Reconnaissance Geology of the Mesozoic and Lower Cenozoic Rocks of the Southern Papago Indian Reservation, Arizona: A Preliminary Report

by

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Abstract

Reconnaissance geologic mapping and uranium-lead isotopic geochronology indicate that the Mesozoic and lower Tertiary rocks of the southern Papago Indian Reservation consist of four broad units: lower Mesozoic rhyolitic to andesitic volcanic rocks, and conglomerate, sandstone, and siltstone; Middle and Upper Jurassic granitic to granodioritic plutons; upper Mesozoic sandstone, conglomerate, and subordinate intermediate volcanic rocks; and leucocratic garnet—biotite—muscovite granites of Late Cretaceous and early Tertiary age. Precambrian and Paleozoic rocks are rare. Rocks of the first three units have been variably affected by a Late Cretaceous and earliest Tertiary episode of regional metamorphism accompanied by thrust faulting and intrusion of the garnet—two—mica granites. Several areas of the southern Reservation have also been affected by a core-complex metamorphic episode of early and middle Tertiary age.

Introduction

Reconnaissance geologic mapping by members of the U.S. Geological Survey and uranium-lead isotopic geochronology by Wright have outlined the geology of the southern Papago Indian Reservation (Figs. 1, 2, 3). Although field work has been nearly completed, uranium-lead (U-Pb) and potassium-argon (K-Ar) geochronologic studies, map compilation, and petrographic and chemical studies are still in progress, so the interpretations presented here are provisional and subject to revision. In particular, some of the age assignments given in this paper are based on preliminary interpretations of discordant U-Pb isotopic dates or on lithologic correlations with isotopically dated rocks and may have to be revised as more complete isotopic age data become available. The extensive middle and upper Cenozoic volcanic rocks of the western part of the Reservation (Fig. 3) are being studied but are not discussed here. In addition, some areally restricted rocks of unknown or uncertain age have been omitted.

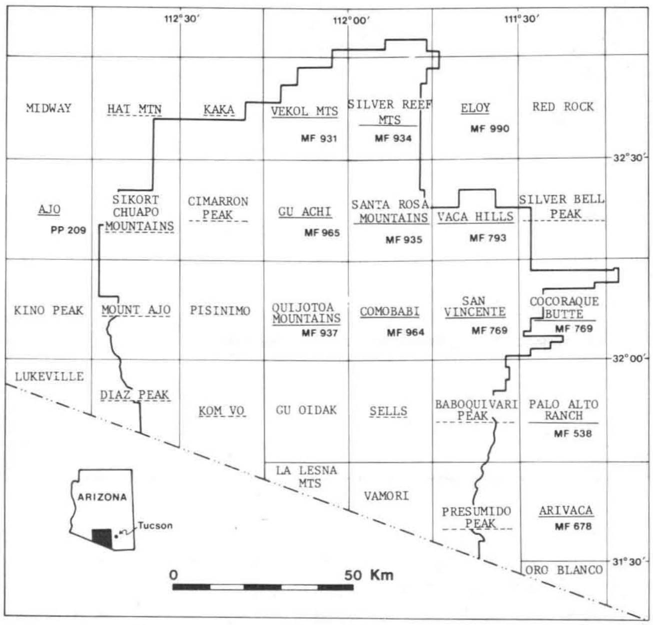

Fig. 1. Index to 15-minute quadrangle geologic maps of the Papago Indian Reservation and some adjacent areas, southern Arizona. Heavy line is Reservation boundary. Geologic maps with solid underline are published, with dashed underline in preparation. MF, U.S.G.S. Miscellaneous Field Studies Map; PP, U.S.G.S. Prof. Paper.

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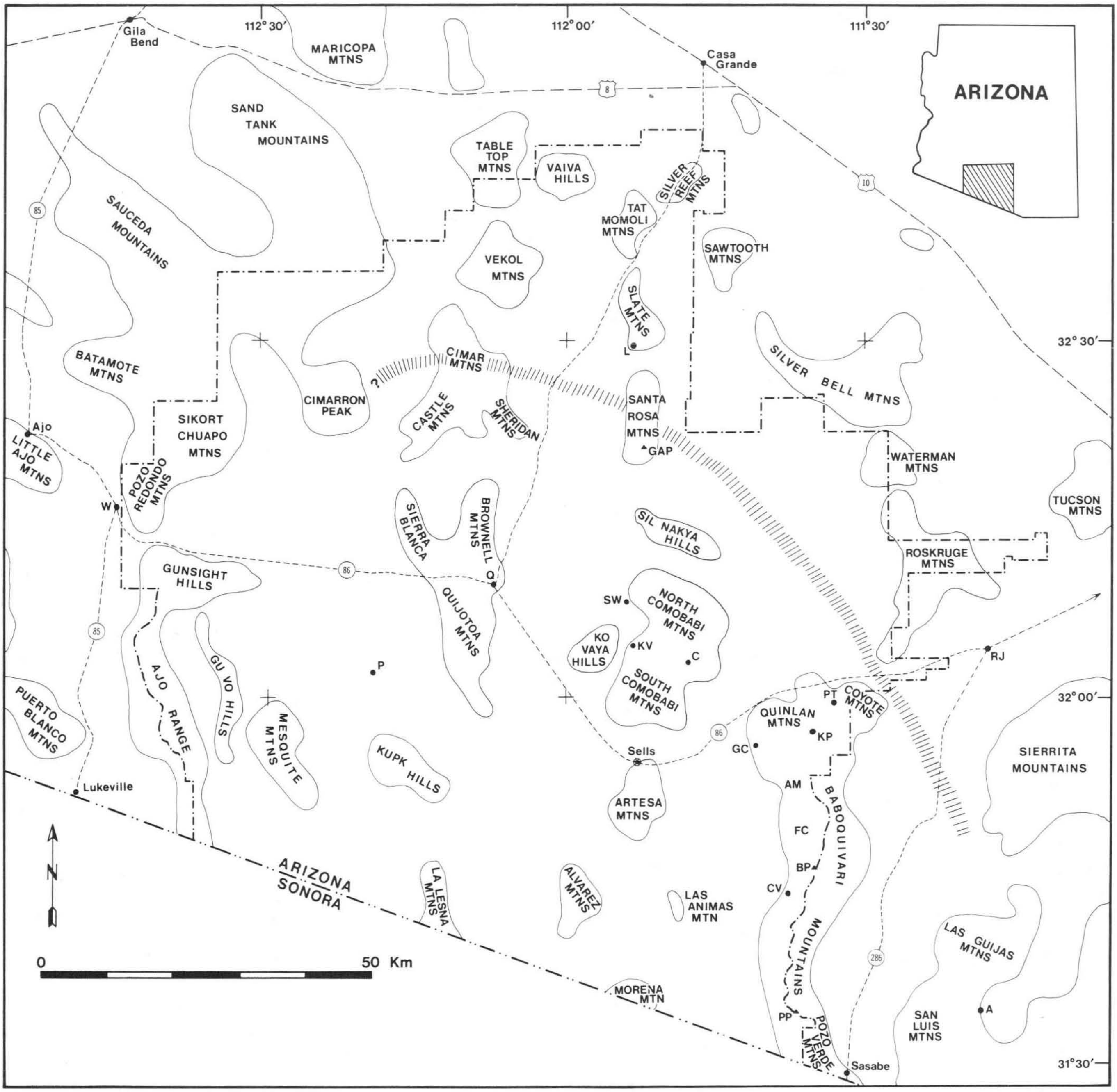

Fig. 2. Location map, showing mountain ranges of the Papago Indian Reservation and villages and other features referred to in the text. Dash-dot line is Reservation boundary. Hachure line is gradational boundary zone separating northern and southern Papago terranes, defined in text. A, Arivaca; AM, Ali Molina Canyon; BP, Baboquivari Peak; CV, Chutum Vaya; C, Comobabi; FC, Fresnal Canyon; GAP, Gu Achi Peak; GC, Gu Chuapo; KP, Kitt Peak; KV, Ko Vaya; L, Lakeshore mine; PT, Pan Tak; P, Pisinimo; PP, Presumido Peak; RJ, Robles Junction (Three Points); SW, Sand Wells; W, Why.

The time scale used here is that of Armstrong (1978, Fig. 2, Table 6), wherein the ages assigned to the beginning of the Triassic, Jurassic, Cretaceous, and Tertiary Periods are approximately 247, 212, 143, and 65 million years (m.y.), respectively. We use the plutonic

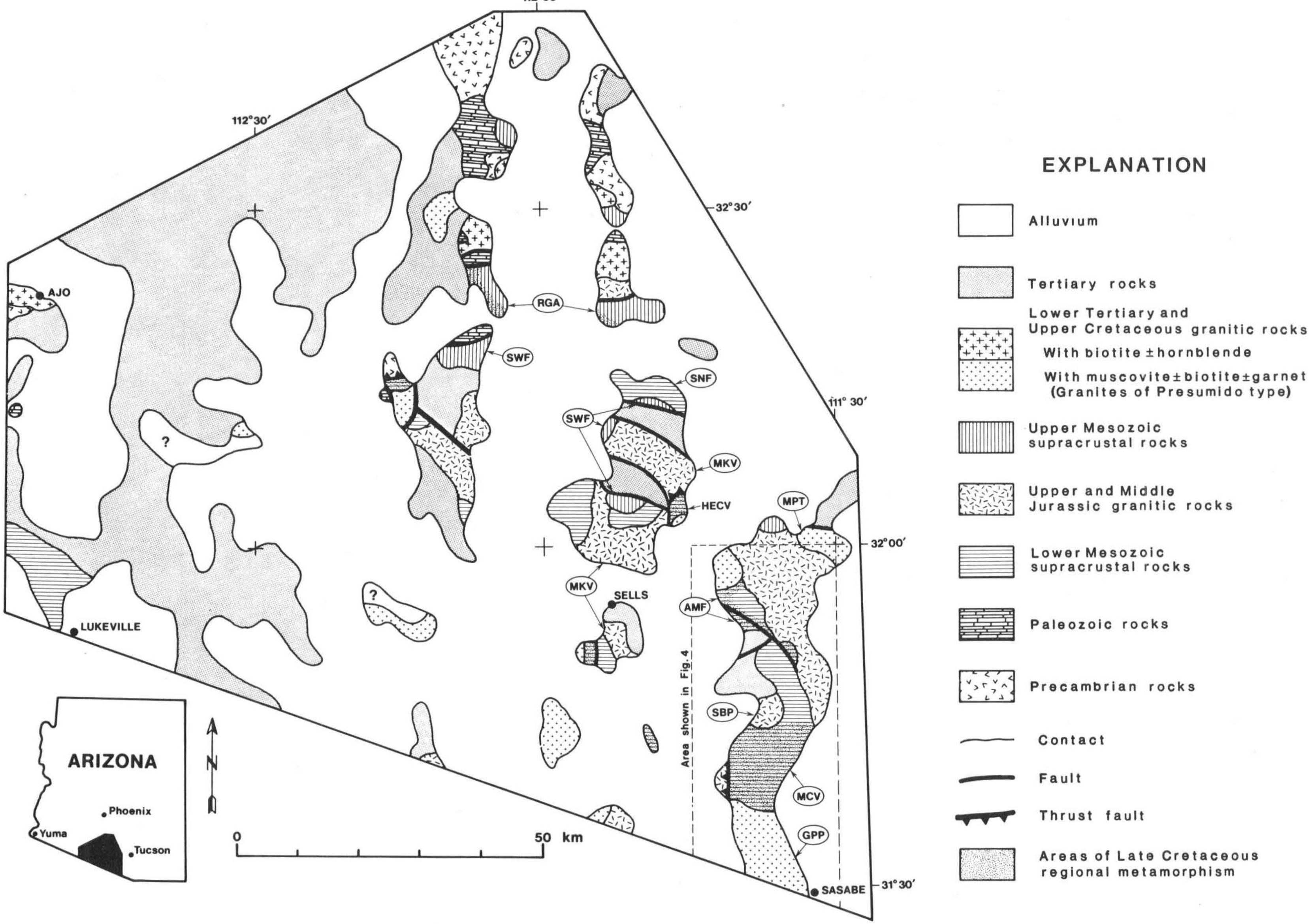

Fig. 3. Interpretive geologic sketch map of the southern Papago Indian Reservation and some adjacent areas. Traced from Wilson, Moore, and Cooper (1969) with substantial modifications from unpublished geologic mapping and isotopic geochronology by the authors and from the published maps listed in Figure 1. Encircled letters with arrows show location of some rock units discussed in the text: AMF, Ali Molina Formation; GPP, granite of Presumido Peak; MCV, metamorphic rocks (or schist) of Chutum Vaya; MKV, monzogranite of Ko Vaya and related plutonic rocks; MPT, monzogranite of Pan Tak; RGA, rocks of Gu Achi; SBP, syenogranite of Baboquivari Peak; SNF, Sil Nakya Formation; SWF, Sand Wells Formation. HECV designates the hills east of Comobabi village. Queried unit is the granite of the Gunsight Hills, of uncertain age (see text).

rock classification of Streckeisen (1976). For the rocks discussed here, zircon isotopic dates are considered to be concordant when the $^{206}Pb^*/^{238}U$ and $^{207}Pb^*/^{235}U$ apparent ages differ by less than 1 m.y.

The Papago Indian Reservation and immediately adjoining areas to the east can be divided into a northern terrane and a southern terrane (Fig. 2), which are characterized by significantly different rock assemblages and geologic histories. The transitional boundary zone between these two terranes is a broad northwest-trending arc (Fig. 2) passing between the Sierrita Mountains and Baboquivari Mountains, between the Roskruge Mountains and Coyote Mountains, through the Santa Rosa Mountains, and through the Cimar Mountains. This boundary zone probably cannot be extended farther west, because pre-Cenozoic rocks are sparse to the longitude of Ajo (Fig. 2, 3), and the rocks of the Ajo district (Gilluly, 1946) and the Cabeza Prieta National Wildlife Refuge (Haxel and Tosdal, unpublished reconnaissance geologic mapping, 1979) have affinities to both Papago terranes.

The Precambrian through early Tertiary geologic history of the northern Papago terrane is broadly similar to that of the region of Phoenix–Globe–Tucson and southeastern Arizona (Silver, 1978; Shride, 1967; Peirce, 1976; Hayes and Drewes, 1978; Coney, 1978; Peterson, 1962; Anderson and Silver, 1977; Davis, in press). In the area of the Slate, Vekol, and Cimar Mountains (Blacet, Bergquist, and Miller, 1978; Dockter and Keith, 1978; Briskey and others, 1978; and references therein), the Pinal Schist is intruded by Oracle Granite (of Peterson, 1938), and these "older Precambrian" crystalline rocks are overlain by the "younger Precambrian" Apache Group, which is intruded by diabase sills and dikes. The Precambrian rocks are overlain by Paleozoic sandstone, limestone, dolomite, and siltstone (McClymonds, 1959; Chaffee, 1974; Armstrong and Mamet, 1978) and by unmetamorphosed Mesozoic sedimentary and volcanic rocks (Heindl, 1965a). All of these rocks are intruded by Late Cretaceous and (or) early Tertiary biotite- and (or) hornblende-bearing granodiorites, granites, and related porphyries.

The southern Papago terrane differs from the northern terrane and most of the rest of south-central and southeastern Arizona in several respects (Fig. 3):

1. Precambrian rocks appear to be absent; the only exception is an allochthonous mass of augen orthogneiss of probable Precambrian age at the north end of Sierra Blanca.

2. Paleozoic rocks are very sparse. Within or south of the boundary zone, Paleozoic rocks occur only as slivers within a complex fault zone between the Cimar and Sheridan Mountains (Briskey and others, 1978), in a few small, fault-bounded or allochthonous blocks (for example, on the west side of Sierra Blanca) and in isolated hills near those blocks, and in a couple of small pendants within Jurassic or Late Cretaceous-early Tertiary plutons. Paleozoic rocks appear to be entirely absent on the Reservation south of a line from Why to Pan Tak, in the North Comobabi Mountains, and in the main part of the Santa Rosa Mountains.

3. Mesozoic sedimentary and volcanic rocks of the southern terrane have been affected by a Late Cretaceous regional metamorphic event.

4. In the southern terrane, the Late Cretaceous and early Tertiary (= "Laramide") magmatic episode of southern Arizona (Coney and Reynolds, 1977; Keith, 1978) is represented by unusual muscovite- and garnet-bearing granitic plutons.

Geologic mapping and U-Pb geochronologic data show that the Mesozoic through lower Tertiary rocks of the southern Papago terrane can be divided into four broad units (Fig. 3):

1. Lower Mesozoic supracrustal[1] rocks older than, to coeval with, the Jurassic plutons of unit (2)

2. Middle and Late Jurassic plutonic rocks

3. Upper Mesozoic supracrustal rocks younger than the Jurassic plutons

4. Late Cretaceous and early Tertiary granitic rocks.

In many areas, some or all of these rocks have been metamorphosed and deformed during a Late Cretaceous regional metamorphic episode and (or) during a core-complex metamorphic episode (Davis, in press) of presumed early(?) and middle Tertiary age.

Lower Mesozoic Supracrustal Rocks

Coherent and relatively thick sequences of lower Mesozoic supracrustal rocks crop out in the Baboquivari Mountains, in the Sil Nakya Hills, at Las Animas Mountain, and in the Comobabi and Artesa Mountains (Fig. 3).

[1]The term "supracrustal" is used here to designate rocks that originally accumulated at the surface of the Earth, that is, sedimentary and volcanic rocks and their metamorphic derivatives.

In the Baboquivari Peak quadrangle (Fig. 4), incipiently to moderately metamorphosed volcanic and sedimentary rocks of the Ali Molina Formation[2] along the west side of the Baboquivari Mountains are separated by a high-angle fault system from a thick (>4,000 m) section of unmetamorphosed sedimentary and volcanic rocks to the south and west in the Fresnal Canyon area (Fig. 4; Fair, 1965; Heindl and Fair, 1965). The stratigraphic relations between these two sequences cannot be determined in this quadrangle, but geologic mapping of the Presumido Peak quadrangle (Fig. 4) demonstrates that the lower part of the unmetamorphosed section in the Fresnal Canyon area can be traced some 15 km southward into phyllite, schist, epidotized sandstone, and metaconglomerate identical to that of the upper (westward) part of the Ali Molina Formation. Furthermore, the metamorphic rocks that make up most of the Baboquivari Mountains in the northern part of the Presumido Peak quadrangle, herein called the metamorphic rocks (or schist) of Chutum Vaya (Fig. 4), include metarhyolitic rocks and quartzite very similar to rocks characteristic of the Ali Molina Formation. Bedding probably has been locally transposed into foliation in the schists of the westernmost Ali Molina Formation, but numerous observations of crossbeds in the quartzite of the Ali Molina Formation and of channels in the Pitoikam Formation (Fig. 4, and below) show that, on the whole, both the metamorphosed and unmetamorphosed sequences in the Baboquivari Peak quadrangle face homoclinally westward. On the basis of these relations, the following premetamorphic gross stratigraphic sequence can be reconstructed, in descending stratigraphic order (see Heindl and Fair, 1965; and Fair, 1965, for more detailed descriptions):

1. Tertiary sedimentary and volcanic rocks

Unconformity

2. Conglomerate (Tertiary or Cretaceous)

Unconformity

3. Chiuli Shaik Formation (Cretaceous or Jurassic)

    A. Andesitic flows and breccias and rhyolitic tuffs and related subvolcanic intrusions

    B. Conglomerate, sandstone, and volcanic rocks

Unconformity

4. Mulberry Wash Volcanic Formation (Lower Jurassic)

    A. Latitic, rhyodacitic, and andesitic flows

    B. Rhyodacitic volcanic breccia to conglomerate

    C. Porphyritic rhyodacitic to andesitic volcanic flows, which intertongue southward with volcanic-clast breccias and conglomerates with subordinate flows

5. Pitoikam Formation (Lower Jurassic)

    A. Chiltepines Member: siltstone, with subordinate shale, sandstone, conglomerate, and, in the upper part of the member, intermediate volcanic flows

    B. Contreras Conglomerate Member: volcanic-clast conglomerate with minor interbedded sandstone and siltstone

    C. Unnamed lower member: conglomerate, sandstone, and siltstone

6. Ali Molina Formation (Lower Jurassic)

    A. Sandstone and conglomerate

    B. Rhyodacitic volcanic rocks with interbedded layers of quartzite and minor arkosic quartzite

Because of metamorphism and faulting, the exact startigraphic relation between unit 6A (now metamorphosed) and unit 5C (unmetamorphosed) is uncertain. Likewise, it is not known whether the contact between the Ali Molina and Pitoikam Formations was originally conformable or unconformable. The metamorphic rocks of Chutum Vaya apparently were derived from units 6B through 5A inclusive. Although the contact between the Pitoikam Formation and the Mulberry Wash Volcanic Formation may be a minor unconformity in the Fresnal Canyon area (Heindl and Fair, 1965), the two formations are in general conformable, because they grade into one another in the southern Baboquivari Peak quadrangle and northern Presumido Peak quadrangle.

Isotopic analysis of discordant zircons from rhyolitic rocks in the Ali Molina Formation and

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[2]The Ali Molina Metamorphic Complex of Heindl and Fair (1965) is hereby renamed the Ali Molina Formation, because the main part of the unit (Fig. 4) is a stratigraphically coherent homoclinal sequence.

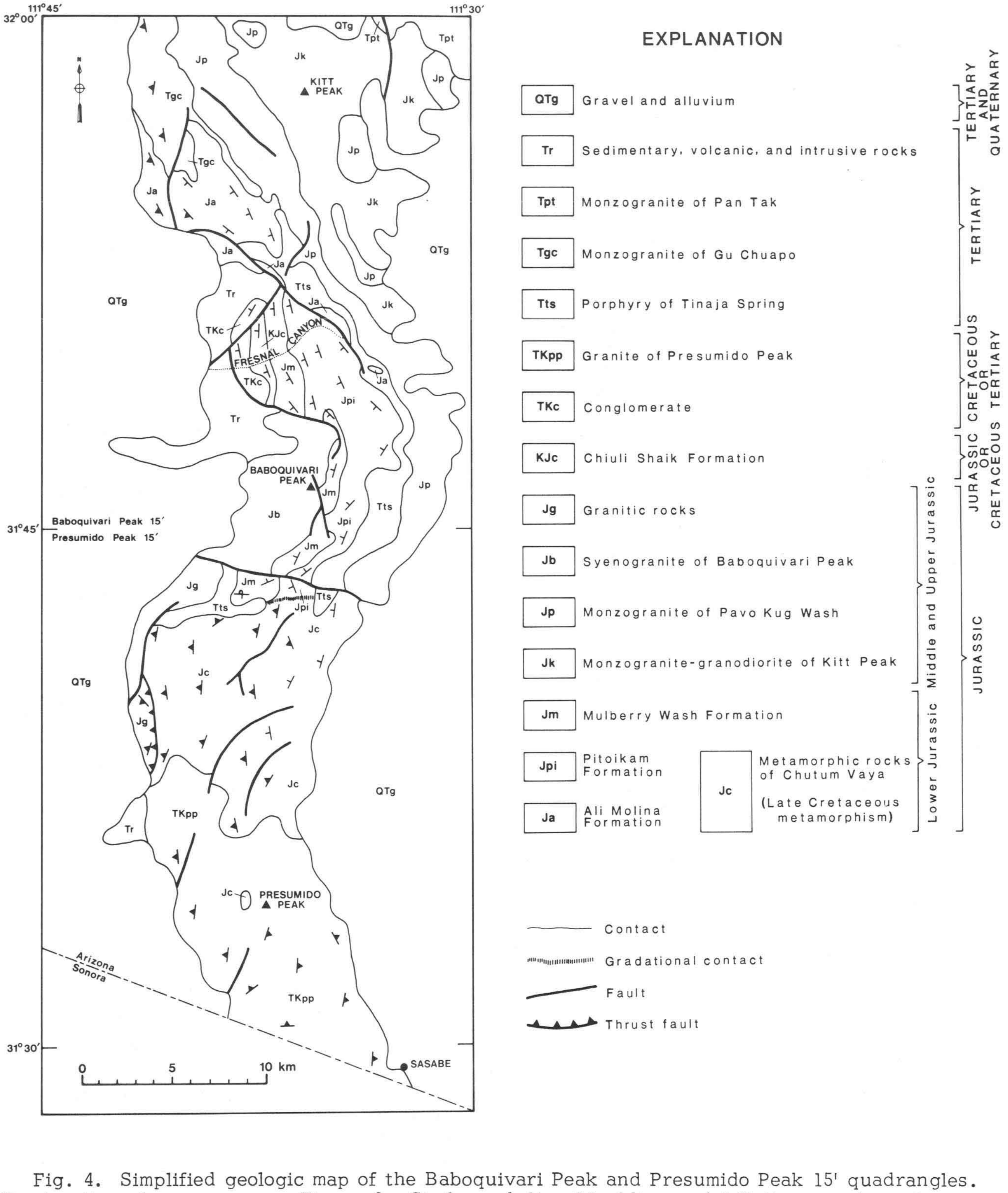

Fig. 4. Simplified geologic map of the Baboquivari Peak and Presumido Peak 15' quadrangles. For location of map area, see Figure 3. Strike and dip of bedding and foliation are shown by conventional symbols. The metamorphic rocks of Chutum Vaya were produced by Late Cretaceous (or earliest Tertiary) metamorphism of the Lower Jurassic Ali Molina and Pitoikam Formations. The monzogranite of Pan Tak, the monzogranite of Gu Chuapo, and the granite of Presumido Peak are included in the "granites of Presumido type" (see text).

the lower part of the Mulberry Wash Volcanic Formation shows that both are of Early Jurassic age. The Mulberry Wash Volcanic Formation is intruded by the syenogranite of Baboquivari Peak (Fig. 4; SBP, Fig. 3), which has an apparent U-Pb isotopic age of 147 m.y. The ages of the Chiuli Shaik Formation and the conglomerate (unit 2), both of which are bounded by unconformities, are poorly constrained, except that the conglomerate contains clasts of the syenogranite of Baboquivari Peak.

Metamorphic rocks derived from sedimentary and volcanic rocks similar to those of the lower Mesozoic sequence of the Baboquivari Mountains also occur in the hills east of Comobabi village (see Fig. 2), the western Artesa Mountains, Las Animas Mountain, and Sierra Blanca.

The Sil Nakya Formation (Heindl, 1965b; Haxel and others, 1978; SNF, Fig. 3) of the Sil Nakya Hills is a south-facing sequence (>2,500 m thick) of rhyolite flows and welded tuffs with interbedded wacke, siltstone, and quartz arenite or quartzite. These rocks are broadly similar in lithology, though not in appearance, to the rhyolitic rocks and quartzite of the Ali Molina Formation. The presently available U-Pb isotopic data suggest that the Sil Nakya, Ali Molina, and Mulberry Wash Volcanic Formations are all approximately the same age.

The characteristic association of rhyolitic volcanic rocks and quartzite in the Ali Molina and Sil Nakya Formations also occurs east of the Reservation in the Ox Frame Volcanics and Mount Wrightson Formation of the Sierrita Mountains and Santa Rita Mountains, respectively (Hayes and Drewes, 1978; Bilodeau and Keith, 1979). On the basis of published lithologic descriptions and age data (Cooper, 1971; Drewes, 1971) and of our examination of the Ox Frame Volcanics, it seems likely that these four formations are correlative in the sense that they contain rocks deposited at about the same time in similar environments. Correlation of the other lower Mesozoic rocks of the Baboquivari Mountains with lower Mesozoic sequences in southeastern Arizona (Hayes and Drewes, 1978) is less clear.

A different suite of lower Mesozoic supracrustal rocks, the "Artesa-type," occurs in the Comobabi and Artesa Mountains. Most of the Comobabi Mountains is made up of two rock units: (1) andesitic to trachytic volcanic rocks and related small intrusions, which are intruded by (2) the monzogranite of Ko Vaya and related plutonic rocks (MKV, Fig. 3). Detailed geologic mapping by J. A. Briskey (*in* Haxel and others, 1978) in the Ko Vaya Hills strongly suggests that the volcanic rocks and the monzogranite are coeval, and in places the monzogranite grades structurally upward into a porphyry border phase. On the basis of these and other relations, the Comobabi Mountains and Ko Vaya Hills are interpreted as a dissected volcano-plutonic complex. Isotopic analysis of zircons from the plutonic rocks of the complex indicates a Middle or Late Jurassic age.

In the Artesa Mountains, an apparent stratigraphic sequence consists of the following units, in probable descending stratigraphic order:

1. Greenstone, derived from andesitic volcanic rocks

2. Quartzofeldspathic schist and metaconglomerate

3. Quartzite

4. Argillite, sandstone and conglomeratic sandstone, and subordinate intermediate and silicic volcanic rocks.

The andesitic rocks of unit 1 are very similar to some of the andesites of the volcanic unit of the Comobabi Mountains, and the Artesa Mountains sequence is intruded by monzogranite identical to the monzogranite of Ko Vaya. Metamorphism of the supracrustal rocks appears to predate the monzogranite and probably occurred during Early or Middle Jurassic time. Other unmetamorphosed or slightly metamorphosed rocks considered to belong to the "Artesa-type" sequences occur in several areas of the Quijotoa quadrangle (Rytuba and others, 1978) and in the southern La Lesna Mountains. Correlation of the "Artesa-type" sequences with the lower Mesozoic rocks of southeastern Arizona is not attempted here.

The age and structural relations between the "Baboquivari-type" and the "Artesa-type" lower Mesozoic sequence are incompletely understood. The most likely age relation, based on the information summarized above and on regional age relations (Hayes and Drewes, 1978), is that the "Artesa-type" sequence is, at least in part, younger. The two sequences are separated by a Late Cretaceous thrust fault (see below) and a Tertiary high-angle fault system on the east side of the Comobabi Mountains, and by high-angle faults in the Artesa Mountains and on the southeast side of Sierra Blanca (Fig. 3).

Jurassic Plutonic Rocks

Plutons with concordant U-Pb isotopic zircon ages between 165 and 145 m.y. have been identified in the Quinlan, Coyote, Baboquivari, and Comobabi Mountains. Other plutons considered to be of Middle or Late Jurassic age, on the basis of either preliminary U-Pb isotopic data or lithologic correlation with concordantly dated plutons, occur in the Comobabi, Quijotoa, Artesa, southern Santa Rosa, and southern La Lesna Mountains, at Morena Mountain, in the Kupk Hills, and in the western foothills of the southern Baboquivari Mountains (Fig. 3).

Most of these plutons consist of relatively quartz-rich rocks, ranging from alkali-feldspar granite to granodiorite. In the North Comobabi Mountains there is a stock of hastingsite- and arfvedsonite-bearing quartz syenite (Haxel and others, 1978), and the South Comobabi Mountains contain nepheline- and cancrinite-bearing dioritic rocks (Bryner, 1959) of uncertain extent.

Field and U-Pb isotopic studies conducted by Anderson and Silver (1978) during the past decade have identified Middle and Late Jurassic granitic rocks, and Lower Jurassic volcanic rocks, over an extensive area in Sonora, Mexico.

Upper Mesozoic Supracrustal Rocks

The upper Mesozoic supracrustal rocks of the southern Papago Indian Reservation are sedimentary rocks and subordinate volcanic rocks that form two units: the Sand Wells Formation (SWF, Fig. 3; Heindl, 1956b), which crops out in the Comobabi Mountains and Sil Nakya Hills and in hills north of the Brownell Mountains, and the rocks of Gu Achi (RGA, Fig. 3), which occur in the southern Santa Rosa Mountains around Gu Achi Peak and in the Sheridan Mountains. Although these two units are lithologically dissimilar and their mutual age relations are unknown, the age of each is bracketed by the same geologic relations: both units contain clasts of Middle or Late Jurassic plutonic rocks and both are intruded by igneous rocks of known or presumed Late Cretaceous or early Tertiary age. Neither unit can be confidently correlated with the upper Mesozoic sequences of southeast Arizona.

The most complete section (~1,900 m thick) of the Sand Wells Formation occurs on the north side of the South Comobabi Mountains (Haxel and others, 1978). The sequence here is, in descending stratigraphic order (see Bryner, 1959, for more detailed descriptions):

1. Middle Tertiary conglomerate

Angular unconformity

2. Sand Wells Formation (Cretaceous or, possibly, Upper Jurassic)

   A. Volcanic breccias and flows of intermediate composition, with minor sandstone

   B. Sandstone, siltstone, conglomerate, mudstone, and subordinate volcanic rocks

   C. Basal conglomerate

Intertonguing contact

3. Andesite porphyry flows

Inferred unconformity

4. Middle or Upper Jurassic volcanic and plutonic rocks

On the west side of the North Comobabi Mountains, the Sand Wells Formation in some places includes a thin basal unit of distinctive red rhyolite flows. In this area, the Sand Wells Formation rests depositionally on, and locally contains clasts of, the porphyry border phase of the Middle or Late Jurassic monzogranite of Ko Vaya. In the Sil Nakya Hills, the Sand Wells Formation unconformably overlies and contains clasts of the Lower Jurassic Sil Nakya Formation.

The rocks of Gu Achi of the Sheridan Mountains consist of variably metamorphosed (see below) arkose and arkosic conglomerate, arenitic sandstone, graywacke, siltstone, and andesitic volcanic and volcaniclastic rocks (see Briskey and others, 1978, for petrographic descriptions). These supracrustal rocks are intruded by premetamorphic greenstone probably related to the andesitic volcanic rocks. The conglomerate contains rare clasts of quartzite and fossiliferous limestone of probable Paleozoic age and sparse clasts of distinctive coarse-grained granite of uncertain provenance. In the southern Santa Rosa Mountains (Bergquist, Blacet, and Miller, 1978), the rocks of Gu Achi consist of coarse thick-bedded conglomerate with subordinate sandstone and siltstone. These rocks are in high-angle fault contact with a Middle or Late Jurassic granodiorite pluton that makes up most of the central Santa Rosa Mountains. The conglomerate contains sparse clasts of this granodiorite.

Late Cretaceous and Early Tertiary Granites

Leucocratic muscovite- and garnet-bearing granitic rocks crop out in some ten ranges of the southern Papago Reservation (Fig. 3). These granites can be designated by the informal term "granites of Presumido type" (Fig. 3), chosen because the largest body underlies the area around Presumido Peak in the southern Baboquivari Mountains (Fig. 4).

The granites of Presumido type are somewhat variable, both from one range to another and within each range, but are characterized by the following features:

1. All combinations of one, two, or all three of the accessory minerals biotite, muscovite (that is, white mica), and garnet are common. Hornblende is absent.

2. Most of the granite bodies consist of two phases: an older, leucocratic, rusty-weathering phase in which garnet is sparse to typically absent; and a younger, highly leucocratic, white-weathering phase in which garnet is common to locally sparse. In several ranges, one phase or the other is subordinate or even apparently absent; but in most areas the two phases are both common and occur together, with the younger phase intruding the older phase on a scale of meters to hundreds of meters. The younger phase typically grades into, and in some areas consists largely of, pegmatite.

3. Most of the granitic rocks of Presumido type are chiefly leucocratic monzogranites that in the field are not seen to be associated with any hornblende-bearing rocks or any granodioritic or tonalitic rocks. In other words, the granites apparently are not part of a "normal" granitic differentiation sequence.

The granites of Presumido type are sharply intrusive into their country rock, and there is no field evidence to suggest that these granites were derived by anatexis or mobilization of the rocks they now intrude. In many areas, for example the southern Coyote Mountains, the country rocks of the granites of Presumido type are flooded with pegmatite dikes.

The monzogranite of Pan Tak (one of the granites of Presumido type) makes up most of the northern Coyote Mountains. Zircons from this rock are very strongly discordant, and the pattern of discordance for five isotopically analyzed size fractions suggests mixing of Precambrian and Late Cretaceous-early Tertiary zircons. The *lower* concordia intercept of the chord defined by the zircon isotopic data, and the inferred age of the monzogranite of Pan Tak, is 58± 3 m.y.(Wright and Haxel, 1980). None of the other granites of Presumido type have yet been completely dated, but we presume that all of them are of approximately the same age, and there may be a slight westward increase in age (Coney and Reynolds, 1977; Keith, 1978).

In the northern Papago terrane, granitic to tonalitic rocks of Late Cretaceous age, based on a concordant zircon age of 68 m.y. from the Cimar Mountains and three biotite K-Ar ages of 67 m.y. (Johnston, 1972) from the Lakeshore stock, occur in the Cimar, Vekol, southern Slate, and northern Santa Rosa Mountains (Fig. 3). Many of these mesocratic to leucocratic Late Cretaceous plutonic rocks contain hornblende, and the plutonic rocks of the Cimar Mountains (Briskey and others, 1978) constitute a differentiation sequence from biotite-hornblende granodiorite through biotite monzogranite to monzogranitic pegmatite and aplite. The petrologic contrast between these plutonic rocks and the granites of Presumido type is clear and probably has genetic significance. Although we as yet have no chemical or stable-isotope data, the mineralogical similarity of the Late Cretaceous granitic to tonalitic rocks of the northern Papago terrane and the granites of Presumido type of the southern terrane to the I- and S-type granites, respectively, of Chappell and White (1974) is intriguing.

The hornblende-bearing biotite granite and orthogneiss unit of the Gunsight Hills (Fig. 3), which also crops out in the Kupk Hills, has yielded K-Ar biotite ages of 39 and 46 m.y. (analyses by P. E. Damon; see Tosdal, 1979, items K14, K15). These dates probably result from partial argon loss, and the granite may be of either Jurassic age or Late Cretaceous or early Tertiary age.

Late Cretaceous Metamorphic Episode

Greenschist-facies regionally metamorphosed rocks, including quartzofeldspathic to quartzose phyllite and schist, arkosic semischist, epidotized siltstone and sandstone, metaconglomerate, quartzite, metarhyolite, and greenschist, crop out in a number of areas of the southern Papago Reservation (see, for example, the descriptions of map units Mzgu of Briskey and others, 1978; and Mzs of Haxel and others, 1978). These areas are shown by an overprint pattern in Figure 3. Foliation attitudes in the metamorphic rocks are rather variable, but westward dips predominate. Mineral lineation fairly consistently plunges gently to moderately north-northwest to northeast or south to southwest. In most ranges, the foliation and lineation are locally folded by mesoscopic kink or crenulation folds with axes that plunge gently to the west.

These metamorphic rocks were derived from both the "Baboquivari-type" lower Mesozoic sequence and the upper Mesozoic rocks of Gu Achi. Two features suggest that the metamorphic rocks, though derived from protoliths of two different ages, are products of the same metamorphic episode. First, in all areas the metamorphic rocks have similar textures and fabrics; in particular, the same set of gently west-plunging kink or crenulation folds is developed in metamorphic rocks derived from both protoliths. Second, in all areas the metamorphic rocks include layers of distinctive epidote-bearing metasedimentary rocks, varying from epidotized sandstone and siltstone to quartz + epidote ± amphibole schist and gneiss, that show a characteristic wavy, variegated banding or coarse lamination. The regionally metamorphosed, crystalloblastic metasedimentary and metavolcanic rocks will hereafter be referred to collectively as schist to avoid confusion with the two varieties of locally developed mylonitic metaplutonic rocks introduced below.

At the north end of the hills east of Comobabi village (HECV, Fig. 3; Haxel and others, 1978), the schist is overlain along a thrust fault by the Jurassic monzogranite of Ko Vaya. Similarly, in the western foothills of the southern Baboquivari Mountains, granitic rocks of probable Jurassic age tectonically overlie the schist of Chutum Vaya (Fig. 4). At the north end and on the west side of Sierra Blanca, the schist is overlain by a thrust plate of augen orthogneiss of probable Precambrian age (Fig. 3). In all three areas, foliation and lineation in blastomylonite or mylonite gneiss (Higgins, 1971) at the base of the upper plate is parallel to foliation and lineation in the underlying schist of the lower plate, indicating that thrusting and metamorphism were related. The direction and magnitude of thrusting are unknown, and the regional extent and significance of these thrust faults is still uncertain.

In the Sheridan Mountains and on the southwest flank of Gu Achi Peak, the degree of metamorphism, as expressed by development of foliation and lineation and obscuration of bedding, extent of recrystallization, and strength of deformation of clasts in metaconglomerate, increases markedly toward the southwest. The cause of this southwestward textural upgrading is hidden by alluvium.

The granites of Presumido type have a strong spatial association with schists derived from the "Baboquivari-type" lower Mesozoic sequence (Fig. 3). The most common relation between the fabric of the granite and the crystalloblastic fabric of the schists is that granite which is unfoliated or only locally foliated cuts sharply across the foliation of the schist, and in the hills east of Comobabi village the foliation and lineation of the schist appear to have been folded by emplacement of the granite. A less common but still widespread relation is that the granite and the schist have parallel foliation and lineation. Where the latter relation occurs, the granite is commonly a weakly to strongly blastomylonitic orthogneiss, whereas the schist is crystalloblastic. These relations demonstrate that the granites of Presumido type are (late?) synmetamorphic to postmetamorphic with respect to the schist. Additional evidence comes from the west side of Sierra Blanca, where in one outcrop a thin dike of muscovite granite is mylonitized in the thrust zone, but in a nearby outcrop another small intrusion of muscovite granite truncates the foliation of the mylonite gneiss just above the base of the upper plate. These relations, taken together, suggest that metamorphism, thrusting, and granitic plutonism may all have been aspects of a single protracted tectonic and thermal episode.

The regional metamorphic episode postdates the Middle or Late Jurassic plutons, because the metamorphosed rocks of Gu Achi contain clasts of one of these plutons and because the monzogranite of Ko Vaya is mylonitized along a thrust fault that is synmetamorphic with respect to the schist. In the Sheridan Mountains, the schist is intruded by postmetamorphic granodiorite that has a concordant U-Pb isotopic age of 68 m.y. In several other ranges, field relations suggest that some of the granites of Presumido type, the easternmost (and youngest(?)) of which is about 58 m.y. old, were emplaced during the late or waning stages of the metamorphic episode. Although these data suggest that the age of metamorphism may have differed slightly from one area to another, the overall age of the regional metamorphic episode is tentatively considered to be latest Cretaceous, and perhaps also earliest Tertiary.

Metamorphic Core Complexes

The metamorphic core complexes (Coney, 1979) of southern Arizona and northern Sonora are areas of distinctive tectonic style characterized by ductile to brittle extensional structures of Tertiary age (Davis and Coney, 1979; Anderson, Silver, and Salas, 1977). G. H. Davis (1977, and in press) has found that the structural features typical of the early(?) and middle Tertiary (Keith and others, in press) metamorphic core complexes of the Tucson area occur in several of the ranges of the southern Papago Indian Reservation. We find that fabrics and structures typical of this core-complex metamorphic episode are variably superimposed on fabrics and structures developed during the older, Late Cretaceous metamorphic episode. Some areas of the Reservation have been affected by only the older metamorphic episode, others by only the younger episode, and some by both episodes. In the areas affected by both metamorphic episodes, the deformational effects of the two episodes can be difficult to distinguish. The following discussion of these three types of metamorphic areas concentrates on those ranges from which the most evidence is available.

Sizable areas of schist apparently unaffected by core-complex deformation include the western slope of the northern Baboquivari Mountains (area of the Ali Molina Formation), the Sheridan Mountains, and almost all of the area of the schist of Chutum Vaya (Fig. 4). In the northern Coyote Mountains (Davis, in press), core-complex deformation has been imposed on rocks apparently unaffected by the older metamorphic episode.

At least three areas of the Reservation appear to have been significantly affected by both metamorphic episodes. Along the west side of the hills east of Comobabi village, the schist and the mylonitic rocks along the overlying thrust fault (see previous section) are disrupted by a discontinuous zone of brecciation, folding, and hematitic alteration that is very similar to décollement zones associated with more typical metamorphic core complexes east of the Reservation (G. H. Davis and P. J. Coney, personal communication, 1979). Similar relations occur on the southeast and west sides of Sierra Blanca. In the western foothills of the southern Baboquivari Mountains (Fig. 4), the mylonitic rocks along the thrust fault that places Jurassic(?) plutonic rocks atop the schist of Chutum Vaya are intruded by post-mylonite dikes of the granite of Presumido Peak, of presumed Late Cretaceous or early Tertiary age. Both the mylonitic rocks and the granite are overprinted by mild brecciation and hematitic and chloritic alteration. Furthermore, this brecciation also affects a quartz porphyry of probable middle Tertiary age. In the south-central Baboquivari Mountains (Fig. 4), the schist of Chutum Vaya is postmetamorphically intruded by the granite of Presumido Peak. In this area the granite is, except locally, unfoliated. Southward the granite becomes progressively more strongly foliated and lineated and, in the Pozo Verde Mountains and near Sasabe, is converted to mylonitic orthogneiss typical of metamorphic core complexes (Davis, in press).

Both of these lines of evidence from the southern Baboquivari Mountains suggest that the Late Cretaceous metamorphic episode and the younger core-complex metamorphic episode were temporally distinct. On the other hand, in areas such as Sierra Blanca and the hills east of Comobabi village, moderately mylonitic orthogneisses derived from granites of Presumido type are in part synmetamorphic with respect to the crystalloblastic schists they intrude, but are also of core complex aspect. It is not clear whether the mylonitic fabric in these granites was produced entirely during the older metamorphic episode or is a composite product of both episodes. The temporal relation between the two metamorphic episodes is poorly constrained, because the timing of the older, latest Cretaceous (to earliest Tertiary) episode is not known in detail, and the younger episode is presumed to be of early(?) and middle Tertiary age only by analogy with other areas of similar structural style elsewhere in southern Arizona. K-Ar and U-Pb geochronologic studies in progress should help to elucidate the thermal and deformational history of these polymetamorphic areas of the southern Papago Indian Reservation.

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This report has not been edited to conform with stratigraphic nomenclature and classification adopted by the U.S. Geological Survey.

Note Added in Press

U-Pb isotopic analyses completed in August 1979 suggest that the body of granitic rock 15 to 20 km due west of 32°30' N., 112°00' W. (Fig. 3) is of Precambrian age rather than Late Cretaceous or early Tertiary age. This finding sharpens the spatial distinction between the northern and southern Papago terranes.

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