# GEOLOGY AND STRUCTURE OF THE NORTHERN DOME ROCK MOUNTAINS, LA PAZ COUNTY, ARIZONA

by

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## ABSTRACT

In the northern Dome Rock Mountains, a north-dipping mylonitic shear zone places sheared Precambrian and Mesozoic granitic rocks and intensely folded Paleozoic and Mesozoic(?) strata over greatly disrupted and metamorphosed Mesozoic(?) sedimentary, volcanic, and granitic rocks. This shear zone is part of a regional fault system that places cratonic rocks over Mesozoic rocks of the McCoy Basin and that marks the southwestern limit of unequivocal North American cratonic stratigraphy in the southern Cordillera. Latest movement on the shear zone was apparently left-lateral transpressive. Rocks and structures in the range record deep-seated middle Mesozoic(?) south to southwest-directed compressional tectonism and later Mesozoic(?) northeast-directed deformation. Syntectonic metamorphism locally reached amphibolite grade. Structurally high in the range, deformational fabrics and a post-kinematic(?) granite are overprinted by a low-angle mylonitic fabric that probably records mid-Tertiary(?) extension.

# INTRODUCTION

## Location, Physiography, and Access

The northern Dome Rock Mountains lie just east of the Colorado River in the low desert region of the Basin and Range province in southwestern Arizona. The range separates La Posa plain to the east from the Colorado River basin to the west. The study area is located in La Paz County, 25 km northeast of Blythe, California and 12 km northwest of Quartzsite, Arizona (Figure 1). It is bordered on the west by the Colorado River Indian Reservation.

The narrow north-trending range is low but generally quite rugged, and rises sharply from the surrounding, gently sloping, dissected pediments and alluvial plains. The breadth and elevation of the range diminishes northward; elevations range from 620 m (2024 ft) in the south to 160 m (530 ft) at the northern tip. A prominent notch, Boyer Gap, cuts the range in the center of the map area. The Tyson Wash drainage borders the area to the north and east, and separates this range from the Moon Mountains to the north. Exposure in the range is nearly 100%, but a dark desert varnish coats most outcrops and masks lithologies.

Access into the map area is good along a number of unimproved dirt roads constructed during earlier mining activity (Figure 2). These roads are easily reached from Interstate 10 and Arizona 95 in the vicinity of Quartzsite.

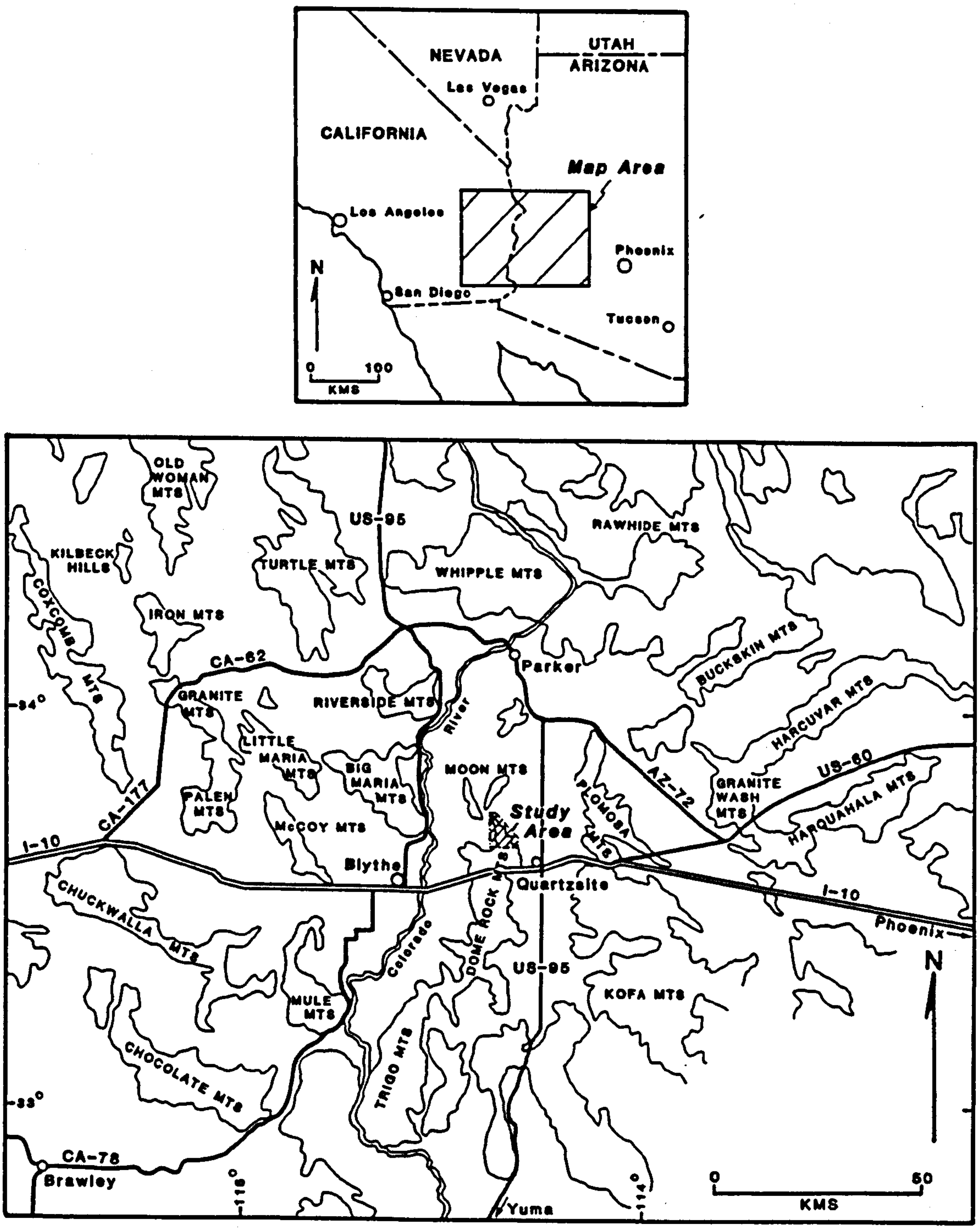


Figure 1. Location maps for the northern Dome Rock Mountains study area.

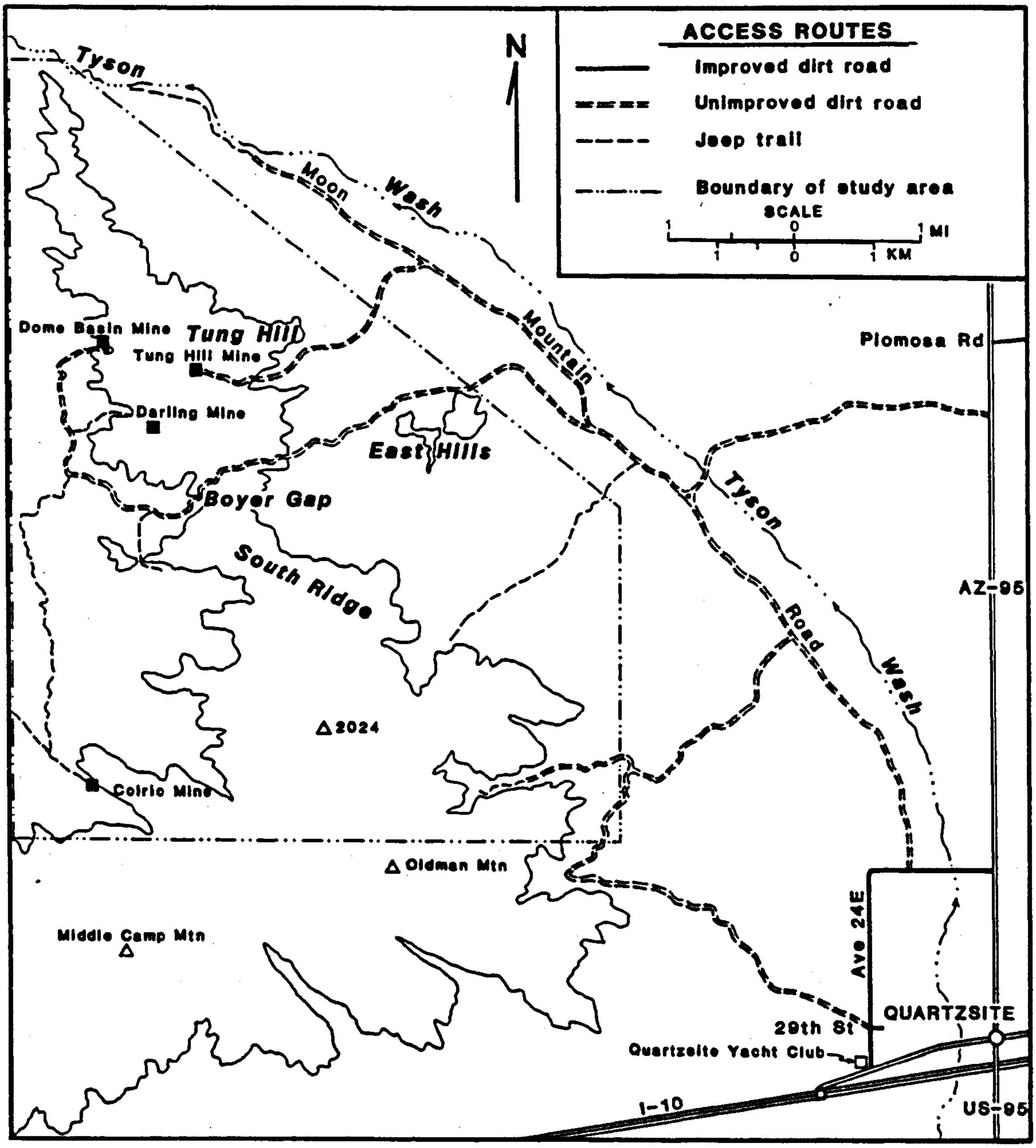


Figure 2. Map of access routes into the northern Dome Rock Mountains study area.

## Purpose and Scope of Study

The geologic and tectonic importance of the northern Dome Rock Mountains was first perceived by Harding (1982), who recognized a major north-dipping ductile reverse fault in Boyer Gap that places sheared Precambrian basement and a south-facing synclinorium of cratonic Paleozoic strata against greatly disrupted Mesozoic(?) metasedimentary, metamorphic, and plutonic rocks (Figure 3). Harding interpreted the lower-plate rocks as part of the structural McCoy Basin and the ductile fault in Boyer Gap as part of the northern boundary thrust system of the basin. No cratonic basement or Paleozoic strata have been recognized anywhere to the southwest of this boundary. This study was undertaken to document the geology and structure along this well-exposed, yet previously unmapped, segment of a significant tectonic boundary.

The primary objectives of this study were to generate the first detailed geologic map of the northern Dome Rock Mountains and to document and describe major lithologic and structural elements as well as critical contact relationships in the range. Other objectives were to interpret the style, kinematics, and timing of deformational events, and to integrate these results into the tectonic framework of the region.

This study is limited to the major lithologic and structural elements of this complex area. Quantitative kinematic analysis of minor fold structures and tectonite petrofabrics, and detailed metamorphic and geochronologic analyses were not part of this investigation. Discussions on these topics should be considered preliminary. Mineralized zones, although widespread in the range, were not studied. It is hoped


Figure 3. Overview of the Boyer Gap area.

View to the west-northwest from South Ridge into Boyer Gap (BG), showing juxtaposition along north-dipping ductile reverse fault zone. To the north, light-colored Paleozoic marbles (1) core south-facing synclinorium which is flanked by dark-colored Precambrian basement (2). To the south, Mesozoic(?) metasedimentary and volcanic rocks (3) are interleaved with Mesozoic(?) granitic augen gneiss (4). Note the prominent north-dipping structural fabric of the area. Beyond the range to the west is the Colorado River basin and, on the skyline, the Big Maria Mountains.

that the products of this study, especially the geologic map, will provide a sound base for future detailed investigations in the range.

## Methodology and Terminology

Approximately 13 square miles of the northern Dome Rock Mountains were mapped during 45 days of field work conducted between January and mid-April, 1984. Enlargements of the 1:24,000 scale U.S.G.S. Middle Camp Mountain and Moon Mountain SE topographic quadrangle maps were used as a topographic base. The results of this mapping are presented on a 1:12,000 scale geologic map and structure section (Figure 4).

Thin sections were cut and stained for K-feldspar from representative samples of all rock units except the Paleozoic metasedimentary rocks. Thin sections were studied for composition, texture and metamorphic fabric. Point-counting (200-400 points) was employed to attain modal percentages in less tectonized samples and to ascertain correlations between widely scattered exposures of variably deformed lithologies.

Foliation, lineation, and fold axis orientations measured in the field were divided into three structural and geographic domains and plotted or contoured on lower-hemisphere, equal-area stereographic projections using a computer graphics program developed at the University of Arizona. Synoptic stereograms are presented in a single domainal illustration (Figure 5) so that the orientations of structural elements throughout the map area can be easily compared.

Twenty oriented thin sections were cut from mylonitic rocks and analyzed for kinematic indicators of sense of shear. Suitably oriented outcrop faces of mylonitic rocks were examined for mesoscopic kinematic indicators in the field.

Most of the rock units discussed in this report cannot be assigned formation names based on correlation. To simplify discussions in this report, formal and informal names for physiographic features in the area are used to modify the lithologic names of certain rock units. These informal names are enclosed within quotation marks where they first appear in the text. Igneous rock classification follows I.U.G.S. recommendations (Streikeisen, 1976). Metamorphic rock classification mostly follows guidelines suggested by Williams, Turner, and Gilbert (1982).

The meaning of the term "mylonitic" is currently a subject of discussion and debate. In this report, "mylonitic" is used in a broad non-genetic sense to describe LS-tectonites that exhibit contrasting brittle and plastic behavior of mineral components, and which show a pronounced reduction in grain size rather than significant grain growth. Foliation is largely defined by a strong preferential orientation of micas, flattened quartz aggregates, feldspar porphyroclasts, and matrix minerals. Foliation surfaces contain a lineation typically defined by trains of micas, strongly elongated quartz aggregates, and lensoidal feldspar porphyroclasts. Microscopic textures indicate that most feldspar porphyroclasts, epidote, sphene, and some micas have deformed brittlely whereas quartz, matrix minerals, and most micas have deformed plastically. Relict asymmetric "S-C" fabrics are commonly discernible in outcrops or sections when viewed parallel to foliation and perpendicular to lineation, and may be used to interpret sense of shear. These fabrics are largely obscured in thin section by subsequent recrystallization. Mylonitic tectonites are not necessarily spacially associated with discrete shear zones, but rather are distributed throughout the map area. This use of the term "mylonitic" conforms to the definition first proposed by Bell and Etheridge (1973). Detailed descriptions of mylonites, S-C fabrics, and methods of determining sense of shear are given by Berthe and others (1979), Simpson and Schmid (1983), and Lister and Snoke (1984). Textural classification in this report follows Sibson's (1977) recommendations.

## Previous Studies

The earliest workers in the Dome Rock and Moon Mountains (Bancroft, 1911; Jones, 1916; Darton, 1925) described the physiography, mineral deposits, and general lithologies of parts of the ranges, but did not mention the northern Dome Rock Mountains specifically. Wilson mapped the area in reconnaissance while preparing the Geologic Map of Yuma and La Paz Counties (Wilson, 1960). He mapped Mesozoic gneisses, schists, metasedimentary rocks and granites with scattered Laramide intrusives within the study area. Keith (1978) has indexed mineral properties and outlined the history of mineral exploration in the range. The northern Dome Rock Mountains are discussed briefly by Marshak (1979, 1980) and Harding (1982), but detailed geologic studies have been limited to the central (Crowl, 1979) and southern (Marshak, 1979, 1980;

Harding, 1982; Tosdal, 1982, 1984) portions of the range. No detailed geologic studies have been conducted in the adjacent Moon Mountains.

Only within the past two decades have detailed geologic maps and reports been produced in the region. Several investigations have focused on various aspects of the thick Mesozoic sedimentary sequences exposed in the region (Harding, 1978, 1980; LeVeque, 1981, 1982; Marshak, 1979, 1980; Miller, 1979; Pelka, 1973; and Robison, 1980). Harding (1982) synthesized these earlier efforts in a regional analysis of the McCoy Mountains Formation. Harding correlated the formation across six ranges, discussed its tectonic setting and significance, and delineated the faulted boundaries of the structural McCoy Basin. Several workers have mapped and described complex structures that involve cratonic basement and Paleozoic strata along the northern boundary of the basin (Hamilton, 1982; Miller, 1970; Miller and McKee, 1971; Reynolds, Keith, and Coney, 1980; Richard, 1983; and Scarborough and Meader, 1983). There have also been structural investigations north of the basin (Ellis, 1982; Emerson, 1982; Lyle, 1982; and Reynolds, 1982) and along the southern margin of the basin (Tosdal, 1982, 1984). Other workers have synthesized the geologic framework of western Arizona (Reynolds, 1980) and the adjacent Mojave Desert region (Burchfiel and Davis, 1981). Stone, Howard, and Hamilton (1983) have compiled a regional correlation of cratonic Paleozoic strata.

Most current references for the region may be found in one of four volumes (Jenney and Stone, eds., 1980; Ernst. ed., 1981; Howard, Carr, and Miller, eds., 1981; and Frost and Martin, eds., 1982a).

## REGIONAL GEOLOGIC SETTING

The northern Dome Rock Mountains sit astride the northern boundary of the west-northwest-trending, structurally complex, fault-bounded McCoy Basin of Harding (1982) (Figure 6). This boundary is a system of north-dipping faults that place crystalline basement and overlying cratonic Paleozoic and Mesozoic strata over Mesozoic rocks of the basin. It is the southwestern limit of exposed unequivocal cratonic stratigraphy in the southwestern United States. The basin, as defined by Harding, is composed of Jurassic Palen Formation, metasedimentary rocks, a thick section of Jurassic volcanic and hypabyssal rocks, and an overlying 5-7 km-thick section of quartzofeldspathic clastic rocks, the McCoy Mountains Formation of Pelka (1973) and Harding (1982). These rocks are probably floored by cratonic basement and Paleozoic strata, based on paleomagnetic data and plutonic xenoliths, but no basement or Paleozoic rocks are exposed within the margins of the basin. The basin is bounded to the south by a system of south-dipping faults that place Precambrian and Mesozoic crystalline rocks of the Tujunga terrane of Blake, Howell, and Jones (1982) over basin rocks. The McCoy Basin is approximately 140 km long and 25 km wide, and presently extends from the Coxcomb, Palen, and McCoy Mountains in southeastern California to the Dome Rock and southern Plomosa Mountains of southwestern Arizona (Harding, 1982; Harding and Coney, 1985). A schematic structure section across the basin in the Dome Rock Mountains is displayed in Figure 7.

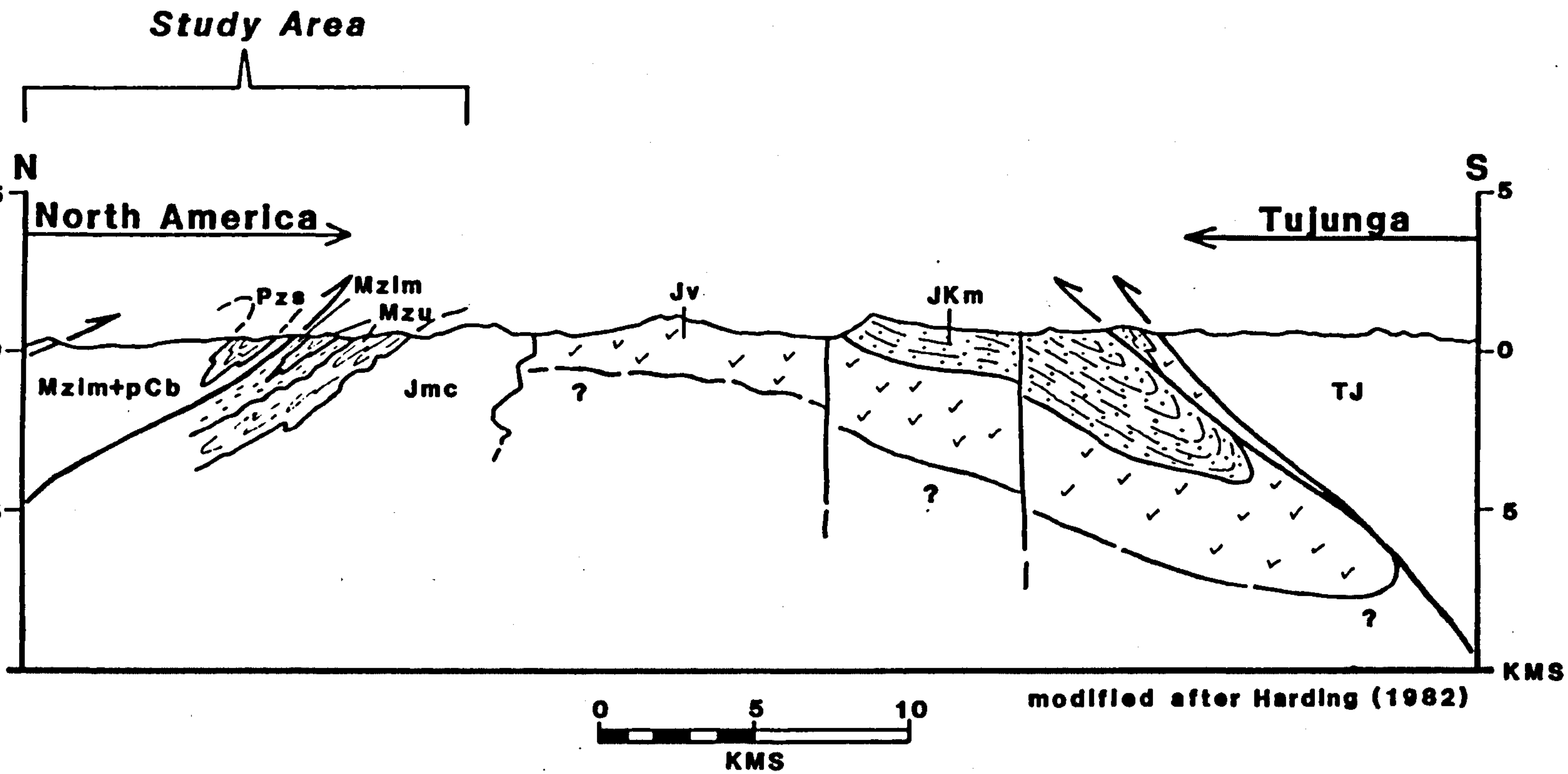


Figure 7. Schematic structure section through the Dome Rock Mountains.

Refer to Figure 6 for legend.

To the north of the basin, Precambrian basement is composed of granitic rocks, mostly 1.4 b.y.-old megacrystic potassic granites, and locally of older, high-grade gneisses and schists. These rocks are overlain depositionally by a distinctive section of Paleozoic strata that have been correlated to stratigraphic sections of either the Grand Canyon-Colorado Plateau region or southeastern Arizona (cf., Hamilton, 1982; Miller, 1970). No Paleozoic rocks have been recognized within or south of the McCoy Basin. In several ranges, the Paleozoic section is overlain depositionally by a thin heterogeneous stack of clastic rocks that have been correlated to Triassic and lower Jurassic sections in the Mojave Desert and Colorado Plateau regions. The Jurassic Palen Formation of Pelka (1973) and LeVeque (1981, 1982), located beneath the northern boundary fault of the McCoy Basin in the Palen Mountains, has been correlated in part to these sections.

A thick terrane of volcanic and hypabyssal rocks depositionally overlie and locally intrude older rocks to the north and south of the McCoy Basin, and are up to 5 km thick (Crowl, 1979) within the basin itself. Two age determinations, early to middle Jurassic in the central Dome Rock Mountains (U-Pb, L. T. Silver, cited by Crowl, 1979) and 176 m.y. in the Palen Mountains (K-Ar plagioclase, Pelka, 1973), and stratigraphic position suggest that the volcanic sequence is mostly lower to middle Jurassic in age. The volcanics range from rhyolitic to basaltic in composition, and are associated with, and locally intruded by, a suite of middle Jurassic granitic plutons. These plutons have yielded ages of 160-165 m.y. in the southeastern Mojave Desert region (John, 1981) and in the Big Maria Mountains (L. T. Silver, cited by

Hamilton, 1982). The Middle Camp pluton in the Dome Rock Mountains is considered part of this suite (Crowl, 1979; John, 1981).

Three sequences of continental clastic strata are known to depositionally overlie, and locally interfinger with, the Jurassic volcanic terrane: 1) the anomalously thick McCoy Mountains Formation; 2) the thinner but laterally correlative Apache Wash Formation (Harding, 1982) to the north of the McCoy Basin; and 3) the Winterhaven Formation (Haxel and others, in press) to the south of the basin. These sequences are distinct from the classic Mesozoic stratigraphy exposed to the north on the Colorado Plateau. Harding (1982) interprets the former two sequences to have been deposited in deep structural basins associated with high angle and strike-slip faulting. Correlation with the Jurassic(?) Winterhaven Formation is uncertain at present (Harding and Coney, 1985). The age of the McCoy Mountains Formation remains controversial. The formation is considered by some to be Cretaceous and possibly Paleocene in age, based on analyses of fossil wood and pollen (e.g., Pelka, 1973; Crowell, 1981; Hamilton, 1984). However, recent geologic, structural, and paleomagnetic evidence suggest that the entire formation may be no younger than late Jurassic in age (see Harding, 1982; Harding and others, 1983; Harding and Coney, 1985). The late Cretaceous Coxcomb pluton intrudes the McCoy Mountains Formation in the Coxcomb Mountains of southeastern California (Harding, 1982).

The stratigraphy of the region is greatly disrupted by complex structures and metamorphism loosely constrained as middle to late Mesozoic in age. Along the northern margin of the basin, Precambrian basement is infolded and faulted with Paleozoic and Mesozoic rocks.

Spectacular south to southwest-vergent nappe structures occur in the Little Maria and Big Maria Mountains of California, where the cratonic Paleozoic section is locally attenuated down to 1% of its Grand Canyon stratigraphic thickness in the limbs of huge south-facing, gently west-plunging recumbent synclines (Emerson, 1982; Hamilton, 1982). These structures appear to extend eastward into the northern Dome Rock Mountains (Figure 3). These folds are associated with a south-vergent fault system (Emerson, 1982; Krummenacher and others, 1981; LeVeque, 1981, 1982) which Harding (1982) suggests constitutes the northern boundary fault of the McCoy Basin, placing Precambrian and Paleozoic rocks over younger Jurassic volcanics, Palen and McCoy Mountains Formations. To the east, in the southern Plomosa and Granite Wash-Harquahela Mountains, the McCoy Mountains and Apache Wash Formations or laterally correlative rocks are overlain by low-angle imbricate thrust sheets of Precambrian and Paleozoic rocks (Miller and McKee, 1971; Reynolds and others, 1980; Reynolds and others, 1983; Richard, 1983). The McCoy Mountains Formation and Jurassic volcanics are overturned and overlain by crystalline rocks along the north-vergent Mule Mountain Thrust (Tosdal, 1982, 1984) in the Mule and southern Dome Rock Mountains. Rocks of the McCoy Basin and laterally correlative units generally occur in the lowest structural position beneath thrust faults throughout the region. Whereas rocks along the northern margin of the basin are strongly deformed and metamorphosed up to amphibolite grade, most of the McCoy Mountains Formation is homoclinal and only weakly metamorphosed (Harding, 1982). Upper Cretaceous plutons (ranging 90-65 m.y.) cut strong deformational fabrics in the Palen (Pelka, 1973), Little Maria (Emerson, 1982), Big Maria (Hamilton, 1982), northern Plomosa (Scarborough and Meader, 1983), and Granite Wash Mountains (Reynolds and others, 1983). Recent paleomagnetic data from the McCoy Mountains Formation suggests that some of the deformation may be Middle to Late Jurassic in age (Harding and others, 1983).

Mid-Tertiary low-angle normal faults (detachment faults) are now recognized as fundamental regional structures in the Colorado River region (Davis and others, 1980; Frost and Martin, 1982b; Spencer, 1984) and to the east (Rehrig and Reynolds, 1980; Reynolds, 1982). Major detachment faults greatly obscure and offset all previous stratigraphic and structural relationships. These faults are locally associated with mylonitization of lower-plate rocks and brittle faulting and rotation of upper-plate rocks. In general, mylonitic foliations are low-dipping and contain well-developed northeast-plunging mineral lineations. Upper-plate rocks as young as mid-Tertiary dip moderately to the southwest and are cut by northeast-dipping normal faults. The northern Dome Rock Mountains appear to structurally underlie the northeast-dipping Moon Mountain detachment fault (Baker, 1981), the lowest(?) of a probable imbricate stack of detachment structures in the region (Spencer, 1984).

Ranges in the region are cut by late Tertiary(?) high-angle normal faults and locally by northwest-striking, right-separation faults (Crowl, 1979; Hamilton, 1982; Krummenacher and others, 1981; Miller, 1970). Flat-lying volcanic rocks, dated at about 17 to 19 m.y. (Eberly and Stanley, 1978; Shaffiquillah and others, 1980) cap the southern Plomosa and Kofa Mountains.

## ROCK UNITS

### Geologic Framework of the Northern Dome Rock Mountains

Rocks exposed in the northern Dome Rock Mountains range from Precambrian to Tertiary in age. The study area is largely underlain by a variety of strongly deformed and moderately metamorphosed sedimentary, volcanic, hypabyssal, and plutonic rocks. These rocks are intruded by several types of less-deformed igneous rocks.

A significant stratigraphic discontinuity exists between certain rock units exposed to the north and south of Boyer Gap (Figures 3, 4). To the north, a distinctive sequence of metasedimentary rocks that are correlative to Paleozoic cratonic rocks rests depositionally on Precambrian granitic basement. Farther north in the Tung Hill area, a thick section of metasedimentary rocks ("Tung Hill metasedimentary rocks") that are roughly similar to lower Mesozoic cratonic rocks exposed in nearby ranges (e.g., Emerson, 1982; Hamilton, 1982; Stoneman, 1985) lies completely embedded in granitic rocks. In contrast, Mesozoic(?) rocks within a very thick metasedimentary and volcanic assemblage exposed only to the south of Boyer Gap have no clear cratonic correlatives. The assemblage, composed largely of quartzofeldspathic schist, gneiss, and quartzite, is associated with and locally intruded by a large body of metarhyodacite porphyry. These rock units roughly resemble rocks exposed elsewhere within the structural McCoy Basin. The stratigraphic relationship between these rock units ("McCoy Basin rocks") and the cratonic stratigraphy exposed only to the north of Boyer Gap is unknown.

Much of the map area is underlain by a variety of igneous and metaigneous rocks, most of which are probably Jurassic or younger in age. The Middle Camp pluton intrudes McCoy Basin rocks in the southern part of the area. Lithologically similar gneissic monzogranites and lesser gneissic leucogranites occur throughout the area, but are most prevalent north of the Tung Hill and Dome Basin mines. These rocks locally intrude cratonic stratified rocks. A granodiorite schist is in sheared intrusive contact with Paleozoic rocks in the central part of the area. A very thick body of granitic augen gneiss ("South Ridge augen gneiss") underlies a prominent west-northwest-trending ridge south of Boyer Gap, and locally intrudes McCoy Basin rocks. Another granitic augen gneiss ("Tyson augen gneiss") is exposed in tectonic contact above Tung Hill metasedimentary rocks. Lenses of amphibole schist, metadiorite, and metarhyolite crop out mostly within McCoy Basin rocks. A biotite granite pluton ("Tyson Wash granite") and numerous leucogranite intrusives cut across well-developed structural fabrics, but are themselves variably deformed. Finally, the area is cut by widely scattered northwest-trending undeformed diorite dikes.

Deformed and sheared rock units variably contain secondary muscovite, biotite, epidote, actinolite, and chlorite, but generally lack higher grade metamorphic minerals. This is indicative of at least upper greenschist (biotite) grade regional metamorphism (Williams and others, 1982). However, the intensity and style of deformation, and abundance of gneissic and schistose lithologies, suggest that much of the syntectonic metamorphism may have been amphibolite grade (Hyndman, 1972), and that present mineral assemblages are largely due to retrograde metamorphism.

Rock units are divided into three major groups for description: 1) cratonic stratigraphy, 2) McCoy Basin rocks, and 3) metaigneous and igneous rocks. The units cannot be outlined in a strict chronological order because the actual and relative ages of many units are uncertain or unknown. Most rock units are discussed in the following order: distribution, general characteristics, lithology, and contact relations, followed by an interpretation of age and correlation.

## Cratonic Stratigraphy

### Precambrian Basement

The only definite Precambrian lithology exposed in the northern Dome Rock Mountains is a variably sheared megacrystic leucocratic syenogranite. It underlies the flanks of a huge synclinorium of Paleozoic rocks in the central part of the map area, but has not been recognized north of the Tung Hill shear zone or south of the Boyer Gap shear zone.

Outcrop appearance greatly depends on the degree of deformation. Least deformed granite forms low dark knobby hills littered with weathered-out megacrysts, whereas more strongly sheared granite forms dark ledges and forbidding cliffs. The granitic basement is now largely gneissic granite and augen gneiss, but it grades into banded ultramylonite within the Boyer Gap shear zone. Where it is least deformed, the granite characteristically contains abundant (30-60%) rectangular

K-feldspar megacrysts, ranging 1-5 cm in length, in a fine to coarse-grained, quartz-rich matrix (Figure 8). Feldspar megacrysts appear as light-gray to buff, rounded knots in a medium to dark-gray, crudely foliated groundmass.

The granite is composed of 35-60% K-feldspar, 5-15% plagioclase, 20-35% quartz, 0-5% relict biotite, and 5-10% recrystallized biotite, secondary muscovite, and chlorite. Accessory minerals include epidote, sphene, zircon, tourmaline, rutile, and opaque oxides. In thin section, most primary mineral components are partially to wholly recrystallized. Quartz occurs in sutured aggregates and exhibits undulose extinction. Fine-grained micas form seams that wrap around larger grains and fill fractures within broken megacrysts. Feldspar megacrysts are variably sericitized and recrystallized, but are universally broken, bent, or shattered. Where strongly sheared, the bulk of the groundmass is composed of microcrystalline material.

The granite is in sharp depositional contact with basal Cambrian Bolsa quartzite. It is strongly sericitized and iron stained within several meters of the Precambrian-Cambrian unconformity, which is commonly sheared and inverted (Figure 9). The megacrystic leucocratic granite is lithologically similar to granite dated at about 1.4 b.y. in the Big Maria Mountains (U-Pb by L. T. Silver, cited by Hamilton, 1982), and to an extensive suite of 1.4 b.y.-old granites that compose much of the cratonic crust in the region (Silver and others, 1977).

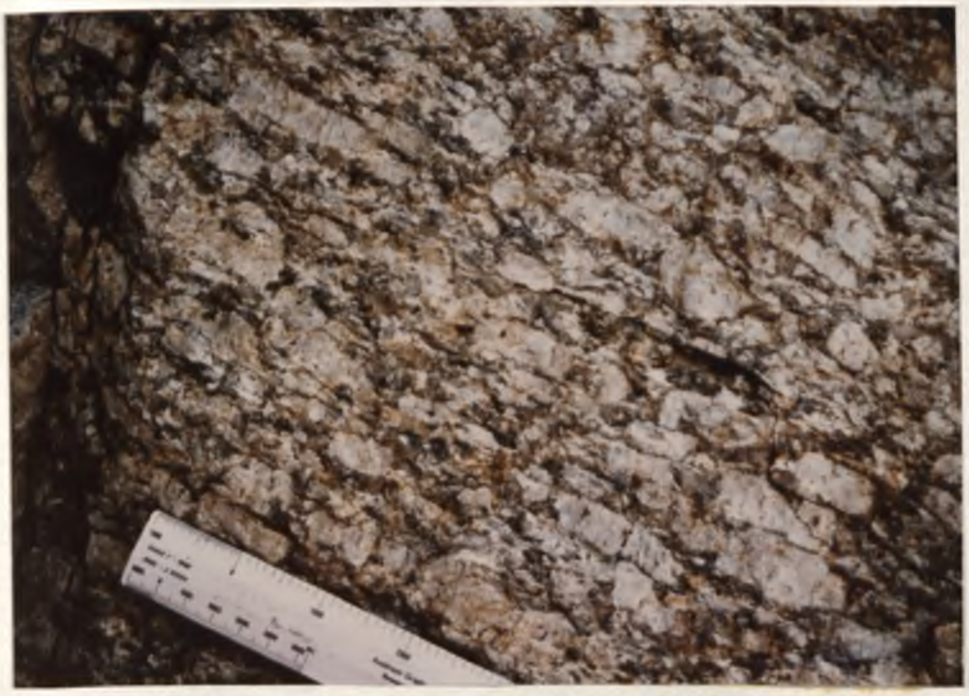

Figure 8. Foliated Precambrian megacrystic granite.

Figure 9. Inverted Precambrian-Cambrian unconformity.

View to the east in Boyer Gap. Precambrian granitic basement structurally overlies Cambrian Bolsa quartzite. Note hammer in foreground for scale.

## Paleozoic Metasedimentary Rocks

A distinctive section of highly deformed unfossiliferous metasedimentary rocks, lithologically similar to cratonic Paleozoic strata of the Grand Canyon (McKee, 1969) and southeastern Arizona (Bryant, 1968; Pierce, 1976), is exposed in a huge south to southwest-facing synclinorium in the central part of the map area (Figures 3, 4). Similar metasedimentary sections derived from cratonic Paleozoic strata have been documented in the nearby Big Maria (Hamilton, 1982), Little Maria (Emerson, 1982), Riverside (Lyle, 1982), and Plomosa Mountains (Miller, 1970), but were previously not recognized in the northern Dome Rock Mountains (e.g., Stone and others, 1983). The nearest exposed section of unmetamorphosed fossiliferous Paleozoic strata occurs 30 km to the east in the southern Plomosa Mountains (Miller, 1970). The lower part of that section is strikingly similar to the stratigraphy found in the map area, so formation names and age interpretations used here follow from correlation with the section in the southern Plomosa Mountains as described by Miller (1970).

Four units are recognized in the metasedimentary section: 1) basal quartzite, 2) quartz-mica schist, 3) calcitic and dolomitic marbles, and 4) interlayered quartzite, marble, and calc-silicate. These units are correlated, respectively, with the 1) Cambrian Bolsa Quartzite, 2) Cambrian Abrigo Shale, 3) Devonian Martin and Mississippian Escabrosa Limestones, and 4) Pennsylvanian-Permian Supai Formation. The entire sequence is best exposed in an inverted section north of the Dome Basin Mine (Figure 10).


Figure 10. Inverted and attenuated Paleozoic metasedimentary section.

View to the northwest in the Dome Basin Mine area. Key to numbers: 1 - Cambrian Bolsa quartzite, 2 - Cambrian Abrigo schist, 3 - Devonian Martin and Mississippian Escabrosa marbles, 4 - Pennsylvanian-Permian Supai formation.
West ridge of the Moon Mountains in middle distance; Big Maria Mountains on left skyline.

The Paleozoic units are internally transposed and isoclinally folded at all scales, and exhibit both severe attenuation and thickening. However, the stratigraphic sequence and formation boundaries have remained remarkably intact and provide excellent structural marker horizons in the field. Original bedding is completely transposed into a north-dipping foliation. Primary structures have been totally destroyed by deformation and metamorphism. Contacts between units largely represent transposed primary lithologic contacts or gradational changes in lithology. Structural thicknesses given here were determined in the field or by map pattern. Rock units are described chronologically and, where appropriate, metamorphic lithologic names are applied to formation names.

Bolsa Quartzite. The basal quartzite unit rests depositionally on Precambrian granitic basement (Figure 9). It forms resistant shiny ledges and ridges, is gray to dark gray where fresh, and weathers to dark brown and red hues. Its composition varies from medium to coarse-grained, thick-layered feldspathic quartzite near its base to fine-grained laminated quartzite with interlayered quartz-mica schist high in the section. The quartzite is well-foliated and commonly lineated, and has a well-defined slabby micaceous parting. Small rootless intrafolial isoclines are abundant, but are commonly difficult to recognize. However, complex mesoscopic fold structures are locally well-exposed (see Figure 26). Present structural thickness of the metamorphosed Bolsa varies widely from 2 to 150 m. Stratigraphic thickness in the southern Plomosa Mountains reference section is 20 m

(Miller, 1970). Intercalations of thin-layered quartzite and schist high in the section likely reflect transposition of the original gradational contact between the Bolsa and Abrigo formations. The contact with Abrigo schist is picked at the first thick schist layer.

Abrigo Schist. Quartz-mica schist forms dark recessive slopes stratigraphically above the Bolsa quartzite. This unit consists largely of dark greenish-gray, medium-grained schist with minor intercalations of thin (0.5-3 cm) laminated quartzite layers. Micas are variably biotite, muscovite, and chlorite. Platy schistosity is well developed and minor isoclinal folds are ubiquitous. The metamorphosed Abrigo is locally completely attenuated; its structural thickness ranges from 0 to 65 m. Its stratigraphic thickness in the reference section in the southern Plomosa Mountains is 45 m (Miller, 1970). The contact between the schist and succeeding marble is sharp, but commonly the units are tectonically interleaved.

Martin and Escabrosa Marbles. Calcitic and dolomitic marbles form light-colored outcrops that sharply contrast with other dark, desert-varnished lithologies (Figures 3, 10). The marbles form prominent ridges in Boyer Gap (Figure 3), but elsewhere weather to low hills (Figure 10). A crude stratigraphy is commonly discernible, even in highly attenuated sections. Locally exposed at the base of the section is a bluish-gray to brown, coarse-grained, foliated calcitic marble, ranging in thickness from 0 to 20 m. The marble exhibits thin laminations defined by color contrasts and variable mica content. Overlying this marble is a fine to medium-grained, thinly foliated to massive dolomitic marble that comprises most of the rock unit. It is gray to white on fresh surfaces, but weathers to shades of tan and buff-brown. A thin (0-5 m), white, coarse-grained calcitic marble locally forms a prominent marker at the top of the section (see Figure 3). The marbles are locally interleaved with thin bands of green and brown, laminated calc-silicate rocks. Mineralized zones rich in magnetite, epidote, and scheelite are common within the marbles and have been the focus of earlier mining and prospecting activity. Highly contorted minor folds are visible in thinly layered marbles (see Figure 27), but are indistinct in more massive ones. The marbles exhibit the most severe ductile deformation and attenuation of the Paleozoic units. Combined structural thickness varies widely from 2 to 300 m. Combined stratigraphic thickness in the southern Plomosa Mountains reference section is 220 m (Miller, 1970). The contact between the marbles and quartzites of the overlying metamorphosed Supai Formation is quite sharp and easily traced in the field.

Supai Formation Impure quartzite, with interlayered dolomitic marble and minor calc-silicate rocks, forms very dark ridges and forbidding cliffs in the core of the synclinorium (Figure 10). The quartzite is variably fine to coarse grained, laminated to thick-layered, and brown to greenish gray. It is characteristically quite resistant and coated with a shiny, dark brown desert varnish. Inter-layered marbles and calc-silicates form thin, less resistant, light brown layers that sharply contrast with the quartzite, revealing spectacular contorted fold structures in outcrop (see Figure 28).

Hillside-scale cascade folds are visible from a distance in the Dome Basin Mine area, where the unit is thickest and best exposed. Here, lower slopes are commonly covered by a thick, cemented surficial breccia composed of Supai clasts. The structural thickness of the metamorphosed Supai ranges from 4 m in Boyer Gap to 350 m in the Dome Basin Mine area. Stratigraphic thickness of Supai redbeds in the southern Plomosa Mountains reference section is about 160 m (Miller, 1970).

Paleozoic(?) Metasedimentary Rocks. Limited outcrops of rocks similar to those in the main Paleozoic section occur north of the synclinorium in the East Hills area (Figure 4). These rocks include, in sequence, a massive, coarse-grained feldspathic quartzite, quartz-mica schist, and micaceous marble. Total structural thickness is less than 10 m. The quartzite (Bolsa?) is plated against strongly foliated Precambrian granite. The sequence is intruded by weakly foliated leucogranite.

Tung Hill Metasedimentary Rocks

A heterogeneous section of previously undescribed metasedimentary rocks forms the hills northeast of the Tung Hill Mine (Figure 4). Like the Paleozoic rocks, these rocks are severely deformed and isoclinally folded, with bedding completely transposed into a north-dipping foliation. This transposition layering gives the section the appearance of a deceptively uniform "stratigraphy" from a distance (Figure 11a). The rocks weather to form greenish-brown hills with moderate to gentle slopes capped by ribs of resistant dark lithologies. Total structural thickness ranges from approximately 80 to 250 m. The

a.

b.

Figure 11. Tung Hill metasedimentary rocks: a) overview to the west, b) outcrop view.

In photo a., thin yellow-brown-colored lenses are micaceous marble; rocks on left far ridge are granodiorite schist and Paleozoic marble. In photo b., micaceous marble is interleaved with quartzofeldspathic schist and impure quartzite.

section is composed of quartzofeldspathic schists interlayered with lenses of impure quartzite, quartz-pebble metaconglomerate, and micaceous and calc-silicate marbles. Lenses of various lithologies are generally tabular and discontinuous along foliation strike. Several lithologies are locally interleaved within a single exposure (Figure 11b). These lithologies are described below in decreasing order of relative abundance.

The dominant rock type is fine to medium-grained, thin-layered quartzofeldspathic schist. The schist varies upsection from greenish-gray to bluish-green with a white sericitic luster, and weathers to olive-brown platy slopes (Figure 11a). It is composed largely of recrystallized quartz with lesser feldspar and variable amounts of sericite, chlorite, and epidote. Thin elongate quartz aggregates (10-20 mm in length) or quartz eyes are common components. Structurally high in the section, small (1-2 mm) green amphibole and red piedmontite porphyroblasts are locally visible on foliation surfaces. The schist typically has a well-developed mineral lineation within foliation surfaces.

Medium to coarse-grained, foliated, impure quartzite lenses vary from 0.1 to 2 m in thickness and are laminated to thick-layered. The quartzite is dark greenish-gray to dark gray on fresh surfaces, and weathers to dark brown, varnished, resistant ledges. It contains minor feldspar and variable amounts of sericite, chlorite, and epidote. Elongate aggregates of light-colored quartz are visible within the darker matrix on many outcrop surfaces. Foliation surfaces commonly contain a weak mineral lineation. Minor isoclinal fold structures are abundantly displayed in this unit.

Foliated metaconglomerate lenses are compositionally similar to the impure quartzites, but contain 20-30% rounded quartz-pebble clasts. The clasts are greatly attenuated and commonly refolded with aspect ratios of up to 15:1 (see Figure 31). The elongate clasts stand out as tan-colored knobs in a dark brown varnished matrix on weathered surfaces. Metaconglomerate lenses are massive and 0.5 to 1 m thick, forming dark varnished resistant ledges.

Micaceous calcitic marble is medium to coarse-grained, weathers to yellowish-brown colors, and forms several highly visible thin (0.5-1 m) lenses high in the section (Figure 11a, b). Micaceous layers are more resistant than the marble, accentuating the schistosity on weathered surfaces. The marble is composed of calcite and sericite with minor quartz and pyrite. Marble lenses pinch and swell in thickness and are markedly discontinuous. Outcrop patterns suggest that some of the calcitic marble lenses may have originally been a single continuous unit. Coarse-grained, massive calc-silicate marble forms a 1-5 m-thick resistant lens structurally low in the section. It is gray-green to light pink where fresh, but weathered surfaces are dark brown and pitted. The marble is crudely foliated.

A 30 m-thick section of highly deformed metasedimentary rocks, containing all of the rock types described above, is exposed 2 km to the northwest (Figure 4). Striking similarities in lithology and structural position indicate that this section is a northwest extension of the main Tung Hill section.

Tung Hill metasedimentary rocks structurally overlie Jurassic(?) granitic rocks along a sheared but locally intrusive contact, and are plated beneath the Tyson augen gneiss along the "Tyson thrust" shear zone. Metamorphism intensifies upward in the unit toward this zone.

Age determination and correlation of the Tung Hill section is made difficult by a lack of fossils or contacts with known stratigraphy, and by the severity of subsequent tectonism. The rocks are intruded by deformed Jurassic(?) granite, but do not resemble any known Precambrian or Paleozoic rocks in the region. Lithologic characteristics and heterogeneity suggest that the sedimentary protoliths were originally deposited in a continental fluvial system. Roughly similar heterogeneous early Mesozoic clastic sequences, resting depositionally on the Permian Kaibab Limestone (or marble), occur in neighboring ranges of California (e.g., Emerson, 1982; Hamilton, 1982; Lyle, 1982) and Arizona (S. Reynolds, personal communication, 1985; Stoneman, 1985). Lithologically similar sequences in the adjacent Mojave Desert region have been correlated to the early Triassic Moenkopi Formation on the Colorado Plateau (Walker and others, 1984). The Tung Hill section of metasedimentary rocks is thus tentatively interpreted to be derived from rocks of early Mesozoic (Triassic?) age.

## McCoy Basin Rocks

Rocks labeled "Mesozoic(?) metasedimentary rocks" on the tectonic map of the McCoy Basin (Harding, 1982) include a complex assemblage of metasedimentary and metavolcanic rocks, and a metarhyodacite porphyry. These rocks are exposed only to the south of Boyer

Gap (Figure 4). They are greatly sheared and metamorphosed; primary stratigraphic and contact relationships are smeared and cryptic.

### Metasedimentary-volcanic Assemblage

This unit, informally referred to here as the "metasedimentary-volcanic assemblage", comprises a very thick assemblage of schists, gneisses, and quartzites that form broad belts of exposures in the southwestern and southeastern parts of the map area. Compositional and textural similarities suggest that these belts, although isolated by other lithologies, contain rocks probably derived from an initially coherant stratigraphic section. Present exposed structural thickness varies from 200 to at least 500 m, but actual total thickness may be much greater (see Figure 4, structure section). The assemblage forms dark green to reddish-brown ledgy hillsides and ridges with a prominent north-dipping foliation (Figure 12). This foliation is in part tectonic, metamorphic, and relict-stratigraphic. The section is intensely sheared and folded into cascades of isoclines; bedding is completely transposed. The degree of metamorphism and shearing recorded is somewhat variable and generally intensifies northward. For example, in the eastern belt of exposures, metaarkosic rocks and quartzites exhibit some relict clastic textures on the south side of the ridge, but exhibit crude compositional segregation banding on the north side. The most highly deformed rocks occur in the northern portions of the western belt, particularly in the section bounded by the South Ridge augen gneiss. No distinct "stratigraphy" is preserved in the assemblage. The


Figure 12. Overview of metasedimentary-volcanic assemblage, metarhyodacite porphyry, and Middle Camp granite.

Metasedimentary-volcanic assemblage (1) forms dark, layered exposures in foreground and lower part of skyline ridge; metarhyodacite porphyry (2) caps skyline ridge. Contact shown by dashed line. Middle Camp granite (3) is exposed in left middle distance.

most complete and relatively least-deformed section is exposed on the south face of the easternmost ridge in the map area.

Lithology. The assemblage is characterized by the intercalation of compositionally and texturally variable rock types (Figure 13). However, exposures of the assemblage have a rather monotonous, uniform appearance from a distance due to dark desert varnish and the predominance of quartzofeldspathic lithologies. The thickness of any one lithology is highly variable, ranging up to about ten meters. Lenses of any one lithology are markedly discontinuous along the strike of foliation due to profound shearing, folding, and transposition. Three major groups of lithologies are recognized, based on composition: 1) quartzofeldspathic schists and gneisses, 2) quartzose schists and impure quartzites, and 3) mafic schists.

Quartzofeldspathic schists and gneisses are the dominant rock types within the assemblage. (The term "gneiss" is used here to describe crudely foliated, mica-poor, granular metamorphic rocks, and includes a range from coarse-grained metamorphosed arkosic rocks with relict clastic textures to equivalent layered gneisses, some with crude segregational banding.) These rocks are brownish-gray to light gray on fresh surfaces, but weather to a dark brown desert varnish. Locally they are heavily iron-stained. Schists range from very fine to medium grained and are thinly layered with a strong schistosity. Gneisses are variably fine to coarse grained and granular and are well layered (2 mm to massive), but exhibit only a weak schistosity due to the paucity of micas. Some gneisses exhibit relict clastic textures and are clearly

Figure 13. Layering in metasedimentary-volcanic assemblage.

Light-colored units are quartzofeldspathic gneiss and schist, and impure quartzite. Dark-colored units are biotite-actinolite schist. Outcrop in the eastern exposure belt.

derived from arkosic rocks. The coarser-grained gneisses are resistant and form benches up to several meters thick within platy slopes of schist.

In thin section, most mineral components of the gneissic rocks are recrystallized into a variably fine to very fine-grained matrix of quartz, feldspar, and mica. Partially recrystallized relict detrital feldspar grains range 0.3 to 2 mm in diameter and compose 15 to 40% of the rock. Quartz (35-50%) occurs within the matrix and in coarser-grained aggregates whose dimensions roughly equal those of relict feldspar grains. The quartzofeldspathic rocks contain widely variable amounts of biotite, sericite, chlorite, and epidote, with accessory schorlite, calcite, sphene, magnetite, and pyrite. No lithic components have survived metamorphism.

Quartzose schists and impure quartzites include foliated feldspathic and schistose quartzite, quartz-mica schist, and rare quartz-pebble metaconglomerate. These lithologies are less abundant than the quartzofeldspathic schists and gneisses, and form lenses (3 cm to several meters thick) interlayered with other lithologies. Quartzitic rocks are fine to medium grained, well-layered to laminated, and medium gray, weathering to reddish-brown or dark brown, resistant plates or slabs with a micaceous parting. Reddish-brown flaggy quartzite is locally prevalent and forms extensive exposures in the eastern belt. Minor fold structures within the assemblage are best preserved and exposed by laminated quartzite layers (see Figure 22). All mineral components listed above for the quartzofeldspathic schists and gneisses are also present in these rocks. Feldspar (0-20%) and mica

(5-40%) contents are variable, but no pure vitreous quartzites have been found. Pyrite is a common accessory and many weathered exposures are rusty with iron staining. Several scattered thin lenses of quartz-pebble metaconglomerate are exposed in the eastern belt of exposures. Metaconglomerate clasts are very difficult to recognize and are easily overlooked because of severe attenuation and dark desert varnish, so the extent of metaconglomerate in the section is probably greater than indicated here.

Mafic schists are concordantly interleaved with quartzo-feldspathic and quartzitic rocks (Figure 13) and are most prevalent in the western belt of exposures. These rocks include chlorite-biotite schist and quartz-biotite-actinolite schist. Chlorite-biotite schist is dark green and medium grained with a prominent wavy schistosity, and forms rather thin (0.2-1.5 m) layers. Quartz-biotite-actinolite schist is more abundant and forms layers up to several meters thick. It is dark greenish-gray, fine to medium grained, and thinly layered with a platy micaceous parting. Prominent mineral constituents include blue-green actinolite, biotite, quartz, feldspar, chlorite, and epidote. Blue-green hornblende was identified in some thin sections. High quartz content (15-30%) suggests possible derivation from tuffaceous volcanic or lithofeldspathic sedimentary rocks (Williams and others, 1982).

Contact Relations. The metasedimentary-volcanic assemblage is bound on the north and south by plutonic and metaplutonic masses and in the center by an extensive body of metarhyodacite porphyry (Figure 4). Contacts with the South Ridge augen gneiss and the Middle Camp granite are typically sheared and north-dipping, semi-concordant to foliation. However, locally, in pockets of low strain, these contacts are clearly intrusive (Figures 14, 15). On a larger scale, these contacts locally truncate metamorphic layering in assemblage rocks. Assemblage rocks occur in xenoliths within the Middle Camp pluton along the contact, and in sheared "pendants"(?) within the South Ridge augen gneiss. Tectonized "sills" of South Ridge augen gneiss intrude the assemblage, particularly in the eastern belt. Contacts with the structurally overlying metarhyodacite porphyry are generally quite cryptic and difficult to interpret, and commonly the units appear to be interleaved. However, the metarhyodacite porphyry locally intrudes the assemblage and truncates lithologic layering. These relationships are best viewed in outcrops in the southwest quarter of section 11 (Figure 4).

Age and Correlation. No firm maximum age constraint can be placed on the metasedimentary-volcanic assemblage at present. The intrusive relationship with the mid-Jurassic Middle Camp pluton sets a minimum age contraint for the protoliths of the assemblage. The assemblage is interpreted to represent a relatively coarse-grained arkosic and quartzitic detrital sequence with minor volcanic sediments and volcanics. The intensity of subsequent tectonism and metamorphism, and the lack of fossils, precludes accurate stratigraphic correlation and age determination. However, three possibilities are that the rocks are derived, at least in part, from rocks correlative to 1) Precambrian stratified rocks, 2) the Palen Formation, or 3) the McCoy Mountains Formation. These options are discussed below.

Figure 14. Intrusive contact of South Ridge augen gneiss "sill" into quartzofeldspathic assemblage rocks.

Figure 15. Intrusive contact of weakly foliated Middle Camp granite into well-foliated quartzitic assemblage rocks.

1) The nearest stratified Precambrian rocks are exposed 120 km to the east in the Bighorn Mountains (S. Reynolds, 1985, personal communication), and 140 km and 250 km to the northeast in the Bagdad and Jerome-Prescott areas (Anderson and Silver, 1976) in central Arizona. In the Jerome-Prescott area, these mid-Proterozoic (1.7-1.8 b.y.) rocks are known as the Yavapai Series, and reach a total thickness of over 12,000 m. The rocks are composed predominantly of andesitic and basaltic flows with minor rhyolite and tuffaceous sandstone and shale interbeds (Anderson and Silver, 1976). These mostly volcanic sequences are not lithologically similar to the mostly metasedimentary assemblage in the northern Dome Rock Mountains. Elsewhere in western Arizona, limited exposures of non-plutonic, mid-Proterozoic rocks consist of high-grade gneiss, mica schist, amphibolite, and minor quartzite, and typically contain a northeast-striking, steeply-dipping foliation (Reynolds, 1980). High-grade metamorphic minerals and this foliation orientation have not been recognized in the metasedimentary-volcanic assemblage, although they could have been obliterated by subsequent tectonism.

2) The lower Jurassic Palen Formation, exposed 70 km to the west in Palen Pass (see Figure 6), contains a distinct stratigraphy of litho-feldspathic, arkosic, and quartzitic sedimentary rocks, and may be up to 1200 m thick. These strongly folded rocks are overlain and locally intruded by a lower to middle Jurassic rhyodacite porphyry (Pelka, 1973; LeVeque, 1981, 1982). The Palen has been interpreted to be temporally associated with extensive early to middle Mesozoic volcanism in the region (LeVeque, 1981,1982). The formation is only exposed beneath the

northern bounding thrust fault (Palen Pass thrust) of the structural McCoy Basin (Figure 6). The metasedimentary-volcanic assemblage is similar to the Palen Formation in several aspects: lithologic characteristics, association with volcanics, intrusive relationships, and structural position. However, a distinct stratigraphy such as that recognized in the Palen Formation is not found in the metasedimentary-volcanic assemblage. If some assemblage rocks are derived from rocks lithologically and temporally correlative to the Palen, a lower Mesozoic(?) age may be inferred. Because this correlation is the most reasonable one based on available data, this interpretation is favored by the author.

3) The McCoy Mountains Formation contains some 5500 m of relatively coarse-grained quartzofeldspathic sedimentary rocks (Harding, 1982), and is exposed only 12 km to the south of the assemblage (Figures 6, 7). The formation includes quartzitic, arkosic, and lithofeldspathic rocks, and interfingers with volcanic rocks at its base. The McCoy Mountains Formation provides a nearby exceedingly thick source of rocks lithologically similar to those expected for protoliths of the assemblage. However, it depositionally overlies Jurassic rhyodacitic rocks that are quite similar to undated rocks that structurally overlie and locally intrude the assemblage. It is possible that the contact between the metarhyodacite porphyry and assemblage rocks is structurally inverted and in-part depositional, but this has not been substantiated in the field. The intrusive contact of the assemblage with the mid-Jurassic Middle Camp pluton does not eliminate this possible

correlation because a maximum Jurassic age for the McCoy Mountains Formation has not yet been tightly constrained.

Metarhyodacite Porphyry

A large mass of strongly foliated metarhyodacitic rocks underlies the high hills in the south-central part of the map area (Figure 4), and forms prominent cliffs, ledges, and blocky outcrops (Figure 12). Outcrops have a layered appearance due to parting parallel to foliation surfaces. The leucocratic rock is tan to gray on fresh surfaces and weathers to orange and reddish-brown hues. It is very fine to medium grained and contains up to 60% stretched quartz and feldspar eyes that range 1 to 20 mm in length (Figure 16). In thin section, feldspar eyes are composed of broken and partially recrystallized K-feldspar, and quartz eyes are composed of aggregates of recrystallized grains. Mylonitic fabrics are moderately to well developed. The metarhyodacite is composed of about 35-40% quartz, 20-35% plagioclase, and 25-40% K-feldspar, with accessory amounts of sericite, biotite, chlorite, epidote, sphene, schorlite, and pyrite. Large (0.5-2 cm) pyrite cubes are exposed in some outcrop faces. Deformed quartz veins are locally prevalent. Biotite and chlorite schists are locally associated with the porphyry, forming thin concordant lenses.

The metarhyodacite porphyry largely overlies the metasedimentary-volcanic assemblage along a cryptic, commonly interleaved, contact that is locally intrusive. The South Ridge augen gneiss and Middle Camp granite both intrude this unit, but contacts are typically sheared. Unfoliated leucogranite also intrudes the porphyry.


Figure 16. Metarhyodacite porphyry.

Light-colored eyes are feldspar; gray-colored eyes are quartz.

The porphyry is interpreted to represent a strongly sheared hypabyssal intrusive mass. It predates the mid-Jurassic Middle Camp pluton, but no maximum age constraint can be set without radiometric dating. Lithologic similarities imply that these rocks may be correlative to Jurassic rhyodacitic subvolcanic rocks widely exposed throughout southeastern California and western Arizona. A thick sequence of rhyodacite porphyry, exposed only 8 km to the south, has yielded U-Pb ages of early to middle Jurassic (L.T. Silver, cited in Crowl, 1979). Rhyodacite porphyry that intrudes the Palen Formation in Palen Pass has been dated by K-Ar on plagioclase at 175 m.y. (Pelka, 1973). Less-deformed metarhyodacitic rocks in the map area bear striking resemblance to the porphyry in Palen Pass.

## Igneous and Metaigneous Rocks

### Tyson Augen Gneiss

This unit is exposed structurally above the Tyson thrust fault in the northern part of the map area (Figure 4). The augen gneiss is biotite-rich and medium grained, with up to 30% of rectangular to rounded (1-3 cm in length), tan-colored K-feldspar porphyroclasts. It is streaked tan and dark gray on fresh surfaces, and weathers to dark, slabby outcrops. The gneiss contains about 35% K-feldspar, 20% plagioclase, 18% quartz, and 20% biotite, with accessory amounts of muscovite, chlorite, sphene, and opaque minerals; the protolith was probably a porphyritic biotite granite.

Mylonitic foliation and mineral lineation are moderately to strongly developed. In thin section, feldspar porphyroclasts are bent, broken, and partially recrystallized, and quartz is recrystallized into long thin aggregates. Biotite is largely recrystallized and wraps around larger grains, but some biotite is bent or splayed. Much of the gneiss is composed of seams of microcrystalline matrix material. Within a meter of the Tyson thrust shear zone, the gneiss grades into a very dark thinly plated mylonite.

The age of the protolith is unknown, but is probably either Precambrian or Jurassic, based on the widespread occurrence of lithologicaly similar granites of these ages in the region. It is intruded by the Tyson Wash granite.

South Ridge Augen Gneiss

A very thick belt of granitic augen gneiss underlies the prominent west-northwest-trending ridge just south of Boyer Gap (Figures 3, 4). The foliated gneiss weathers to form resistant, dark, greenish-brown ledges and imposing cliffs with a conspicuous north-dipping planar fabric (Figure 17). These rocks characteristically contain large, stubby, purplish to light gray K-feldspar porphyroclasts in a medium-grained, greenish-gray, schistose matrix that is dominated by clots of biotite (Figure 14). Porphyroclasts are rounded and variably broken, bent, recrystallized, and altered. They range 1 to 6 cm in length and compose 10-35% of the gneiss. The gneiss contains about 30-35% K-feldspar, 25-30% plagioclase, 15-25% quartz, and 5-20% biotite, with accessory sphene, epidote, muscovite, chlorite, and opaque minerals. In thin section, biotite is largely recrystallized into fine-grained mats, but some larger grains are bent or broken. Coarse (0.5-2 mm) broken

Figure 17. South Ridge augen gneiss.

View to the southeast along South Ridge. Low notches in far ridge contain sheared "pendants" of metasedimentary-volcanic assemblage rocks.

sphene crystals locally compose up to 3% of the gneiss. This composition suggests a porphyritic sphene-bearing biotite monzogranite protolith. The augen gneiss variably exhibits crude to well-developed metamorphic fabrics (compare Figures 14, 19, and 20). Mylonitic textures are prevalent, but mineral lineation is typically less developed than foliation and difficult to see, partly because of coarse grain size.

The South Ridge augen gneiss locally intrudes the McCoy Basin rocks along mostly sheared contacts. It forms 1 to 3 m-thick tectonized intrusive "sills" with chilled margins within the metasedimentary-volcanic assemblage (Figure 14) and contains sheared "pendants"(?) of these rocks (Figure 17). Gneissic leucogranite intrudes the gneiss along its northern margin.

The age of the South Ridge augen gneiss protolith is uncertain at present. It clearly postdates McCoy Basin rocks in the map area, and predates gneissic leucogranite. The augen gneiss roughly resembles the mid-Jurassic Middle Camp granite in composition, and locally in outcrop appearance. Purplish, stubby megacrysts, clotty biotite and sphene are indicative of Jurassic granites elsewhere in the region (John, 1981; Hamilton, 1982). It is inferred here that the protolith is probably Mesozoic (Jurassic?) in age, but in fact an older (Precambrian?) age cannot be ruled out because the age of the McCoy Basin rocks into which it intrudes is also equivocal. Radiometric dating of this unit could yield critical information about the age of the McCoy Basin rocks.

## Amphibole Schist and Metadiorite

Very dark green amphibole-rich rocks crop out in discontinuous 0.5 to 2 m-thick lenses mostly within the metasedimentary-volcanic assemblage, metarhyodacite porphyry, and South Ridge augen gneiss (Figure 4). Textures range from fine to very coarse grained and from crudely schistose to compositionally banded with acicular amphibole crystals grown across foliation. Thin section analysis shows that these rocks are composed of 30-50% blue-green hornblende, 10-40% blue-green actinolite, and 35-40% altered or recrystallized plagioclase, with variable amounts of epidote, biotite, chlorite and quartz. Hornblende forms larger altered subhedral crystals, while actinolite generally forms smaller, subhedral to euhedral, acicular crystal mats. These schists may represent retrograded amphibolites.

These rocks form sheared intrusive "sills" within the McCoy Basin rocks, and are cut by the Middle Camp granite. Their relationship with the South Ridge augen gneiss is problematic; lenses of amphibole schist are locally truncated by the gneiss, but elsewhere are tectonically(?) interleaved with it. These amphibole schists and metadiorites postdate McCoy Basin rocks, but predate the Middle Camp granite.

## Middle Camp Granite

The northern end of a pluton of the Middle Camp granite, which underlies much of the central Dome Rock Mountains, dominates the southern border of the map area (Figure 4). The pluton was first named the Middle Camp quartz monzonite by Crowl (1979). The pluton consists of a variably foliated, porphyritic biotite monzogranite (I.U.G.S.

classification) with scattered, small (10-30 cm in diameter) mafic inclusions. The granite forms rounded, knobby outcrops that are light green to dark green-brown in color, due to an abundance of secondary epidote (Figure 12). The rock contains sparse, stubby (0.5-2 cm-long), purplish to light gray K-feldspar phenocrysts in a medium-grained matrix composed mostly of feldspar, quartz, and clots of biotite (Figure 15). In thin section, the granite is composed of 35% K-feldspar, 30% plagioclase, 20-25% quartz, and 10-15% biotite, with notable accessory sphene, epidote, chlorite, and opaque minerals. Feldspars are highly epidotized and sericitized, and commonly show brittle fractures. Biotite and quartz are variably recrystallized, depending on the degree of deformation.

In general, the Middle Camp granite is only weakly foliated in the interior of the pluton, but is moderately to strongly foliated near its contact with McCoy Basin rocks. This contact is largely tectonitic, but is locally clearly intrusive (Figure 15). At this margin, the granite is finer-grained and less-porphyritic and locally encloses xenoliths of schist, gneiss, and quartzite. Also, it usually exhibits a much weaker metamorphic fabric than the rocks into which it intrudes. Discrete highly sheared zones up to several meters wide occur within the pluton in this area and to the south (Crowl, 1979). Where it is sheared, the Middle Camp granite is quite similar in appearance to gneissic monzogranites exposed to the north.

The age of the Middle Camp granite is probably middle Jurassic. It is lithologically correlative to middle Jurassic plutons throughout the Mojave Desert region (John, 1981), and to porphyritic granites in the Big Maria Mountains that have been dated at 160 m.y. (geochronology by L. T. Silver, cited by Hamilton, 1982). It intrudes lower to the middle Jurassic volcanics to the south, but is not in contact with the overlying McCoy Mountains Formation (Crowl, 1979; Harding, 1982).

### Gneissic Monzogranites

This unit comprises variably sheared porphyritic biotite monzogranites that crop out extensively in Boyer Gap and to the north. These rocks were mapped as one unit in the field on the basis of lithologic similarities, and should not be inferred to be derived necessarily from an initially coherent igneous mass. The rocks can be traced from moderately foliated granite to mylonitic augen gneiss within a single outcrop belt, but recognizable lithologic similarities usually persist. Metamorphic fabrics are generally well-developed, but their intensity can vary markedly within a single outcrop (Figure 18). Where they are least deformed (below the easternmost exposures of Tung Hill metasedimentary rocks) these rocks form light greenish-gray, foliated outcrops that contain sparse, stubby (0.5-1.5 cm), purplish to light gray K-feldspar phenocrysts in a fine to medium-grained matrix composed of K-feldspar, plagioclase, quartz, and clots of biotite (Figure 18). Sparse 1 to 2 mm crystals of sphene and locally abundant secondary green epidote are visible in hand sample. Scattered mafic inclusions occur locally.

More strongly sheared monzogranites are medium to dark greenish-gray and form more resistant, platy outcrops that typically are coated with a dark brown desert varnish. K-feldspar phenocrysts are broken and

Figure 18. Variably sheared gneissic monzogranite.

sheared into augen that retain their purplish to light gray color. Augen typically compose only 10 to 15% of the rock and range 0.5 to 2 cm in length, but they are more abundant (20-30%) and larger (up to 5 cm) in some exposures northwest of the Tung Hill metasedimentary section. Mats of biotite, elongate quartz aggregates, and stretched porphyroclasts form a generally well-developed mylonitic foliation and lineation, particularly in the northern part of the map area.

In thin section, least-deformed monzogranite contains approximately 30-35% K-feldspar, 25-30% plagioclase, 25% quartz, and 15% biotite, with up to 3% sphene and opaque minerals. Secondary epidote, sericite, and chlorite are common in all samples. Biotite is largely recrystallized. Seams of very fine-grained recrystallized material comprise variable amounts of the groundmass.

Gneissic monzogranites are in sheared intrusive contact with the Cambrian Bolsa quartzite and lower Mesozoic(?) Tung Hill metasedimentary rocks, as well as Precambrian basement rocks. Grain size is reduced and phenocrysts (or augen) are less abundant near many of these contacts. Small plugs occur within the Tung Hill metasedimentary pile. The monzogranites are intruded by both gneissic and weakly foliated leucogranites and the Tyson Wash granite.

Two lines of evidence indicate that the monzogranite protolith is probably middle Jurassic in age: 1) the contact relationships outlined above, and 2) notable lithologic similarities with the Middle Camp granite and prolific middle Jurassic granitic rocks in the neighboring Big Maria Mountains (Hamilton, 1982) and elsewhere in the Mojave Desert region (John, 1981).

Granodiorite Schist

Dark greenish-gray, thinly plated schist is exposed along the northern flank of the major synclinorium in the central part of the area. The schist is mostly fine grained with sparse, small (2-3 mm) feldspar porphyroclasts, but is coarser grained (gneissic) toward the center of its main body of exposures. The schist forms very dark resistant ledges, but is difficult to distinguish from other foliated granitic rocks from a distance because of dark desert varnish. In thin section, the schist contains roughly 15% K-feldspar, 40% plagioclase, 25% quartz, and 10-20% biotite, with accessory epidote, altered hornblende(?), chlorite, sericite, schorlite, and opaque minerals. All primary mineral components are recrystallized, except for some feldspar porphyroclasts that exhibit brittle fractures. Mylonitic foliation and lineation are locally well developed.

The granodiorite schist is in sheared intrusive contact with Paleozoic metasedimentary rocks and Precambrian basement rocks, and locally contains small xenoliths of these rocks. It is plated beneath gneissic monzogranites along the Tung Hill shear zone. Weakly foliated leucogranite intrudes the schist.

The protolith is clearly Mesozoic in age. Lithologic similarities with granodioritic rocks of middle Jurassic age in the Big Maria Mountains (Hamilton, 1982) suggest that the protolith is probably middle Jurassic in age.

Leucocratic Granites

Unfoliated to strongly sheared leucocratic granites occur in small intrusive masses, commonly in spatial association with Jurassic(?) granitic rocks. Unfoliated to weakly foliated granites are mapped separately from well-foliated to gneissic granites, but compositionally these units are indistinguishable. The rocks are light gray, tan to dark brown-weathering, fine to medium grained, and equigranular to slightly porphyritic.

Least deformed leucogranite contains 1 to 2 mm-long K-feldspar phenocrysts in a fine to medium-grained matrix of K-feldspar, plagioclase, quartz, and minor biotite. In thin section, it is composed of 36-40% K-feldspar, 22-25% plagioclase, and 30-35% quartz, with accessory biotite, zircon, and opaque minerals. Biotite is mostly altered to chlorite, and feldspars are sericitized and epidotized. Feldspars are variably broken or bent and quartz is partially recrystallized, even in mesoscopically unfoliated samples. Muscovite and epidote become more prevalent in strongly deformed leucogranites. In these rocks, the bulk of the groundmass is composed of very fine-grained recrystallized material.

The well-foliated to gneissic leucogranites form 0.5 to 20 m thick sheared intrusive "sills" within Jurassic(?) granitic rocks, the South Ridge augen gneiss, Paleozoic rocks, and Precambrian basement. Mylonitic fabrics are generally well developed. The unfoliated to weakly foliated leucogranites clearly cross-cut older deformational fabrics, but contacts are locally sheared in the Tung Hill and East Hills areas. Leucogranites along the northern margin of the Middle Camp pluton are mesoscopically undeformed and form small intrusive plugs and dikes with undeformed margins.

The leucogranites are undated, but are no older than Mesozoic in age. They probably represent at least two plutonic episodes, but clear age distinctions based solely on the degree of fabric development cannot be made because some shearing may not have been penetrative throughout the area, and several intrusive bodies exhibit quite variable foliation development. Strongly deformed leucogranites occur in association with mid-Jurassic granitic rocks in the adjacent Big Maria Mountains (Hamilton, 1982) and in southwestern Arizona (Haxel and others, 1980). Variably deformed Cretaceous(?) leucogranites crop out in the Riverside Mountains to the northwest (Carr and Dickey, 1980). The unfoliated to weakly foliated leucogranites in the map area are lithologically and texturally correlative to the Laramide(?) Diablo quartz monzonite of Crowl (1979) in the central Dome Rock Mountains.

### Tyson Wash Granite

A variably foliated biotite-bearing granite underlies the northern tip of the range (Figure 4). It is light gray to white with dark clots of biotite, tan to gray-weathering, medium to fine grained, and equigranular. In thin section, the unit is composed of 27% K-feldspar, 32% plagioclase, 30% quartz, and 7% biotite, with accessory sphene and opaque minerals. Epidote, muscovite, and chlorite are common secondary components. Biotite and quartz are largely recrystallized. Foliation and lineation vary from weak to well developed and mylonitic; the intensity of this fabric increases northward (structurally upward).

The Tyson Wash granite intrudes Jurassic(?) monzogranites, lower Mesozoic(?) Tung Hill metasedimentary rocks, and the Tyson augen gneiss along a mostly sheared north-dipping contact. Several thin discordant dikes intrude the gneissic monzogranites south of this contact. The granite is much less deformed than the rocks into which is intrudes.

The Tyson Wash granite is undated, but is probably either late Mesozoic or Tertiary in age, based on the occurrence of similar granites of these ages in the region. It is a key plutonic rock for radiometric dating because it appears to post-date most of the ductile deformation and metamorphism in the range.

### Dike Rocks

Porphyritic Rhyolite Dikes. Several east-west-trending, 0.5 to 2 m-thick, well-foliated rhyolite dikes are exposed in the south-western corner of the map area. The light-gray, tan to reddish-brown-weathering rhyolite contains 1 to 5 mm-long phenocrysts of feldspar (mostly K-feldspar), quartz, and minor biotite in an aphanitic ground-mass of recrystallized feldspar and quartz. The dikes are variably sheared and dip 20 to 25 degrees to the north. This unit cross-cuts the McCoy Basin rocks and the Middle Camp granite, but is intruded by unfoliated leucogranite. These relationships indicate that these dikes are Mesozoic in age.

Aplite Dikes. Sparse, scattered, 0.3 to 1 m-thick, light-gray aplite dikes crop out locally within Precambrian basement rocks, grano-diorite schist, and gneissic monzogranites in the north-central part of the area (Figure 4). The aplites are felsic and very fine grained with a chonchoidal break; dendrites cover many fracture surfaces. A faint foliation and lineation are visible on some surfaces. The dikes are north-dipping and subparallel to foliation in the host rocks, but they clearly cut across these fabrics in outcrop. A late Mesozoic or Tertiary age is inferred for the aplite dikes because they appear to post-date most of the ductile deformation and metamorphism in the range.

Diorite Dikes. Undeformed, northwest-striking, steeply-dipping diorite dikes form sparse, widely scattered outcrops throughout the map area. The 0.5 to 1.5 m-thick dikes range up to 50 m in length and locally occupy brittle fault zones. The variably altered diorite is dark greenish-gray, green to dark brown-weathering, and aphanitic with locally abundant 1 mm-long hornblende phenocrysts. The rocks are composed of hornblende and plagioclase with rare biotite and quartz.

These dikes cross-cut all ductile deformational fabrics and are the youngest rocks exposed in the range. They are undated, but are probably middle Tertiary in age. Crowl (1979) reported undeformed Tertiary diorite dikes in the central Dome Rock Mountains. A lithologically similar swarm of northwest-trending microdiorite dikes in the Harquahala and western Harquvar Mountains (Reynolds, 1982) have yielded K-Ar biotite and hornblende ages of about 25 m.y. (Shafiqullah and others, 1980).

## Late Tertiary-Quaternary Surficial Deposits

Surficial deposits that surround bedrock exposures of the northern Dome Rock Mountains are undifferentiated on the geologic map (Figure 4). These deposits underlie dissected gravel pediments and benches, alluvial fans, and plains that slope gently away from the range. Unmapped deposits also occur in most drainages within the range. The deposits include boulder to cobble-sized colluvium, poorly consolidated to unconsolidated gravels, and sandy gravels of modern washes. Many deposits are mantled with a hard, angular desert pavement. Smooth, well-rounded pebbles found in a small deposit in Boyer Gap may be related to the ancestral Colorado River drainage system.

# STRUCTURAL GEOLOGY

## Structural Framework of the Northern Dome Rock Mountains

Rocks in the northern Dome Rock Mountains exhibit spectacular structures and deformational fabrics that record a complex history of basement-involved ductile shearing, faulting, and folding. The structural grain of the area is north-dipping; foliations, layering, sheared contacts, fold axial surfaces, and shear zones dip northward, and mineral lineations and fold axes plunge northward. The area is a zone of distributed shear in which deformational fabrics are penetratively developed. In general, metaigneous rocks are well-foliated and commonly mylonitic, and metasedimentary rocks are isoclinally folded and completely transposed. Syntectonic metamorphism, reflected in axial planar schistosity and gneissosity, was likely upper greenschist (biotite) to amphibolite grade, and was most intense south of Boyer Gap.

Shear zones (ductile faults) are mapped and most easily recognized where they juxtapose contrasting lithologies. The area is cut by three significant north-dipping mylonitic shear zones: the Boyer Gap, Tung Hill, and Tyson thrust shear zones (Figure 4). The widest and tectonically most important of these structures is the Boyer Gap shear zone, which places Precambrian basement and overlying Paleozoic strata over Mesozoic(?) rocks of the McCoy Basin. The Tung Hill shear zone places lower Mesozoic(?) Tung Hill metasedimentary rocks and Jurassic(?) granitic rocks above Precambrian and overturned Paleozoic strata. Finally, the Tyson thrust shear zone places granitic rocks of unknown age over Tung Hill metasedimentary rocks. Leucogranites and the Tyson Wash granite truncate shear zones but are variably foliated themselves. Only late Tertiary diorite dikes are undeformed.

The structural geology of the map area is described below in terms of three structural domains (southern, central, and northern) and the Boyer Gap shear zone. The domains are lithologic and geographic as well as structural. Each domain includes a distinct assemblage of rock units and reflects variations in structural style, fabric orientation, and sense of kinematic indicators. Also, the domains appear to record progressively later deformation from south to north. Stereograms of foliations, lineations, and fold axes are presented in a synoptic domainal illustration (Figure 5) so that orientations may be readily compared and contrasted. Each domain is discussed in the following order: 1) review of major field relationships and structural geometry, 2) description of structural elements (metaigneous and metasedimentary fabrics, folds, and shear zones), and 3) interpretation of kinematics.

## Southern Domain

The southern domain, which encompasses all areas south of the Boyer Gap shear zone, is dominated by the Middle Camp pluton, metasedimentary-volcanic assemblage, metarhyodacite porphyry, and South Ridge augen gneiss. The South Ridge augen gneiss and Middle Camp granite both intrude McCoy Basin rocks along mostly sheared and north-dipping contacts. Strongly deformed McCoy Basin rocks are truncated by weakly foliated Middle Camp granite in the west half of section 10 and the south half of section 11 (Figures 4, 15). The metarhyodacite porphyry structurally overlies and locally intrudes the metasedimentary-volcanic assemblage along a cryptic, tectonically interleaved contact. Amphibole schists and metadiorite occur in concordant north-dipping sheared lenses. Unfoliated leucogranites cross-cut well-developed fabrics and sheared contacts.

## Structural Elements

Metaigneous Fabrics. Foliation and lineation in metaigneous rocks are variably developed. Foliation in the Middle Camp pluton intensifies from weak to well-developed only within about 100 m of its margin, and usually does not contain a distinct mineral lineation. In contrast, the South Ridge augen gneiss and gneissic leucogranites and monzogranites are pervasively foliated and commonly lineated. In these units, foliation is moderately to well-developed, generally mylonitic, and gradational into compositional layering (Figure 19). The prominent foliation is defined by the preferred orientation of platy minerals (mostly biotite), inequent matrix grains, feldspar porphyroclasts, and flattened quartz aggregates. In rare exposures, a very gently north-dipping spaced cleavage crenulates moderately north-dipping compositional layering foliation. This cleavage is also found in several exposures of the metasedimentary-volcanic assemblage. Foliation surfaces dip moderately northward (see Figure 17) with an average orientation of N 75$^{o}$W, 30$^{o}$NE (Figure 5). Foliation surfaces generally contain a much less developed mineral lineation that is defined by parallel alignment of elongate feldspar porphyroclasts and quartz aggregates, and trains of mica. Lineation is obscured or absent in

Figure 19. Mylonitic foliation and compositional layering in South Ridge augen gneiss.

coarser-grained, less sheared rocks. Lineations plunge moderately to the north and northwest (average 25°, N 35°W) or about 5-15°, N 85°E (Figure 5). This latter group occurs only in rocks within 0.5 km of the Boyer Gap shear zone (Figure 4).

Foliation surfaces in the metarhyodacite porphyry dip moderately to the north (average N 75°E, 25°NW), and contain mineral lineations that plunge, on average, 25°, N 15°W (Figure 5). These fabrics are largely mylonitic; foliation is defined by parallel alignment of fine-grained micas, quartz and feldspar lenses, and matrix minerals, whereas lineation is defined by the alignment of strongly elongated quartz rods, prolate brittlely deformed feldspar porphyroclasts, and trains of mica.

Asymmetric fabrics and a second discrete foliation are visible in some mylonitic rocks when outcrop faces or thin sections are viewed parallel to foliation and perpendicular to lineation. Where best developed, the penetrative (mylonitic) foliation anastamoses in and out of discrete surfaces or shear bands (Figure 20). The small oblique angle between these two foliations, and the deflection of augen tails, quartz aggregates, and trains of mica into these surfaces of shear, create asymmetric fabrics. Following the nomenclature suggested by Berthe and others (1979) for similar fabrics in mylonitic gneisses, the penetrative foliation is herein termed an S-surface (foliation or schistosity), while the discrete foliation is termed a C-surface ("cisaillement" or shear). In thin section, so-called "S-C fabrics" are largely obscured by subsequent recrystallization, but asymmetry is still discernible in the obliquity of oriented micas (defining S-surfaces)


Figure 20. Shear bands in South Ridge augen gneiss.

Outcrop is just above shear zone contact with metasedimentary-volcanic assemblage. View to the northeast, parallel to foliation (N 75°E, 35°NW) and perpendicular to mylonitic lineation (35°, N 35°W). S-C fabric indicates top to the right (south-southeast) sense of shear.

with respect to C-surfaces. S-surfaces dip 10-30$^{\circ}$ more steeply than C-surfaces in outcrop faces or thin sections oriented parallel to north-northwest-plunging lineations and east-northeast-plunging lineations in this domain. In the most highly strained rocks, these surfaces become subparallel and indistinct from one another.

Metasedimentary-volcanic Assemblage Fabrics. Penetrative foliation in the metasedimentary-volcanic assemblage is a combination of transposed lithologic layering, schistosity, and gneissic layering. Manifestation of this foliation is dependent on lithology; quartzose units are commonly laminated with a sharp flaggy cleavage, whereas coarser-grained arkosic rocks have rougher gneissic layering, and pelitic and metavolcanic rocks have a thin platy schistosity. Lineations are most visible in schistose lithologies and are defined by trains of mica and elongate feldspar and quartz grains. Assemblage rocks are locally strongly mylonitic and phyllonitic. In the eastern exposure belt, foliation orientations range from an average of N 65$^{\circ}$W, 40$^{\circ}$NE in the north and east to about N 10$^{\circ}$W, 40$^{\circ}$SW in the southwest, and mineral lineations plunge moderately to the north-northwest (average 30$^{\circ}$, N 20$^{\circ}$W) (Figures 4, 5). In the western belt, foliations dip moderately to the north (average N 80$^{\circ}$W, 30$^{\circ}$NE), and lineations plunge 10 to 30$^{\circ}$ to the north and northeast. East-northeast-plunging lineations occur only in assemblage rocks just south of Boyer Gap within the South Ridge augen gneiss (Figure 4).

Quartzofeldspathic layers and strained quartz veins locally exhibit boudinage. One particularly fine example occurs in the northern exposures of the western belt, 0.5 km south of the Boyer Gap shear zone (Figure 21). Here, a quartzofeldspathic lens is cut into boudins by small imbricate normal faults. Quartz veins also exhibit convolute folding in exposures throughout the assemblage.

Folds. Minor folds are generally not well preserved in the metasedimentary-volcanic assemblage because they are obscured by the monotony of quartzofeldspathic lithologies, desert varnish, or subsequent smearing-out by intense shearing. Close inspection of outcrops typically reveals contorted intrafolial folds and cascades of folds within an otherwise planar foliated section. Minor folds are best displayed by laminated quartzose lithologies (Figure 22). Folds are tight to isoclinal, recumbant to reclined, and commonly rootless. They range from 0.1 to 5 m in wavelength and have similar fold forms with thickened hinges and greatly attenuated limbs. Fold hinges are typically curved, but generally parallel mineral lineations. Axial surfaces parallel the enveloping foliation surfaces. Schistosity is axial planar to folds, but axial planar cleavage is only rarely visible. Fold axes plunge gently to moderately to the north and northwest (average $30^{\circ}$, N $30^{\circ}$W).

Foliations in the eastern belt of the metasedimentary-volcanic assemblage and Middle Camp granite are arched about a large open fold that plunges $25^{\circ}$, N $40^{\circ}$W (Figures 4, 5). This structure rotates foliations and parallels lineations, and does not appear to affect foliations in the south ridge augen gneiss. Locally, metaigneous

Figure 21. Boudinage and antithetic normal faults in quartzofeldspathic lens within metasedimentary-volcanic assemblage.

View to the south of outcrop just south of Boyer Gap. Offset on small normal faults is to the east-northeast. Associated mylonitic lineation plunges $8^{\circ}$, N $85^{\circ}$E. Interpreted sense of shear is top to the right (west-southwest).

Figure 22. Minor folds in laminated quartzite within metasedimentary-volcanic assemblage.

View to the northwest in eastern exposure belt. Minor fold hinges plunge generally 20$^{o}$, N 35$^{o}$W.

foliations are openly folded or broadly warped about gently west to northwest-plunging axes (Figure 5).

Shear zones. Although shear strain is distributed throughout the southern domain in general, it is locally concentrated within numerous minor west-northwest-striking, north-northeast-dipping shear zones. These concordant zones are marked by greater intensity of mylonitic foliation and lineation development, but they are mappable only where they coincide with major lithologic contacts. West-northwest-trending contacts tend to be more highly sheared than contacts in other orientations (e.g. north margin of Middle Camp pluton). Shear zones, 0.5 to 2 m thick, are widely scattered within the weakly foliated interior of the Middle Camp pluton. Similar zones occur throughout the south ridge augen gneiss. Metasedimentary-volcanic assemblage rocks and amphibole schists enclosed within South Ridge augen gneiss are plated into the gneiss along mylonitic contacts.

Shear zone (ductile fault) contacts between granitic rocks and the eastern belt of the metasedimentary-volcanic assemblage are well exposed in two washes. In the northwest quarter of section 12 (Figure 4), thinly banded mylonitic and phyllonitic rocks are plated against sheared Middle Camp granite along a sharp north-dipping contact (Figure 23). In the southwest quarter of section 2, tightly folded and contorted schists underlie the South Ridge augen gneiss along a mylonitic contact. Shear bands are beautifully exposed in highly sheared augen gneiss along this contact (Figure 20). Fold axes in the schists are parallel to the mylonitic lineation in the augen gneiss.

Figure 23. Shear zone contact between mylonitic assemblage rocks and sheared Middle Camp granite.

View to the west. Light-colored quartzofeldspathic assemblage rocks structurally overlie gray-colored Middle Camp granite.

Elsewhere, in less strained areas, the primary intrusive nature of these contacts is preserved (see Figures 14, 15).

Kinematics

Interpretation of the kinematic significance of mylonitic fabrics is currently a subject of considerable discussion and debate. Recently, Simpson and Schmid (1983) and Lister and Snoke (1984) have documented the use of asymmetric "S-C" fabrics in mylonitic rocks as kinematic indicators to deduce sense of shear and displacement in shear zones. Their models assume non-coaxial or rotational strain and shear zone geometry as described by Ramsay (1980). Simply, during rotational strain, the prominent foliation (schistosity or S-surface) forms in the flattening plane of the finite strain ellipsoid while mineral lineations form parallel to the stretching axis within this flattening plane. C-surfaces are considered to be discrete surfaces of high shear strain that generally form parallel to the shear zone boundaries. S-surfaces are initially oriented at 45$^{\circ}$ to C-surfaces, but with continued rotational strain this angle decreases and S-surfaces deflect into C-surfaces. At highest strains, the surfaces become subparallel. Thus, S-C angular relationships may be interpreted to indicate sense of shear (e.g. Figures 20, 30) and mineral lineation interpreted to lie parallel to the tectonic transport direction. These interpretations are followed here.

Several criteria may be used to deduce sense of shear and define S-C fabric relationships in mylonitic granitoid rocks (see Simpson and Schmid, 1984). Because mylonitic fabrics are largely obscured by subsequent recrystallization throughout the map area, only asymmetric augen tails, displaced broken grains, and the obliquity of oriented inequant grains (especially micas) to C-surfaces could be employed in outcrop and thin section. In the southern domain, the prominent north-dipping metaigneous foliation is considered to be a flattening foliation which contains a less-developed stretching mineral lineation oriented parallel to the direction of shear (transport). S-C fabrics in rocks with a north to northwest-plunging lineation consistently indicate top to the south and southeast (thrust) sense of shear (Figure 20). Near Boyer Gap, S-C fabrics in rocks with a shallow east-northeast-plunging lineation indicate top to the west-southwest sense of shear. This sense of shear is consistent with boudinage of a quartzofeldspathic lens exposed in that area (Figure 21). On the geologic map (Figure 4), arrows on lineation symbols indicate sense of shear as deduced either in outcrop or thin section.

Foliation and gneissic layering in the metasedimentary-volcanic assemblage is largely the result of severe synmetamorphic transposition and shearing of primary volcanic and sedimentary layering. North to northwest-plunging fold axes and mineral lineations are generally subparallel to metaigneous mylonitic lineations (Figure 5). This parallelism of fabrics suggests that fold hinges have been refolded and rotated into the transport direction during progressive shearing, in the manner of sheath folds (see Minnigh, 1980). Reclined cascades of similar-style folds indicate passive folding with significant flattening strain.

The Middle Camp granite is clearly less deformed and may post-date some shearing and metamorphism in the southern domain (e.g. Figure 15). However, the pluton is locally well-foliated, particularly along its margins. Four possible reasons for this are: 1) the pluton was intruded syn- or late-kinematically, 2) it lies at the southern margin of severe tectonism in the range, 3) it does not develop deformational fabrics as strongly as more anisotropic rocks in the domain, or 4) it post-dates some distinct earlier deformational episode that has not been recognized. The northwest-plunging arch in metasedimentary-volcanic assemblage and Middle Camp foliations (Figure 4), which does not appear to fold South Ridge augen gneiss fabrics, may result from the pluton behaving as a semi-rigid mass during tectonism.

## Boyer Gap Shear Zone

### Structural Elements

A north-dipping zone of intense ductile shear, herein called the Boyer Gap shear zone, cuts through the center of the northern Dome Rock Mountains, marking the southern limit of exposure of definite Precambrian and Paleozoic rocks in the range. The zone is delineated on the map by two distinct bands of thinly laminated recrystallized mylonite and ultramylonite between which lie highly sheared augen gneiss, granitic banded gneiss, laminated mylonite, amphibole schist, and foliated quartzite (Bolsa?). The zone contains the most severely deformed granitic rocks in the map area. The 0.3 to 0.5 m-thick bands of mylonite and ultramylonite form low resistant ribs in the gap (Figure 24a) and are best developed between Precambrian basement and

a.

b.

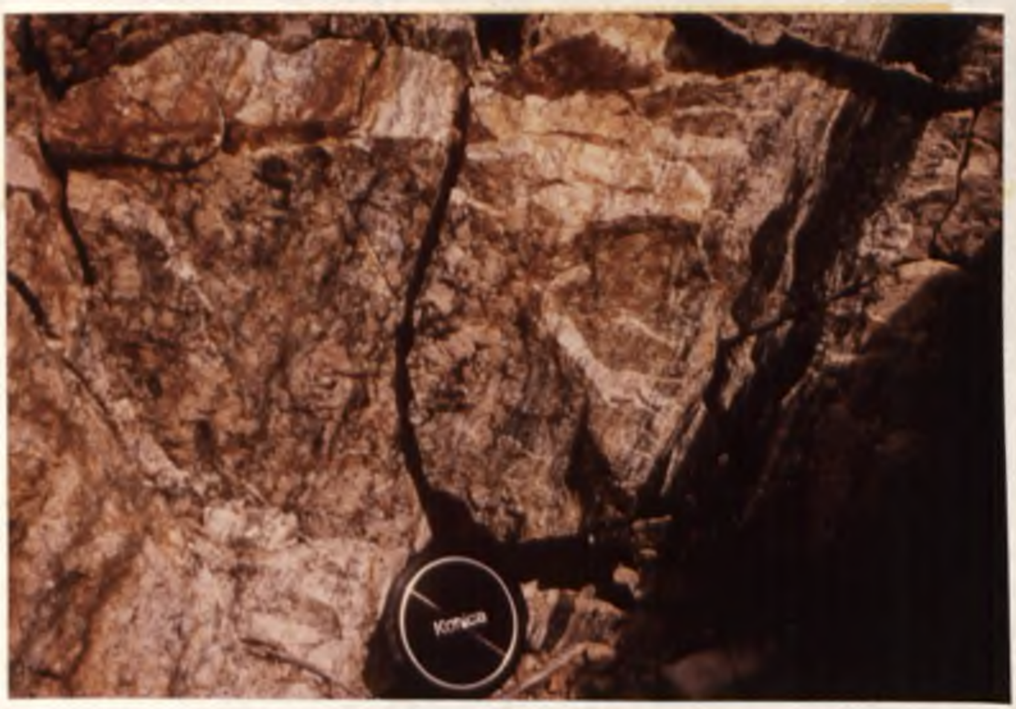


Figure 24. Boyer Gap shear zone: a) overview to the east, b) close-up view to the east.

In photo a., resistant mylonite band separates overlying Precambrian basement (brown) from monzogranite gneiss (gray). In photo b., foliated Precambrian granitic rock (left) grades into ultramylonite (right) within mylonite band.

Jurassic(?) monzogranite gneiss. The mylonite bands are cohesive quartzofeldspathic rocks composed of thin laminae of dark gray to black microcrystalline ultramylonite and light gray, very fine-grained mylonitic gneiss. Precambrian granitic basement can be traced into the mylonite bands (Figure 24b) and appears to be the protolith for most of the rocks within the zone.

The zone presently dips 35 to 70$^{\circ}$ to the north, and is roughly concordant to adjacent upper and lower-plate foliations, particularly those of Precambrian and Paleozoic rocks to the north within Boyer Gap. Foliation attitudes within the zone dip moderately to the north (Figure 5). Mylonitic lineations within the zone plunge: 1) moderately to the north-northwest, 2) gently to the east-northeast in Boyer Gap, and 3) gently to the west-northwest in the East Hills area. The north-northwest lineation occurs in relatively less strained tectonites within the zone and is cut by the the east-northeast lineation, which is associated with the mylonite bands.

Six thin sections of oriented mylonitic samples were analyzed for S-C fabric orientations within the zone. S-surfaces dip more steeply than C-surfaces in all samples in which the mylonitic lineation plunges moderately to the north-northwest or gently to the east-northeast. The sample from the East Hills was inconclusive due to recrystallization.

The mylonite bands are locally kinked about small asymmetric north-plunging S-folds (S-shaped when viewed down plunge). Foliations are broadly warped or concentrically folded around open to tight folds with sub-horizontal east-west-trending axes. Many of these folds have

Z-shaped asymmetry when viewed looking west. This later warping and folding locally oversteepens mylonitic foliations and bands to near-vertical orientations.

Kinematics

Mylonitic S-C fabrics in the north-dipping zone indicate two directions of shearing: 1) top to the south-southeast, and 2) top to the west-southwest. Thus the zone may by interpreted to have accomodated at least two episodes of shearing: 1) thrusting to the south and southeast, followed by 2) left-lateral transpressive shearing. West-vergent kink folds in the mylonite bands probably reflect late stages of left-lateral movement. Fabrics sympathetic to the first episode are also found in both the southern and, to a lesser degree, central domains. In contrast, the second fabric is found only within the Boyer Gap shear zone and up to 0.5 km to the south within the southern domain. Clearly, the fabrics associated with left-lateral transpression are the most strongly developed within the zone. The amount of displacement on the Boyer Gap shear zone is unknown, but is probably substantial. The relative importance of the two shearing episodes to the present juxtaposition of Precambrian basement against and structurally above Mesozoic(?) McCoy Basin rocks is also unclear. However, this juxtaposition requires a thrust component of displacement on the order of several kilometers.

## Central Domain

The central domain, bracketed by the Boyer Gap and Tung Hill shear zones, is dominated by a south to southwest-facing synclinorium of

Paleozoic metasedimentary rocks flanked by Precambrian basement and Mesozoic metaigneous rocks. In general, lithologic contacts dip to the north and are variously sheared. Precambrian and Paleozoic rocks are intruded by the protoliths of granodiorite schist, gneissic monzogranite and gneissic leucogranite. Unfoliated to weakly foliated leucogranite intrusives cross-cut strongly foliated fabrics, but their contacts are locally sheared.

The distinctive Paleozoic stratigraphy provides excellent structural markers for defining the major fold patterns in the domain. Despite severe attenuation and overthickening, the stratigraphic sequence is largely preserved intact. Locally, individual formations are ductilely attenuated to 1% of their stratigraphic thickness in the correlative unmetamorphosed section in the southern Plomosa Mountains (Miller, 1970).

## Structural Elements

Metaigneous Fabrics. Foliations and lineations in metaigneous rocks are defined by the same elements as those described in the southern domain. Foliation surfaces are more pronounced than mineral lineations. Foliation attitudes steepen from northwest (Dome Basin Mine) to southeast (Boyer Gap-East Hills), but usually dip moderately to the north (average N 80$^{\circ}$W, 30$^{\circ}$NE, Figure 5). The intensity of foliation development is quite variable, but is strongest in the vicinity of sheared lithologic contacts and the domain-bounding shear zones. For example, Precambrian basement granite varies from a foliated megacrystic gneissic granite in northeastern Boyer Gap to a mylonitic banded augen gneiss in southwestern Boyer Gap. Platy schistosity in the granodiorite schist intensifies upward into the Tung Hill shear zone. The plunge and trend of mineral lineations vary widely from 10 to $40^{o}$, N $35^{o}$W to N $70^{o}$E (Figure 5). Southwest-plunging lineations result from broad warping and folding of foliation. The trend of lineations varies crudely from northeastward to north-northwestward from west to east within the domain (Figure 4).

Mylonitic samples with clear S-C relationships (see kinematic discussion for southern domain) were found only in the Tung Hill Mine area. Two samples of Precambrian granitic rock from outcrops southeast of the mine contain a north-northwest-plunging mylonitic lineation and S-surfaces (schistosity) that dip more steeply to the north than C-surfaces (shear). More detailed study is required to determine S-C relationships in mylonitic rocks elsewhere in the domain. Most appropriately oriented outcrops in the domain yielded inconclusive results.

Metasedimentary Fabrics. Foliation in Paleozoic metasedimentary rocks is marked by transposition layering and schistosity. The expression of this foliation differs in each formation due to contrasts in lithology. In the Bolsa quartzite it is expressed by a sharp micaceous cleavage parallel to a penetrative laminar fabric, whereas in the Abrigo schist it is defined by a platy schistosity and thin interleaved quartzite layers. Foliation is less pronounced in the Martin and Escabrosa marbles, but is expressed by a micaceous parting parallel to lithologic layering. Transposition layering is best preserved in the Supai Formation due to sharp contrasts between dark quartzite and interlayered light-colored dolomite marble. Metasedimentary foliations dip moderately to the north (Figure 5) but vary in average orientation from N 50°W, 20-30°NE in the Dome Basin Mine area to N 90°W, 40-60°N in Boyer Gap. Mineral lineations are defined by parallel alignment of mica grains on foliation surfaces, but are commonly obscure in outcrop. Locally in the Supai Formation, a subparallel lineation is defined by small rods and boudins of quartzite parallel to minor fold axes. Rods and boudins are also common in the Paleozoic marbles, where they parallel mineral lineations and fold axes. Most measured lineations plunge 10° to 40°, N 20°W to N 60°E (Figure 5). They commonly parallel the fold axes of minor folds in outcrop. In stereographic projection, metasedimentary and metaigneous fabrics are roughly concordant (Figure 5).

Folds. The most visually striking structures in the northern Dome Rock Mountains are the complex major and minor folds displayed in the Paleozoic metasedimentary rocks. These rocks are exposed within a huge south to southwest-vergent isoclinal synclinorium that has a wavelength of about 1 km (Figure 4). The trace of the major axis is defined by gross Paleozoic stratigraphy and belies the internal complexity of the synclinorium. Cascades of large south to southwest-facing isoclinal folds (wavelengths on the order of tens of meters) parallel the main synclinal axis along its length. In the northwest quarter of section 34 in Boyer Gap, the synclinorium is broken into a series of synclines and anticlines. The axis of the synclinorium plunges gently to the west and northwest. The axial surface, which subparallels metasedimentary layering, changes strike and steepens from about N 55°W, 25°NE in the Dome Basin Mine area to E-W, 45-60°N in Boyer Gap. This apparent counterclockwise rotation and steepening is observable in layering orientations, but not in lineation or minor fold axis orientations. Within Boyer Gap the axial surface and layering are concordant to the orientation of the Boyer Gap shear zone. In Boyer Gap, the upright limb of the synclinorium is overthickened and the overturned limb is attenuated, but south of the Dome Basin Mine, the upright limb is greatly attenuated (Figure 4).

The Precambrian-Cambrian unconformity is spectacularly folded. The folded unconformity is particularly well exposed in the northeast quarter of section 34 in Boyer Gap, and reflects the extreme ductile nature of the deformation. The Cambrian Bolsa quartzite is tightly folded into Precambrian granitic rock in 0.5 to 20 m-wide south-vergent isoclinal folds to which the metagranitic foliation is clearly axial planar (Figure 25).

Although formation boundaries have remained relatively intact and planar (see Figure 10), formations are internally sheared and isoclinally folded at all scales (Figure 26a, b). Folding styles vary with each formation and the relative ductility of interlayered lithologies. Minor fold geometries in the Bolsa quartzite range from near-concentric to similar with hinge closures that are rounded to kinked. These folds are locally disharmonic where quartzite and schist are interlayered (Figure 26b). They are commonly intrafolial and can occur as small isolated hinges within an otherwise planar foliated sequence.

Figure 25. South-vergent isoclinal fold in the Precambrian-Cambrian unconformity.

View to the east in Boyer Gap. Precambrian granitic rock cores the fold, surrounded by Cambrian Bolsa quartzite. Foliation in Precambrian rock is axial planar to fold and coplanar to axial planar cleavage in Bolsa quartzite. Note hammer in top center of photo for scale.

a.

b.

Figure 26. Folds in Bolsa quartzite: a) outcrop view, b) close-up view.

Photo a. is view to the northwest of large recumbant fold. Photo b. is close-up view into the core of this fold. The area in photo b. is up and to the left of the hammer in photo a.

Minor folds in the Abrigo schist are expressed by thin quartzite layers that form small similar non-cylindrical folds with thickened hinges and sharply attenuated limbs. The Martin and Escabrosa marbles, the most ductile lithologies in the section, exhibit the most pronounced effects of flow and attenuation. Fold geometries are similar, non-cylindrical, and locally harmonic (Figure 27). Folds are typically intrafolial with totally attenuated limbs and sharply curved or domal hinges. Chaotic minor folding is best observed in the Supai Formation, where sharp ductility and weathering contrasts between resistant, dark quartzite layers and less resistant, light marble layers create spectacular well-exposed fold geometries (Figure 28). Folds are non-cylindrical, near-concentric to similar, convolute, and disharmonic with attenuated limbs and thickened hinges.

Minor folds are universally inclined or reclined with axial surfaces that parallel enveloping foliation surfaces. Fold amplitudes and wavelengths vary greatly from several centimeters to about ten meters; amplitude generally exceeds wavelength. Tight to isoclinal Class 1C, 2, and 3 folds (Ramsay, 1967) with thickened hinges are most common. Axial planar cleavage is notably absent except in some folds of the Bolsa quartzite (Figure 25).

Measured minor fold axes do not group tightly in stereographic projection (Figure 5). In the field it was observed that larger folds (amplitudes of 1-10 m) tend to plunge gently to the west or northwest, subparallel to the major synclinal axis, whereas smaller folds (amplitudes of 0.05-1 m) commonly plunge at angles oblique or perpendicular to this axis. The orientations of S- and Z-shaped asymmetric minor folds

Figure 27. Minor folds in Paleozoic marble.

Figure 28. Minor folds in Supai rocks.

were not analyzed quantitatively as vergence indicators. In the field, these fold geometries were highly complex and indicated inconsistent senses of vergence even within a single exposure. The major large-scale fold structures exposed in the Paleozoic rocks are clearly south to southwest-vergent. The axial surfaces of major, minor, and refolded folds are roughly coplanar.

Metaigneous foliations are locally brittlely warped or folded about west to northwest-trending near-horizontal fold axes (Figures 4, 5). Most folds have moderately to gently north-dipping axial surfaces and are broadly open to tight with rounded hinges and wave-lengths between several meters and hundreds of meters. Several markedly asymmetric folds are Z-shaped when viewed toward the west. Folds that refold the foliation in Precambrian rocks harmonically with the Precambrian-Cambrian unconformity and Bolsa quartzite also have north-vergent asymmetry.

Shear Zones. Although most lithologic contacts are tectonized to some degree, shear zones within the central domain are mapped only where Precambrian basement is juxtaposed against upper Paleozoic formations. South of the Dome Basin Mine, Precambrian basement is plated beneath the Supai Formation along a sheared contact that dips 10-20$^{o}$ to the northeast. The contact is a 0.5 m-thick strongly foliated zone that locally contains thin lenses of (Bolsa?) quartzite, marble, and vein quartz. Just south of this zone, the Bolsa quartzite and Paleozoic marbles are attenuated to about 1 m each with no intervening

Abrigo schist. The shear zone is concordant to upper and lower-plate foliations.

Metaigneous rocks become increasingly foliated and mylonitic structurally upward toward the Tung Hill shear zone. It places probable lower Mesozoic(?) strata and Jurassic(?) granitic rocks over inverted Paleozoic strata and Precambrian basement, a younger-on-older relationship. The zone is best exposed north of the Tung Hill Mine as a topographic bench along which granodiorite schist is plated beneath sheared gneissic monzogranite. The zone is much less pronounced where well-foliated granitic basement is plated beneath gneissic monzogranite further to the west. Weakly foliated leucogranite apparently truncates the shear zone to the east. Shear is distributed across the zone; a single line representing the zone on the map is drawn along the major lithologic breaks for clarity. The zone strikes about N 65-75$^{\circ}$W and dips 20-25$^{\circ}$NE, concordant to adjacent upper and lower-plate foliations. However, the zone dips about 25$^{\circ}$ less steeply to the north than structures in Boyer Gap (see Figure 4, structure section). Penetrative mylonitic lineations along the zone plunge gently to the northeast. In appropriately oriented outcrop faces, S-surfaces were observed to dip less steeply to the north than C-surfaces.

## Kinematics

As in the southern domain, metaigneous foliation is considered to be largely a flattening mylonitic foliation developed during non-coaxial rotational strain. Mineral lineations are interpreted to result from stretching parallel to direction of transport. These lineations plunge variably north-northwest to northeast, suggesting tectonic transport directions of north-northwest--south-southeast to northeast--southwest. Metasedimentary mineral lineations have roughly the same trends (Figure 5). Two samples in the Tung Hill mine area yield S-C fabrics that indicate top to the south-southeast sense of shear. Metaigneous foliation in Boyer Gap formed syntectonically and axial planar to major folds in Paleozoic rocks.

The major synclinorium and cascades of larger folds within the Paleozoic rocks are clearly south to southwest-vergent and were formed by south to southwest-directed ductile nappe-style overfolding. Minor folds are more difficult to interpret, but the parallelism of many fold hinges with metasedimentary and metaigneous lineations (generally perpendicular to major fold trends) suggests that many are refolded and rotated into the direction of shear (i.e. sheath folds). Abundant arcuate and domal hinges support this interpretation, but a <u>sense</u> of shearing is not clear from available data. Folding styles are ubiquitously quasi-flexural to passive.

Apparent counterclockwise rotation and steepening of metasedimentary foliations and the axial surface of the synclinorium from northeast to north-dipping may be interpreted as a large-scale drag feature sympathetic to left-lateral transpressive movement of the Boyer Gap shear zone. Dips within Boyer Gap are concordant to the zone (Figure 4, structure section). Lineations and fold axes are not observed to systematically rotate, but the resolution of data may be too poor to detect this.

The Tung Hill shear zone represents a dramatic shift in kinematic sense of shear and displacement from areas to the south. S-C fabrics here indicate top to the northeast shearing along a presently north-dipping zone. Upper-plate Jurassic(?) granitic rocks and lower Mesozoic(?) Tung Hill rocks have apparently been displaced "down" and to the northeast relative to mostly older lower-plate rocks. This movement appears to predate intrusion of leucogranite southeast of the Tung Hill Mine. Northeast-directed kinematic indicators have not been recognized to the south within the central domain; the extent to which this shearing penetrates into this domain is not known. More detailed study is required to understand to what extent northeast-plunging linear fabrics (minor fold hinges, mineral lineations) in the central domain are related to south to southwest-vergent overfolding or northeast-directed shearing.

Thus, the central domain records south-southeast to southwest-vergent shearing and folding with possible subsequent drag of large-scale fold structures on the Boyer Gap shear zone. Northeast-plunging linear fabrics record northeast--southwest-directed shearing, but the sense(s) of this shearing is presently unclear. Late north to northeast-vergent brittle folds refold earlier ductile fabrics.

## Northern Domain

Rock units exposed north of the Tung Hill shear zone include gneissic monzogranite, gneissic leucogranite, the Tyson augen gneiss, the Tyson Wash granite, and Tung Hill metasedimentary rocks. All units are moderately to strongly foliated and lineated, and most lithologic contacts are sheared. Detailed mapping confirms that the gneissic monzogranite intrudes the Tung Hill section, and the Tyson Wash granite intrudes these two units and the Tyson augen gneiss. Although the Tyson Wash granite is relatively less deformed than these units and clearly truncates major structural trends, its metamorphic fabric is concordant to that in adjacent units.

## Structural Elements

Metaigneous Fabrics. Prominent measured metaigneous foliations in the northern domain are defined, as in other domains, by the parallel alignment of platy minerals (mostly biotite) and inequent grains (feldspar augen and matrix grains) and are mostly mylonitic. Foliation surfaces contain a well-developed mineral lineation defined by elongate stretched augen, quartz aggregates, and trains of mica. In contrast to the other domains, linear fabrics are commonly more pronounced than planar fabrics (Figure 29). The fabrics can vary greatly in intensity within a single outcrop (see Figure 18), but are, in general, well developed. The fabric in the Tyson Wash pluton intensifies northward from weak to moderately developed and mylonitic. Metaigneous foliation, excluding the Tyson Wash pluton, dips gently to moderately to the north-northeast (average N 70$^\circ$W, 25$^\circ$NE, Figure 5), with mineral lineations that plunge gently to moderately to the northeast and north-northeast (10-30$^\circ$, N 5-55$^\circ$E, Figure 5). Tyson Wash granite foliations dip quite gently to the northeast (average N 30$^\circ$W, 15$^\circ$NE) with mineral lineations that plunge about 5$^\circ$, N 20$^\circ$E (Figure 5). These fabrics appear to be roughly concordant stereographically and especially at map scale

Figure 29. Linear fabric in gneissic monzogranite. Lineated outcrop face strikes north-northeast.

(Figure 4, section 21), despite the obvious truncation of the Tyson thrust shear zone. No overprinting fabric relationships have been recognized in the field.

Asymmetric mylonitic fabrics, like those described previously, occur in these tectonites. In many unambiguous outcrops and oriented thin sections from the gneissic granites and the Tyson Wash granite, S-surfaces dip <u>less</u> steeply to the north-northeast and northeast than C-surfaces. In exceptional exposures, S-surfaces can be observed to asymptotically deflect into thin mesoscopic C-surface shear bands (Figure 30). In contrast, within the Tyson augen gneiss in the northeast quarter of section 27 (Figure 4), asymmetric augen tails, quartz aggregates, and platy minerals define S-C fabrics in outcrop in which S-surfaces appear to dip <u>more</u> steeply to the northeast than C-surfaces. Only the former relationship is observed in and north of section 21, but in other areas many exposures and several oriented thin sections are ambiguous. Throughout the domain, however, the former S-C relationship is far more prevalent than the latter.

<u>Metasedimentary Fabrics</u>. Metasedimentary foliation in the Tung Hill section is defined by several subparallel fabrics: transposition layering, schistosity, and axial planar cleavage. Physical expression of foliation is dependent on lithology, as previously described in the Paleozoic section. Foliation surfaces contain lineations defined by elongate mineral aggregates (quartz and feldspar), stretched quartzite clasts, trains of elongate micas, and more rarely by the intersection of lithologic layering and axial planar cleavage in the hinge zones of

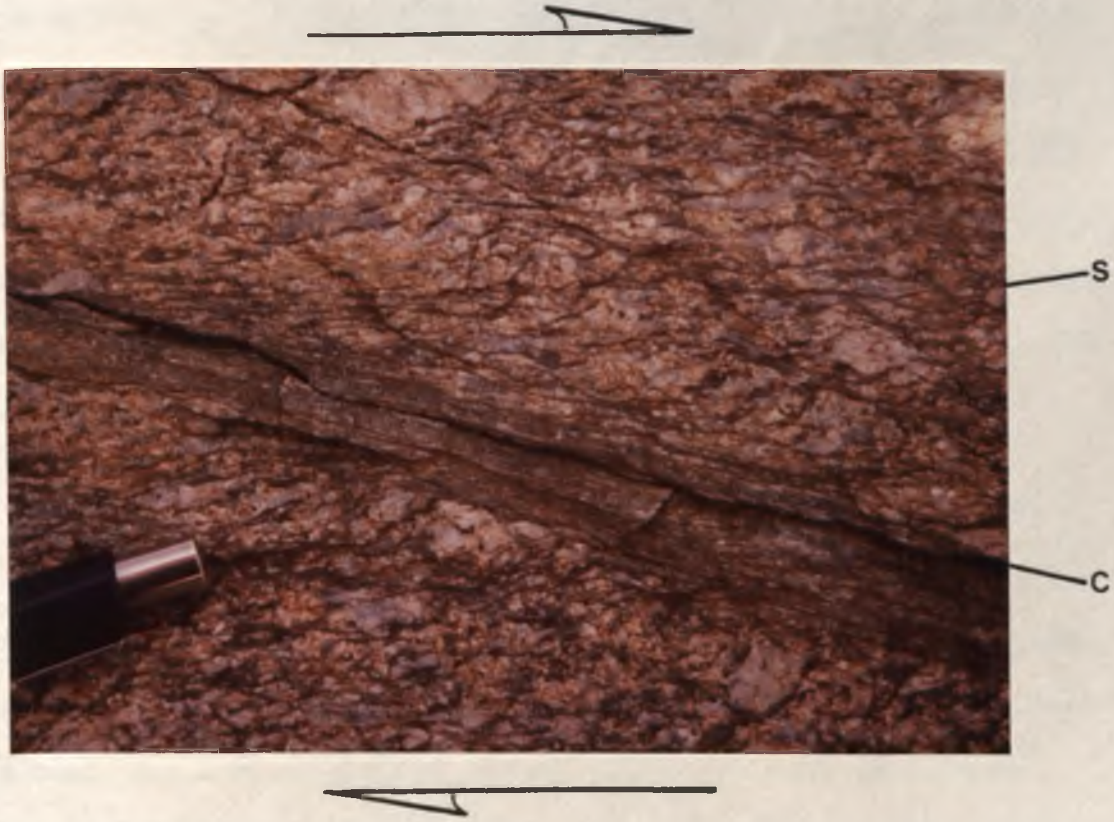


Figure 30. Shear bands in gneissic monzogranite.

View to the northwest, parallel to foliation (N 80°W, 25°NE) and perpendicular to mylonitic lineation (24°, N 15°E). S-C fabric indicates top to the right (north-northeast) sense of shear.

minor folds. The axial planar cleavage is only apparent where fold hinges are well exposed. In several exposures, a very gently north-dipping spaced cleavage crenulates moderately north-dipping layering foliation. The extent of this cleavage within the rest of the section is not known. Foliation surfaces dip gently to moderately to the north and east (average N 50$^{o}$W, 25$^{o}$NE, Figure 5). All linear fabrics plunge gently to moderately to the northeast (10-30$^{o}$, N 10-70$^{o}$E, Figure 5).

Elongate quartz rods up to 5 cm in diameter and 1 m in length occur within quartzose schists and plunge consistently to the northeast, parallel to adjacent mineral lineations and minor fold hinges. The long axes of stretched and folded quartzite conglomerate clasts, with aspect ratios up to 15:1, also plunge to the northeast.

Folds. Fold styles in the transposed Tung Hill section are similar to those in the Paleozoic section, except for the notable development of axial planar cleavage. Cascades of large south-facing folds with wavelengths on the order of 10 m are discernible in several hillsides, but are, in general, poorly defined. These folds trend roughly N 75$^{o}$W (Figure 5) with axial surfaces that dip gently to the north. Small minor folds plunge consistently to the northeast (average 20$^{o}$, N 30$^{o}$E, Figure 5) and occur in stacked cascades or as individual rootless isoclinal hinges enveloped by planar foliation surfaces. Minor fold geometries are variably open to isoclinal, non-cylindrical, and near-concentric to similar. Hinge zones are rounded to kinked. Fold hinges are thickened and limbs are attenuated; Class 1C, 2, and 3 folds (Ramsay, 1967) are most common. The folds are inclined to reclined with axial surfaces and, locally, axial planar cleavage that dip gently to the north. Refolded folds are common. The intensity of ductile folding is exemplified within a conglomeratic quartzite unit (Figure 31) where quartzite layers and stretched clasts are passively contorted.

The intrusive contact between the metasedimentary section and gneissic monzogranite is complexly folded about gently N 20°E-plunging axes 0.5 km northwest of the Tung Hill Mine (Figure 32). Here, the foliation in the granitic rocks is axial planar to the folds and parallel to metasedimentary axial planar cleavage.

Metaigneous foliation and lineation are locally folded about asymmetric kink-like folds (Figure 33). The folds plunge gently to the west-northwest (Figure 5) and are consistently Z-shaped when viewed down-plunge. The folds are inclined to recumbant with axial surfaces that dip very gently to the north. Fold wavelengths are generally 1 to 3 m but range up to the tens of meters. These folds are better developed and show a more consistent sense of vergence than west-northwest-trending in folds in metaigneous rocks described in domains to the south.

In section 21 (Figure 4), foliations in the gneissic monzogranite and Tyson Wash granite are warped about two broad gently north-northeast-plunging synformal folds. The axes are subparallel to mylonitic mineral lineations in that area.

Shear Zones. The Tung Hill shear zone, which defines the southern boundary of this domain, is described in the central domain section of this chapter. Contacts between the metasedimentary section

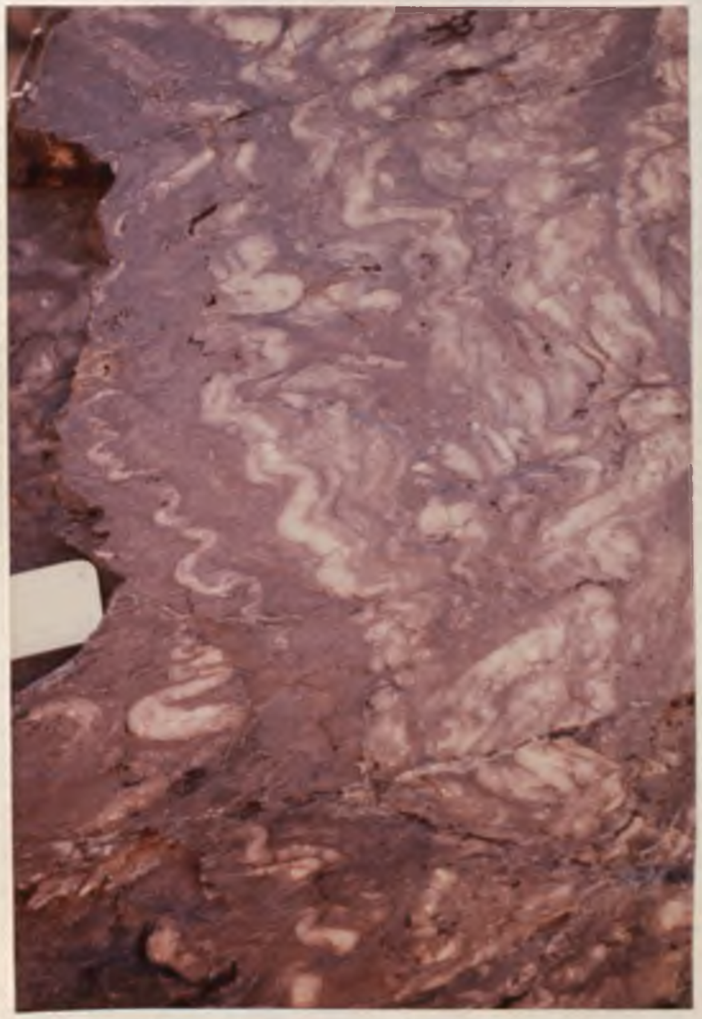

Figure 31. Contorted folds in quartz-pebble metaconglomerate within Tung Hill metasedimentary section.

View to the north-northeast.


Figure 32. Folded intrusive contact between gneissic monzogranite and Tung Hill metasedimentary rocks.

Figure 33. Asymmetric kink fold in gneissic monzogranite.

Brittle fold is Z-shaped as viewed down the plunge of the fold ($5^{o}$, N $70^{o}$W).

and gneissic monzogranite are largely tectonic. Along these contacts, sheared metasedimentary rocks are tightly plated into well-foliated and lineated metagranite. Metasedimentary and metaigneous foliations and lineations are typically concordant across the zones. These zones grade laterally into less sheared intrusive contacts. The contact between the Tyson Wash granite and gneissic monzogranite is variably sheared and dips gently northward concordant to metaigneous foliations. This contact becomes steep and oblique to foliations to the east where it truncates the structural trend of metasedimentary rocks and the Tyson augen gneiss.

The Tyson thrust shear zone strikes about N $60^{\circ}$W and dips $20-25^{\circ}$ to the northeast and places crystalline rocks of unknown age (the Tyson augen gneiss) over metasedimentary rocks of the Tung Hill section. Augen gneiss grades into thinly plated mylonitic gneiss and mylonite within 1 m of the contact. Metasedimentary rocks just below the contact are more strongly foliated and metamorphosed than rocks elsewhere in the section. Mylonitic lineation in the zone gently plunges about N $30^{\circ}$E. Several small asymmetric kink folds in the mylonitic fabric within the zone are Z-shaped when viewed looking west-northwest. S-surfaces appear to dip more steeply to the northeast than C-surfaces in augen gneiss just above the zone.

Kinematics

Kinematic interpretation of the northern domain is made difficult by conflicting or ambiguous vergence indicators and a lack of clear cross-cutting or overprinting fabric relationships in an area apparently affected by multiple deformational episodes. Perhaps earlier fabrics are transposed or destroyed by subsequent remobilization and (or) fabrics formed by multiple episodes are nearly coplanar and colinear.

Foliation and lineation in metaigneous rocks are clearly mylonitic and probably developed through non-coaxial rotational strain (see southern domain kinematics for discussion). Both metaigneous and metasedimentary linear fabrics are more strongly developed in this domain than to the south. These fabrics suggest that extensional strain was more severe than flattening strain during a significant part of the ductile deformation in this domain. Mylonitic metaigneous lineations (excluding the Tyson Wash granite), metasedimentary lineations, and most minor fold hinges are generally colinear in stereographic projection. This is interpreted to indicate a transport direction of northeast--southwest. Sense of tectonic transport is much more difficult to interpret, and may be both southwest and northeast-directed.

Southwest tectonic transport is indicated by 1) cascades of large south-southwest-facing isoclinal folds within the Tung Hill section, and 2) top to the southwest S-C relationships within the Tyson augen gneiss (in section 22). These relationships suggest that initial shearing on the Tyson thrust was likely southwest-directed. This movement could be substantial, particularly if the protolith of the Tyson augen gneiss is Precambrian. Fold styles and facing are sympathetic to clearly southwest-vergent isoclinal folding of Paleozoic rocks in the central domain.

Northeast and north-northeast tectonic transport is indicated by: 1) unambiguous top to the northeast and north-northeast S-C relationships in mylonitic outcrops and thin sections throughout the domain (although many other outcrops and several thin sections were ambiguous and some possibly southwest-vergent), 2) northeast-directed displacement and shearing on the Tung Hill shear zone, 3) small northeast-vergent asymmetric kink folds within the (reactivated?) Tyson thrust shear zone and elsewhere within the Tung Hill section, and 4) north to northeast-vergent asymmetric brittle folds that refold mylonitic fabrics.

Northeast-plunging minor folds were not analyzed for kinematic sense of vergence, but their hinges are generally subparallel to northeast-vergent mylonitic metaigneous lineations. This suggests that they may have been refolded and rotated into parallelism with a northeast direction of shearing. This has not been substantiated quantitatively, however.

The Tyson Wash pluton clearly truncates the Tyson thrust shear zone, but its metamorphic fabric is both coplanar and colinear to the prominent fabric in adjacent more highly strained units into which it intrudes (Figure 4). All S-C fabrics in the Tyson Wash pluton and adjacent units indicate top to the north-northeast (about N $20^{o}$E) sense of shear. Foliations are warped about broad synformal folds that plunge very gently parallel to mylonitic lineation (about N $20^{o}$E). Intrusion of the Tyson Wash granite clearly postdates most of the severe shearing in the domain and ductile faulting associated with the Tyson thrust, but predates (or is syntectonic to) low-angle N $20^{o}$E-directed shearing and broad synformal warping. Earlier fabrics in adjacent rocks may have been transposed and remobilized into concordance with Tyson Wash granite fabrics during this shearing event.

Thus, possibly four deformational phases may be recorded in the northern domain: 1) southwest-vergent isoclinal folding and ductile faulting (Tyson thrust); 2) northeast-directed shearing within the domain and along the Tung Hill shear zone (and Tyson thrust?), with probable refolding of Tung Hill metasedimentary rocks; 3) north to northeast-vergent brittle refolding of metaigneous foliations; and, following emplacement of leucocratic granites and the Tyson Wash granite, 4) low-angle N $20^{o}$E-directed shearing and gentle warping in the northern, structurally highest part of the range. The ages of these events hinge on the ages of the undated cross-cutting intrusives. Based on lithologic similarities with similar plutons in the region, these intrusives are likely late Cretaceous or early Tertiary in age.

## Brittle Faults

Very few brittle structures occur in the northern Dome Rock Mountains, but several high angle normal faults locally offset ductile structures in the area (Figure 5). The faults generally strike northwest and dip steeply to the southwest. Apparent offsets vary from one to several tens of meters. The faults are defined by topographically low zones of iron-stained gouge or breccia less than 1 m thick. A brecciated normal fault zone up to 2 m thick strikes east-west through a saddle in Boyer Gap. The zone dips near-vertically to the north. Displacement on the zone is not known, but does not appear to be significant. Steep foliations in the Boyer Gap shear zone may be partly due to rotation during this brittle faulting.

## Structural Evolution

Kinematic and chronological interpretation of the structural evolution of the northern Dome Rock Mountains is made difficult by the extremely ductile nature of superposed deformation and a present lack of absolute ages on many rock units. Clearly, however, rocks in the range were profoundly affected by generally south to southwest-directed compressional tectonism followed and overprinted by northeast-directed shearing and refolding in structurally higher parts of the range. Six deformational phases are recognized in the structural development of the range: 1) south-southeast to southwest-directed ductile shearing, folding, and thrusting; 2) west-southwest-directed left-lateral transpressive ductile faulting along the Boyer Gap shear zone; 3) northeast-directed shearing; 4) north to northeast-vergent brittle refolding; 5) late N 20$^{\circ}$E-directed shearing; and 6) brittle normal faulting. Highly ductile fabrics associated with the first three phases suggest they occurred at moderate to deep crustal levels under upper greenschist to amphibolite-grade metamorphic conditions. The metamorphic history of the range is likely as complex as the structural history. High-grade rocks, particularly in the southern domain, have been retrograded to greenschist-grade. The structural development of the range is discussed below in apparent chronological sequence.

1) Rocks in the northern Dome Rock Mountains were first affected by severe south-southeast to southwest-directed ductile compression and

syntectonic moderate to high-grade metamorphism. The direction of tectonic transport may have shifted from south-southeast to southwest during generally south-directed compression, but two distinct events have not been recognized. This compression was accompanied by complete transposition of primary stratigraphic features and development of synmetamorphic isoclinal folds and strong mylonitic fabrics. Paleozoic strata, and probably also lower Mesozoic(?) Tung Hill strata, were ductilely folded into large south to southwest-vergent overturned isoclinal folds with attendant extreme attenuation on the limbs of some folds. Metaigneous foliations formed axial planar to these folds. This intense deformation is interpreted to have been synchronous with southward thrusting of cratonic Precambrian and Paleozoic rocks over Mesozoic(?) McCoy Basin rocks. Possible southwest-directed movement on the Tyson thrust also likely occurred during this phase. This deformation postdates intrusion of several Jurassic and Jurassic(?) igneous rocks, but may predate, at least in part, intrusion of the mid-Jurassic (probably 160-165 m.y.) Middle Camp pluton. Metamorphism and locally intense shearing recorded in the pluton suggest it was intruded syn- to late-kinematically to shearing in the southern domain.

2) Left-lateral transpressive ductile faulting on the Boyer Gap shear zone is likely a late stage of continued southwest-directed compression. The most intense mylonitic fabrics in the range are found in the Boyer Gap shear zone in association with this ductile faulting. West-southwest-directed shearing penetrated at least 0.5 km structurally below the zone. The huge southwest-vergent synclinorium of Paleozoic strata possibly was rotated and steepened into parallelism with the

Boyer Gap shear zone by counterclockwise drag during left-lateral shearing. Total distance of transport along the Boyer Gap shear zone is not known, but juxtaposition of Precambrian basement against and over probable Mesozoic strata suggests substantial thrust and lateral components of displacement.

3) Rocks in the structurally higher parts of the range, especially the northern domain, were later affected by northeast-directed shearing. Fabrics associated with apparent northeast-directed displacement along the Tung Hill shear zone discordantly cut steeper fabrics associated with south-directed compression (see Figure 4, structure section). Minor folds in Tung Hill metasedimentary rocks (and Paleozoic rocks?) were apparently refolded into subparallelism with northeast-directed mylonitic fabrics. The prominence of linear fabrics over planar fabrics suggests that compressive (flattening) strain was less significant during this event. Jurassic(?) granitic rocks correlative to the Middle Camp pluton are strongly affected by this deformation.

4) Metaigneous (and locally metasedimentary) foliations and lineations in all parts of the range, but especially in the central and northern domains, are brittlely refolded about open to tight asymmetric folds. These folds, widely variable in size, are consistently north to northeast-vergent where sense of overturning is discernible. This refolding is interpreted to represent a late stage of continued northeast-directed tectonism.

Small plugs and moderately-sized plutons of leucocratic granite intrude and cross-cut strongly-developed ductile fabrics and major structural features. They appear to truncate fabrics associated with both south and northeast-directed tectonism. The leucogranites vary from unfoliated in the south to weakly foliated in the Tung Hill Mine and East Hills areas, and are thus inferred to be late to post-kinematic to the major ductile deformation in the range. The Tyson Wash granite also clearly cross-cuts strongly developed ductile fabrics and truncates major structural trends in the north end of the range. The fabric developed in this pluton is concordant to the fabric in adjacent rock units. Either the pluton is late-kinematic to northeast-directed shearing, or it is post-kinematic and the fabric reflects a younger event that also overprints older fabrics in rocks adjacent to the pluton. The latter possibility is favored here. These undated late to post-kinematic granites are lithologically similar to "Laramide-age" plutons throughout the region, which suggests they are probably late Cretaceous to early Tertiary in age. Thus, the major ductile deformational events in the range can be loosely constrained as Jurassic to late Cretaceous-early Tertiary in age.

5) A very gently north-dipping mylonitic foliation with a consistent N $20^{o}$E-plunging lineation overprints the Tyson Wash granite and other rocks in the northernmost, structurally highest part of the range. Kinematic indicators consistently indicate north-northeast-directed transport. Foliations are gently warped about synformal folds that plunge parallel to lineation. This deformation postdates the Tyson Wash granite and is likely associated with mid-Tertiary extension. The range is structurally overlain by a mid-Tertiary northeast-dipping

detachment fault, exposed 8 km to the north in the Moon Mountains. Arching of earlier fabrics may have been associated with this event.

6) Generally northwest-striking and southwest-dipping high-angle normal faults affect older structures in the range. The faults appear to be associated with northwest-striking undeformed diorite dikes. These features appear to reflect late Tertiary northeast-directed extension.

In summary, structures in the northern Dome Rock Mountains record: 1) south-southeast to southwest-directed compression, 2) west-southwest-directed left-lateral transpressive shearing, 3) northeast-directed shearing, 4) north to northeast-vergent refolding, 5) north-northeast-directed ductile extension, and 6) northeast--southwest brittle extension.

## TECTONIC SYNTHESIS

In this chapter, the geology and structure observed in the northern Dome Rock Mountains are discussed in relation to known regional geologic and structural relationships and integrated into the tectonic framework of the region. Regional implications of this study are also discussed. The northern Dome Rock Mountains are located along the trend of several major tectonic elements within the southern Cordillera: 1) the southwestern boundary of unequivocal North American cratonic stratigraphy, 2) the northwest-trending Jurassic continental arc (Coney, 1978; Dickinson, 1981), 3) the northwestern extension of the proposed Jurassic Mojave-Sonora megashear (Anderson and Silver, 1979), 4) the McCoy Basin (Harding, 1982), 5) a belt of south-directed nappe-style folds and thrusts (Krummenacher and others, 1981), and 6) a northwest-trending belt of "metamorphic core complexes" (Rehrig and Reynolds, 1980). Proximity to these various features indicates that the tectonic history of the area is apt to be complex. Indeed, the tectonic evolution of the region is only now coming into better focus with the recent dramatic increase in geologic investigations in the area.

The southwestern boundary of unequivocal North American cratonic stratigraphy cuts through the northern Dome Rock Mountains along the Boyer Gap shear zone. This boundary is exposed as south-vergent thrust faults to the west in Palen Pass (LeVeque, 1981, 1982) and to the east in the southern Plomosa Mountains (Miller and McKee, 1971), and marks the northern margin of the structural McCoy Basin (Harding, 1982)

(Figure 6). Paleomagnetic evidence and a xenolith of Paleozoic(?) marble in the Middle Camp pluton suggest that cratonic rocks floor the McCoy Basin, but crystalline terranes to the south do not appear to have cratonic affinities (Harding and Coney, 1985). Paleozoic metasedimentary rocks exposed north of Boyer Gap rest depositionally on cratonic basement and are clearly derived from the classic southwestern cratonic sequence. The Tung Hill metasedimentary section appears to have lithologic affinity to heterogeneous sequences of lowermost Mesozoic strata that depositionally overlie Paleozoic rocks elsewhere in the region (e.g., Emerson, 1982; Lyle, 1982; Stoneman, 1985) and that may be correlative to the cratonic Moenkopi Formation of Triassic age (Walker and others, 1984). The Tung Hill section is tentatively interpreted to be derived from cratonic rocks of lower Mesozoic (Triassic?) age based on this lithologic correlation and its intrusive relationships with mid-Jurassic granitic rock.

Intense deformation and metamorphism preclude accurate stratigraphic correlation of the thick metasedimentary-volcanic assemblage exposed to the south of Boyer Gap. Although no maximum age constraint can be assigned, lithologic evidence suggests that the assemblage is probably derived from stratified rocks of lower to middle Mesozoic age. The assemblage has lithologic affinity to parts of the lower Jurassic Palen Formation and the exceedingly thick McCoy Mountains Formation, which is exposed only 12 km to the south (see previous discussion). The assemblage is clearly intruded by the mid-Jurassic (probably 160-165 m.y.) Middle Camp pluton. This relationship does not preclude the possibility that part of the assemblage is meta-McCoy Mountains

Formation because a maximum Jurassic age for the formation has not yet been tightly constrained (see Harding, 1982; Harding and Coney, 1985). In fact, if future detailed studies show that the assemblage is indeed partly meta-McCoy Mountains Formation, this intrusive contact would provide critical evidence about the age of this controversial formation. Based on available data, however, the assemblage is tentatively correlated temporally and in-part lithologically to the lower Jurassic Palen Formation of Pelka (1973) and LeVeque (1981, 1982). The assemblage, like the Palen Formation, underlies a northern boundary fault of the McCoy Basin and is overlain and locally intruded by a rhyodacite porphyry. The undated metaporphyry in the map area is strikingly similar to that in Palen Pass, dated at 176 m.y. (K-Ar plagioclase, Pelka, 1973). The metaryhodacite porphyry is interpreted to represent a hypabyssal compo- nent of the extensive continental Jurassic arc terrane (Coney, 1978; Dickinson, 1981) that is widely exposed within and around the McCoy Basin.

The Middle Camp granite and variably deformed monzogranites and granodiorite exposed throughout the map area are interpreted to represent somewhat younger plutonic components of the Jurassic arc. Similar granitic rocks are widely distributed throughout the region and generally range 160-165 m.y. in age (John, 1981; Hamilton, 1982). The South Ridge augen gneiss is interpreted to be derived from related Jurassic monzogranite, based on lithologic similarities and its intrusive contact with the metasedimentary-volcanic assemblage and metarhyodacite porphyry. The Middle Camp pluton also intrudes these units in the map area and Jurassic rhyodacite porphyry in the central Dome Rock Mountains (Crowl, 1979).

Harding and Coney (1985) have proposed that the exceedingly thick volcanic terrane and overlying McCoy Mountains Formation within the McCoy Basin may have been emplaced and deposited within a rhombochasm associated with transtensional left-lateral strike-slip movement on the northwest extension of the Mojave-Sonora megashear of Anderson and Silver (1979). This fault system is presumed to have been active from early to mid-Jurassic time. Perhaps the thick metasedimentary-volcanic assemblage represents older Jurassic deposits within the basin. If this is true, the Boyer Gap shear zone may reflect compressional reactivation of an earlier transtensional basin-bounding fault. Harding and Coney further propose that the basin must have been closed by opposite-verging thrust faults soon after transtensional faulting ceased, because paleomagnetic data suggests that major deformation of the McCoy Mountains Formation was complete by middle Late Jurassic time.

The earliest deformation recognized in the northern Dome Rock Mountains was south-southeast to southwest-directed compressional shearing and folding with attendant moderate to high-grade metamorphism. South-southeast-directed fabrics may predate, at least in part, intrusion of the mid-Jurassic Middle Camp granite in the southern part of the map area. These fabrics and the south to southwest-vergent synclinorium of Paleozoic rocks are interpreted to have developed during continuous southward ductile thrusting of cratonic basement and cover rocks over Mesozoic(?) rocks of the McCoy Basin in middle Mesozoic time. Late or synkinematic intrusion of the Middle Camp pluton would appear to substantiate the Middle to Late Jurassic minimum age for major deformation of the basin indicated by paleomagnetic data from the McCoy Mountains Formation (Harding and others, 1983). However, a minimum Mesozoic age constraint for this event within the study area is not known, and significant later deformation is clearly evident in structurally higher parts of the range.

Southeast to southwest-vergent large scale compressional folding and faulting of middle to late Mesozoic age are also evident in all other ranges along the northern margin of the McCoy Basin. The earliest phase of Mesozoic deformation recognized in the Granite Wash, Harquahala, and Little Harquahala Mountains (Reynolds, 1982; Reynolds and others, 1983; Richard, 1983; Laubach and others, 1984) involves south to southeast-vergent folding of rocks probably correlative to the McCoy Mountains Formation. This folding is succeeded by southwest-directed folding and thrusting of crystalline rocks over these rocks in the Granite Wash and Little Harquahala Mountains (Reynolds and others, 1983; Richard, 1983; Laubach and others, 1984). The northern Dome Rock Mountains are the eastern extension of a belt of generally south to southwest-vergent basement-involved fold and thrust nappes of Paleozoic strata that are exposed in the Big Maria, Little Maria, Arica, and Riverside Mountains, and Palen Pass in southeastern California (Krummenacher and others, 1981).

West-southwest-directed left-lateral transpressive movement on the Boyer Gap shear zone is indicated by mylonitic S-C fabrics and possible counterclockwise drag of the Paleozoic synclinorium on the structure. This sense of movement appears to be unique in the region, and is interpreted to reflect the last phase of oblique thrusting of cratonic rocks over the McCoy Basin. Amount of displacement is not known, but is likely substantial. It is intriguing to consider that the sense of left-lateral movement on the zone is the same as that presumed for the Mojave-Sonora megashear strike-slip fault system. If this phase of deformation is Jurassic in age, then it is feasible that the Boyer Gap shear zone could be related to late-stage transpressive slip on this system. This possibility cannot be substantiated without better age constraints for this movement on the Boyer Gap shear zone.

Northeast-directed shearing and refolding, probably associated with northeast-directed displacement along the Tung Hill shear zone, reflect a later phase of severe deformation in the structurally higher (northern) parts of the range. North to northeast-vergent brittle refolding of ductile fabrics is considered to be a late stage of this deformation. Late to post-kinematic granites of probable late Cretaceous to early Tertiary age cross-cut these fabrics.

Northeast-vergent structures of probable late Mesozoic age that truncate or disrupt south-vergent structures have been documented in several nearby ranges and are perhaps related to the structures observed in the study area. In the Big Maria Mountains, the south-facing fold nappes are apparently crossfolded by northeast-vergent recumbant folds developed by northeast-directed shearing (Hamilton, 1982). Similar but more brittle northeast-vergent folds have been documented in the Riverside (Lyle, 1982), northern Plomosa (Stoneman, 1985), and Granite Wash Mountains (Laubach and others, 1984). North to northeast-vergent structures are also exposed in the Harquahala Mountains (Reynolds and others, 1980; Reynolds, 1982). Upper Cretaceous to lower Tertiary plutonic rocks cut all of these structures.

A gently north-dipping mylonitic foliation overprints the late(?) to post-kinematic Tyson Wash granite and adjacent rocks in the northernmost, structurally highest part of the range. S-C fabrics and a consistent N 20°E-plunging lineation indicate a normal sense of shearing toward the north-northeast. Broad open synformal warps plunge parallel to this lineation. These features are interpreted to be related to mylonitization and detachment faulting associated with profound mid-Tertiary crustal extension and the development of "metamorphic core complexes" in the region (e.g., Crittendon and others, 1980; Hamilton, 1982; Spencer, 1984). The northern Dome Rock Mountains structurally underlie the gently northeast-dipping Moon Mountain detachment fault, exposed 8 km to the north (Baker, 1981). This fault is probably linked to similar structures that overlie the Big Maria and southern Plomosa Mountains (Hamilton, 1982; Spencer, 1984) and juxtapose deeper (more ductile) crustal levels directly against shallow (more brittle) crustal levels. Spencer (1984) has suggested that the Moon Mountain detachment fault is the lowest of an imbricate of similar northeast-dipping structures. Indeed, low-angle mid-Tertiary extensional structures appear to be lacking in the Big Maria (Hamilton, 1982) and Dome Rock Mountains, and within the McCoy Basin (Harding, 1982).

In the northern Plomosa Mountains, Tertiary rocks in the upper plate of the Moon Mountain detachment fault appear to have been back-rotated up to 60° to the south-southwest, indicating a north-northeast sense of transport (Stoneman, 1985). Kinematic indicators on the overlying Plomosa detachment fault also indicate north-northeast sense of transport (Scarborough and Meader, 1983). The kinematic coordination of these brittle structures and ductile fabrics in the structurally highest part of the study area suggest that they are related.

Broad large-scale arching and doming of the adjacent Big Maria and Little Maria Mountains has been attributed to mid-Tertiary extensional tectonics (Emerson, 1982; Ellis, 1982). This doming may also have affected the northern Dome Rock Mountains, and could explain why northeast-directed apparently Mesozoic structures dip consistently northward, giving an apparent "normal" sense of displacement. No clear evidence of this doming has been found in the study area, however.

Northwest-striking normal faults in the range were likely formed during continued northeast--southwest extension associated with late Tertiary Basin and Range faulting. Northwest-striking strike-slip faults, prevalent in nearby areas (e.g., Crowl, 1979; Miller and McKee, 1971; Hamilton, 1982), are not found in the northern Dome Rock Mountains.

# CONCLUSIONS

In summary, a major stratigraphic discontinuity exists between stratified rocks exposed to the north and south of Boyer Gap in the northern Dome Rock Mountains. Paleozoic and lower Mesozoic(?) rocks to the north have affinity to the North American craton, whereas Mesozoic(?) rocks to the south have uncertain affinity, but may record early deposition in the McCoy Basin during transtensional faulting on the Mojave-Sonora megashear. Hypabyssal and later plutonic masses record prolific magmatism associated with the Jurassic continental magmatic arc. Leucocratic intrusives of probable late Cretaceous to early Tertiary age are late to post-kinematic to the major deformation recorded in the range.

Intense middle Mesozoic compression resulted in south-southeast to southwest-vergent folding, shearing, and thrusting that caused basement and cover rocks of the North American craton to be telescoped southward over Mesozoic(?) rocks of the McCoy Basin. This deep-seated compression culminated in left-lateral transpressive ductile faulting along the Boyer Gap shear zone, a north-bounding fault of the McCoy Basin. Late Mesozoic(?) northeast-directed shearing, low-angle ductile faulting, and brittle refolding overprinted earlier fabrics in structurally higher parts of the range. The range became a deep-level core to profound north-northeast-directed extension in mid-Tertiary(?) time.

The rocks and structures of the northern Dome Rock Mountains record a complex tectonic history along the southwestern margin of cratonic North America. Questions raised by this study can only be resolved through detailed geochronologic, metamorphic, petrologic, and structural analyses. It is hoped that this study, with its geologic map, will provide a sound base for further investigations in the range.

LIST OF REFERENCES

Anderson, C.A., and Silver, L.T., 1976, Yavapai Series--A Greenstone Belt: Ariz. Geol. Soc. Digest, v. 10, p. 13-26.

Anderson, T.M., and Silver, L.T., 1979, The role of the Mojave-Sonora Megashear in the tectonic evolution of northern Sonora, in T.M. Anderson and J. Roldan-Quitana, editors, Geology of Northern Sonora: Geol. Soc. America Ann. Mtg. Field Trip Guide No. 27, p. 59-68.

Baker, J., 1981, Structural reconnaissance of detachment faulting in the Moon Mountains, Yuma County, Arizona: Senior Thesis, San Diego State University, San Diego.

Bancroft, H., 1911, Ore deposits of northern Yuma County, Arizona: U.S. Geol. Survey Bull. 451, 130 p.

Bell, T.H., and Etheridge, M.A., 1973, Microstructure of mylonites and their descriptive terminology: Lithos, v. 6, p. 337-48.

Berthe, D., Choukroune, P., and Jegouzo, P., 1979, Orthogneiss, mylonite, and noncoaxial deformation of granites: the example of the South Amorican Shear Zone: J. Structural Geology, v. 1, no. 1, p. 31-42.

Blake, M.C., Howell, D.G., and Jones, D.L., 1982, Preliminary tectono-stratigraphic terrane map of California: U.S. Geol. Survey Open-File Report 82-593.

Bryant, D.L., 1968, Diagnostic characteristics of the Paleozoic formations of southeastern Arizona: Southern Arizona Guidebook III, Ariz. Geol. Soc., p. 33-47.

Burchfiel, B.C., and Davis, G.A., 1981, Mojave Desert and environs, in W.G. Ernst, editor, The Geotectonic Development of California: Prentice-Hall, Inc., p. 217-252.

Carr, W.J., and Dickey, D.D., 1980, Geologic Map of Vidal, CA and Parker SW, CA-AZ quadrangles: U.S. Geol. Survey Map I-1125.

Coney, P.J., 1978, Mesozoic-Cenozoic Cordilleran plate tectonics: Geol. Soc. America Memoir 152, p. 33-50.

Crittenden, M.D., Jr., Coney, P.J., and Davis, G.H., editors, 1980, Cordilleran Metamorphic Core Complexes: Geol. Soc. America Memoir 153, 480 p.

Crowell, J.C., 1981, An outline of the tectonic history of southeastern California, _in_ W.G. Ernst, editor, The Geotectonic Development of California: Prentice-Hall, Inc., p. 583-600.

Crowl, W.J., 1979, Geology of the central Dome Rock Mountains, Yuma County, Arizona: M.S. Thesis, University of Arizona, Tucson, 76 p.

Darton, N.Y. 1925, A resume of Arizona geology: Ariz. Bur. Mines Bull. 119, p. 219-21.

Davis, G.A., Anderson, J.L., Frost, E.G., and Shackelford, T.J., 1980, Mylonitization and detachment faulting in the Whipple-Buckskin-Rawhide Mountains terrane, southeastern California and western Arizona: Geol. Soc. America Memoir 153, p. 79-129.

Dickinson, W.R., 1981, Plate tectonic evolution of the Southern Cordillera, _in_ W.R. Dickinson and W.D. Payne, editors, Relations of Tectonics to Ore Deposits in the Southern Cordillera: Ariz. Geol. Soc. Digest, v. 14, p. 113-136.

Eberly, L.D., and Stanley, T.B., Jr., 1978, Cenozoic stratigraphy and geologic history of southwestern Arizona: Geol. Soc. America Bull., v. 89, p. 921-940.

Ellis, M.J., 1982, Structural analysis of the Big Maria Mountains, Riverside County, California, _in_ Frost, E.G., and Martin, D.L., editors, Mesozoic-Cenozoic Tectonic Evolution of the Colorado River Region, CA, AZ and NV, Anderson-Hamilton Volume: Cordilleran Publ., San Diego, p. 222-233.

Emerson, W.S., 1982, Geologic development and late Mesozoic deformation of the Little Maria Mountains, Riverside County, California, _in_ Frost, E.G., and Martin, D.L., editors, Mesozoic-Cenozoic Tectonic Evolution of the Colorado River Region, CA, AZ and NV, Anderson-Hamilton Volume: Cordilleran Publ., San Diego, p. 245-254.

Ernst, W.G., editor, 1981, The Geotectonic Development of California, Rubey Volume I: Prentice-Hall, Inc., 706 p.

Frost, E.G., and Martin, D.L., editors, 1982a, Mesozoic-Cenozoic Tectonic Evolution of the Colorado River Region, California, Arizona and Nevada, Anderson-Hamilton Volume: Cordilleran Publ., San Diego, 608 p.

________, 1982b, Comparison of Mesozoic compressional tectonics with mid-Tertiary detachment faulting in the Colorado River area, California, Arizona and Nevada, in Geologic Excursions in the California Desert: Geol. Soc. America 78th Ann. Mtg. Field Trip Guide, p. 113-158.

Hamilton, W., 1982, Structural evolution of the Big Maria Mountains, northeastern Riverside County, southeastern California, in Frost, E.G., and Martin, D.L., editors, Mesozoic-Cenozoic Tectonic Evolution of the Colorado River Region, CA, AZ and NV, Anderson-Hamilton Volume: Cordilleran Publ., San Diego, p. 1-27.

________, 1984, Generalized geologic map of the Big Maria Mountains region, northeastern Riverside County, southeastern California: U.S. Geol. Survey Open-File Report 84-xxx, 7 p.

Harding, L.E., 1978, Petrology and tectonic setting of the Livingston Hills Formation, Yuma County, Arizona: M.S. Thesis, University of Arizona, Tucson, 57 p.

________, 1980, Petrology and tectonic setting of the Livingston Hills Formation, Yuma County, Arizona, in Jenney, J.P., and Stone, C., editors, Studies in Western Arizona: Ariz. Geol. Soc. Digest, v. 12, p. 135-146.

________, 1982, Tectonic significance of the McCoy Mountains Formation, southeastern California and southwestern Arizona: Ph.D. Dissertation, University of Arizona, Tucson, 197 p.

Harding, L.E., Butler, R.F., and Coney, P.J., 1983, Paleomagnetic evidence for Jurassic deformation of the McCoy Mountains Formation, southeastern California and southwestern Arizona: Earth Plan. Sci. Letters, v. 62, p. 104-114.

Harding, L.E., and Coney, P.J., 1985, The geology of the McCoy Mountains Formation, southeastern California and southwestern Arizona: Geol. Soc. America Bulletin.

Haxel, G., Wright, J.E., May, D.J., and Tosdal, R.M., 1980, Reconnaissance geology of the Mesozoic and lower Cenozoic rocks of the southern Papago Indian Reservation, Arizona: a preliminary report, in Jenney, J.P., and Stone, C., editors, Studies in Western Arizona: Ariz. Geol. Soc. Digest, v. 12, p. 17-29.

Haxel, G., Tosdal, R.M., and Dillon, J.T., in press, Tectonic setting and lithology of the Winterhaven Formation, a new Mesozoic stratigraphic unit in southeasternmost California and southwestern Arizona: U.S. Geol. Survey Bulletin.

Howard, K.A., Carr, M.D., and Miller, D.M., editors, 1981, Tectonic Framework of the Mojave and Sonoran Deserts, California and Arizona: U.S. Geol. Survey Open-File Report 81-503, 125 p.

Hyndman, D.W., 1972, Petrology of Igneous and Metamorphic Rocks: McGraw-Hill, New York, 533 p.

Jenney, J.P., and Stone, C., editors, 1980, Studies in Western Arizona: Ariz. Geol. Soc. Digest, v. 12, 322 p.

John, B., 1981, Reconnaissance study of Mesozoic plutonic rocks in the Mojave Desert region, in Howard, K.A., Carr, M.D., and Miller, D.M., editors, Tectonic Framework of the Mojave and Sonoran Deserts, CA and AZ: U.S. Geol. Survey Open-File Report 81-503, p. 48-50.

Jones, E.L., 1916, Gold deposits near Quartzsite, Arizona: U.S. Geol. Survey Bull. 620, p. 47-57.

Keith, S.B., 1978, Index of mining properties in Yuma County, Arizona: Ariz. Bur. Geol. Min. Tech. Bulletin 192, 185 p.

Krummenacher, D., Martin, D.L., Baltz, R.M., Demaree, R.G., Ellis, M.J., Emerson, W.S., Kies, R.P., Lafferty, M.R., Lyle, J.H., and Frost, E.G., 1981, Middle Mesozoic compressional tectonics and Tertiary extensional overprint in the Big Maria, Little Maria, Riverside and Arica Mountains and Palen Pass areas of Riverside County, California: Geol. Soc. America Abstracts with Programs, v. 13, p. 492.

Laubach, S.E., Reynolds, S.J., Spencer, J.E., and Marshak, S., 1984, Polyphase deformation history of Mesozoic metasedimentary rocks in western Arizona: Geol. Soc. America Abstracts with Programs, v. 16, no. 6, p. 570.

LeVeque, R.A., 1981, Stratigraphy and structure of the Palen Formation, Palen Mountains, southeastern California: M.S. Thesis, University of Arizona, Tucson, 58 p.

________, 1982, Stratigraphy and structure of the Palen Formation, Palen Mountains, southeastern California, in Frost, E.G., and Martin, D.L., editors, Mesozoic-Cenozoic Tectonic Evolution of the Colorado River Region, CA, AZ and NV, Anderson-Hamilton Volume: Cordilleran Publ., San Diego, p. 266-273.

Lister, G.S., and Snoke, A.W., 1984, S-C Mylonites: J. Structural Geology, v. 6, no. 6, p. 617-638.

Lyle, J.H., 1982, Interrelationship of late Mesozoic thrust faulting and mid-Tertiary detachment faulting in the Riverside Mountains, southeastern California, in Frost, E.G., and Martin, D.L., editors, Mesozoic-Cenozoic Tectonic Evolution of the Colorado River Region, CA, AZ and NV, Anderson-Hamilton Volume: Cordilleran Publ., San Diego, p. 470-491.

Marshak, S., 1979, A reconnaissance of Mesozoic strata in northern Yuma County, southwestern Arizona: M.S. Thesis, University of Arizona, Tucson, 110 p.

_______, 1980, A preliminary study of Mesozoic geology in the southern Dome Rock Mountains, southwestern Arizona, in Jenney, J.P., and Stone, C., editors, Studies in Western Arizona: Ariz. Geol. Soc. Digest, v. XII, p. 123-134.

McKee, E.D., 1969, Stratified rocks in the Grand Canyon, in Colorado River Region and John Wesley Powell: U.S. Geol. Survey Prof. Paper 669-B.

Miller, F.K., 1970, Geologic Map of the Quartzsite Quadrangle, Yuma County, Arizona: U.S. Geol. Survey Geol. Quad. Map GQ-891.

Miller, F.K., and McKee, E.H., 1971, Thrust and strike-slip faulting in the Plomosa Mountains, southwestern Arizona: Geol. Soc. America Bull., v. 82, p. 717-722.

Minnigh, L.D., 1980, Structural analysis of sheath folds in a meta-chert from the western Italian Alps: J. Structural Geology, v. 1, no. 4, p. 275-282.

Pelka, G.J., 1973, Geology of the McCoy and Palen Mountains, southeastern California: Ph.D. Dissertation, University of California, Santa Barbara, 160 p.

Pierce, H.W., 1976, Elements of Paleozoic tectonics in Arizona: Ariz. Geol. Soc. Digest, v. 10, p. 37-57.

Ramsay, J.G., 1967, Folding and fracturing of rocks: McGraw-Hill, New York, 568 p.

_______, 1980, Shear zone geometry: a review: J. Structural Geology, v. 2, no. 1-2, p. 83-99.

Rehrig, W.A., and Reynolds, S.J., 1980, Geologic and geochronologic reconnaissance of a northwest-trending zone of metamorphic core complexes in southern and western Arizona: Geol. Soc. America Memoir 153, p. 131-157.

Reynolds, S.J., 1980, Geologic framework of west-central Arizona, in Jenney, J.P., and Stone, C., editors, Studies in Western Arizona: Ariz. Geol. Soc. Digest, v. 12, p. 1-16.

________, 1982, Multiple deformation in the Harquvar and Harquahala Mountains, west-central Arizona, in Frost, E.G., and Martin, D.L., editors, Mesozoic-Cenozoic Tectonic Evolution of the Colorado River Region, CA, AZ and NV, Anderson-Hamilton Volume: Cordilleran Publ., San Diego, p. 137-142.

________, 1985, personal communication: Arizona Bureau of Geology and Mineral Technology, University of Arizona, Tucson.

Reynolds, S.J., Keith, S.B., and Coney, P.J., 1980, Stacked overthrusts of Precambrian crystalline basement and inverted Paleozoic sections emplaced over Mesozoic strata, west-central Arizona, in Jenney, J.P., and Stone, C., editors, Studies in Western Arizona: Ariz. Geol. Soc. Digest, v. 12, p. 45-52.

Reynolds, S.J., Spencer, J.E., and Richard, S.M., 1983, A field guide to the northwestern Granite Wash Mountains, west-central Arizona: Ariz. Bur. Geol. Min. Tech. Open-File Report 83-23, 9 p.

Richard, S.M., 1983, Structure and stratigraphy of the southern Little Harquahala Mountains, La Paz County, Arizona: M.S. Thesis, University of Arizona, Tucson, 154 p.

Robison, B.A., 1980, Description and analysis of Mesozoic "red beds", western Arizona and southeastern California, in Jenney, J.P., and Stone, C., editors, Studies in Western Arizona: Ariz. Geol. Soc. Digest, v. 12, p. 147-154.

Scarborough, R.B., and Meader, N., 1983, Reconnaissance geology of the northern Plomosa Mountains, La Paz County, Arizona: Ariz. Bur. Geol. Min. Tech. Open-File Report 83-24, 35 p.

Shaffiqullah, M., Damon, P.E., Lynch, D.J., Reynolds, S.J., Rehrig, W.A., and Raymond, R.H., 1980, K-Ar geochronology and geologic history of southwestern Arizona and adjacent areas, in Jenney, J.P., and Stone,C., editors, Studies in Western Arizona: Ariz. Geol. Soc. Digest, v. 12, p. 201-260.

Sibson, R.H., 1977, Fault rocks and fault mechanisms: J. Geol. Soc. London, v. 133, p. 191-213.

Silver, L.T., Bickford, M.E., Van Schmus, W.R., Anderson, J.R., Anderson, T.H., and Madaris, L.G., Jr., 1977, The 1.4-1.5 b.y. transcontinental anorogenic plutonic perforation of North America: Geol. Soc. America Abstracts with Programs, v. 9, no. 7, p. 1176-1177.

Simpson, C., and Schmid, S.M., 1983, An evaluation of criteria to deduce the sense of movement in sheared rocks: Geol. Soc. America Bull., v. 94, p. 1281-1288.

Spencer, J.E., 1984, Geometry of low-angle normal faults in west-central Arizona: Ariz. Bur. Geol. Min. Tech. Fieldnotes, v. 14, no. 3, p. 6-8.

Stone, P., Howard, K.A., and Hamilton, W., 1983, Correlation of metamorphosed Paleozoic strata of the southeastern Mojave Desert region, California and Arizona: Geol. Soc. America Bull., v. 94, p. 1135-1147.

Stoneman, D.A., 1985, Structural geology of the Plomosa Pass area, northern Plomosa Mountains, La Paz County, Arizona: M.S. Thesis, University of Arizona, Tucson.

Streikeisen, A.L., 1976, To each plutonic rock its proper name: Earth Science Reviews, v. 12, p. 1-33.

Tosdal, R.M., 1982, The Mule Mountains Thrust in the Mule Mountains, California and its probable extension in the southern Dome Rock Mountains, Arizona; a preliminary report, in Frost, E.G., and Martin, D.L., editors, Mesozoic-Cenozoic Tectonic Evolution of the Colorado River Region, CA, AZ and NV, Anderson-Hamilton Volume: Cordilleran Publ., San Diego, p. 55-60.

________, 1984, Tectonic significance of the late Mesozoic Mule Mountains Thrust, southeast California and southwest Arizona: Geol. Soc. America Abstracts with Programs, v. 16, no. 6, p. 676.

Walker, J.D., Burchfiel, B.C., and Wardlaw, B.R., 1984, Early Triassic overlap sequence in the Mojave Desert: its implications for Permo-Triassic tectonics and paleogeography: Geol. Soc. America Abstracts with Programs, v. 16, no. 6, p. 685.

Williams, H., Turner, F.J., and Gilbert, C.M., 1982, Petrography, an introduction to the study of rocks in thin section, 2nd edition: W.H. Freeman and Co., San Francisco, 626 p.

Wilson, E.D., 1960, Geologic Map of Yuma County, Arizona: Ariz. Bur. Mines, 1:375,000.

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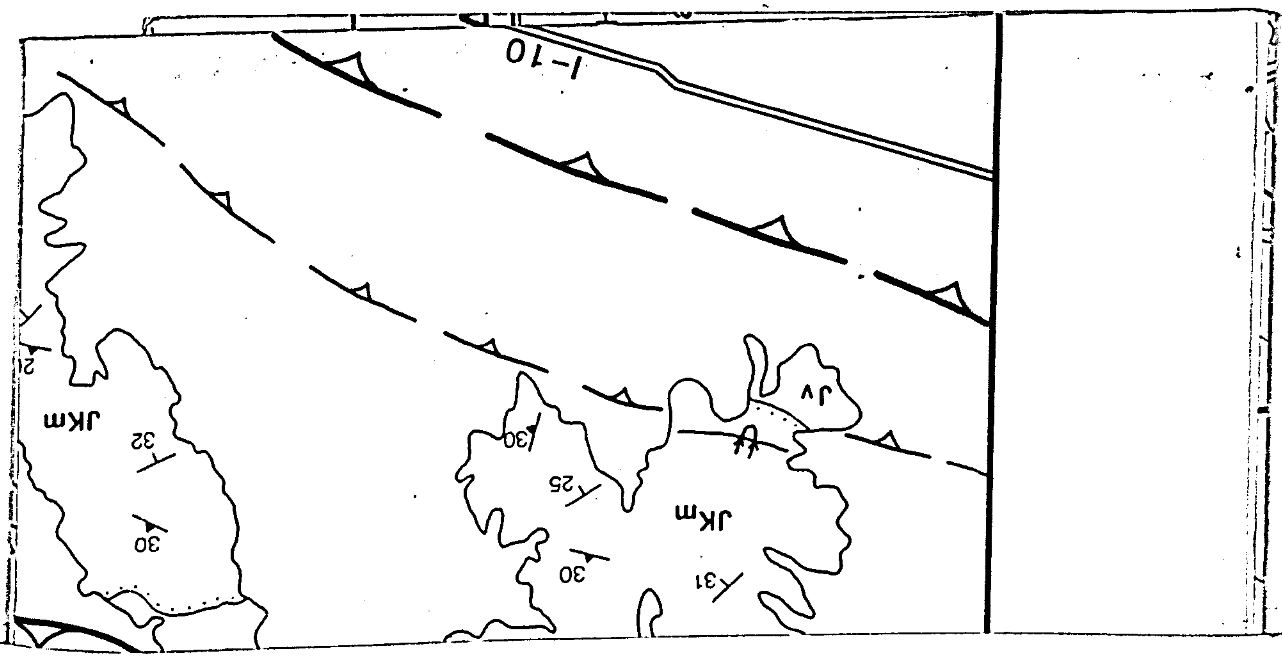
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Figure 23. Shear zone contact between mylonitic assemblage rocks and sheared Middle Camp granite.

View to the west. Light-colored quartzofeldspathic assemblage rocks structurally overlie gray-colored Middle Camp granite.

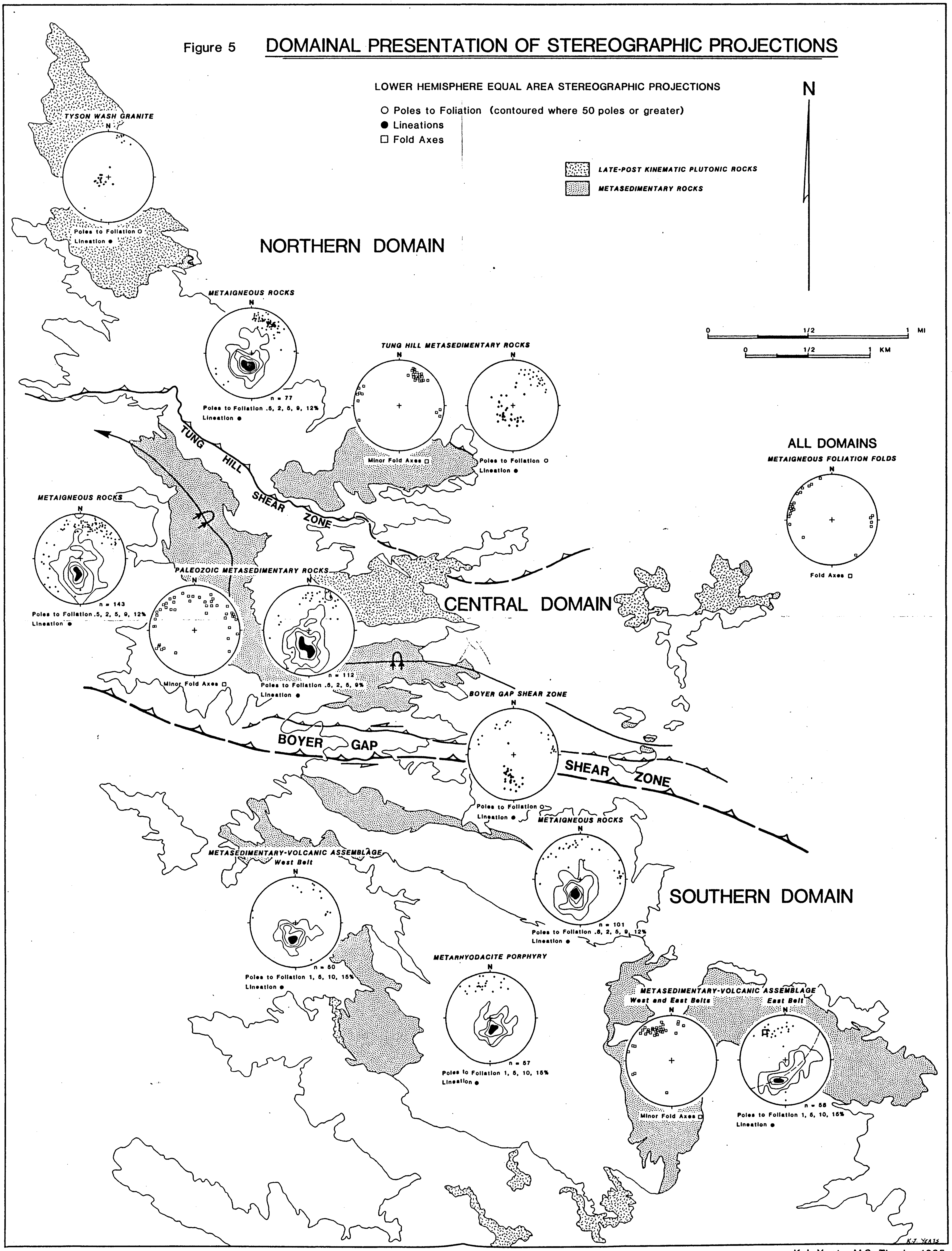


Figure 5. Domainal Presentation of Stereographic Projections


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**University of Arizona**

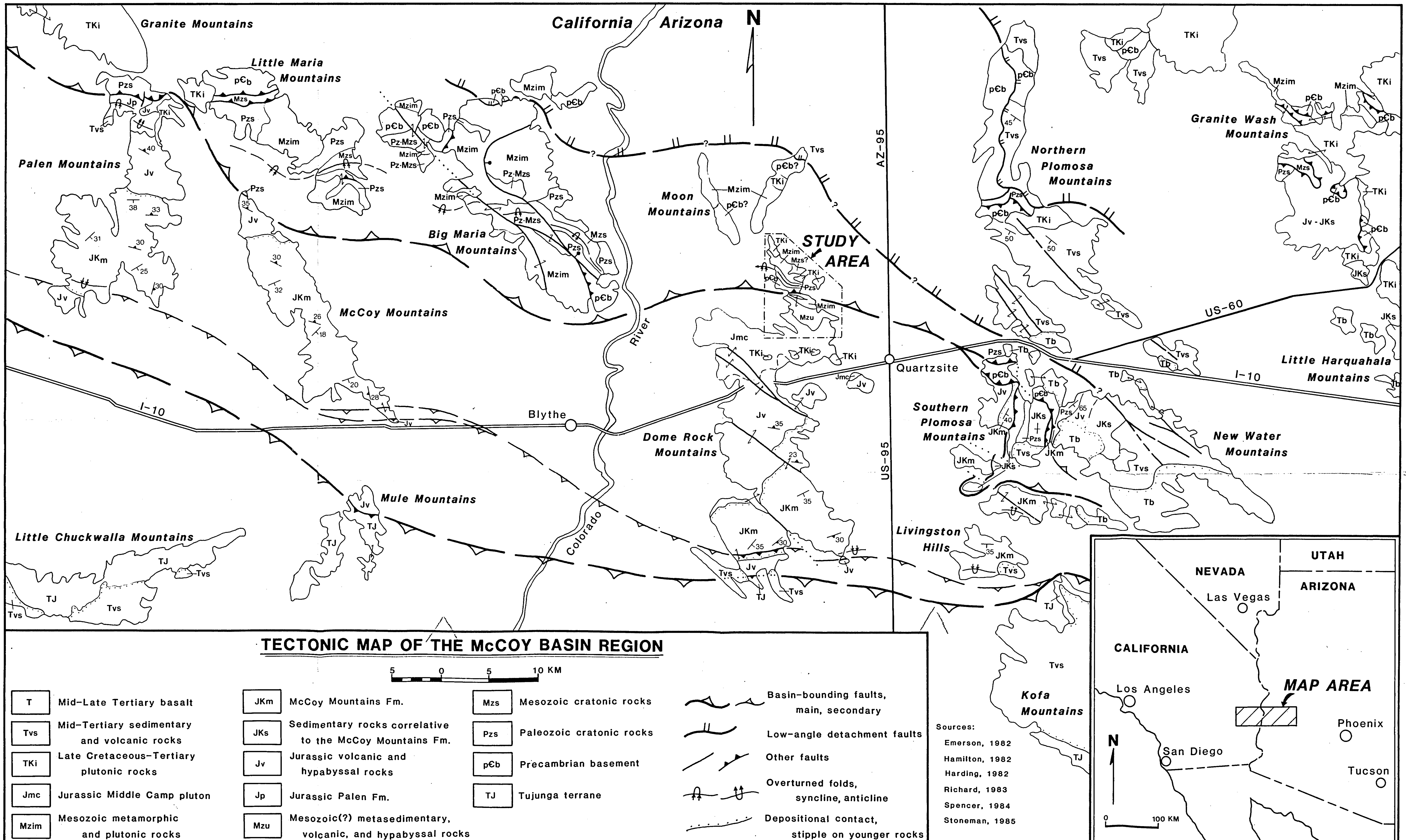


Figure 6. Tectonic map of the McCoy Basin region

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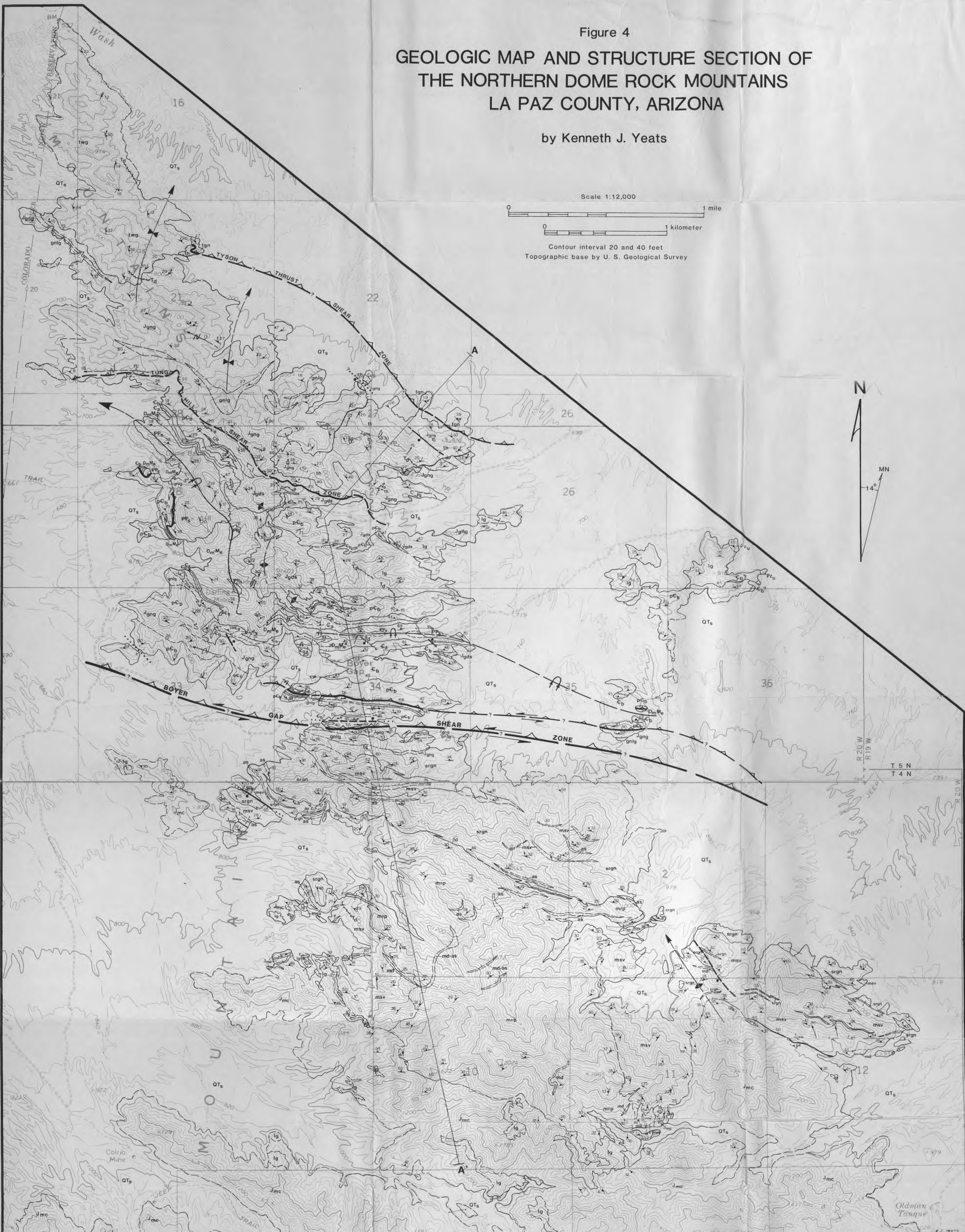
Figure 4

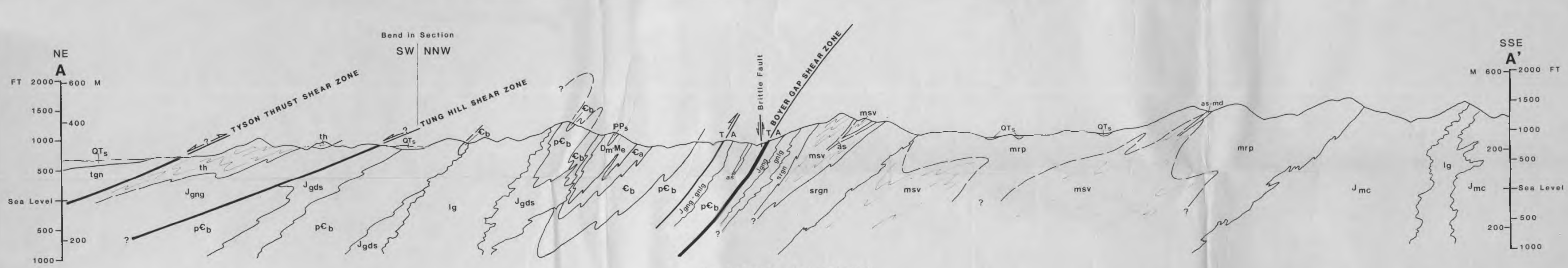
# GEOLOGIC MAP AND STRUCTURE SECTION OF THE NORTHERN DOME ROCK MOUNTAINS LA PAZ COUNTY, ARIZONA

by Kenneth J. Yeats

Scale 1:12,000

Contour interval 20 and 40 feet
Topographic base by U. S. Geological Survey




## EXPLANATION

### ROCK UNITS

**LATE TERTIARY-QUATERNARY**

- $QT_s$ SURFICIAL DEPOSITS

### Cratonic Stratigraphy

**EARLY MESOZOIC(?)**

- th TUNG HILL METASEDIMENTARY ROCKS

**PALEOZOIC**

- $Pz_u$ PALEOZOIC(?) ROCKS, undivided
- $PP_s$ SUPAI FORMATION
- $D_m$-$M_e$ MARTIN AND ESCABROSA MARBLES
- $Є_a$ ABRIGO SCHIST
- $Є_b$ BOLSA QUARTZITE

**PRECAMBRIAN**

- $pЄ_b$ GRANITIC BASEMENT

### McCoy Basin Rocks

**MESOZOIC(?)**

- mrp METARHYODACITE PORPHYRY
- msv METASEDIMENTARY-VOLCANIC ASSEMBLAGE

### Igneous and Metaigneous Rocks

**TERTIARY**

- $T_d$ DIORITE DIKES - undeformed

**LATE MESOZOIC OR EARLY CENOZOIC**

- twg TYSON WASH GRANITE
- a APLITE DIKES - foliated
- lg LEUCOGRANITE - unfoliated to weakly foliated

**MESOZOIC - JURASSIC(?)**

- gnlg GNEISSIC LEUCOGRANITE
- $J_{gng}$ GNEISSIC MONZOGRANITES
- $J_{mc}$ MIDDLE CAMP GRANITE
- $J_{gds}$ GRANODIORITE SCHIST

**MESOZOIC(?)**

- srgn SOUTH RIDGE AUGEN GNEISS
- r PORPHYRITIC RHYOLITE DIKES - foliated
- as-md AMPHIBOLE SCHIST AND METADIORITE

**PRECAMBRIAN OR MESOZOIC**

- tgn TYSON AUGEN GNEISS

### STRUCTURAL SYMBOLS

**CONTACTS**

Dashed where approximately located or inferred, dotted where concealed

- 45 Depositional or intrusive contact, variably sheared, showing dip
- 30 Strongly sheared lithologic contact, showing dip
- 25 Shear zone (ductile fault), sawteeth on upper plate, showing dip and relative displacement
- High-angle brittle normal fault, barbell on hanging wall

**FOLDS**

Axial trace of folds, showing direction of plunge

- Antiformal fold in foliation
- Synformal fold in foliation
- Asymmetric S-fold in foliation
- 10 Asymmetric Z-fold in foliation, showing dip of axial surface
- Overturned syncline
- Overturned anticline
- Minor folds, general trend and plunge

**FOLIATIONS AND LINEATIONS**

- 37 Strike and dip of foliation:
  - showing trend of lineation
  - showing trend of mylonitic lineation and sense of shear (top in direction of arrow)
- 10 Strike and dip of cleavage

Figure 4.

Geologic map and structure section of the northern Dome Rock Mountains, La Paz County, Arizona

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