UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Generalized geologic map of the Big Maria Mountains region, northeastern Riverside County, southeastern California

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This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature

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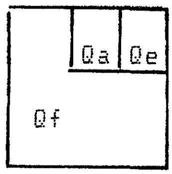
MAP EXPLANATION

SURFICIAL MATERIALS

Quaternary
  Holocene
  Pleistocene
Tertiary
  Pliocene



Qa Alluvium, mostly silt and sand, of modern Colorado River floodplain.

Qe Eolian sand.

Qf Fanglomerate and alluvium, mostly of local origin and of diverse Quaternary ages. Includes algal travertine and brackish-water strata of Bouse Formation of Pliocene age along east and south sides of Big Maria and Riverside Mountains. Fanglomerate may locally be as old as Pliocene.

MIOCENE INTRUSIVE ROCKS

Tertiary
  Miocene

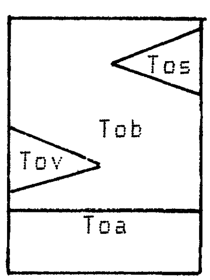
In Riverside Mountains, dikes of leucorhyolite intruded along detachment fault.

In northern Big Maria Mountains, plugs and dikes of hornblende-biotite and biotite-hornblende rhyodacite and quartz latite. These predate steep normal faults, and may include rocks both older and younger than low-angle detachment faults. Two hornblende K-Ar determinations by Donna L. Martin yield calculated ages of 10.1 ± 4.5 and 21.7 ± 2.8 m.y.

ROCKS ABOVE DETACHMENT FAULTS

ROCKS DEPOSITED SYNCHRONOUSLY WITH EXTENSIONAL FAULTING

Lower
  Miocene
  or upper
  Oligocene



Tob Slide breccias, partly monolithologic, and extremely coarse fanglomerate.

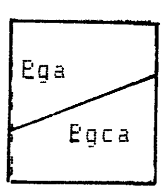
Tos Fluvial and lacustrine strata, mostly red.

Tov Calc-alkalic volcanic rocks: quartz latitic ignimbrite, and altered dacitic and andesitic flow rocks. Age of 23.5 m.y. calculated by D. L. Martin from one whole-rock K-Ar determination of andesite.

Toa Coarse-grained red arkose.

BASEMENT ROCKS

Middle
  Proterozoic



Ega Potassic granite, coarsely megacrystic, mostly red, variably altered.

Egca Gneiss complex. Biotitic, hornblendic, and granitic gneisses, much altered and variably brecciated.

ROCKS BENEATH DETACHMENT FAULTS

ROCKS OF MCCOY MOUNTAINS

Age	Unit	Description
Lower Tertiary or Upper Cretaceous	TKm	McCoy Mountains Formation of G. J. Pelka (PhD thesis, University of California at Santa Barbara, 1973). Fluvial sandstone and conglomerate, deformed with south-verging structures and metamorphosed slightly.

METAMORPHOSED GRANITIC ROCKS

Middle Jurassic

Jg	Jd	Jgb	Jm

Jg is younger than Jgb and is the granitic component of Jm. Relative age of Jd is not known.

Unit	Description
Jg	Metamorphosed granodiorite and adamellite, with sparse equant megacrysts of purplish K-spar; now mostly augen gneiss. Includes many irregular masses of alaskite. Two zircon U-Pb determinations by Leon T. Silver indicate magmatic ages of about 160 m.y.
Jd	Fine-grained metadiorite.
Jgb	Hornblende gabbro. (Small masses, now mostly amphibolite, are included in Jg.)
Jm	Metamigmatite. Host rocks are of Jurassic, Triassic, and Proterozoic ages.

METAMORPHOSED STRATIFIED ROCKS

Age	Unit	Description
Middle Jurassic	Jv	Meta-ignimbrite. Lower part is rhyodacitic, upper part is quartz latitic. Rocks mostly gray and green schists at low metamorphic grade, and fine-grained gray quartzofeldspathic gneisses at high grade.
Lower Jurassic	Ja	Aztec Quartzite. Fine-grained quartzite, variably ferruginous; in part hematitic and red, in part epidotic and granular, in part muscovitic, platy, and white.
Triassic	TR	Metasedimentary rocks. Metamorphosed shale, siltstone, sandstone, conglomerate, and tuffaceous rocks, now mostly greenish schists. Includes anhydrite schist in Little Maria Mountains. May include rocks of Late Permian or very early Jurassic age.
Jurassic and Triassic	JTR	Jv, Ja, and TR, undivided. In Riverside Mountains, includes impure calcareous metasedimentary rocks and metamorphosed hypabyssal granitic rocks.
Jurassic to Permian	JP	Jv, Ja, TR, and Pk, undivided

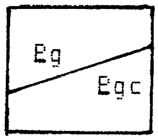
Age	Unit	Description
Lower Permian	Pk	Kaibab and Toroweap Marbles. Mostly metamorphosed cherty calcite limestone, now coarse-grained calcite marble interlayered with quartzite and calc-silicate rocks; much dolomite marble; includes anhydrite schist in Little Maria and northwestern Big Maria Mountains.
	Pch	Coconino Quartzite (above) and Hermit Schist (below). Coconino Quartzite: fine-grained light-colored vitreous quartzite. Hermit Schist: pale-green quartzitic calc-silicate schist.
	Ps	Supai Formation. Metamorphosed calcareous and dolomitic redbeds; now widely varying dark-weathering impure quartzites, calc-silicate rocks, and minor marbles. May include rocks of Late Pennsylvanian age.
Mississippian to Middle Cambrian	M€	Metamorphosed carbonate rocks. In order from youngest to oldest: Redwall Marble (Mississippian). Pure, white, coarse-grained calcite marble; minor metachert and dolomite. Dolomite marble, unnamed. Probably includes units of Devonian to Cambrian ages. Uniform, fine-grained, white dolomite marble, weathering buff, yellow, or brown. Calc-silicate rocks. Thin unnamed unit, probably of Cambrian age. Muav Marble (Middle Cambrian). Pure, white, foliated, coarse-grained calcite marble, typically weathering yellow and gray.
Middle and Lower? Cambrian	€bt	Bright Angel Schist (above) and Tapeats Quartzite (below). Bright Angel Schist: metamorphosed shale, siltstone, and sandstone, now mostly greenish schist in south-eastern Big Maria Mountains, and coarse-grained biotite schist elsewhere. Tapeats Quartzite: quartzite of widely varying grain size, variably pure to meta-arkosic; red, buff, or white.

Groupings of units of Paleozoic age, as required by map scale

Units	Grouping	Grouping	Grouping
Pk, Pch, Ps	Pzu	Pzc	Pz
M€, €bt	Pzl		
Section complete; all units in order			Section incomplete or disordered

METAMORPHOSED BASEMENT ROCKS

Middle Proterozoic

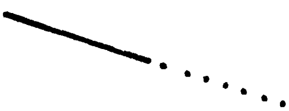


Eg Potassic granite, coarsely megacrystic; now mostly leucocratic augen gneiss. Two zircon U-Pb determinations by L. T. Silver indicate magmatic age of about 1400 m.y.

Egc Gneiss complex of biotitic and hornblendic gneisses

FAULTS

Low-angle detachment (extensional) fault of late Oligocene or early Miocene age. Dotted where concealed.



Faults of various types, dotted where concealed. Includes Miocene normal faults (upthrown and downthrown sides marked by U and D), Miocene or early Pliocene strike-slip faults (sense of relative offset indicated by arrows), and low-angle faults of middle Tertiary, and possibly also Cretaceous, age.

BASE MAP

Base map from U.S. Geological Survey topographic quadrangle maps Big Maria Mountains NW, NE, SW, and SE (scale 1:24,000, contour interval 40 feet), Blythe NE and McCoy Wash (1:24,000, 20 feet), and McCoy Mountains and Midland (1:62,500, 80 feet).

GEOLOGIC MAPPING

Geology of the Big Maria and Riverside Mountains generalized from detailed mapping by Warren Hamilton, 1958-1983, assisted by W. H. Hays, 1958, L. R. Palmer, 1962, P. T. Dumapit, Jr., 1963, R. Smith, 1964, R. W. Simpson, Jr., 1978, L. E. Cordell, 1979, W. A. Bothner, 1980, W. B. Myers, 1981 and 1983,and J. W. Cady, 1982. Geology of the Little Maria Mountains adapted by Hamilton from his reconnaissance and from mapping by Roman Shklanka (PhD thesis, Stanford University,1963). Geology of the McCoy Mountains by G. J. Pelka (PhD thesis, University of California at Santa Barbara, 1973).

OUTLINE OF GEOLOGY

The Big Maria Mountains consist mostly of mid-crustal crystalline rocks that lie structurally beneath a detachment fault of middle Tertiary age. Middle Proterozoic gneiss and potassic granite, and unconformably overlying cratonic lower Mesozoic and Paleozoic strata (Lower Jurassic Aztec Quartzite through Cambrian Tapeats Quartzite, the metamorphosed equivalents of a stratigraphic section generally like that of the western Grand Canyon) were overlain by Middle Jurassic ignimbrites. Minor deformation within Late Permian or Triassic time is indicated by the presence of conglomerates which contain clasts, including large boulders, of all Paleozoic formations and of Proterozoic granitic rocks; but within the map area, Triassic strata lie only on the Permian Kaibab and Toroweap Marbles. Lower Jurassic Aztec Quartzite also lies directly upon Permian marble in part of the range. The Proterozoic to Middle Jurassic rocks were intruded by Middle Jurassic granodiorite, adamellite, and alaskite, in domed plutons. The ignimbrites presumably are the extrusive equivalents of these or related plutons. The stratified rocks are preserved mostly in a large syncline between two major plutons, and in the sidewall--which evolved by the depression and outward crowding of the floor--of one of them. During Cretaceous time, all of these rocks, including the Proterozoic and Jurassic plutonic rocks, were metamorphosed at greenschist facies in the southeast part of the range, and at epidote-amphibolite and amphibolite facies elsewhere, and were transposed pervasively into cascades of recumbent tight to isoclinal folds. Formations are internally isoclinal even where external contacts are continuous and unfolded. The complete Paleozoic section, which had a stratigraphic thickness of about 1000 m, was attenuated by the combined effects of Jurassic and Cretaceous flattening, shearing and transposition to as little as 10 m, yet the individual units in general maintain coherence and stratigraphic order. Lithologies and outcrop appearances were replicated throughout transposition: outcrop-scale layering reflects stratal contrasts, but does not represent bedding. Isoclinal folding records shearing and transposition, not compression, and refolded folds were produced by continuing deformation, not by superimposed events of unrelated deformation. Cretaceous deformation was due to top-to-the-northeast laminar shear with varying velocity gradients. Although widespread contact metamorphism must have accompanied emplacement of the Jurassic plutons, only locally is contact metamorphism recognizable through the overprint of Cretaceous regional metamorphism; no small-scale deformation attributable to the Jurassic intrusions has been recognized through the pervasive transposition of the Cretaceous deformation. A swarm of muscovite pegmatites of Late Cretaceous K-Ar age postdates the major metamorphism and deformation, but predates the ductile shearing, structurally high in the northern part of the range, that is related to middle Tertiary detachment faulting.

The geology of the Little Maria Mountains within the map area is similar to that of the moderately to highly metamorphosed parts of the Big Maria Mountains.

The eastern part of the Riverside Mountains within the map area also lies structurally beneath a detachment fault, and consists of upper Paleozoic cratonic sedimentary rocks, and lower Mesozoic cratonic strata and volcanic and hypabyssal rocks, metamorphosed at lower greenschist facies. Cretaceous shearing and transposition here also were directed northeastward, but in much of the Riverside Mountains they resulted in severe disruption of the stratigraphic section, widespread mylonitization, and complex tectonic intercalations of units.

The results of late Oligocene or early Miocene crustal extension are shown in the map area by detachment faults. Upper-crust crystalline rocks (entirely

Proterozoic within the Big Maria Mountains and that part of the Riverside Mountains that is within the map area) and overlying middle Tertiary slide breccias, extremely coarse fanglomerates, fluvial and lacustrine strata, and volcanic rocks, were rotated down to steep dips to the south-southwest, and were truncated downward against undulating, broadly domiform, detachment faults. The abundance within the Tertiary section of strata that must have been deposited close to a high scarp indicates that major normal faulting occurred at the surface during deposition. The detachment faults are marked by zones 1-10 m thick of brittle gouge and breccia. Upper-plate rocks are variably brecciated and offset by small brittle faults. Extensive mylonitization of the structurally highest part of the Big Maria Mountains beneath the detachment fault predated the final detachment faulting but postdated the swarm of Cretaceous(?) pegmatites that in turn postdated the pervasive metamorphism and transposition of all Jurassic and older rocks. Some gently dipping post-Cretaceous faults within the Big Maria Mountains, far beneath the detachment fault, are marked by brittle gouge and breccia, and others are marked by ductile, greenschist-facies mylonite. Gently dipping faults are broken by steeper normal faults and by subvertical strike-slip faults, these young faults being marked by brittle gouge and breccia.

In the McCoy Mountains, as in the Palen Mountains beyond them to the west, the McCoy Mountains Formation, 6 km or so thick, of mostly south-dipping fluvial strata, depositionally overlies Middle Jurassic ignimbrites. The McCoy section is only slightly metamorphosed and deformed within the map area, but at the south end of the McCoy Mountains the rocks are isoclinally deformed, strongly foliated, and metamorphosed at greenschist facies. Abundant petrified angiosperm wood in the McCoy section precludes an age older than late Early Cretaceous, and a tentative date of Paleocene has been obtained for pollen (G.J. Pelka, oral commun., 1983). (Recently published speculation that the rocks are of Late Jurassic age is certainly invalid.) The metamorphism and deformation are thus no older than Late Cretaceous, and may be of Tertiary age. Structures verge southward in both the slightly and severely metamorphosed sectors of the McCoy Mountains, in contrast to the northeastward vergence of Cretaceous deformation in exposures beneath detachment faults in the other ranges of the map area. My interpretation is that the McCoy Mountains Formation was deposited in a large basin formed by crustal shortening in Late Cretaceous time, the basin and the flanking mountains that supplied its voluminous sediments having been shallow manifestations of the pervasive middle-crust deformation displayed in the nearby Big Maria and Little Maria Mountains. I infer that the rocks now exposed in the McCoy Mountains lie structurally beneath a middle Tertiary detachment fault, the plate above which has been entirely removed by erosion. I infer further that the south-verging deformation of the range is also of middle Tertiary age, that it was produced by crustal extension, and that its vergence records the direction of slip between upper-plate rocks and McCoy rocks. If this is correct, then upper plate rocks were rotated down to dip and face north above the lower-plate McCoy rocks, whereas upper-plate rocks were rotated in the opposite sense above the Big Maria and Riverside lower-plate rocks.

I infer from relationships in this map area, and from geologic and geophysical data throughout the Basin and Range Province, that Cenozoic extension of the middle part of the continental crust was accomplished by discontinuous ductile flow, represented by the sliding apart of great lenses separated by gently dipping ductile faults. The composite tops of the highest lenses are termed detachment faults, which mark a change in style, but not the deep limit, of deformation. Beneath the detachment faults, the lenses of mid-crustal rocks are defined by anastomosing, gently dipping zones of mylonite. The interiors of the lenses retain their pre-extension structures and fabrics. Sliding apart of the midcrust lenses resulted in the increase of the area of their composite top--that is, of the detachment faults--and the brittle upper crust above responded by collapsing in rotating fault blocks, bounded in part by downward-flattening listric faults and in part by moderately dipping faults. The initial depth of transition from brittle to ductile faulting, and hence of the shallowest of the gently dipping structures that evolved into the detachment faults, was controlled by the temperature at which the strength of quartz became very low (under the ambient low strain rates and moderately hydrous conditions); this corresponds to a depth of at least 10 km, a depth in accord with petrobarometric indicators in rocks beneath the detachment faults here and elsewhere. As extension progressed and the crust was thinned, most parts of the system rose toward the surface, progressively less ductile structures and fabrics were superimposed on the products of deeper deformation, and detachment faults were broken by steep, brittle faults. Extensional structures formed in the lower crust, deeper than about 20 km, are not known to be exposed in this region but are inferred, from seismic-reflection profiles in southern Arizona and from rock-mechanic considerations, to be products of more pervasively ductile flow than are those of the exposed middle crust.

The lower-plate rocks of the Riverside Mountains formed beneath a detachment fault, but they display structural and metamorphic features indicating markedly shallower depths of Cretaceous deformation than do the sub-detachment rocks of the Big Maria Mountains. The Riverside lower-plate assemblage is of rocks that could once have lain directly above that of the Big Maria Mountains. I infer that the Riverside crustal lens did indeed lie above the Big Maria one until they were separated by middle Tertiary extension, and thus that the initial displacement on the gently-dipping structures that evolved into the Big Maria detachment began at a depth perhaps 5 km deeper than that atop the Riverside lens. Upper-plate crystalline rocks of both the Big Maria and Riverside Mountains do correspond to shallow equivalents of some of the lower-plate rocks in the subjacent plates, but not to the complete assemblages there, so substantial horizontal transports are inferred for the faults beneath upper-plate rocks. Large offsets for the detachment faults also are required by the elision across them of large thicknesses of crust. If the rocks of the McCoy Mountains are interpreted correctly as having been beneath a detachment fault, then the initial depth of that fault within the crust was, like that of the fault marking the top of the Riverside Mountains crustal lens, shallower than the initial depth of the tops of the Big Maria and Little Maria crustal lenses. I thus picture the detachment fault exposed atop Riverside Mountains lower-plate rocks, and that inferred above McCoy Mountains ones, to have evolved directly from the highest ductile fault within the extending crust. The detachment fault above the Big Maria and Little Maria Mountains, by contrast, evolved from a deeper zone of ductile shear that became shallower as a result of tectonic denudation.

All faults that reach the eastern and southern parts of the Big Maria and Riverside Mountains appear to predate the deposition of the Bouse Formation of Pliocene age. Slight warping of the Bouse likely has occurred, but no faulting.

Further information on lithology, structural geology, and metamorphism of the Big Maria Mountains has been published elsewhere: Hamilton, Warren, 1982, Structural evolution of the Big Maria Mountains, northeastern Riverside County, southeastern California, <u>in</u> E.G. Frost and D.L. Martin, <u>eds</u>., Mesozoic-Cenozoic tectonic evolution of the Colorado River region, California, Arizona, and Nevada: San Diego, Cordilleran Publishers [Department of Geological Sciences, San Diego State University], p. 1-27.