO | 9.12 | 9.264 | 84 | 69.2±2.1 | T52–4 |
| 116 | BIO | 9.29 | 9.550 | 94 | 70.0±2.1 | T51–4 |
| 116A | BIO | 9.15 | 9.412 | 91 | 70.1±2.1 | M15–7 |
| 117 | BIO | 9.15 | 9.358 | 90 | 69.7±2.1 | T59–4 |
| 118 | BIO | 9.11 | 9.381 | 93 | 70.1±2.1 | T58–4 |
| 119 | BIO | 8.95 | 9.546 | 93 | 72.6±2.2 | T56–4 |
| 120 | BIO | 9.18 | 9.499 | 94 | 70.5±2.1 | T57–4 |
| 121 | BIO | 9.06 | 9.003 | 86 | 67.7±2.0 | M16–4 |
| 122 | BIO | 9.52 | 9.996 | 91 | 71.5±2.1 | M18–4 |
| 123 | BIO | 9.13 | 10.85 | 90 | 80.7±3.2 | M17–4 |
| 123A | BIO | 9.08 | 15.65 | 85 | 116±3.5 | M13–7 |
| | HBL | .564 | 15.15 | 63 | 178±5.3 | |
| 123B | BIO | 9.37 | 21.66 | 86 | 154±4.6 | M14–7 |
| | HBL | .517 | 1.312 | 38 | 168±5.0 | |
| 124 | BIO | 9.72 | 10.21 | 87 | 71.5±2.1 | M4–4 |
| 125 | BIO | 9.26 | 9.264 | 82 | 68.2±2.0 | M5–4 |
| | HBL | .916 | .9844 | 77 | 73.1±3.7 | |
| 126 | BIO | 9.28 | 9.862 | 93 | 72.3±2.2 | M43–4 |
| 127 | BIO | 9.60 | 10.01 | 94 | 71.0±2.1 | M25–4 |
| | HBL | .727 | .7633 | 60 | 71.5±2.1 | |
| 128 | BIO | 9.22 | 10.08 | 77 | 74.4±2.2 | M42–4 |
| | HBL | .769 | 1.502 | 72 | 131±3.9 | |
| 129 | BIO | 9.10 | 9.094 | 90 | 68.1±2.0 | T19–4 |
| | MUS | 10.75 | 11.24 | 95 | 71.2±2.1 | |
| 130 | BIO | 9.37 | 13.10 | 96 | 94.6±2.8 | M22–4 |
| 131 | BIO | 9.56 | 10.40 | 94 | 74.0±2.2 | M24–4 |
| 132 | BIO | 8.99 | 14.60 | 85 | 109±3.3 | M44–4 |
| 133 | BIO | 9.31 | 10.75 | 94 | 78.5±2.4 | M20–4 |
| | HBL | .996 | 1.608 | 74 | 109±6.5 | |
| 133A | BIO | 9.26 | 17.35 | 95 | 126±3.8 | M12–7 |
| | HBL | .649 | 1.628 | 63 | 166±5.0 | |
| 134 | BIO | 8.86 | 16.05 | 96 | 122±5.4 | M21–4 |
| 135 | BIO | 9.36 | 21.62 | 95 | 154±4.6 | M47–4 |
| 136 | BIO | 8.70 | 21.31 | 97 | 163±4.9 | M45–4 |
| | HBL | .635 | 1.551 | 69 | 162±4.9 | |
| 136A | BIO | 8.79 | 19.59 | 83 | 148±4.4 | M96–7 |
| | HBL | 0.472 | 1.312 | 56 | 183±5.5 | |

[1]With pyrex flux.
[2]Recollected.
[3]Replicate.
[4]11 percent pyroxene.
[5]15 percent pyroxene.

The experimental precision of the dating method for most samples is 2–3 m.y. This precision justifies a contour interval no smaller than 5 m.y. In places such as the southern Mojave Desert and most of the San Bernardino Mountains, the apparent age gradient is so low that the detailed configuration of features generated by contouring the apparent ages may or may not be real. This area was first contoured using a 5-m.y. interval. The overall trends and positions of apparent-age highs and lows were basically the same as shown on plate 1*C*, but visually these features did not show up well. We therefore used the 2-m.y. interval on plates 1*C* and 1*D* simply to graphically accentuate the location and basic trends of apparent-age highs and lows in areas with low apparent-age gradients. Little value should be placed on the detailed configurations of individual features in these areas. Except for the apparent-age high between Big Bear Lake and Lake Arrowhead, the total apparent-age range in this area is only about 7 m.y.

All the apparent ages were computer contoured to test the objectivity of the hand contouring. Even though basic forms and trends of the contours generated by the two methods did not differ significantly, the hand contouring is preferred because the available computer program was not able to create a grid sufficiently detailed so that a contour of some particular value consistently passed exactly through and not just near a sample locality yielding that age. In addition, around the margins of the area, where the concentration of data points decreased, the computer-generated contour maps showed unjustifiable creativity.

Within the area of anomalous cooling ages bounded by the discordant age zone, the apparent potassium-argon age of any particular rock seems to be a function of location and is independent of the composition, rock type, and age of emplacement. The apparent ages within this area can be contoured so that they show a regular and orderly change from place to place. These changes are both within and across the boundaries of individual plutons so that the configuration of the contours shows little or no relation to the shape of the individual plutons.

The systematic relation between apparent age and geographic locality is true only for the completely reset apparent ages, not for the entire area covered by the contours on plates 1*C* and 1*D*. The justification for contouring the apparent ages lies in the assumption that the entire contoured region at some point in geologic time underwent a thermal event that affected all existing rocks, and that the event caused all radiogenic argon existing at the time to be outgassed. This assumption, though partly justified for some of the region, is obviously not entirely justified for the region as a whole. Outside the zone of discordance, for example, the rocks are only slightly or not at all affected by the thermal event, and from the zone of discordance, the rocks were only partly outgassed. With a few possible exceptions discussed in a later section, the rocks within the area enclosed by the discordant zone were probably outgassed fairly completely at the time of the thermal disturbance, because coexisting mineral pairs commonly give concordant or near-concordant numbers, and because known Precambrian and Permian to Triassic rocks give the same Cretaceous apparent ages as the surrounding younger plutonic rocks.

The contours may reflect not just a simple cooling pattern for a uniform thermal disturbance but the actual or relative chronology of the disturbance from place to place, the completeness of outgassing from place to place, or some combination of these. Probably the contours within the area of anomalous cooling ages are a reflection of all the factors mentioned. Within the discordant zone, the contours must be interpreted differently than those within the zone of anomalous cooling history, and outside the discordant zone, where the ages may approach emplacement ages, they cannot be contoured. Using only the potassium-argon method, it is not possible to determine whether the thermal disturbance began and developed uniformly over the entire region at the same time, although the method can furnish information on how the disturbance ended and in approximately what span of time.

## THE ZONE OF DISCORDANT AGES

The zone of discordant ages is one of the more obvious features defined by the contours. It ranges in width from about 6 km to at least 12 km. On the contour maps, plates 1*C* and 1*D*, most of the zone is shown with a stippled overprint. The inner margin is poorly defined because it is gradational. Therefore, the shaded overprint is shown only from the 80-m.y. contour where the contour interval jumps from 2 m.y. to 10 m.y. We chose the 80-m.y. contour as marking the beginning of the discordant zone, because beyond that contour, the apparent ages of the reset rocks rise rapidly, and the discordance between coexisting hornblende and biotite increases markedly.

Where best defined, the zone shows an extremely steep gradient in the center two-thirds that declines rapidly to less steep gradients both toward the "emplacement ages" on the outside and the more completely reset apparent ages on the inside. The zone is well developed north of the Pinto Mountain fault between Yucca Valley and Twentynine Palms for a distance of about 40 km north of the fault where it intersects the Camprock fault. Along this 40-km segment, the zone trends north-northwest except at the southeast end, where it appears to swing sharply eastward. As the eastward swing is controlled by only one apparent age (sample 136A), the validity of this change in strike of the contours is not well established.

At present, only six apparent ages have been determined east of the Camprock fault, enough to locate the zone but not enough to establish the trend on the east side of the fault (see pl. 1*D*).

About 25 km north of where the zone intersects the west side of the Camprock fault, it is again seen on the west side of the fault, but in this segment, the overall trend, though sinuous, is more easterly oriented. The zone is fairly well defined westward for about 50 km but appears to be offset by the Johnson Valley-Lenwood and Helendale faults (pl. 1*D*). West of the Mojave River, alluvium cover over a large area precludes sampling, so it is not known if the zone continues westward. If it does, the contours must bend sharply northward or southward to carry the zone around the collection of 67-m.y. to 83-m.y. apparent ages between Lancaster and Victorville. It is not known if those apparent ages fall inside or outside the discordant zone, although if the manner in which the contours are drawn in this area on the maps is approximately correct, then these apparent ages should be south of the discordant zone. The location of the east-trending part of the zone beyond where it is shown on plates 1*C* and 1*D* is not precisely known. Reconnaissance dating of granitic rocks to the north suggests that the zone may turn sharply back on itself, forming a roughly west-pointing prong of relatively "older" apparent ages that has an axis just north of where the zone is shown on plate 1*C*. The apparent-age high of relatively low gradient defined by the cluster of ages between Victorville and Lancaster could reflect the westward projection of this axis. Dating in the northern Mojave is not complete enough as yet, however, to preclude the possibility of the zone turning again and intersecting either the Garlock or the San Andreas fault. It is also not known where the zone continues south of the Pinto Mountain fault at the opposite end although some samples have been taken from that area.

Control for the east-trending segment of the discordant zone is not so good as for the north-northwest-trending segment because the apparent ages used for the contouring are on rocks that may have a considerable range in age of emplacement. Samples 79B (71 m.y.), 101 (76 m.y.), and 103 (74 m.y.) in particular may have considerably younger emplacement ages than most of the samples contoured to define the discordant zone. If the apparent ages that define the discordant zone are measured on rocks from plutons that have a range in emplacement ages, the contours generated by these apparent ages may be misleading. This is particularly true where the rocks were only partially reset as they are in the discordant zone, and where the range in emplacement ages is considerable. Since the rocks within the zone were not completely outgassed at the time of the thermal disturbance, they were not reset to a common starting point, and since they are of different emplacement ages, there was no common initial starting point. Contouring the apparent ages is essentially a graphic method of comparing one apparent age to another, but for samples from within the discordant zone that were not completely reset and that did not have the same emplacement age, it may be a case of comparing apples and oranges.

Some control on this problem, however, is provided by an easily recognized porphyritic hornblende-biotite granodiorite and a group of highly mafic bodies that are widely distributed in the eastern and northeastern part of the area shown on plates 1*C* and 1*D*. These rocks were emplaced during at least two, and possibly several, periods of plutonism that appear to be separated by a relatively short period of geologic time. They therefore provide at least a somewhat common starting point to compare degrees of resetting. The maximum time span between the beginning of emplacement and the end could be as much as 50 m.y., but it is probably closer to 30 m.y. Even though these rocks are not reset from a single emplacement age, the difference in emplacement ages is small compared to the time interval represented by the difference between emplacement age and reset apparent ages.

The porphyritic granodiorite yielded apparently concordant hornblende and biotite ages of 162 and 163 m.y., respectively, from a sample (No. 136) outside the discordant zone. There is some question, however, as to whether the 162-m.y. hornblende age is valid, because sample 136A, from the same pluton, yielded a hornblende age of 183 m.y. and a biotite age of 148 m.y. It was discovered after sample 136 was analyzed that many hornblendes from this region are highly refractory and do not release all radiogenic argon at standard laboratory fusion temperatures. Because the amount of hornblende remaining from sample 136 was insufficient for a reanalysis, sample 136A was collected from freshly blasted outcrops close to the original locality. This sample and sample 123B from the same pluton, which yielded apparent ages of 154 m.y. on biotite and 168 m.y. on hornblende, were analyzed after the refractory nature of the hornblende was discovered. The argon was extracted at higher than normal temperatures. Because these later samples yielded lower biotite and higher hornblende apparent ages than the corresponding minerals from sample 136, it is thought that the hornblende from sample 136, if reextracted, would yield an apparent age exceeding 168 m.y., and probably greater than 183 m.y.

Samples 123B, 136, and 136A are the only representatives of the porphyritic hornblende-biotite granodiorite from which coexisting hornblende-biotite pairs have been analyzed. Samples 100, 104, and 123 are from this plutonic rock type, but only biotite was analyzed from them. Only biotite was analyzed from samples 75 and 135, which have strong lithologic similarities to the porphyritic hornblende-biotite granodiorite but may or may not be the same genetic unit.

The highly mafic bodies, which have wide distribution in the eastern and northeastern parts of the area, yield biotite apparent ages that range from 74 to 145 m.y., and hornblende apparent ages that range from 109 to 199 m.y. years. Figure 3 illustrates the degree to which hornblende is more retentive of argon than biotite in these samples. The cluster or hornblende apparent ages between 163 and 199 m.y. represents rocks that have been reset varying degrees, as indicated by the much wider scatter of coexisting biotite apparent ages.

Of 24 apparent ages on biotite from samples unquestionably within the discordant zone, 5 (samples 100, 104, 123, 123B, and 136 A) were from the porphyritic hornblende-biotite granodiorite, and 14 (samples 72, 73, 73D, 75, 76, 78, 78A, 78B, 78C, 79, 81, 122, 133, and 134) were from mafic plutonic types that are probably from 160 m.y. to more than 200 m.y. old on the basis of their apparent potassium-argon ages. Six samples either in or on the periphery of the zone were from plutons of unknown age; none of the apparent ages within the zone that were used in the contouring were on rocks known to be post-Jurassic in age. Samples 73A and 73B purposely were not used in the contouring because they are both from a pluton that is probably about 75 m.y. old.

The outer limits of the discordant zone are not well defined because the apparent age gradient becomes progressively less steep away from the center of the zone. The discordant ages in the outermost part of this zone probably grade very gradually into concordant near-emplacement ages over a distance of as much as 10 km. Samples 134, 135, 136, and 136A and their contours appear to be representative of this gradation. The gradient between samples 134 and 135 is very steep but changes sharply somewhere near sample 135, then rises very gradually for 20 km eastward to the apparently near emplacement age at 136.

#### AREA OF ANOMALOUS COOLING AGES

Apparent ages on biotite from samples collected within the area enclosed by the discordant zone range from a low of 57 m.y. in the San Gabriel Mountains to a high of 82 m.y. in the San Bernardino Mountains. The

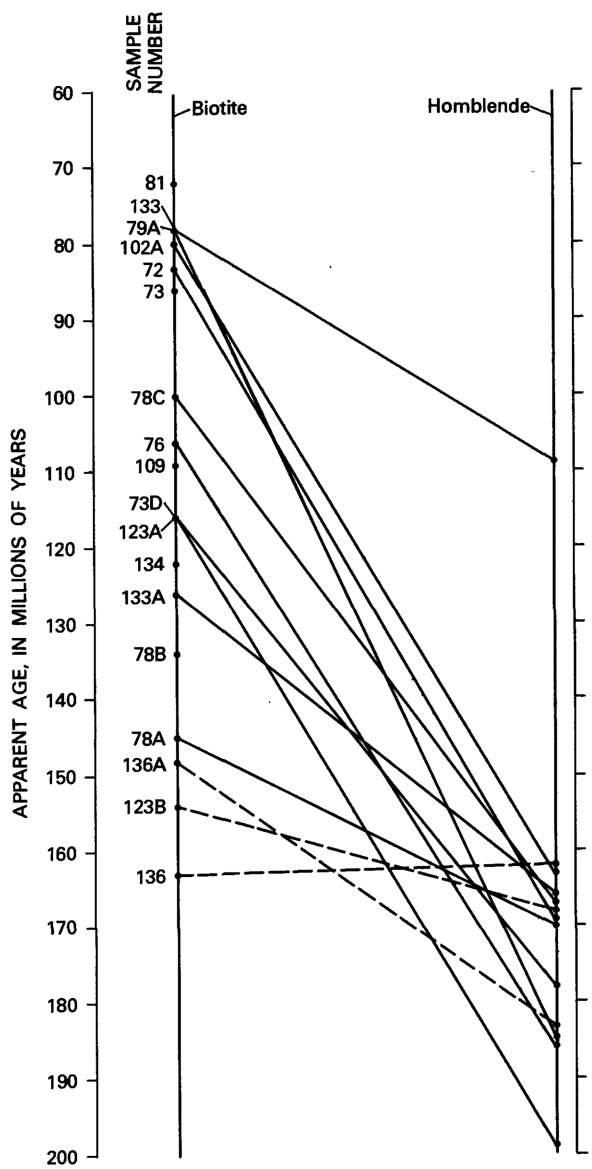


FIGURE 3.—Apparent ages of coexisting hornblende-biotite pairs from pre-Cretaceous rocks. Line from labeled biotite sample connects coexisting hornblende. No line indicates only biotite dated; dashed lines connect samples from the porphyritic hornblende-biotite granodiorite.

99-m.y. and 88-m.y. biotite ages on samples 1 and 1A, respectively, are not included in this discussion because there may be a large fault separating the basement rocks of the Santa Monica Mountains, where the two samples were collected, from the basement rocks of the San Gabriel Mountains to the east.

The spacing between samples in most of the San Gabriel Mountains is close enough that the contours accurately portray the arcuate trough in the center of the range. The small apparent-age high located just east of the trough is probably real, but the northern prong defined by the 72-m.y. contour may not be.

Except for the northwest-trending apparent-age high in the western San Bernardino Mountains, the detailed configuration of features defined by the contours east of the San Andreas fault may or may not be real. The gradient of the contours is so low that the experimental error of the dating method is great enough to change the details of these features in many places. Even though the detailed configuration may be different than shown, the existence, location, and general trends defined by the apparent-age highs and lows probably are real. In the eastern half of the San Bernardino Mountains, for example, the 66-m.y. and 68-m.y. troughs and the 72-m.y. high that separates them are probably real, although the actual shape of these features and their exact magnitude may be slightly different than shown.

The east-west structural trends characteristic of the Transverse Ranges are prominently reflected by the apparent-age contours in the southern part of the San Gabriel Mountains and show up well on both contour maps. The northwest trends in the northeasternmost part of the range (pl. 1*C*) may or may not be real because they were generated by including apparent ages from samples on the northeast side of the San Andreas fault. If the displacements proposed for the San Andreas fault are accurate (Hill and Dibblee, 1953; Crowell, 1962; Ehlig, 1968; and Ehlert and Ehlig, 1977), the trends within the San Gabriel Mountains generated by using apparent ages on the northeast side of the fault are probably not real. Contours using only ages within individual blocks (pl. 1*D*) show only eastward trends in the eastern San Gabriel Mountains and may more accurately portray the real trend of the contours than the map using all biotite ages. This may obtain in the southern San Bernardino Mountains south of the Santa Ana Canyon fault where the contours show a fairly pronounced east trend on line with the east trends along the front of the San Gabriel Mountains. The gradient of the contours south of the fault in Santa Ana Canyon, as shown on plate 1*D*, however, is so shallow that these trends may or may not be real.

Most of the control for the trough of low ages near the intersection of the Pinto Mountain and north branch of the San Andreas fault (pl. 1*C*) is from a single date on a sample (112A) collected south of the San Andreas fault. The contours were drawn to connect this relatively young apparent age with the area of young apparent ages northeast of the San Andreas fault. The contour pattern generated by connecting these two areas may be misleading, however, as the geologic setting in the area of sample 112A is the same as that in the eastern San Gabriel Mountains and not the same as that on the northeast side of the San Andreas fault. The entire block bounded by the San Andreas, San Jacinto, and Banning faults appears to have been displaced southeastward along the San Jacinto fault.

## EMPLACEMENT OR NEAR-EMPLACEMENT AGES

Only six samples, 136, 136A, 123B, 78A, 73B, and 1, have yielded dates that approach concordance and may be close to emplacement ages; three others, 135, 100, 73A, on the basis of their position relative to the discordant zone, might yield near-concordant potassium-argon ages if coexisting minerals were dated or were available to be dated. The paucity of concordant numbers outside the discordant zone is in part misleading owing to the fact that the zone of discordance lies near the limit of our sampling. It is not known how far east or northeastward the rocks will yield emplacement or near-emplacement potassium-argon ages, although Lanphere (1964) reports a 1,190-m.y. potassium-argon apparent age on biotite from a sample taken in the Marble Mountains, about 60 km northeast of the locality of our sample 136. The same rock yielded a $^{206}Pb/^{238}U$ zircon age of 1,450 m.y. (Silver and McKinney, 1963). The 18-percent difference between the lead-uranium age and the potassium-argon apparent age is probably produced by contact effects of nearby mesozoic plutonic rocks on the biotite; if it is, then the plutonic rocks in the Marble Mountains do not reflect the regional resetting found west of the discordant zone.

The ambiguity of sample 136 yielding an apparently concordant age, 163 m.y. on biotite and 162 m.y. on hornblende, is discussed in the section on the discordant zone. The emplacement age of this rock is probably greater than 183 m.y. as indicated by the apparent hornblende age from sample 136A.

The 170-m.y. apparent age of hornblende from sample 78A may be approaching the emplacement age of that rock, because the coexisting biotite yielded an apparent age only 25 m.y. younger. The pluton from which this sample was taken is a medium-grained hornblende-biotite granodiorite. It is texturally and modally different from the porphyritic hornblende-biotite granodiorite of sample 136, but because of their close apparent ages, the two plutonic types may have been emplaced at about the same time.

Sample 73B (75 m.y., biotite;) 72 m.y. hornblende is a leucocratic hornblende-biotite quartz monzonite that yielded a concordant age that probably is close to the emplacement age of the rock. Sample 73A, 76 m.y., biotite, is from the same pluton, but only biotite was dated from this sample. Note that not all granitic rock outside the zone of discordance is necessarily old—in the 150-m.y. to 200-m.y. range. Samples 73A and 73B are cases in point; both were collected from a relatively young pluton that is near the limits of the thermal disturbance. Because they are younger than the rocks whose apparent ages are used in the contouring, and because contouring of apparent ages outside the discordant zone has essentially no meaning, these younger apparent ages have not been used in any of the contouring.

### OTHER ANOMALOUS FEATURES OF THE APPARENT AGES

The relative ability of hornblende and biotite to retain radiogenic argon at elevated temperatures is well documented both experimentally (Mussett, 1969) and empirically (Hart, 1964; Hanson and Gast, 1967; Miller and Engels, 1975). In almost all cases, if coexisting hornblende and biotite give discordant apparent ages, the hornblende will give the older age of the two. Hart (1964) and Mussett (1969) in particular showed that over a fairly wide range of temperatures, hornblende is much better able to retain radiogenic argon at any given temperature within that range.

The refractory character of hornblende is particularly well demonstrated in samples from the report area. After most of the hornblende-biotite pairs had been dated, it became apparent that an unusually large number of them (about 35 percent) gave results in which the hornblende was younger than the biotite by 3 m.y. or more. When checks on analytical procedures were made, we discovered that many of the hornblendes dated were extremely refractory and were not completely melting during the argon-extraction process. As a result, all hornblendes for which a sufficient amount of sample remained were reextracted at much higher than normal melting temperatures for much longer than normal melting times, and for one sample, sample 1, a flux of pyrex glass was used to insure that melting was absolutely complete. Samples were recollected at a few localities and new mineral separates prepared. Most of the new determinations on hornblende gave apparent ages that were as old or older than coexisting biotite.

Three of the 45 hornblende-biotite pairs still gave apparent hornblende ages younger than the coexisting biotite. Even though the amount by which the hornblende was "younger" than the biotite is less than the analytical error of the method, we considered it significant that 7 percent of the pairs showed a bias in the direction opposite that which is normal for this mineral pair.

Although only three of the redetermined samples, 31, 54, 73B, gave apparent hornblende ages that showed the reversal, the amount of sample remaining was insufficient to redetermine ages on five other samples, 25, 50, 52, 101, and 136. Recollection and redetermination of these five samples may or may not remove the unexpected hornblende-biotite apparent age reversal; nonetheless, the three results obtained appear to have well-established reversals that are real.

In southern California, this reversal phenomenon appears to be limited to rocks from the San Gabriel Mountains and from east of the San Andreas fault. Of about 30 discordant ages on coexisting hornblende-biotite pairs reported by Krummenacher, Gastil, Bushee, and Douport (1975) from the Peninsular Ranges province, southern California, hornblende is in all cases older than the coexisting biotite. Even more detailed dating by F. Miller, D. Morton, and C. Smith (unpubl. data, 1979) and by V. Todd and W. Hoggatt (oral commun., 1977) in the northern part of the Peninsular Ranges bear out the apparent absence of hornblende-biotite apparent-age reversals in that province. Possible exceptions to this generalization are near-concordant ages reported by Dalrymple (1976) from two samples of the San Marcos Gabbro on the west side of the Peninsular Ranges that show the apparent hornblende-biotite reversal. The complete absence of reversals in all other potassium-argon dating done in the Peninsular Ranges suggests that the argon extractions on these two hornblendes may not have been at high enough temperatures for long enough periods to obtain all radiogenic $^{40}Ar$.

Reversals in southern California have been reported on 20-m.y.-old plutonic rocks from the Chocolate Mountains southeast of the Salton Sea on the east side of the San Andreas fault (Miller and Morton, 1977). In all samples dated, hornblende was younger than coexisting biotite, but the difference was small enough that all dates were concordant. It is not known if the age reversal in these rocks is produced by refractory hornblende, however, because the refractory nature of hornblendes from southern California rocks was not known when the paper was published.

The most refractory hornblendes appear to come from two groups of rocks: (1) hornblende-biotite rocks in which the hornblende-biotite ratio is near one or greater than one and (2) rocks that show cataclasis. The rocks having near one or greater than one hornblende:biotite ratio generally have a higher color index than rocks that contain relatively nonrefractory hornblende. Only one of the relatively leucocratic quartz monzonite plutons with a low hornblende:biotite ratio, sample 73B, may contain anomalously refractory hornblende. Since this is one of the samples that was not rerun, it is not known if the hornblende is unusually refractory or if it indeed is yielding an apparent age lower than the coexisting biotite. Rocks that show signs of cataclasis, particularly in the San Gabriel Mountains, contained refractory hornblende; samples 19 and 46 are examples.

In addition to the samples showing hornblende-biotite reversals, a few other samples yielded unexpected apparent ages that warrant explanation or at least mention. Sample 13 is a highly porphyritic biotite-bearing phase of the Mount Lowe Granodiorite of Miller (1926). It contains no hornblende, but it does contain small amounts of muscovite, which is probably a late-stage primary mineral or could be secondary. Because the 6-m.y. difference in the biotite-muscovite apparent ages, regardless of the origin of the muscovite, is outside the error of our measurements, the pair should be considered discordant.

Samples 22 and 22A were collected within 100 m of one another; not only did both give discordant ages, but the difference in hornblende ages—29 m.y. (22, 118 m.y.; 22A, 147 m.y.)—is greater than might have been expected from samples collected so close together. Although both rocks are hornblende-biotite diorite, sample 22A is almost a hornblendite; it has a color index of about 80, whereas sample 22 has an index of 50. Sample 22A is also slightly coarser grained than 22 and in places exhibits pegmatitic textures. The difference in the apparent ages yielded by the hornblendes could be a function of differences in emplacement ages although both samples appear to be no more than different phases from a single contiguous body. Most likely, the difference in apparent ages is a result of differences in the structure of the hornblende crystals of each sample and their relative ability to retain argon under conditions conducive to partial outgassing of the argon.

Samples 8 and 40 also yielded discordant hornblende-biotite pairs, although sample 40 is barely discordant by our definition. Both of these samples are relatively mafic hornblende-biotite granodiorites, and both contained hornblende that was highly refractory. Samples 59 and 89 from the San Bernardino Mountains are both discordant, but they are surrounded on all sides except the south by concordant reset ages.

The samples from localities 8, 13, 22, 59, and 89 yield discordant apparent ages; they may indicate a transition from a zone of concordant anomalous ages to a discordant zone similar to that found north and east of the San Bernardino Mountains. However, the lack of datable material northwest of localities 8 and 13 and the fault boundary and local structural complications south of localities 22, 59, and 89 make it impossible to test this hypothesis. It is not known why sample 40 is discordant, as it appears to be in a part of the area of anomalous ages where the resetting is fairly complete. Sample 37, only 16 km to the northwest, is a gneiss of probable Precambrian age, but it gives an apparent biotite age of 72 m.y.

Sample 85, taken northwest of Big Bear Lake in the San Bernardino Mountains, is from a mafic hornblende-biotite monzonite that appears to differ chemically and petrologically from all other plutonic rocks in the San Bernardino Mountains. The rock contains 18 modal percent less quartz than the average for all plutonic rocks in the range, and plots well off the apparent differentiation curve for all other plutonic rocks in the range. Much of the hornblende in this rock has a core of partly altered pyroxene that could not be separated completely from the hornblende. Two splits of different purity (determined by grain counts of separates in immersion oils) were analyzed for argon; one with 11 percent pyroxene gave an apparent age of 126 m.y.; and the other, with 15 percent pyroxene, gave an apparent age of 197 m.y. Because of these results and past experience where pyroxene yielded anomalously old potassium-argon ages (see Engels, 1975; and Dalrymple and Lanphere, 1969, p. 125), the hornblende apparent ages obtained for this sample are not considered indicative of emplacement age or degree of resetting by a younger thermal event, even though the rock is probably older than the biotite apparent age indicates (see Miller, 1976).

## INTERPRETATION OF APPARENT POTASSIUM-ARGON AGES

With the possible exception of samples from a few restricted areas, the potassium-argon apparent ages of rocks surrounded by the zone of discordance appear to be the result of almost complete resetting by a thermal disturbance that culminated in Late Cretaceous to early Tertiary time. Three independent lines of evidence point up the degree to which the completeness of the resetting has occurred.

1. Rocks known to be much older than their potassium-argon ages indicate resetting similar to that of the Mesozoic plutonic rocks. Samples 94 and 110 from the Precambrian Baldwin Gneiss of Guillou (1953) yield Cretaceous potassium-argon apparent ages that fit exactly the contoured apparent ages for the surrounding Mesozoic granitic rocks. Sample 94, in fact, yielded concordant potassium-argon apparent ages on coexisting muscovite and biotite. The Precambrian age of the Baldwin Gneiss is well established on the basis of a lead-uranium date on zircon (1750 m.y., Silver, 1971) and because it is unconformably overlain by late Precambrian and Paleozoic sedimentary rocks (Stewart and Poole, 1975). Sample 37 from the San Gabriel Mountains and samples 59A and 116A from the San Bernardino Mountains are from unnamed gneisses of probable Precambrian age. All of these samples give Cretaceous apparent ages that fit the contouring of the Mesozoic granitic rocks. Sample 79 is from a hornblende-gneiss of probable Precambrian age

in the Mojave Desert. Although it gives an age about 20 m.y. older than what a biotite would be predicted to yield at that locality, it is located only about 3 km from the steep gradient of the discordant zone, and therefore it is probably strongly reset.

2. Coexisting mineral pairs within the area enclosed by the discordant zone in general yield concordant or near-concordant ages. Many of these concordant ages are on rocks known to be much older than the measured potassium-argon age on the basis of lithologic correlation with rocks outside the reset area.

3. The apparent ages yielded by different samples from the same pluton are dependent on where in the pluton the samples were collected. The form of the contours generated by these apparent ages shows no relation to the configuration of the pluton, nor does the form of the contours of all the apparent ages in the region show any relation to the configuration of any single pluton. A large quartz monzonite pluton that occupies most of the area between Lake Arrowhead and Big Bear Lake is an excellent example to illustrate the range of apparent ages yielded by a single plutonic body. Samples 60 (66 m.y.), 87 (70 m.y.), 86 (71 m.y.), 88 (74 m.y.), and 91 (70 m.y.) were all collected within this pluton, and sample 93 (68 m.y.) was collected from a slightly more mafic marginal phase. The 8-m.y. range in apparent ages is beyond the experimental error of our measurements, and the configuration of the contours generated by these apparent ages is independent of the shape of the pluton.

The thermal disturbance that caused such complete resetting may or may not have been associated with the emplacement of the major part of the plutonic rocks in the region. Study and limited geologic mapping of the plutons to date does not support or disprove the association. A reconnaissance examination of the plutonic rocks in the Transverse Ranges and southern Mojave Desert was made during the potassium-argon sampling. Even though the petrology, extent, and internal and contact relations of these bodies could not be studied in detail, a qualitative estimate of the rock types, their gross distribution, and their relative abundance was gained. On the basis of petrologic associations and geologic relations with dated rocks outside the discordant zone, it is felt that many of the plutons in the area enclosed by the discordant zone east of the San Andreas were emplaced 70–80 m.y. ago. These plutons, voluminous in the San Bernardino Mountains and smaller and more widely scattered in the Mojave Desert, consist of biotite quartz monzonite to granodiorite. They are clearly younger than most, if not all, other plutonic rocks in that region. Where intrusive relations with other granitic rocks are exposed, these plutons clearly intrude the other rocks. They have almost no internal structures such as foliation or lineation and commonly crosscut these structures in older plutonic rocks. These younger bodies, in most cases, are considerably more leucocratic than the plutonic rocks they intrude.

The chief line of evidence supporting the association between the resetting and the relatively young plutonic rocks just described (Cretaceous) is the coincidence of the large area of "young" apparent ages in the San Bernardino Mountains, and three probable Cretaceous plutons of almost batholithic size that form the core of the range. Even though these "younger" plutons are more widely separated in the southern Mojave Desert, they could be more voluminous at a relatively shallow depth. If they have more volume at depth, then the large reset area of anomalous ages and the enclosing discordant zone could have been produced by emplacement of this large volume of relatively young plutonic rock. The complex potassium-argon apparent-age patterns that exist at present, then, presumably result from emplacement of the relatively young plutons and resetting of older rocks by the younger bodies, compounded by a nonuniform cooling history for the region.

Two other lines of evidence, though not completely negating the presumed younger plutons in the region as being the cause of the anomalous ages, suggest that they may have a minor role, if any at all. (1) Reconnaissance potassium-argon dating by the authors and by Janet Morton of the U. S. Geological Survey suggests that the anomalous-age zone may be more extensive than is now known, extending much farther northwest, at least to the Garlock fault. In much of this area of reconnaissance dating, none of the presumed younger plutons occur. A large number of contrasting plutonic types yield approximately the same potassium-argon apparent ages, suggesting complete resetting. (2 The large area of relatively young potassium-argon apparent ages in the San Gabriel Mountains is not associated with any plutons that even approach being as young as the apparent ages. In fact, most of these rocks are probably in the 100–220-m.y. range.

The relatively young apparent ages in the San Gabriel Mountains may be a special case, however, as there appears to be a general relation between the Vincent thrust fault and other thrust faults correlated with it and areas of unusually low apparent ages in southern California. In the San Gabriel Mountains, the youngest apparent ages lie above the projection of the Vincent thrust (pl. 1*C*), and the area of young apparent ages in the Whitewater River area is above the projection of a probable correlative of the Vincent. Two alaskite masses from the upper plate of the Chocolate

Mountains thrust, a Vincent correlative, yielded 49.2 m.y. and 53.0 m.y. apparent ages on muscovite. Ehlig, Davis, and Conrad (1975) consider the minimum age of the Vincent thrust to be 52.7 m.y. on the basis of a rubidium-strontium isochron. If the relatively young rubidium-strontium and potassium-argon apparent ages are related to the thrust fault, it suggests that the potassium-argon resetting in the vicinity of the thrust may extend some distance into the upper plate; and that the thrust underlies a large part of southern California. Although there is a coincidence between exposures of the Vincent thrust and the areas of unusually low apparent ages, there is no evidence to either support or refute a relation between the resetting of the entire region and the thrust faulting.

Since the anomalous cooling ages apparently extend over such a large region, the geologic process that caused the resetting presumably operated over as great or greater an area. The anomalous cooling ages may in fact be related to continued plate motion beneath the region of resetting for an extended period after magma generation and pluton emplacement in this region had ceased (R. O. Castle, oral commun., 1978). After emplacement of plutons in the Cretaceous, continuing motion of the Pacific plate being thrust beneath the North American plate may have furnished sufficient heat to the region so that the temperature of the plutonic rocks did not fall beneath the closing temperatures of biotite, hornblende, and muscovite until latest Cretaceous or early Tertiary.

Coney and Reynolds (1977) have suggested that the regional distribution in the ages of plutonic rocks in western North America is a function of the angle at which the subducting plate plunged under the continent; that is, the shallower the plate angle, the farther inland plutons were generated and emplaced. They conclude from the distribution of ages that the angle of the plunging plate was relatively steep in the Early Cretaceous, and plutons were intruded near the edge of North America. As the angle became progressively shallower, younger plutons were intruded farther inland. Finally, about 40 m.y. ago, the angle began to steepen, and plutons were again emplaced closer to the edge of the continent. During this process, the combination of regional heating by emplacement of Cretaceous plutons and continued heat generation by the downgoing Pacific plate at progressively shallower levels may have kept the crystalline rocks of our sample area at a temperature too high to permit the minerals used for potassium-argon dating to retain argon.

There appears to be no relation between topography and apparent age. Even though the main part of the area of anomalous ages coincides with the San Gabriel and San Bernardino Mountains, it extends into the topographically lower Mojave Desert.

Although the significance of the association is not understood, several geologic features that occur in the Transverse Ranges may possibly be related; the zone of anomalous ages is one.

1. The mountain ranges themselves, the internal features within the ranges, and the bounding structures all aline in an eastward trend. These features have long been recognized and are well summarized by Baird, Morton, Baird, and Woodford (1974), who discuss the interdependent relations between the various east-trending features.

2. The western part of the 1959–74 southern California uplift identified by Castle, Church, and Elliott (1976) and another uplift that occurred between 1897 and 1906 (R. O. Castle, oral commun., 1978) coincide closely in form, trend, and location to the western Transverse Ranges.

3. The east-trending alinement of the mountain ranges with the Murray fracture zone has long been recognized, but the two features are considered to be only indirectly related by von Huene (1969), who has investigated the association.

4. A prominent high-velocity zone (8.3 km/sec), identified by Hadley and Kanamori (1977) utilizing P-wave delay times from natural and artificial seismic events occurring in southern California, is roughly east-trending and coincides closely with the location of the Transverse Ranges. This zone, which they interpret to be at a depth of about 40 km beneath the Transverse Ranges, crosses the San Andreas fault and is neither offset by the fault nor shows any reflection of the fault. The high-velocity zone, which appears to be an extremely fundamental feature, may represent the link between the Transverse Ranges and Murray fracture zone, suggested by von Huene (1969, p. 475), "Possibly a fundamental lineament in the crust, an extension of the Murray, inactive since at least the mid-Tertiary, provided a convenient trend for development of the Transverse Ranges in response to deformation along the San Andreas fault system." Since the Tranverse Ranges and the Transverse Ranges structures cross the San Andreas fault, and because the Transverse Ranges structures and the San Andreas fault are contemporaneously active and have been for some time, it would appear that whatever controls development of the Transverse Ranges structures is of a nature fundamental enough to persist at depth on both sides of the San Andreas fault despite continued movement on the fault.

The high-velocity zone identified by Hadley and Kanamori crosses the San Andreas, and in a similar way, so does the zone of anomalous cooling ages as shown on plate 1*C*. The configuration and extent of both the P-wave delay-time contours and the zone of anomalous cooling ages show a remarkable similarity on the east side of the San Andreas. Even some of the specific areas of minimum P-delay times correspond fairly well to areas of minimum apparent potassium-argon ages.

Although Hadley and Kanamori are able to interpret the anomalous P-delay times as indicating the relatively shallow occurrence of a high-velocity zone beneath the Transverse Ranges, the significance of the zone of anomalous ages is not clear to us beyond the speculations made in preceding paragraphs. If the similarity in configuration of the two unlike phenomena is indicative of a relation between the two, particularly a cause and effect relation, then the relation must date back to at least 60 m.y. to 70 m.y. ago because of the completeness of resetting to this general age range in the zone of anomalous ages.

#### FAULT OFFSETS OF CONTOURS

In contouring the apparent ages within individual fault blocks (pl. 1*D*), only those blocks bounded by major faults with a relatively long trace length were considered. These include the westernmost three of the major northwest-trending faults in the southern Mojave Desert, that fault system that bounds the north side of the San Bernardino Mountains, the fault in Santa Ana Canyon, the San Andreas fault, the San Gabriel fault, the Sierra Madre fault, and the frontal fault system for the San Gabriel Mountains. Only the apparent ages within an individual fault-bounded block were used for contouring that particular block; no apparent ages outside a particular block were allowed to affect the form or position of the contours within that block. Where data were particularly sparse or an interpretation particularly subjective, the contours were not extended to the boundary of the particular block.

It should be kept in mind that since the apparent-age contours are poorly understood features, all apparent offsets are at best only estimates. The contours represent the smoothed surface trace of planes of equal apparent age and the attitude of these planes is essentially unknown. If in places the planes have a low dip, then any component of vertical movement would cause a large apparent offset.

By far the best feature to indicate offsets across faults is the zone of discordance north and east of the San Bernardino Mountains. Control on the zone is relatively good, and the apparent age gradient is steep. It is not known, however, if the attitude of the contours (planes of equal age) is steep even though the gradient is steep.

The only faults intersected by the discordant zone are three in the Mojave Desert—the Helendale, the Lenwood, and the Camprock faults. At present, age control east of the Camprock fault is insufficient for contouring; therefore only the Helendale and Lenwood faults are discussed here. The contours appear to be offset by both of these faults, but the amount and sense of offset do not agree with estimates from other geologic evidence (Garfunkle, 1974).

Apparent left-lateral displacement of about 8 and 10 km is suggested by offset of the projections of the 80-m.y. and 100- m.y. contours, respectively, to the Lenwood fault. The 80-m.y. interval is well controlled by sample 79A on the east side of the fault, but samples 78B and 99 on the west side are 16 km apart. On the west side, the 80-m.y. contour is projected approximately straight, but it could curve as much as 2 km in either direction without causing a contour concentration different from that found on other parts of the map. The 100-m.y. contour has about the same degree of control as the 90- m.y. contour on the west side of the fault, but it is well controlled by sample 78C on the east side. If the contour spacing near the Camprock fault were about constant to the Lenwood fault, the projection of the 120-m.y. contour, for which there is good control on the west side of the Lenwood fault, would show about the same offset as the 100-m.y. contour.

At the Helendale fault, there appears to be a disruption of the discordant zone, but the nature and amount of offset are ambiguous. Because of the lack of control, the drawing of the contours is even more subjective here than on most of the map. As drawn, however, the 80-m.y. contour shows a left-lateral displacement of 4 km, the 80-m.y. contour 3 km, and the 100-m.y. contour 2 km. As drawn on plate 1*D*, a small embayment of 80+ m.y. apparent ages on the east side of the Helendale fault is required by sample 75. This embayment of relatively higher apparent ages is not considered to be the right laterally offset equivalent of higher apparent ages on the west side of the fault. The prong of low apparent ages north of the embayment and the rapidly increasing apparent ages north of the prong are considered more likely to be the offset equivalent of the relatively old ages on the west side of the fault. Little quantitative value is placed on any of these conflicting estimates, although the sharp bend of the contours as drawn on plates 1*C* and 1*D* suggest some sort of disruption at the fault.

S. M. Miller (oral commun., 1977) has pointed out several geologic features showing about 4 km of right-lateral offset across the Camprock fault. These features are shown on the geologic map of the Rodman Mountain quadrangle (Dibblee, 1964b) and include the contact between a tactite and quartzite unit, the west edge of a quartz monzonite pluton, and an offset body of granite and quartz monzonite. Examination of the geologic map of the Apple Valley quadrangle (Dibblee, 1960) shows about 6 km of apparent right-lateral offset of a quartz monzonite body west of Sidewinder Mountain. The quartz monzonite was checked in the field and found to be the same rock type on both sides of the fault, although this particular granitic type is fairly common at many places in the southern Mojave Desert and may or may not be the offset parts of a once-continuous body.

A petrologically distinct pluton occurs in the area where Interstate Highway 15 intersects the Helendale fault. Samples 73A and 73B were collected from this body on opposite sides of the fault. Although the pluton and its outer contacts have not been mapped in detail, inferred extent of the body precludes a right-lateral offset of more than 1 or 2 km.

These estimated offsets are considerably less than those suggested by Garfunkle (1974) and are considered to be more soundly based on the geologic evidence available. The apparent offsets of the 80- and 100-m.y. contours by the Helendale fault do not agree with estimates made from the offset plutons in either sense or amount. The apparent offset of the contours along the Lenwood fault is in the sense opposite that predicted from geologic evidence, and the amount twice as great. The most plausible explanation for the lack of agreement of both faults is that there is a component of vertical displacement on them. If it is assumed that the apparent ages are progressively more reset at depth, and that the contours dip outward from the source of the isotopic disturbance, then the block between the Helendale and Lenwood faults has been uplifted relative to the adjacent blocks. It is not possible, however, to predict the quantitative effects of vertical movement on the contours because of the lack of information on the configuration of the planes of equal age at depth. Presumably, any distortion of these planes would be most apparent in and near the discordant zone where the apparent-age gradient is greatest.

In the western San Bernardino Mountains, the prominent northwest-trending high in apparent ages could be the offset equivalent of the "nose" of high apparent ages immediately north of it on the Mojave Desert. If these two highs were once alined, the component of apparent right-lateral slip across the reverse fault system separating them would be about 15 or 20 km. If this offset is real and the apparent age lows on both sides of the east end of the same fault are real, then the amount of apparent slip across this zone decreases eastward. There is no geologic evidence to suggest a component of strike-slip movement on this fault.

The contour gradient in the vicinity of the Santa Ana Canyon fault immediately to the south is too low to define distinctive features for evaluation of possible offsets. This, however, is true for almost all of the anomalous age zone, and any of the relations suggesting offset should be considered little better than speculation, not only because the gradient of the apparent age contours is very low, but because of the unassessable effect on the contours by vertical movements across the numerous reverse faults in this part of the region.

As contoured on plate 1*C*, there is a clear break in both the contours and the style of the contours at the San Andreas fault. West of the fault, the pattern of the contours is relatively simple, an area of low apparent ages in the central part of the range flanked by a single high to the east. East of the fault, the pattern is considerably more complex and irregular, although the overall east trends occur along the southern part of the San Bernardino Mountains, just as they do along the San Gabriel Mountains west of the fault. As mentioned in an earlier section, however, the gradient of the contours in the southern San Bernardino Mountains is so low that details defined by the contours may or may not be real.

If the two areas of low apparent ages just south of the San Gabriel fault, one defined by a 60-m.y. contour and the other by a 58-m.y. contour, are separate lows, then the low defined by the 58-m.y. contour north of the fault might be the offset part of one of them (pl. 1*D*). If the San Gabriel is considered a right-lateral strike-slip fault and one of the southern lows is the offset segment of the northern one, then presumably it is the more westerly of the two, which would entail a right-lateral separation of roughly 10+ km. The density of control points on the north side of the fault is so low, however, that the suggested correlation of the lows is speculative at best.

## HISTOGRAMS

The histograms shown in figure 4 are probably a fair representation of the relative abundance of potassium-argon apparent ages for the plutonic rocks in the region because the region was sampled in a fairly uniform manner. No particular type or emplacement-age group was preferentially sampled, but, inescapably, most of the plutonic rocks are of Mesozoic emplacement age.

The data show a prominent cluster of apparent ages between 65 m.y. and 75 m.y., with a prominent peak at about 70 m.y. Almost all of the apparent ages that make up this cluster are from the zone of anomalous ages, and most of those trailing off from 90 m.y. to 199 m.y. are from within, or just outside, the discordant zone. If more samples were available from outside the discordant zone, and if the uniform sample distribution were maintained, probably another peak would appear

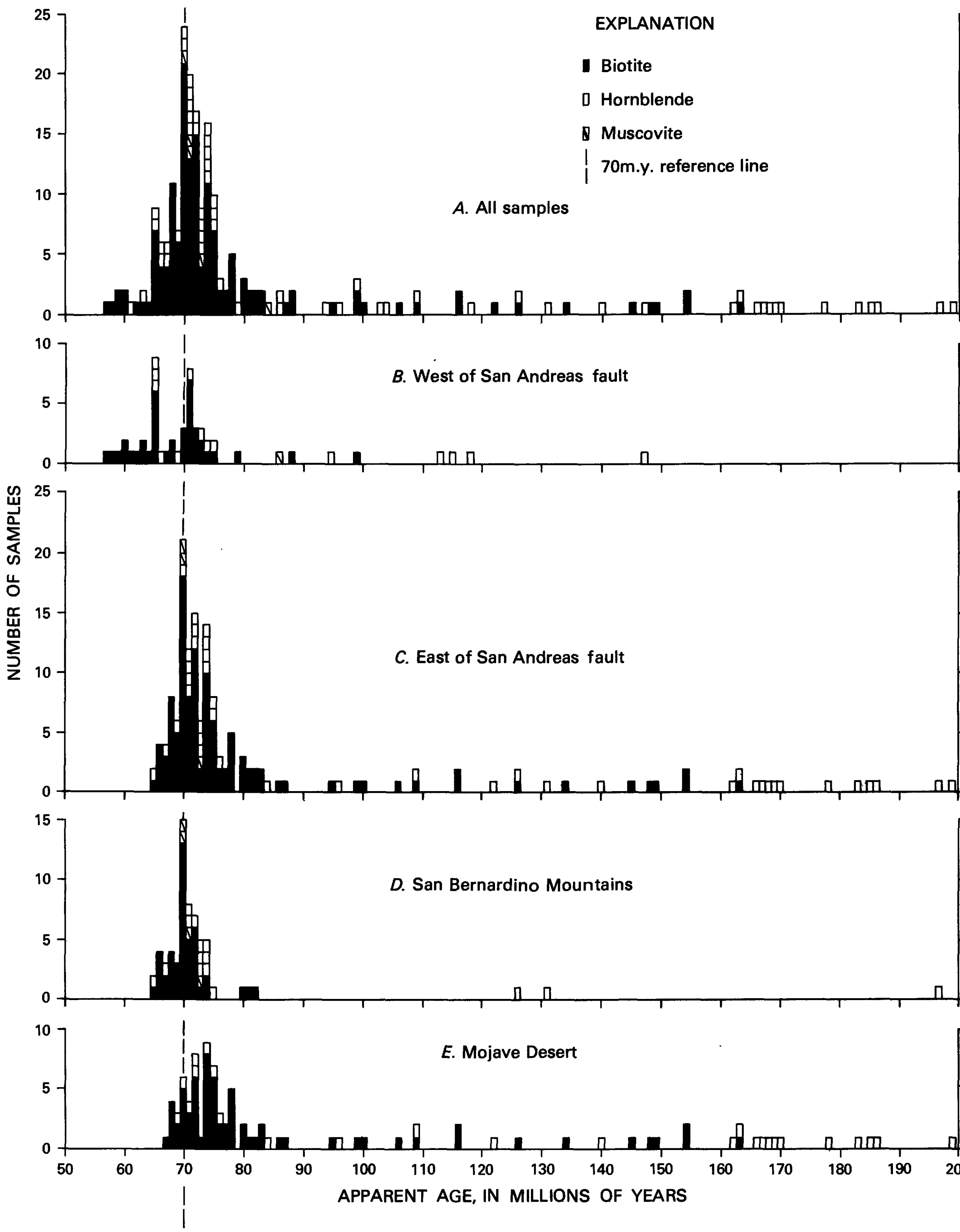


FIGURE 4.—Relative abundance of potassium-argon apparent ages of plutonic rocks in the eastern Transverse Ranges and southern Mojave Desert (*A*) and in selected structural subdivisions (*B–E*).

between 160 m.y. and 200 m.y., the number of ages around 75 m.y. would increase, and possibly a cluster of ages between 200 m.y. and 220 m.y. would appear.

The form of figure 4*C* points out the gradation from the zone of anomalous ages through the discordant zone to essentially emplacement ages on the east side of the San Andreas fault; no such transition exists on the west side (fig. 4*B*). The difference is more striking when it is remembered that the two oldest apparent ages on 4*B* are from essentially the same locality. Almost all the apparent ages older than the main cluster on the east side of the San Andreas fault are from the Mojave Desert (compare figs. 4*C*, *D*, and *E*).

The main cluster of ages west of the San Andreas (fig. 4*B*) shows a distinct bimodal distribution and a slight shift of the mass as a whole toward the young direction. This shift clearly reflects the generally lower ages in the San Gabriel Mountains, and the relative paucity of apparent ages in the mid-sixties may be a function of the relatively steep gradient of the contours in this age interval. The lower age node of the bimodal distribution, however, could reflect resetting that is due primarily to the influence of the Vincent thrust fault. The higher age node and the separating trough could result from a different source of disturbance or could represent the rapid falling off of the effects of the thrust fault. In general, the histograms point up the same basic distribution of apparent ages in each of the major structural subdivisions except for those within and outside the discordant zone.

## REFERENCES CITED

Armstrong, R. L., and Suppe, J., 1973, Potassium-argon geochronometry of Mesozoic igneous rocks in Nevada, Utah and southern California: Geological Society of America Bulletin, v. 84, p. 1375–1392.

Baird, A. K., Morton, D. M., Baird, K. W., and Woodford, A. O., 1974, Transverse Ranges province-A unique structural-petrochemical belt across the San Andreas fault system: Geological Society of America Bulletin, v. 85, p. 163–174.

Beckinsale, R. D., and Gale, N. H., 1969, A reappraisal of the decay constants and branching ratio of $^{40}K$: Earth and Planetary Science Letters, v. 6, p. 289–294.

Bowen, O. E., Jr., 1954, Geology and mineral deposits of the Barstow quadrangle, San Bernardino County, California: California Division of Mines and Geology Bulletin 165, p. 1–185.

Castle, R. O., Church, J. P., Elliott, M. R., 1976, Aseismic uplift in southern California: Science, v. 192, p. 251–253.

Coney, P. J., and Reynolds, S. J., 1977, Cordilleran Benioff zones: Nature, v. 270, p. 403–406.

Crowell, J. C., 1962, Displacement along the San Andreas fault, California: Geological Society of America Special Paper 71, 61 p.

Dalrymple, G. B., 1976, K–Ar age of the San Marcos and related gabbroic rocks of the southern California batholith: Isochron West, no. 15, n.p.

Dalrymple, G. B., and Lanphere, M. A., 1969, Potassium-argon dating—Principles, techniques, and applications to geochronology: San Francisco, W. H. Freeman, 258 p.

Dibblee, T. W., 1960, Preliminary geologic map of the Apple Valley quadrangle, California: U.S. Geological Survey Miscellaneous Field Studies Map MF–232, scale 1:62,500.

——— 1964a, Geologic map of the Ord Mountains quadrangle, San Bernardino County, California: U.S. Geological Survey Miscellaneous Geologic Investigations Map I–427, scale 1:62,500.

——— 1964b, Geologic map of the Rodman Mountains quadrangle, San Bernardino County, California: U.S. Geological Survey Map I–430, scale 1:62,500.

Ehlert, K. W., and Ehlig, P. L., 1977, The "polka dot" granite and the rate of displacement on the San Andreas fault in southern California: Geological Society of America Abstracts with Programs, v. 9, no. 4, p. 415–416.

Ehlig, P. L., 1968, Cause of distribution of Pelona, Rand, and Orocopia Schists along the San Andreas and Garlock faults, *in* Proceedings of Conference on geologic problems of San Andreas fault systems: Stanford University Publications in Geological Sciences, v. 11, p. 294–306.

Ehlig, P. L., Davis, T. E., and Conrad, R. L., 1975, Tectonic implications of the cooling age of the Pelona Schist: Geological Society of America Abstracts with Programs, v. 7, no. 3, p. 314–315.

Engels, J. C., 1975, Potassium-argon ages of the plutonic rocks, section *in* Miller, F. K., and Clark, L. C., Geology of the Chewelah-Loon Lake area, Stevens and Spokane Counties, Washington: U.S. Geological Survey Professional Paper 806, p. 52–58.

Evernden, J. F., and Kistler, R. W., 1970, Chronology of emplacement of Mesozoic batholithic complexes in California and western Nevada: U.S. Geological Survey Professional Paper 623, 42 p.

Garfunkle, Zvi, 1974, Model for late Cenozoic tectonic history of the Mojave Desert, California, and for its relation to adjacent regions: Geological Society of America Bulletin, v. 85, p. 1931–1944.

Garner, E. L., Murphy, T. J., Gramlich, J. W., Paulsen, P. J., and Barnes, I. L., 1975, Absolute isotopic abundance ratios and the atomic weight of a reference sample of potassium: Journal of Research, National Bureau of Standards-A, Physics and Chemistry, v. 79A, p. 713–725.

Guillou, R. B., 1953, Geology of the Johnston Grade area, San Bernardino County, California: California Division of Mines and Geology Special Report 31, 18 p.

Hadley, D., and Kanamori, H., 1977, Seismic structure of the Transverse Ranges, California: Geological Society of America Bulletin, v. 88, p. 1469–1478.

Hanson, G. H., and Gast, P. W., 1967, Kinetic studies in contact metamorphism zones: Geochim. et Cosmochim. Acta, v. 31, p. 1119–1153.

Hart, S. R., 1964, The petrology and isotopic mineral age relations of a contact zone in the Front Range, Colorado: Journal of Geology, v. 72, no. 5, p. 493–525.

Hill, M. L., and Dibblee, T. W., Jr., 1953, San Andreas, Garlock, and Big Pine faults, California: Geological Society of America Bulletin, v. 64, p. 443–458.

Hill, R. L., and Beeby, D. J., 1977, Surface faulting associated with the 5.2 magnitude Galway Lake earthquake of May 31, 1975: Mojave Desert, San Bernardino County, California: Geological Society of America Bulletin, v. 88, p. 1378–1384.

Hsü, K. J., Edwards, G., and McLaughlin, W. A., 1963, Age of the intrusive rocks of the southeastern San Gabriel Mountains, California: Geological Society of America Bulletin, v. 74, no. 4, p. 507–512.

Jennings, C. W., and Strand, R. G., compilers, 1969, Geologic map of California, Olaf P. Jenkins edition, Los Angeles sheet: California Division of Mines and Geology, scale 1:250,000.

Krummenacher, D., Gastil, R. G., Bushee, J., Douport, J., 1975, K-Ar apparent ages, Peninsular Ranges batholith, southern California and Baja California: Geological Society of America Bulletin, v. 86, p. 760–768.

Lanphere, M. A., 1964, Geochronologic studies in the eastern Mojave Desert, California: Journal of Geology, v. 72, p. 381–399.

Miller, C. F., 1976, Alkali-rich monzonites, southern and central California—a unique magmatic episode?: Geological Society of America Abstracts with Programs, v. 8, no. 3, p. 395.

Miller, F. K., and Engels, J. C., 1975, Distribution and trends of discordant ages of the plutonic rocks of northeastern Washington and northern Idaho: Geological Society of America Bulletin, v. 86, p. 517–528.
Miller, F. K., and Morton, D. M., 1977, Comparison of granitic intrusions in the Pelona and Orocopia Schists, southern California: U.S. Geological Survey Journal Research, v. 5, no. 5, p. 643–649.
Miller, W. J., 1926, Crystalline rocks of the middle-southern San Gabriel Mountains, California (abstract): Geological Society of America Bulletin, v. 37, no. 1, p. 149.
Mussett, A. E., 1969, Diffusion measurements and the potassium-argon method of dating: Royal Society of London Geophysical Journal, v. 18, p. 257–303.
Richmond, J. F., 1960, Geology of the San Bernardino Mountains north of Big Bear Lake, California: California Division of Mines Special Report 65, 68 p.
Rogers, T. H., compiler, 1969, Geologic map of California, Olaf P. Jenkins edition, San Bernardino sheet: California Division of Mines and Geology, scale 1:250,000.
Ross, D. C., 1972, Petrographic and chemical reconnaissance study of some granitic and gneissic rocks near the San Andreas fault from Bodega Head to Cajon Pass, California: U.S. Geological Survey Professional Paper 698, 92 p.
Silver, L. T., 1968, Preliminary history for the crystalline complex of the central Transverse Ranges, Los Angeles County, California: Geological Society of America Special Paper 101, p. 201–202.
——— 1971, Problems of crystalline rocks of the Transverse Ranges: Geological Society of America Abstracts with Programs, v. 3, no. 2, p. 193–194.
Silver, L. T., and McKinney, C. R., 1963, U/Pb isotopic studies of a Precambrian granite, Marble Mountains: Geological Society of America Special Paper 73, p. 65.
Silver, L. T., McKinney, C. R., Deutsch, S., Bolinger, J., 1963, Precambrian age determinations in the western San Gabriel Mountains, California: Journal of Geology, v. 71, no. 2, p. 196–214.
Steiger, R. H., and Jager, E., 1977, Subcommission on geochronology: Convention on the use of decay constants in geo- and cosmochronology: Earth and Planetary Science Letters, v. 36, p. 359–362.
Stewart, J. H., and Poole, F. G., 1975, Extension of the Cordilleran miogeosynclinal belt to the San Andreas fault, southern California: Geological Society of America Bulletin, v. 86, p. 205–212.
von Huene, R. E., 1969, Geologic structure between the Murray Fracture Zone and the Transverse Ranges: Marine Geology, v. 7, p. 475–499.

## SAMPLE LOCALITIES AND DESCRIPTIONS

[All measurements from southwest corner of section indicated in feet]

| Map No. | Field No. | Locality | Rock type |
|---|---|---|---|
| 1 | T2–5 | 150 E, 1,160 N, sec. 4, T. 1 S., R. 14 W. | Hornblende-biotite quartz diorite or granodiorite, medium- to coarse-grained. Cataclastic foliation. Sphene-bearing. C.I. ~25 |
| 1A | WT–2 | 4,320 W, 8,960 S, sec. 8, T. 1 N., R. 13 W. | Hornblende-biotite granodiorite, medium-grained, sphene-bearing. C.I. ~15 |
| 2 | T1–5 | 7,650±500 E, 5,150±500 S, sec. 9, T 1 N., R. 13 W. | Hornblende-biotite quartz diorite, medium- to fine-grained. Slight cataclastic foliation. C.I. ~60 |
| 3 | T76–4 | 1,310 E, 3,690 N, sec. 6, T. 2 N., R. 14 W. | Biotite quartz diorite, medium- to fine-grained. Probably metamorphosed. C.I. ~18 |
| 4 | T77–4 | 3,900 E, 980 N, sec. 2, T. 2 N., R. 13 W. | Hornblende-biotite granodiorite, medium-grained, equigranular, C.I. ~18 |
| 5 | T50–4 | 630 E, 7,400 N, sec. 31, T. 2 N., R. 12 W. | Hornblende-biotite granodiorite, coarse-grained, equigranular. C.I. ~20 |
| 6 | T49–4 | 2,800 E, 8,350 S, sec. 31, T. 2 N., R. 12 W. | Hornblende-biotite granodiorite, slightly gneissic. Probably metamorphosed. Medium-grained. C.I. ~25 |
| 7 | T33–4 | 12,500 E, 500 N (approx.), sec. 12, T. 2 N., R. 13 W. | Mount Lowe Granodiorite of Miller (1926), foliate and lineate. Bimodal grain size. Cataclastic, recrystallized. C.I. ~6 |
| 8 | T80–4 | 18,680 E, 10,410 N, sec. 1, T. 2 N., R. 13 W. | Hornblende-biotite granodiorite, medium-to fine-grained, equigranular. C.I. ~20 |
| 9 | T34–4 | 22,000±500 E, 150±200 S, sec. 12, T. 2 N., R. 13 W. | Biotite quartz diorite, medium-grained, slightly foliate. Probably metamorphosed. C.I. ~20 |
| 10 | T79–4 | 2,470 E, 2,650 N, Sec. 24, T. 2 N., R. 12 W. | Hornblende-biotite diorite, medium-to fine-grained. Faint foliation. C.I. ~25 to 30 |
| 11 | T78–4 | 3,150 E, 670 N, sec. 29, T. 2 N., R. 11 W. | Hornblende-biotite granodiorite, medium-grained, equigranular. C.I. ~20 |
| 12 | T48–4 | 2,950 E, 5,060 N, sec. 10, T. 1 N., R. 11 W. | Hornblende-biotite granodiorite, medium-grained, equigranular. C.I. ~22 |
| 13 | T38–4 | 3,825 E, 4,075 N, sec. 4, T. 3 N., R. 11 W. | Muscovite-biotite granodiorite, medium-grained, with phenocrysts to 6 cm in length. Foliate, C.I. ~10. Mount Lowe Granodiorite of Miller (1926). |
| 14 | T82–4 | 460 E, 2,810 N, sec. 19, T. 4 N., R. 10 W. | Biotite quartz monzonite, coarse-grained, foliate. Slightly cataclasized, but recrystallized. C.I. ~12 |

| Map No. | Field No. | Locality | Rock type |
|---|---|---|---|
| 15 | T83–4 | 430 W, 2,220 N, sec. 31, T. 4 N., R. 10 W. | Biotite quartz monzonite, coarse-grained. Slightly porphyritic. C.I. ~5 |
| 16 | T36–4 | 2,450 E, 1,350 N, sec. 13, T. 3 N., R. 11 W. | Biotite quartz monzonite, coarse-grained, equigranular. C.I. ~7 |
| 17 | T35–4 | 4,300±500 E, 100±200 N, sec. 2, T. 2 N., R. 11 W. | Mount Lowe Granodiorite of Miller (1926), foliate and lineate. Bimodal grain size. Cataclastic, recrystallized. C.I. ~10 |
| 18 | T67–4 | 5,500 E, 3,080 N, sec. 25, T. 2 N., R. 11 W. | Biotite quartz monzonite, leucocratic, medium-grained, slightly foliated. C.I. ~4 |
| 19 | T47–4 | 860 E, 2,660 N, sec. 13, T. 1 N., R. 11 W. | Hornblende-biotite granodiorite, mildly cataclasized, coarse-grained. C.I. ~30 |
| 20 | T46–4 | 50 E, 3,200 N, sec. 23, T. 1 N., R. 10 W. | Cataclastic hornblende-biotite granodiorite, coarse-grained foliate. Slightly banded. C.I. ~25 |
| 21 | T68–4 | 50 E, 18,350 N, sec. 2, T. 1 N., R. 10 W. | Hornblende-biotite-bearing granitic gneiss, medium-grained. Incipient segregation bands. C.I. ~25 |
| 22 | T105–4 | 1,500 E,-640 N, sec. 15, T. 1 N., R. 9 W. | Hornblende-biotite diorite or amphibolite, fine-grained. Slightly foliate. C.I. ~50 |
| 22A | T1–6 | 1,500 E, 640 N, sec. 15, T. 1 N., R. 9 W. | Hornblendite. Biotite-bearing, medium-grained. Massive. C.I. ~80 |
| 23 | T41–4 | 1,350 E, 19,100 S, sec. 9, T. 3 N., R. 9 W. | Hornblende-biotite granodiorite, fine-grained, equigranular. Large mafic segregation in more leucocratic plutonic rocks. C.I. ~25 |
| 24 | T37–4 | 4,050 W, 2,030 S, sec. 9, T. 3 N., R. 9 W. | Gneissic biotite quartz diorite. Collected from a zone of mixed metamorphic and granitic rocks. Slightly foliate, medium-grained abundant inclusions. C.I. ~18 |
| 25 | T102–4 | 1,680 E, 3,090 N, sec. 6, T. 4 N., R. 9 W. | Hornblende-biotite granodiorite. Slight cataclasis. Slight foliation. C.I. ~12 |
| 26 | M26–4 | 950 E, 1,950 N, sec. 10, T. 5 N., R. 8 W. | Hornblende-biotite granodiorite, medium-grained. C.I. ~30. Hornblende: biotite ~10:1 |
| 27 | M27–4 | 3,850 E, 420 N, sec. 15, T. 6 N., R. 9 W. | Biotite quartz monzonite. Porphyritic. Large quartz crystals. Medium-grained. C.I. =12 |
| 28 | M30–4 | 4,300 E, 00 N, sec. 7, T. 6 N., R. 8 W. | Hornblende-biotite quartz monzonite. Slightly porphyritic. Medium-grained. C.I. ~15 |
| 29 | M31–4 | 5,110 E, 3,770 N, sec. 6, T. 6 N., R. 9 W. | Muscovite-biotite quartz monzonite, medium-grained. Weathered rock, but micas fresh. |
| 30 | M32–4 | 1,550 E, 3,200 N, sec. 15, T. 7 N., R. 9 W. | Hornblende-biotite quartz monzonite, medium- to coarse-grained, equigranular. C.I. ~15 |
| 31 | M33–4 | 60 E, 5,480 N, sec. 1, T. 7 N., R. 9 W. | Hornblende-biotite quartz monzonite. Probably from same pluton as sample 30. |
| 31A | M52–7 | 200 E, 100 S, sec. 17, T. 8 N., R. 9 W. | Hornblende-biotite granodiorite, coarse-grained. Massive. Large books of biotite. Hornblende: biotite ~ 1:2. Sphene-bearing. C.I. ~15 |
| 32 | M34–4 | 60 E, 650 N, sec. 12, T. 7 N., R. 8 W. | Biotite quartz monzonite, medium- to fine-grained. Biotite very fine grained. C.I. ~5 |
| 33 | M28–4 | 1,030 E, 1,820 N, sec. 9, T. 6 N., R. 7 W. | Hornblende-biotite quartz monzonite, medium-grained, equigranular. C.I. ~12 |
| 34 | M35–4 | 300 E, 3,490 N, sec. 11, T. 7 N., R. 7 W. | Alaskite. Garnet bearing. Contains about 1 percent biotite. Fine-grained, equigranular. |
| 35 | M29–4 | 1,180 E, 5,040 N, sec. 27, T. 7 N., R. 6 W. | Biotite quartz monzonite, medium- to fine-grained. Equigranular. C.I. ~7 |
| 36 | T100–4 | 4,170 E, 3,340 N, sec. 18, T. 4 N., R. 8 W. | Biotite quartz monzonite. Leucocratic, banded. Fine-grained, nonporphyritic. C.I. ~4 |
| 37 | T101–4 | 4,870 E, 5,250 N, sec. 24, T. 4 N., R. 9 W. | Banded gneiss. Biotite is only mafic mineral, no muscovite. Average layer about 5 mm thick. |
| 38 | T84–4 | 2,300±500 E, 2,500±500 N, sec. 11, T. 3 N., R. 9 W. | Hornblende-biotite diorite. Fine-grained, equigranular. C.I. ~60 |
| 39 | T99–4 | 800 E, 3,150 N, sec. 25, T. 4 N., R. 8 W. | Hornblende-biotite quartz diorite. Medium- and fine-grained, bimodal grain size. Nonfoliate. C.I. ~45 |
| 40 | T98–4 | 5,150 E, 2,000 N, sec. 4, T. 3 N., R. 7 W. | Hornblende-biotite granodiorite. Coarse grained, slightly foliate, C.I. ~25 |
| 41 | T106–4 | 4,640 E, 3,060 N, sec. 6, T. 2 N., R. 7 W. | Hornblende-biotite quartz diorite. Medium-grained. Foliate, Biotite all chloritized. C.I. ~25 |
| 42 | T70–4 | 2,930 E, 12,100 N, sec. 1, T. 1 N., R. 9 W. | Hornblende-biotite diorite. Fine-grained, equigranular, but slightly lineate. C.I. ~35 |
| 43 | T71–4 | 1,640 E, 10,550 N, sec. 4, T. 1 N., R. 8 W. | Hornblende-biotite quartz diorite. Medium- to fine-grained, slightly foliate. C.I. ~30 |

| Map No. | Field No. | Locality | Rock type |
|---|---|---|---|
| 44 | T72–4 | 660 E, 2,150 N, sec. 20, T. 2 N., R. 7 W. | Hornblende-biotite quartz diorite. Slightly cataclasized. Coarse-grained, equigranular. C.I. ~30 |
| 45 | T103–4 | 1,260 E, 390 N, sec. 6, T. 1 N., R. 7 W. | Biotite quartz monzonite. |
| 46 | T104–4 | 960 E, 2,120 N,sec. 6, T. 1 N., R. 7 W | Cataclastic hornblende-biotite quartz diorite. Faintly banded. Coarse-grained. C.I. ~25 |
| 47 | T73–4 | 1,680 E, 220 N, sec. 12, T. 1 N., R. 7 W. | Cataclastic hornblende-biotite diorite. Almost a mylonite. Foliate and lineate. C.I. ~40 |
| 48 | T74–4 | 5,025 E, 1,060 N, sec. 8, T. 1 N., R. 7 W. | Cataclastic hornblende-biotite diorite. Coarser than sample 47. Foliate and lineate. C.I. ~30 |
| 49 | T75–4 | 3,380 E, 3,190 N, sec. 1, T. 1 N., R. 7 W. | Hornblende-biotite diorite. Cataclasized. Medium-grained, slightly foliate. C.I. ~25 |
| 50 | T19–3 | 2,700 E, 2,020 N, sec. 11, T. 2 N., R. 7 W. | Cataclastic quartz diorite. Medium-grained. Foliate and lineate. C.I. ~25 |
| 51 | T86–4 | 950 W, 320 S, sec. 17, T. 2 N., R. 6 W. | Same as sample 53, except finer grained, and distinctly lineate. |
| 52 | T4–3 | 2,960 E, 3,450 N, sec. 3, T. 1 N., R. 6 W. | Hornblende-biotite quartz diorite. Coarse-grained, foliate. Cataclastic. C.I. ~20 |
| 53 | T85–4 | 4,600 E, 4,480 N, sec. 27, T. 2 N., R. 6 W. | Cataclasite. Coarse grained. Slightly foliate. Contains hornblende and biotite. |
| 54 | T1–4 | 4,270 E, 1,200 N, sec. 36, T. 3 N., R. 6 W. | Hornblende-biotite-granodiorite. Porphyritic, slightly foliate. |
| 55 | T2–4 | 650 E, 4,000 N, sec. 31, T. 3 N., R. 4 W. | Hornblende-biotite granodiorite. Porphyritic. Same pluton as sample 54. |
| 56 | T3–4 | 200 E, 5,110 N, sec. 35, T. 3 N., R. 4 W. | Biotite quartz monzonite. Equigranular. Slightly weathered. |
| 57 | T53–4 | 1,890 E, 840 N, sec. 10, T. 2 N., R. 4 W. | Hornblende-biotite granodiorite. Porphyritic. Probably same pluton as sample 54. |
| 57A | 416 | 4,760 E, 3,660 N, sec. 19, T. 2 N., R. 4 W. | Medium-grained hornblende-biotite quartz-bearing monzonite. Abundant sphene. C.I. ~20 |
| 58 | T18–4 | 1,180 E, 670 N, sec. 30, T. 2 N., R. 3 W. | Hornblende-biotite quartz diorite, fine-grained. Possibly a hybrid rock. |
| 59 | T66–4 | 4,320 E, 1,220 N, sec. 13, T. 1 N., R. 3 W. | Hornblende-biotite granodiorite. Slightly foliate. Medium-grained. C.I. ~20 |
| 59A | M17–7 | 2,000 E, 3,400 N, sec. 22, T. 1 N., R. 3 W. | Amphibolite, biotite-bearing. Fine-grained. Lineate. Faintly banded. Rock at sample site is heterogeneous banded gneiss. C.I. ~60 |
| 60 | T12–4 | 2,970 E, 2,150 N, sec. 12, T. 1 N., R. 3 W. | Biotite quartz monzonite, nonporphyritic, slightly weathered. |
| 61 | T15–4 | 2,550 E, 3,660 N, sec. 31, T. 2 N., R. 2 W. | Hornblende-biotite granodiorite. Coarse-grained, sparsely porphyritic. |
| 62 | T16–4 | 340 E, 2,830 N. sec. 13, T. 2 N., R. 3 W. | Hornblende-biotite granodiorite. Same pluton as sample 61. |
| 63 | T65–4 | 2,230 E. 5,020 N, sec. 28, T. 3 N., R. 3 W. | Biotite quartz monzonite. Fine-grained, equigranular. C.I. ~8 |
| 64 | T21–3 | 2,625 E, 2,150 N, sec. 31, T. 4 N., R. 2 W. | Biotite quartz monzonite. Porphyritic. Part of the Rattlesnake pluton. |
| 65 | T43–4 | 3,390 E, 3,990 N, sec. 9, T. 3 N., R. 2 W. | Biotite quartz monzonite, porphyritic. Part of the Rattlesnake pluton. |
| 66 | T44–4 | 3,940 E, 3,180 N, sec. 35, T. 3 N., R. 2 W. | Porphyritic biotite quartz monzonite. Nonfoliate. Probably part of Rattlesnake pluton. |
| 67 | M1–3 | 160 E, 4,030 N, sec. 11, T. 4 N., R. 2 W. | Lineate hornblende-pyroxene monzonite. |
| 68 | M2–4 | 1,300 E, 2,880 N, sec. 31, T. 5 N., R. 2 W. | Hornblende-biotite granodiorite. Medium-grained, nonporphyritic, sphene-bearing. |
| 69 | M14–4 | 2,050 E, 2,480 N, sec. 17, T. 5 N., R. 3 W. | Biotite quartz monzonite. Fine-grained. Slightly foliate. May be a hybrid. |
| 70 | M1–4 | 3,840 E, 2,400 N, sec. 10, T. 5 N., R. 4 W. | Leucocratic biotite quartz monzonite. Fine-grained, nonporphyritic. |
| 71 | M9–4 | 2,360 E, 525 N, sec. 29, T. 6 N., R. 4 W. | Hornblende-biotite granodiorite, medium-grained, nonfoliate, nonporphyritic. C.I. ~10. |
| 72 | M8–4 | 4,480 E, 3,550 N, sec. 6, T. 5 N., R. 4 W. | Hornblende-biotite granodiorite, medium-grained, nonfoliate, nonporphyritic. C.I. ~15. |

| Map No. | Field No. | Locality | Rock type |
|---|---|---|---|
| 73 | M7–4 | 2,025 E, 3,600 N, sec. 22, T. 6 N., R. 3 W. | Hornblende-biotite quartz monzonite. Medium-grained, slightly porphyritic. |
| 73A | M3–6 | 250 E, 3,640 N, sec. 16, T. 7 N., R. 3 W. | Hornblende-biotite granodiorite. Medium-grained. Massive. Hornblende: biotite ≃1:5. Euhedral biotite. C.I. ≃10 |
| 73B | M1–7 | 2,550 E, 2,300 N, sec. 18, T. 7 N., R. 3 W. | Same lithology as 73A; these samples from the same pluton. |
| 73C | M2–7 | 1,370 E, 500 N, sec. 2, T. 6 N., R. 3 W. | Biotite quartz monzonite. Coarse-grained. Deeply weathered. Very slight foliation. C.I. ~10 |
| 73D | M3–7 | 4,240 E, 2,460 N, sec. 12, T. 6 N., R. 3 W. | Gabbro. Medium- to coarse-grained with pegmatitic segregations. Mixed with other granitic rocks at sample site. C.I. ~40. |
| 74 | M6–4 | 4,650 E, 150 N, sec. 4, T. 5 N., R. 2 W. | Biotite quartz monzonite. Leucocratic. Fine grained with 7 mm phenocryst of microcline. |
| 75 | T90–4 | 940 E, 1,830 N, sec. 26, T. 6 N., R. 2 W. | Biotite quartz monzonite. Coarse-grained, equigranular. Abundant sphene. C.I. ~6 |
| 76 | T91–4 | 340 E, 3,150 N, sec. 22, T. 7 N., R. 2 W. | Hornblende-biotite granodiorite. Medium-grained, equigranular. C.I. ~15 |
| 76A | M20–7 | 260 E, 4,370 N, sec. 17, T. 6 N., R. 2 W. | Biotite quartz monzonite. Medium-grained. Biotite partly chloritized, but analyzed mineral separate was clean biotite. Nonporphyritic, slight foliation. C.I. ~15 |
| 77 | T92–4 | 2,200 E, 3,300 N, sec. 35, T. 7 N., R. 2 W. | Biotite quartz monzonite. Medium-grained, equigranular. Mixed with other rock types at sample locality. Probably hybridized. |
| 78 | T93–4 | 700 E, 4,850 N, sec. 26, T. 7 N., R. 1 W. | Biotite quartz monzonite, coarse-grained, equigranular. Slightly altered. C.I. ~5 |
| 78A | M5–7 | 1,500 E, 3,900 N, sec. 12, T. 7 N., R. 1 W. | Hornblende-biotite granodiorite. Medium-grained slightly porphyritic. Massive. Hornblende: biotite ≃1:1 Sphene-bearing. C.I. ≃15 |
| 78B | M6–7 | 4,570 E, 3,370 N, sec. 19, T. 7 N., R. 1 E. | Hornblende-biotite granodiorite. Same lithology and same pluton as 78A, except hornblende: biotite ≃1:2. |
| 78C | M7–7 | 950 E, 50 N, sec. 16, T. 7 N., R. 1 E. | Hornblende-biotite diorite. Quartz-bearing. Medium-grained. Equigranular. C.I. ~50. Intruded by alaskite 100 m from sample site. |
| 79 | T94–4 | 1,160 E, 2,440 N, sec. 1, T. 6 N., R. 1 W. | Banded gneiss. Layers from 1 to 30 mm thick. Hornblende is only mafic mineral. |
| 79A | M10–7 | 1,400 E, 4,100 N, sec. 1, T. 6 N., R. 1 E. | Hornblende-biotite granodiorite. Porphyritic. Potassium feldspar is purple-gray. May be same plutonic type as sample 136. C.I. ~20 |
| 79B | M11–7 | 1,700 E, 1,700 N, sec. 7, T. 6 N., R. 2 E. | Biotite quartz monzonite. Leucocratic. Potassium feldspar is pink. Weathered. C.I. ~8 |
| 80 | M13–4 | 1,600 E, 3,900 N, sec. 5, T. 5 N., R. 1 E. | Biotite quartz monzonite. Probably a hybrid rock, contaminated by metamorphic rocks. |
| 81 | T95–4 | 790 E, 920 N, sec. 11, T. 5 N., R. 1 W. | Hornblende-biotite granodiorite. Fine-grained. Slightly foliate. Hornblende has pyroxene cores. C.I. ~20 |
| 82 | T97–4 | 3,080 E, 1,640 N, sec. 4, T. 4 N., R. 1 E. | Hornblende-biotite quartz diorite. Medium-grained, lineate. C.I. ~12 |
| 83 | T89–4 | 2,120 E, 5,090 N, sec. 5, T. 3 N., R 1 E. | Muscovite-biotite quartz monzonite. Medium-to coarse-grained, but micas fine-grained. C.I. ~8 |
| 84 | T96–4 | 4,940 E, 2,300 N, sec. 12, T. 3 N., R. 1 W. | Hornblende-biotite granodiorite. Medium-grained, equigranular. Abundant sphene. C.I. ~20 |
| 85 | T31A–4 | 2,520 E, 3,640 N, sec. 33, T. 3 N., R. 1 W. | Hornblende-biotite monzonite. Hornblende contains altered pyroxene cores that cannot be completely separated from the hornblende. |
| 86 | T54–4 | 3,200 E, 200 N, sec. 10, T. 2 N., R. 2 W. | Biotite quartz monzonite. Medium-grained, slightly porphyritic. C. I. = 6 |
| 87 | T13–4 | 2,940 E, 2,830 N, sec. 34, T. 2 N., R. 2 W. | Biotite quartz monzonite. Sparsely porphyritic. Same pluton as sample 86. |
| 88 | T14–4 | 3,620 E, 4,560 N, sec. 19, T. 2 N., R. 1 W. | Biotite quartz monzonite. Locally contains muscovite. Fine-grained. |
| 89 | T11–4 | 1,320 E, 4,720 N, sec. 3, T. 1 S., R. 1 W. | Hornblende-biotite quartz monzonite. Very porphyritic, slightly foliate. |
| 90 | T10–4 | 1,050 E, 3,350 N, sec. 24, T. 1 N., R. 1 W. | Hornblende-biotite granodiorite. Medium-grained, nonporphyritic. |
| 91 | T55–4 | 4,060 E, 2,750 N, sec. 2, T. 2 N., R. 1 W. | Biotite quartz monzonite. Equigranular. Same pluton as sample 86. |
| 92 | T32–4 | 3,470 E, 2,970 N, sec. 11, T. 2 N., R. 1 W. | Hornblende-biotite granodiorite. Coarse-grained. Slightly porphyritic. |
| 93 | T64–4 | 1,800 E, 3,040 N, sec. 15, T. 2 N., R. 1 E. | Biotite quartz monzonite. Fine-grained, equigranular. |

| Map No. | Field No. | Locality | Rock type |
|---|---|---|---|
| 94 | T30–4 | 5,040 E, 30 N, sec. 23, T. 3 N., R. 1 E. | Baldwin Gneiss of Guillou (1953). Coarse-grained orthogneiss, porphyroblastic. |
| 95 | T87–4 | 2,780 E, 3,780 N, sec. 24, T. 3 N., R. 1 E. | Hornblende-biotite quartz diorite. Medium-grained, equigranular. C.I. ~30 |
| 96 | T5–4 | 3,170 E, 2,960 N, sec. 24, T. 3 N., R. 1 E. | Biotite quartz monzonite. Foliate. Part of Cactus Quartz Monzonite of Guillou (1953). |
| 97 | M3–4 | 1,650 E, 1,300 N, sec. 5, T. 4 N., R. 2 E. | Leucocratic biotite quartz monzonite. Medium- to fine-grained, trace of muscovite. |
| 98 | M10–4 | 4,500 E, 2,920 N, sec. 25, T. 5 N., R. 1 E. | Biotite quartz monzonite. Leucocratic, nonfoliate, nonporphyritic. |
| 99 | M36–4 | 1,020 E, 3,780 N, sec. 36, T. 6 N., R. 1 E. | Hornblende-biotite granodiorite. Porphyritic, medium-grained. C.I.~20 |
| 100 | M38–4 | 5,100 E, 1,720 N, sec. 30, T. 7 N., R. 3 E. | Hornblende-biotite quartz monozonite, fine-grained, porphyritic. Dark feldspar. C.I. ~12 |
| 100A | M44–7 | 1,400 E, 4,030 N., sec. 19, T. 8 N., R. 2 E. | Biotite quartz monzonite. May be same plutonic type as sample 73C. Medium- to coarse-grained. Massive. Pink potassium feldspar. C.I. ~8 |
| 101 | M39–4 | 870 E, 1,120 N, sec. 23, T. 6 N., R. 3 E. | Hornblende biotite quartz monzonite. Medium-grained, sparsely porphyritic. C.I. ~15 |
| 102 | M40–4 | 4,690 E, 1,220 N, sec. 6, T. 5 N., R. 3 E. | Hornblende-biotite quartz monzonite. Porphyritic. Slightly foliate. Medium-grained. C.I. ~14 |
| 102A | M22–7 | 1,650 E, 5,220 N, sec. 2, T. 5 N., R. 2 E. | Hornblende-biotite granodiorite. Same plutonic type as 79A. Porphyritic. C.I. ~15 |
| 103 | M41–4 | 2,330 E, 1,680 N, sec. 21, T, 6 N., R. 4 E. | Hornblende-biotite quartz monzonite. Small, sparse phenocrysts. Medium-grained. C.I. ~10 |
| 104 | M19–4 | 4,520 E, 1,830 N, sec. 5, T. 5 N., R. 4 E. | Same pluton as sample 123. Mixed with numerous other plutonic types at sample locality. |
| 105 | M15–4 | 290 E, 2,100 N, sec. 1, T. 4 N., R. 3 E. | Hornblende-biotite quartz monzonite. Medium-grained, slightly porphyritic. C.I. ~12 |
| 106 | M11–4 | 4,900 E, 4,800 N, sec. 14, T. 4 N., R. 2 E. | Same pluton as sample 98. |
| 107 | M12–4 | 1,020 E, 710 N, sec. 30, T. 4 N., R. 3 E. | Hornblende biotite quartz monzonite. Slightly foliate, medium-grained. C.I. ~12 |
| 108 | T45–4 | 2,980 E, 1,840 S, sec. 17, T. 3 N., R. 3 E. | Hornblende-biotite granodiorite. Slightly foliate. C.I.~25 |
| 109 | T61–4 | 2,460 E, 2,800 N, sec. 3, T. 2 N., R. 2 E. | Muscovite-biotite quartz monzonite. Highly lineate. Medium-grained. C.I. ~12 |
| 110 | T63–4 | 5,100 E, 1,730 N, sec. 14, T. 2 N., R. 2 E. | Baldwin gneiss of Guillou (1953). Foliate and highly lineate. Contains muscovite and biotite. Medium- to fine-grained. |
| 111 | T62–4 | 4,800 E, 3,590 N, sec. 18, T. 2 N., R. 3 E. | Muscovite-biotite quartz monzonite. Medium- to coarse-grained. Garnet-bearing. C.I. ~7 |
| 112 | T9–4 | 5,130 E, 2,110 N, sec. 16, T. 1 N., R. 2 E. | Hornblende-biotite quartz diorite. Medium- to fine-grained, nonporphyritic. |
| 112A | TA–6 | 1,875 E, 400 N, sec. 33, T. 1 S., R. 2 E. | Hornblende-biotite granodiorite or quartz diorite. Massive. Medium-grained. |
| 113 | T60–4 | 3,540 E, 0 N, sec. 24, T. 1 N., R. 2 E. | Biotite quartz monzonite. Fine-grained, equigranular. Contains segregations of dark minerals from partially resorbed inclusions. |
| 114 | T8–4 | 4,110 E, 2,320 N, sec. 1, T. 1 N., R. 2E. | Biotite quartz monzonite. Sparsely porphyritic. |
| 115 | T52–4 | 3,125 E, 350 N, sec. 10, T. 1 N., R. 3 E. | Muscovite-biotite quartz monzonite. Medium- to fine-grained. Nonfoliate, nonporphyritic. |
| 116 | T51–4 | 680 E, 820 N, sec. 16, T. 1 N., R. 4 E. | Biotite quartz monzonite. Medium- to fine-grained, nonporphyritic. |
| 116A | M15–7 | 2,150 E, 200 N, sec. 32, T. 1 S., R. 4 E. | Banded quartzofeldspathic gneiss. Biotite in lenses to 0.5 cm thick is only mafic mineral. Medium-grained. |
| 117 | T59–4 | 940 E, 570 N, sec. 32, T. 2 N., R. 4 E. | Hornblende-biotite granodiorite. Slightly foliate. Medium-grained. C.I. ~15 |
| 118 | T58–4 | 1,920 E, 2,130 N, sec. 10, | Biotite quartz monzonite. Fine-grained, equigranular. Pale-brown color. C.I. ~15 |
| 119 | T56–4 | 4,360 E, 4,830 N, sec. 30, T. 3 N., R. 4 E. | Biotite quartz monzonite. Medium-grained, sparsely porphyritic. C. I. ~10 |
| 120 | T57–4 | 400 E, 1,590 N, sec. 7, T. 3N., R. 4 E. | Biotite granodiorite. Probably metamorphosed. Medium-grained, equigranular. C. I. ~15 |

| Map No. | Field No. | Locality | Rock type |
|---|---|---|---|
| 121 | M16–4 | 2,080 E, 5,020 N, sec. 10, T. 4 N., R. 4 E. | Biotite quartz monzonite. Traces of muscovite. Fine-grained. Leucocratic. |
| 122 | M18–4 | 3,620 E, 4,360 N, sec. 19, T. 5 N., R. 5 E. | Biotite quartz monzonite, pale-gray. Abundant myrmikitic intergrowths. C.I. ~5 |
| 123 | M17–4 | 1,050 E, 800 N, sec. 32, T. 5 N., R. 5 E. | Hornblende-biotite quartz monzonite. Highly porphyritic. C.I. ~15 |
| 123A | M13–7 | 925 W, 125 N, sec. 18, T. 4 N., R. 6 E. | Hornblende-biotite granodiorite. Medium-grained. Nonporphyritic, but probably part of same plutonic type as 133A. C.I. ~25 |
| 123B | M14–7 | 1,180 E, 1,590 N, sec. 5, T. 4 N., R. 6 E. | Hornblende-biotite granodiorite. Medium- to coarse-grained. Same plutonic type as 136. Dark gray, large potassium feldspar phenocrysts. C.I. ~15 |
| 124 | M4–4 | 5,120 E, 4,840 N, sec. 11, T. 3 N., R. 4 E. | Porphyritic biotite quartz monzonite. Biotite is in clusters of fine-grained crystals. |
| 125 | M5–4 | 4,640 W, 7,300 N, sec. 16, T. 2 N., R. 5 E. | Hornblende-biotite granodiorite. Medium-grained, faintly foliate, nonporphyritic. |
| 126 | M43–4 | 570 E, 4,350 N, sec. 33, T. 2 N., R. 5 E. | Biotite quartz monzonite. Medium-grained, porphyritic. Phenocrysts to 2.5 cm in length. C.I. ~12 |
| 127 | M25–4 | 3,460 E, 2,110 N, sec. 34, T. 2 N., R. 5 E. | Hornblende-biotite granodiorite. Medium- to coarse-grained. Nonfoliate. C.I. ~15 |
| 128 | M42–4 | 1,940 E, 1,730 N, sec. 2, T. 1 N., R. 5 E. | Hornblende-biotite granodiorite. Medium-to coarse-grained. Equigranular. C.I. ~18 |
| 129 | T19–4 | 3,780 E, 4,470 N, sec. 29, T. 1 N., R. 5 E. | Muscovite-biotite quartz monzonite. Medium-grained, nonfoliate. |
| 130 | M22–4 | 2,110 E, 1,850 N, sec. 24, T. 1 N., R. 6 E. | Biotite quartz monzonite. Nonfoliate. Slightly cataclasized. C.I. ~10 |
| 131 | M24–4 | 580 E., 5,160 N, sec. 27, T. 2 N., R. 6 E. | Gneissic biotite monzonite. Slightly porphyroblastic. C.I. ~20 |
| 132 | M44–4 | 3,650 E, 4,350 N, sec. 4, T. 2 N., R. 6 E. | Hornblende-biotite granodiorite. Medium-grained, equigranular. C.I. ~25. Much variation in composition on small scale at sample site. |
| 133 | M20–4 | 2,200 E, 2,140 N, sec. 30, T. 3 N., R. 6 E. | Hornblende-biotite quartz diorite. C.I. ~25. Small mafic-rich body associated with large quartz monzonite pluton. |
| 133A | M12–7 | 1,110 E, 360 S, sec. 27, T. 3 N., R. 6 E. | Hornblende-biotite granodiorite. Porphyritic, but with very inhomogeneous phenocryst distribution. Hornblende: biotite ~ 1:1. Dark potassium feldspar. C.I. ~25. |
| 134 | M21–4 | 4,020 E, 3,110 N, sec. 31, T. 2 N., R. 7 E. | Biotite quartz monzonite. Foliate. Slightly porphyritic. Contains abundant allanite. C.I. ~20 |
| 135 | M47–4 | 1,550 E, 920 N, sec. 34, T. 2 N., R. 7 E. | Hornblende-biotite quartz monzonite. Porphyritic. Same plutonic type as sample 123. |
| 136 | M45–4 | 2,130 E, 1,520 N, sec. 34, T. 2 N., R. 9 E. | Hornblende-biotite quartz monzonite. Porphyritic. Same plutonic type as sample 123B. |
| 136A | M96–7 | 3,750 E, 4,800 N; sec. 10 T. 1 N., R. 9 E. | Hornblende-biotite quartz monzonite. Porphyritic. Same pluton as 136. |

GPO 689-143