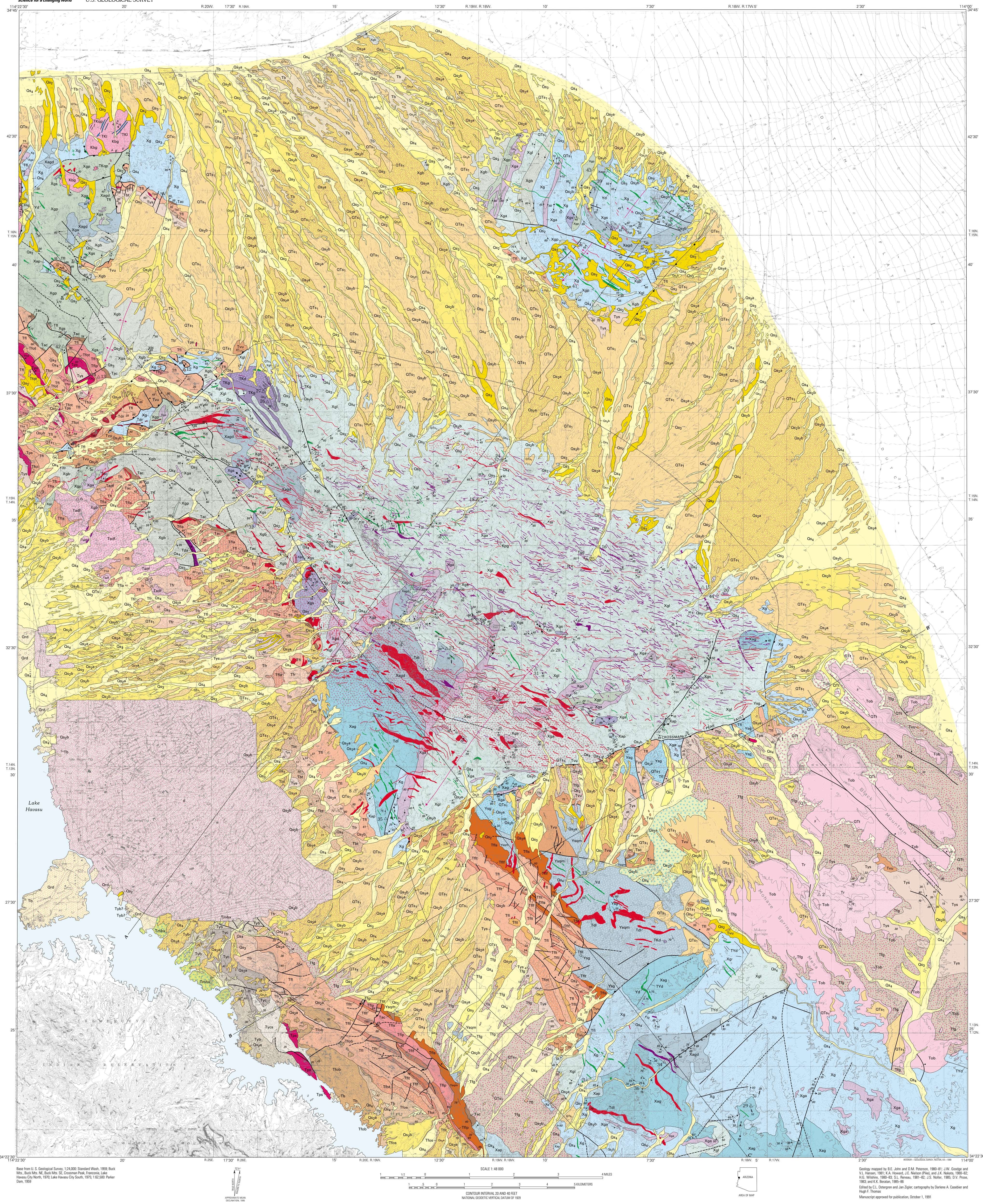
U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

MISCELLANEOUS INVESTIGATIONS SERIES
MAP I–2308 (SHEET 1 OF 2)



Base from U.S. Geological Survey, 1:24,000: Standard Wash, 1959; Buck Mts., Buck Mts. NE, Buck Mts. SE, Crossman Peak, Franconia, Lake Havasu City North, 1970; Lake Havasu City South, 1975; 1:62,500: Parker Dam, 1959

APPROXIMATE MEAN DECLINATION, 1999

SCALE 1: 48 000

CONTOUR INTERVAL 20 AND 40 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

AREA OF MAP

INTERIOR—GEOLOGICAL SURVEY, RESTON, VA—1999

Geology mapped by B.E. John and D.M. Peterson, 1980–81; J.W. Goodge and V.L. Hansen, 1981; K.A. Howard, J.E. Nielson (Pike), and J.K. Nakata, 1980–82; H.G. Wilshire, 1980–83; S.L. Reneau, 1981–82; J.S. Noller, 1985; D.V. Prose, 1983; and K.K. Beratan, 1985–86

Edited by C.L. Ostergren and Jan Zigler; cartography by Darlene A. Casebier and Hugh F. Thomas

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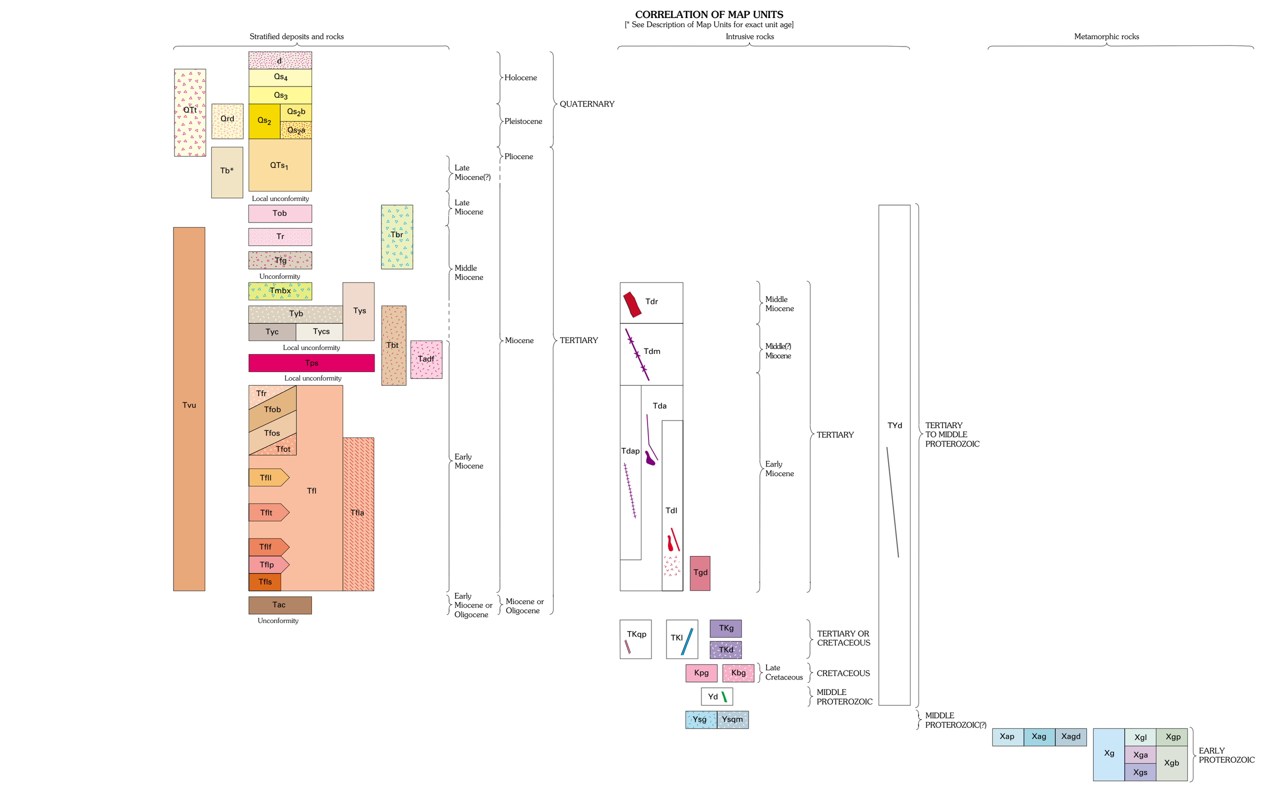
GEOLOGIC MAP OF THE MOHAVE MOUNTAINS AREA, MOHAVE COUNTY, WESTERN ARIZONA

By
K.A. Howard, J.E. Nielson, H.G. Wilshire, J.K. Nakata, J.W. Goodge, S.L. Reneau, B.E. John, and V.L. Hansen
1999

CORRELATION OF MAP UNITS

[* See Description of Map Units for exact unit age]



DESCRIPTION OF MAP UNITS

STRATIFIED DEPOSITS AND ROCKS

d **Disturbed ground**—Ground disturbed for urban development in Lake Havasu City. Overlies chiefly Piedmont sedimentary deposits

QTt **Talus deposits (Holocene to late Miocene?)**—At Black Mountain. Basalt blocks. Calcrete as thick as 1 m commonly veneers basalt rock rubble in nearby mountain ranges, suggesting that blocks form stable surfaces as old as several million years

Qrd **River deposits (Pleistocene)**—Gravel and sand characterized by well-rounded cobbles and pebbles deposited by Colorado River

Piedmont sedimentary deposits (Holocene to Miocene?)—Light-gray to reddish brown fanglomerate deposits about 1 m to more than 35 m thick; variable but commonly subequal proportions of clasts of volcanic and plutonic rocks. Deposits are unfaulted and undeformed. Units are subdivided on basis of geomorphic expression. Units 4, 3, and 2 are pediment terraces developed mainly on deposits of unit 1 (QTs_1) and have no or only thin veneers of new deposits. Divided into:

Qs_4 **Unit 4 (Holocene)**—Equivalent to units Q_4 and Q_{3b} of Bull (1974). Fill of active channels: sand, pebbles, cobbles, and boulders affected by modern floods. Channels unvegetated or occupied by trees and abrasion-tolerant shrubs. Also sand, pebbles, cobbles, and boulders forming bar and swale topography 0.5 to 1 m above active channels. No soil development

Qs_3 **Unit 3 (Holocene)**—Equivalent to unit Q_{3a} of Bull (1974). Fill of inactive channels, 1 to 4 m above local active channels. Sand, pebbles, cobbles, and boulders; commonly has coarse bar and swale surface texture overlying better sorted, finer grained substrate. Surface pavement weakly to moderately varnished. Where present, soil horizons include vesicular A horizon as thick as 2 cm, nonargillic B horizon as thick as 24 cm, thin carbonate pebble coatings from surface to 1.5-m depth

Qs_2 **Unit 2 (Pleistocene)**—Locally divided into:

Qs_2b **Subunit B**—Equivalent to unit Q_{2b} of Bull (1974). Moderately dissected surfaces 1 to 17 m above adjacent drainages with well-developed varnished pavement, inset into subunit A or into substrate of subunit A. Substrate of coarse to medium, poorly to moderately sorted, bedded to massive gravel as thick as 4 m; in sharp contact with underlying unit QTs_1 or older sedimentary deposits. Diversified vegetation community in drainages. Where present, A soil horizon 1 to 7 cm thick, nonargillic B horizon as thick as 25 cm, argillic Bt and Btk horizons as thick as 50 cm, Bk and Bkm calcic horizons as thick as 130 cm

Qs_2a **Subunit A**—Equivalent to unit Q_{2a} of Bull (1974). Moderately to well-dissected surfaces 4 to 17 m above surfaces of adjacent washes, or 1 to 6 m above surface of unit Qs_2b with well-developed varnished pavement. Substrate of coarse to medium, poorly sorted, generally massive gravel as thick as about 4 m thick, in sharp contact with underlying finer grained unit QTs_1 or older sedimentary deposits. Diversified vegetation community in drainages. Where present, soil horizons include vesicular A horizon as thick as 6 cm, nonargillic B horizon as thick as 35 cm, argillic Bt and Btk horizons as thick as 100 cm, and Bk and Bkm calcic horizons as thick as 150 cm

QTs_1 **Unit 1 (Pleistocene, Pliocene, and late Miocene?)**—Equivalent to unit Q_1 of Bull (1974). Dissected surfaces with no relict pavement, underlain by coarse- to medium-grained, poorly to moderately sorted, bedded to massive gravel 1 to 35 m thick. Measurements made in backhoe pits show soil structure: vesicular A horizon as thick as 5 cm, nonargillic B horizon as thick as 20 cm, argillic Bt and Btk as thick as 55 cm, and Bk and Bkm calcic horizons as thick as 150 cm. Petrocalcic zone commonly drapes over ridges underlain by unit QTs_1. Underlies deposits related to younger erosional surfaces at depths of a few meters on east side of Mohave Mountains

Tb **Bouse Formation (Pliocene and late Miocene?)**—Close to Colorado River consists of white, buff, or pink sandstone, gypsiferous claystone, and basal limestone. Near U.S. Highway I-40 north of Mohave Mountains a subaerial facies is present composed dominantly of reddish sandstone and thin interbedded gravels

Tob **Olivine basalt (late Miocene)**—In southeastern part of map area. Vesicular, black to brown olivine basalt with intersertal to diktytaxitic texture. Overlies rhyolite unit (Tr) and fanglomerate unit (Tfg). Whole-rock age determined by potassium-argon (K-Ar) method on Mohave Springs Mesa flow is 8.6±0.3 Ma (Suneson and Lucchitta, 1983) and on Black Mountain flow is 11.1±0.3 Ma (*table 1, No. 1). Vent for Mohave Springs Mesa flow is identified by Suneson and Lucchitta (1983) in Castaneda Hills southeast of map area. Flows 20 to 160 m thick. Queried steeply dipping basalt (Tob?) exposed on west flank of Black Mountain (SE 1/4 sec. 33, T. 14 N., R. 16 W.) possibly is an underlying unit

Tbr **Breccia (late or middle Miocene)**—In eastern Standard Wash. Breccia composed of gneiss, quartz monzodiorite, and andesite clasts, including rocks from units Tda, Ysqm, and Xgl. Underlies unit QTs_1. Probably a landslide deposit derived from Mohave Mountains. May also include outcrops of in-place Proterozoic bedrock

Tvu **Volcanic and sedimentary rocks, undivided (Miocene)**—Volcanic rocks ranging from basalt to rhyolite and interbedded with (or intruded into) sandstone and arkosic to volcaniclastic conglomerate

Tr **Rhyolite (middle Miocene)**—In southeastern part of map area consists of pumice breccia, air-fall and ash-flow tuff, perlite, and glassy rhyolite flows; phenocrysts of quartz, sanidine, and plagioclase; K-Ar sanidine age on ash-flow tuff is 12.7 Ma (table 1, No. 2). North of Lake Havasu City, a flat-lying rhyolite flow remnant that overlies tilted airfall tuff yielded a K-Ar plagioclase age of 10.9 Ma (W.A. Rehrig, oral commun., 1982). Underlies olivine basalt (Tob) and overlies fanglomerate (Tfg) and older units. Correlative with silicic volcanic rocks of Suneson and Lucchitta (1983) in Castaneda Hills, which have K-Ar ages that range from 10.3 to 15.1 Ma, and with rhyolite and silicic volcaniclastic rocks of Sherrod (1988) in Monkeys Head quadrangle. In map area as thick as 150 m

Tfg **Fanglomerate (middle Miocene)**—Fanglomerate composed predominantly of locally derived clasts. Contains fragments of chloritic gneiss near Crossman Peak fault; elsewhere rich in clasts of volcanic or plutonic rocks. East of Lake Havasu City clast population changes abruptly from dominantly volcanic rocks to dominantly granitic gneiss upsection. Fanglomerate commonly reddish. Attitude typically subhorizontal but locally dips reach 35°. Overlies older Tertiary deposits with angular unconformity. Underlies rhyolite (Tr) and olivine basalt (Tob) units. Correlative with Osborne Wash Formation of Davis and others (1980). Highly variable in thickness

Tmbx **Megabreccia (middle Miocene)**—Exposed only in Aubrey Hills, near Lake Havasu. Megabreccia derived from white mylonitic two-mica granite gneiss and from dikes of dark gabbro—rocks typical of footwall of Whipple Mountains detachment fault in western Whipple Mountains, 20 km to west (G.A. Davis, oral commun., 1985). Includes blocks as large as several meters across. Striae along base of deposit and drag folds in underlying sedimentary rocks suggest that deposit is a landslide that was emplaced from southeast direction. Correlated with megabreccia of northern Whipple Mountains (Dunn, 1986). Unit overlies basalt, tuff, and sandstone unit (Tyb). Thickness more than 200 m

Younger conglomerate basalt, and tuff (middle and early Miocene)—Correlative with upper part of arkose of Keenans Camp of Suneson (1980). Overlies Peach Springs Tuff of Young and Brennan (1974). Divided into:

Tys **Sedimentary and interbedded pyroclastic rocks**—Mapped in northwestern and southeastern parts of map area. Conglomerate, fanglomerate, red and brown arkosic sandstone, buff to white volcaniclastic sandstone, tan to red-brown claystone, and interbeds of white air-fall tuff. Local lahar or volcanic mudflow deposits. Conglomerate ranges from dominantly volcaniclastic with tuffaceous matrix containing subrounded pebbles of Peach Springs Tuff, to dominantly arkosic with quartz sandstone matrix containing clasts of gneiss and granite. Clasts of coarse-grained granite (Ysg) and lesser quartzite (Coconino Sandstone) are present near Mohave Wash (sec. 22, T. 13 N., R. 17 W.). Locally boulders are as much as 3 m across. Fanglomerate commonly has purplish matrix and predominantly subangular volcanic clasts. Locally contains large internally brecciated masses of plutonic or volcanic rocks, probably derived as landslides, similar to megabreccia unit (Tmbx). Dips range from 12° to 90°. Overlies Peach Springs Tuff. Thickness highly variable, as much as 1400 m

Tyb **Basalt, tuff, and sandstone**—In Aubrey Hills. Black vesicular olivine basalt flows; interbedded lacustrine or playa deposits of buff volcaniclastic sandstone, shale, mudstone, thin limestone, and white waterlaid tuff; and local fluvial conglomerate. Locally silicified. Conglomerate-clast assemblages range from volcanic to mixed volcanic and plutonic rocks. Correlative with strata in arkose of Keenans Camp of Suneson (1980). Unit generally dips 35° to southwest, but locally near faults dips as much as 50° to north. Queried outcrops 2 km east of Pittsburg Point (sec. 23, T. 13 N., R. 20 W.) are fine-grained andesite. Basalt present as stacks of flows as thick as 12 m. Thickness 100–120 m

Tyc **Conglomerate, sandstone, and tuff**—In Aubrey Hills. Buff to white pebble conglomerate and medium-grained sandstone, and laterally persistent beds of white waterlaid tuff. Local limestone interbeds in sandstone. Conglomerate clasts are predominantly rounded pebbles of mixed volcanic and plutonic rocks; volcanic types include pebbles of Peach Springs Tuff. Sandstones are crudely layered and commonly have large-scale low-angle crossbedding. Unit resembles sedimentary parts of basalt, tuff, and sandstone unit (Tyb) but has a larger proportion of poorly sorted fanglomerate. Grades to southeast into lithologically equivalent fan-slope facies of unit Tycs. Overlies rhyolite tuff, flows, and domes (Tfr). Correlative with sedimentary and pyroclastic rocks (Tys) in other parts of map area. Thickness as much as 200 m

Tycs **Conglomerate and sandstone**—In Aubrey Hills. Brown to red-brown conglomerate and coarsely stratified pebbly sandstone. Upper part of unit is conglomerate with sandstone interbeds. Average grain size of conglomerate is fine pebble, and maximum clast size is 7 cm. Sorting is fair to poor, with no distinct crossbedding. Clasts are predominantly angular to subangular and derived from mafic to intermediate volcanic rocks and Peach Springs Tuff. Rarer clasts are rounded granite, gneiss, and chloritic gneiss. Unit becomes generally finer grained to northwest, where it grades into coeval unit of fluvial and lacustrine deposits of conglomerate, sandstone, and tuff (Tyc). Overlies Peach Springs Tuff (Tps). Correlative with part of sedimentary and pyroclastic rocks (Tys) in other parts of map area. Thickness as much as 500 m

Tbt **Basalt and tuff (middle or early Miocene)**—East of Lake Havasu City and in northwestern part of map area. Comprises basalt and tuff of uncertain stratigraphic position relative to Peach Springs Tuff of Young and Brennan (1974). On east side of Lake Havasu City consists of olivine basalt and interbedded tuff and sedimentary rocks characterized by variable dips 10° to 45° southwest; resembles lithologically tuff and basalt flows (Tfot) and to a lesser degree stratigraphically higher basalt, tuff, and sandstone (Tyb); overlies rhyolite tuff, flows, and domes (Tfr). In northwestern part of map area includes an olivine basalt flow with numerical K-Ar age of 14.6 Ma (whole-rock; table 1, No. 3); flow dips steeply in conformity with underlying rocks of unit Tfl, and it underlies rocks of sedimentary and pyroclastic rocks (Tys); similar basalts nearby underlie and overlie Peach Springs Tuff

Tadf **Andesitic and dacitic flows, dikes, and sills (early Miocene)**—North of Lake Havasu City. Variably altered intermediate lava flows and volcanic breccia capped by silicic plagioclase-bearing welded tuff. Gently dipping. Potassium-argon numerical ages overlap age of Peach Springs Tuff: basal pyroxene-plagioclase-biotite latite flow (SiO_2, 59.5 percent; K_2O, 11.2 percent—19.9±0.5 Ma (biotite, table 1, No. 6); capping welded tuff—17.9±0.5 Ma (plagioclase, table 1, No. 5). Unconformably overlies steeper dipping Miocene volcanic rocks (Tfls, Tfla) and Proterozoic rocks. Thickness as much as 130 m

Tps **Peach Springs Tuff of Young and Brennan (1974) (early Miocene)**—Welded crystal-lithic ash-flow tuff with salmon-pink matrix. Commonly contains adularescent blue sanidine crystals; also biotite, plagioclase, and hornblende; rarer pyroxene, sphene, and quartz. Rich in large fiamme, relatively poor in lithic fragments. Black vitrophyre locally present near base. Extensively exposed in northern Mohave Mountains and Aubrey Hills, where tuff commonly is partly to highly silicified and contains zones of secondary brecciation. Unit dips 30° to 60° southwest. Age of Peach Springs Tuff determined by argon-argon ($^{40}Ar/^{39}Ar$) techniques is 18.5±0.2 Ma (Nielson and others, 1990). Potassium-argon numerical ages on unit are more variable (Glazner and others, 1986; table 1, Nos. 4, 7). Thickness in map area as much as 100 m

Flows, tuff, and sedimentary rocks (early Miocene),—Divided into:

Tfr **Rhyolite tuff, flows, and domes**—In Aubrey Hills and east and north of Lake Havasu City. White stratified air-fall tuff, interbedded flows and domes, and intrusions of plagioclase biotite±hornblende rhyolite. Attitudes highly variable. In area north of Lake Havasu City tuff is commonly silicified and (or) oxidized and invaded by compositionally equivalent domes; underlies unit Tadf. Northeast of Lake Havasu City rocks are silicified and oxidized tuff, partly perlitic rhyolite flows, and massive biotite-bearing crystal-poor rhyolite intrusive into Tertiary and Proterozoic rocks; dips range from 24° southwest to locally vertical and overturned. Dips probably reflect both tectonic and considerable local original dips of deposits. In Aubrey Hills unit comprises dominantly flows with vitrophyric bases, monolithologic avalanche breccia, and minor tuff, all of brittle rhyolite; dips are 35° to 45° to southwest. Interfingers toward southern Aubrey Hills with unit Tfl and locally with unit Tfob. Thickness increases from south to north, to 400 m

Older conglomerate, basalt, and tuff—Correlative with lower part of arkose of Keenans Camp of Suneson (1980). Underlies Peach Springs Tuff of Young and Brennan (1974). Consists of:

Tfob **Basalt, sandstone, and conglomerate**—In Aubrey Hills. Localized unit of altered basalt and andesite or latite flows interbedded with pebbly coarse sandstone and cobble conglomerate. Conglomerate contains mixed volcanic and plutonic clasts, locally very coarse (as much as 2 m across), of coarse-grained granite, gneiss, and schist. Underlies Peach Springs Tuff. Overlies tuff and basalt flows (Tfot), which represent similar but older depositional and eruptive events. Unit grades to northwest into unit Tfl. Thickness as much as about 650 m

Tfos **Tuff, sandstone, and basalt**—In Aubrey Hills. White air-fall tuff, probably waterlaid, interbedded with sandstone, siltstone, and altered basalt flows. Tuff layers are reddened at contacts with overlying basalt flows. Unit contains at least one large mass of internally brecciated diabase, probably a landslide block. With exception of basalt flows, unit represents a depositional environment similar to lacustrine parts of unit Tys, but predates Peach Springs Tuff. Unit interfingers to west and northwest with basal flows of unit Tfob, which it underlies, and to north with upper parts of unit Tfot, which it overlies. Thickness to 750 m

Tfot **Tuff and basalt flows**—In Aubrey Hills and north of Lake Havasu City. Interbedded air-fall tuff, tuff breccia, conglomerate, and andesitic or basaltic flows. Locally tuff is minor so that unit is predominantly basalt flows and mixed-clast conglomerate with volcaniclastic matrix and boulders as large as 5 m in diameter. Clasts are mostly porphyritic granite, gneiss, amphibolite, schist, and more rarely, andesite. Contacts between tuff or conglomerate and basalt flows contain peperite, and flow bases are pervasively altered, indicating extrusion of flows over saturated sediments. Dips range from 30° to 80°. Underlies Peach Springs Tuff north of Lake Havasu City and underlies units Tfob and Tfos in Aubrey Hills. Maximum thickness 350 m

Tfl **Lava flows, sills, tuffs, and sedimentary rocks**—Commonly altered mafic to silicic lava flows and sills interleaved with arkosic and tuffaceous beds, including fine to coarse sandstone, conglomeratic sandstone and conglomerate, welded tuff, and tuff breccia. Individual beds cannot be traced more than a few meters along strike. Lava flows and sills include augite-oxyhornblende-plagioclase andesite(?) (±biotite), hornblende-hypersthene-plagioclase andesite(?) with plagioclase partly altered to potassium feldspar; relatively unaltered hornblende-biotite-quartz-sanidine tuff; hornblende-biotite-sanidine rhyolite porphyry flows with vitrophyric bases, variably altered basalt(?), distinctive trachytic-textured "turkey-track" or "jackstraw" porphyry, lithologically similar to units Tflp and Tfls. Andesite(?) and basalt(?) have contents of SiO_2 and K_2O that resemble latite and trachyte, which may be due to metasomatic additions of these components. K-Ar ages that are considered most reliable as volcanic ages are as follows: rhyolitic flows, north and south of Lake Havasu City, 19.2±0.5 Ma, 19.1±0.6 Ma, and 20.5±1.6 Ma (all on biotite; table 1, Nos. 9–11); basalt sill(?), in north part of Lake Havasu City, 17.9±0.7 Ma (whole-rock; table 1, No. 12); basaltic andesite flow north of Lake Havasu City, 21.5 Ma (whole-rock; W.A. Rehrig, oral commun., 1982). Sedimentary deposits including arkosic conglomerate are locally interbedded with rhyolitic and mafic flows, but may be surrounded or partly to wholly assimilated by mafic or intermediate lavas or sills. Queried exposure lying beneath arkosic conglomerate and sandstone unit (Tac) north of Lake Havasu City (sec. 35, T. 15 N., R. 20 W.) may consist entirely of intrusive rocks. Thickest sections in map area are from 700 to 1200 m thick. Locally mapped as:

Tfla **Altered lava flows and sedimentary deposits**—Northwest of Lake Havasu City. Altered lava flows interbedded with sandstone and conglomerate containing predominantly andesite(?) clasts. Includes some "jackstraw" porphyry lithologically similar to unit Tflp. Dips are between 40° and 90°. Contains abundant dikes of mafic to intermediate rocks (Tda, Tdl). Correlative at least in part with unit Tfl. Underlies andesitic and dacitic flows, dikes, and sills (Tadf)

Tfll **Andesitic to latitic sills and flows**—In Aubrey Hills and Standard Wash. Tan to brown bodies of altered orthopyroxene-bearing andesite, latite, or dacite that form prominent ridges. Thin sedimentary beds locally found at base of unit. Feeder dikes for sills or flows are locally prominent. Dips as much as 60°. Maximum thickness about 200 m in Standard Wash; much less in Aubrey Hills

Tflt **Tuff breccia**—In Aubrey Hills and Standard Wash. Pink to buff, welded to unwelded, unsorted tuff breccia with abundant lithic clasts. Interbedded with mafic flows of unit Tfl. Thicker and welded in Aubrey Hills; thinner and unwelded in Standard Wash. Maximum thickness 135 m

Tflf **Sedimentary and fragmental volcanic rocks**—In Aubrey Hills and Standard Wash. Fluvial and lacustrine sedimentary rocks include conglomerate with boulders as coarse as several meters, mixed arkosic-volcanic conglomerate, and yellowish-green volcaniclastic siltstone and sandstone, commonly with tuffaceous matrix. Fragmental volcanic rocks are lithic volcanic breccia, pumice breccia, and tuff, all of moderately to highly potassic rhyolite. Interbedded with unit Tfl. Parts of unit are intruded and partly to wholly assimilated by mafic flows of unit Tfll; this relation is best exposed at south end of Aubrey Hills. Maximum thickness is 140 m, may have been much thicker before emplacement of lava flows and sills

Tflp **Andesite porphyry**—North of Lake Havasu City, and in Aubrey Hills and Standard Wash; lithologically similar rocks are present elsewhere in other units (Tfls, Tfl, Tfla, and Tdap). Porphyry believed to have original andesitic composition, commonly altered to latite by metasomatic addition of SiO_2 and K_2O. Commonly called "turkey-track" or "jackstraw" porphyry because of trachytic texture characterized by aligned phenocrysts of tabular plagioclase as long as 10 mm, which locally are concentrated at flow tops. Also characterized by smaller equant grains of green pyroxene, which commonly are concentrated in or near flow bases. Dated by K-Ar at 19.8±0.6 Ma (whole rock, table 1, No. 13); high K_2O (3 percent) in dated sample reflects metasomatic enrichment, then date may reflect age of metasomatism. Maximum thickness about 400 m

Tfls **Andesite porphyry and sedimentary rocks**—In Aubrey Hills and Standard Wash. Interbedded sandstone, conglomerate, and "turkey-track" or "jackstraw" andesite(?) porphyry. Thin bed of limestone caps unit in southern Aubrey Hills (secs. 13 and 14, T. 19 W., R. 12 N.). Unit produced by intrusion of lavas as flows or sills into conglomerate and tuffaceous to arkosic sandstone, lithologically similar to unit Tflf. Conglomerate is dominantly rounded pebbles of granite, gneiss, and other Proterozoic rocks, and minor volcanic rocks. Sedimentary units are engulfed or partly to wholly assimilated by lavas. Thickest sections exposed range from 300 to 700 m thick

Tac **Arkosic conglomerate and sandstone (early Miocene or Oligocene)**—Conglomerate and sandstone containing clasts of locally derived gneiss and granitoid rocks, locally with red oxidized matrix. Nonconformably overlies Proterozoic rocks of same lithologies as clasts. Locally includes andesitic and basaltic clasts of unknown provenance. Maximum thickness 200 m

INTRUSIVE ROCKS

Tdr **Rhyolitic dikes (middle Miocene)**—North of Lake Havasu City and east of Arizona Highway 95. Vertical dikes of frothy, flow-banded rhyolitic porphyry containing biotite, plagioclase, quartz, and hornblende phenocrysts. Potassium-argon age on large dike 15.1±0.4 Ma (plagioclase, table 1, No. 14)

Mohave Mountains dike swarm (Miocene)—Divided into:

Tdm **Diorite and fine-grained mafic dikes (middle? and early Miocene)**—In eastern Mohave Mountains, dikes as long as 3 km of fine- to medium-grained hypidiomorphic granular biotite-hornblende diorite cut andesitic dikes (Tda) and leucocratic dikes (Tdl); potassium-argon numerical ages (21 to 27 Ma on hornblende, table 1, No. 15) are suspected to be older than geologic age because of approximately 20-Ma age inferred for older leucocratic dikes (Tdl). Small dikes north of Lake Havasu City cut andesitic and dacitic flows, dikes, and sills (Tadf)

Tdap **Andesite porphyry dikes (early Miocene)**—Trachytic-textured dark-gray andesitic dikes having aligned tabular plagioclase phenocrysts, like "jackstraw" or "turkey-track" lava flows (Tflp). Generally cut andesitic dikes (Tda) and leucocratic dikes (Tdl) but locally are cut by them. A K-Ar numerical age of 42.7 Ma (plagioclase, table 1, No. 16) conflicts with probable Miocene intrusive age of unit

Tda **Andesitic dikes (early Miocene)**—Gray to black, dark-brown-weathering, hornblende andesite, diabase and microdiorite, generally containing small amounts of clinopyroxene phenocrysts; rare interstitial quartz. Xenoliths of gneiss are present locally. Dikes rarely vuggy, chilled margins common. Most dikes are concentrated in Proterozoic rocks but some also cut Miocene volcanic rocks, including unmapped dikes in andesite porphyry (unit Tap) in Standard Wash area. Where in contact, most dikes of this unit cut leucocratic dikes (Tdl). Potassium-argon hornblende, plagioclase, and whole-rock numerical ages of 29 to 78 Ma on unit (table 1, Nos. 17–20) conflict with probable early Miocene geologic age and may reflect excess argon. Most dikes dip northeast at moderate angles. Dikes range from 0.3 to 10 m thick, average 2.3 m

Tdl **Leucocratic dikes (early Miocene)**—Pattern indicates areas of abundant intrusions, including dikes and stocks. Dacite, altered andesite(?), and subordinate rhyolite and aplite. Intrusions of this unit in most cases are cut by andesitic dikes (Tda). Textures include hypidiomorphic granular, spherulitic, and aphanitic types. Granular rocks crop out as knobs and rolling hills; finer grained aphanitic equivalents form spires. Dark-gray chill zones are common and grade inward toward light-colored central zones. More silicic types are cream to light gray on fresh surfaces, weathering to pale orange and shades of brown. Plagioclase and lesser biotite phenocrysts are common; hornblende, quartz, and alkali-feldspar phenocrysts are less common. Potassium-argon ages on biotite range from 19.2±0.2 to 20.8±0.5 Ma on 3 widely separated dikes (table 1, Nos. 22–24) and are interpreted to indicate a probable intrusive age of about 20 Ma. Dikes of this unit are concentrated in Proterozoic rocks; they invade Miocene volcanic units (Tfll, Tfl, Tfls) on west side of Mohave Mountains and in Standard Wash. Most dikes dip northeast at moderate to shallow angles

Tgd **Granodiorite and quartz diorite (early Miocene)**—Small exposure in central part of map area, 3 km north of Crossman Peak (sec. 9, T. 14 N., R. 18 W.). Biotite-hornblende granodiorite and biotite-hornblende quartz diorite. Granodiorite is characterized by stubby hornblende phenocrysts as large as 1 cm; idiomorphic texture at margin of body suggests hypabyssal intrusion; contains epidote of possibly magmatic origin; may be a coarser grained equivalent of leucocratic dikes unit (Tdl); modal composition shown in figure 5. Associated quartz diorite appears to merge into a northwest-trending dike of andesitic dikes unit (Tda); K-Ar age on biotite from quartz diorite, 21.5±0.5 Ma (table 1, No. 25)

TYd **Dikes, undivided (Tertiary to Middle Proterozoic)**—Most dikes are andesite and may be same as andesite dikes of unit Tda. Basalt (Miocene?) present in Bill Williams Mountains. Felsite and aplite present west and southeast of Mohave Springs. A northeast-trending rhyolite dike (Cretaceous or Paleocene?) 2 km southeast of Crossman Peak contains sphene, alkali feldspar, biotite, quartz, and plagioclase phenocrysts and resembles in outcrop leucocratic dikes unit (Tdl), but for its northeast strike and older K-Ar age on biotite: 62.3±1.6 Ma (table 1, No. 28). A hornblende microdiorite dike containing biotite and clinopyroxene in Bill Williams Mountains cuts and has chilled margins against metamorphic fabric of augen gneiss; it yielded a K-Ar numerical age on hornblende of 332 Ma (minimum age?—table 1, No. 29) and may be Proterozoic. Unmapped minette present in southeast Mohave Mountains 3 km northwest of Black Mountain

TKqp **Quartz porphyry dikes (Tertiary or Cretaceous)**—Near northwest corner of map area. Granodiorite porphyry having phenocrysts of sphene, hornblende, biotite, alkali feldspar, prominent quartz, and plagioclase. Cuts biotite granodiorite unit (Kbg). Dikes trend northeast

TKl **Biotite lamprophyre dikes (Tertiary or Cretaceous)**—In northwest corner of map area. Dark northeast-trending dikes, having chilled margins against biotite granodiorite unit (Kbg). Biotite phenocrysts conspicuous. Also contains plagioclase phenocrysts and groundmass alkali feldspar

TKg **Granite (Tertiary or Cretaceous)**—In north-central part of map area (6 km southeast of Boulder Mine, in and near sec. 20, T. 15 N., R. 19 W.). Light-gray sphene-bearing hornblende-biotite monzogranite (fig. 5). Color index 5–8 percent. Locally granophyric. Forms a small pluton and satellitic dikes. Resembles in outcrop biotite granodiorite unit (Kbg). Intrudes and is closely associated with diorite (TKd). Angular xenoliths in intrusion breccia are pictured in figure 10 of Howard and others (1982a). Potassium-argon numerical biotite age of 18.1±0.5 Ma (table 1, No. 26) is probably a minimum age

TKd **Diorite (Tertiary or Cretaceous)**—In north-central part of map area (6 km southeast of Boulder Mine, in T. 15 N., R. 19 W.). Hornblende diorite. Ranges to quartz monzodiorite and granodiorite. Contains small amounts of biotite and clinopyroxene. Texture and grain size vary widely. Cuts ophitic diabase dikes (Yd) and Proterozoic gneiss; cut by granite (TKg). Potassium-argon numerical age on hornblende (32 Ma; table 1, No. 27) is of uncertain significance. Unit also includes a small intrusion in Standard Wash area (sec. 23, T. 13 N., R. 19 W.)

Kpg **Porphyritic granite (Late Cretaceous)**—Near center of map area. Small stock of medium-grained muscovite-biotite monzogranite to granodiorite intrudes Proterozoic gneiss. Coarse-grained alkali-feldspar phenocrysts are zoned by inclusions of other minerals. Resembles porphyritic unit of Late Cretaceous Chemehuevi Mountains Plutonic Suite (John, 1987a, 1988; John and Mukasa, 1990; John and Wooden, 1990) mapped 10 km west of map area

Kbg **Biotite granodiorite (Late Cretaceous)**—In northwestern part of map area (T. 16 N., R. 20 W.). Light-gray, equigranular, medium-grained (2-mm grain size), sphene-biotite granodiorite and monzogranite. Color index 6 to 9. Plagioclase euhedral and oscillatory zoned. Inferred to belong to a single pluton also exposed west of map area on Powell Peak, near where a K-Ar age on biotite of 72.0 Ma was obtained (Nakata and others, 1990). Resembles biotite granodiorite unit of Late Cretaceous Chemehuevi Mountains Plutonic Suite (John, 1987b, 1988; John and Mukasa, 1990; John and Wooden, 1990) mapped 10 km west of map area

Yd **Ophitic diabase dikes (Middle Proterozoic)**—Dark-gray to black dikes. Dike margins commonly chilled. Ophitic to sub-ophitic, locally metamorphosed and foliated. Rocks contain 40 to 50 percent plagioclase laths 1 cm or larger set in a matrix of secondary green hornblende and local relics of pigeonite and augite. As much as 6 percent primary red-brown biotite commonly is present. Dikes are conspicuously dark on aerial photos. Typically weathers recessively to olive brown or locally dark purplish brown. Dikes are 1 to 20 m thick, averaging 3.7 m where measured by Nakata (1982) in Mohave Mountains. Most dikes dip steeply, subparallel to nonconformably overlying Tertiary strata where present in same fault blocks, indicating that dikes were subhorizontal prior to Tertiary tilting. Intrudes coarse-grained granite unit (Ysg) and older rocks and is intruded by biotite granodiorite (Kgd), granite (TKg), and younger rocks. Correlated with Middle Proterozoic diabase intrusions and extrusions in Death Valley, eastern Mojave Desert, Grand Canyon, and southern Arizona that are thought to be about 1100 to 1200 Ma in age (Fitzgibbon and Howard, 1987; Fitzgibbon, 1988)

Granitoids of Standard Wash (Middle Proterozoic?)—Present in upper plate of Crossman Peak fault. Divided into:

Ysg **Coarse-grained granite**—Red-weathering, coarse-grained monzogranite characterized by coarse tabular gray to cream phenocrysts of alkali feldspar, commonly rimmed by plagioclase. Color index about 11±5, locally as high as 28; mafic minerals (biotite and opaques, rarely hornblende) are aggregated. Also includes lesser amounts of red-weathering medium-grained equigranular biotite granite and leucogranite. Locally contains biotite-rich lenses 1 or 2 m thick or amphibolite enclaves. Locally finely laminated. Lithologically similar to, and tentatively correlated with, Parker Dam granite of Anderson (1983) and Anderson and Bender (1989), dated by uranium-lead method at 1401 Ma. Also resembles porphyritic granite subunit of augen gneiss unit (Xap). Grades to and locally cuts quartz monzonite (Ysqm)

Ysqm **Quartz monzonite**—Dark-gray, locally reddish-weathering, monzogranite, quartz monzonite, granodiorite, quartz monzodiorite, and quartz diorite. Medium- to fine-grained, equigranular to seriate. Color index mostly 15 to 20, ranges from about 12 to 25. Contains medium-grained spots of plagioclase and hornblende, but most mafic mineral grains (biotite, hornblende, and opaques) are recrystallized to clots of fine and very fine grains. Alkali feldspar is interstitial. Generally massive but locally well foliated. Lithologically similar to, and is tentatively correlated with, Bowmans Wash pluton of Anderson and Bender (1989) dated by uranium-lead method at 1407 Ma

METAMORPHIC ROCKS

Augen gneiss (Early Proterozoic)—Coarse to medium-grained biotite orthogneiss characterized by augen of alkali feldspar. Present in several bodies. Garnet present in small bodies north of Crossman Peak fault southeast of Crossman Peak (sec. 35, T. 14. N., R. 18 W. and sec. 6, T. 13 N., R. 18 W.) and in a large body in Bill William Mountains that yielded a U-Pb age (zircon) of 1642 Ma (table 1, No. 36; Wooden and Miller, 1990). Unit tends to be least metamorphosed and most felsic where closest to Proterozoic-Tertiary nonconformity. Bodies southeast of Lake Havasu City and in Bill Williams Mountains are accordingly divided into gradational lithotypes varying subtly in degree of metamorphic fabric development and in modal mineralogy (fig. 6). Gradational variation is interpreted as reflecting a paleodepth profile before Tertiary tilting. Divided into:

Xap **Porphyritic granite unit**—Least foliated unit. Coarse- to medium-grained porphyritic monzogranite (ranging to syenogranite and granodiorite). Color index 5 to 20, mostly about 10. Igneous texture is recrystallized but foliation is not pronounced except for local mylonite zones. Contains xenoliths of leucocratic granite gneiss (perhaps Xgl) and amphibolite in northwestern part of map area (Howard and others, 1982a, fig. 8 photo). Small body of syenogranite in southeastern Mohave Mountains (sec. 35, T. 14 N., R. 18 W.) contains garnet, hornblende, and muscovite and cuts fabric in adjacent gneisses. Lithologically similar to coarse-grained granite unit (Ysg)

Xag **Granite augen gneiss unit**—Intermediate to units Xap and Xagd in composition and development of metamorphic texture. Medium- to coarse-grained augen gneiss of monzogranite (ranging locally to syenogranite and granodiorite) composition. Color index mostly between 5 and 22. Mylonite and ultramylonite zones present in Bill Williams Mountains. Cut by ophitic diabase dikes (Yd). Cut in Fall Springs Wash (Mohave Mountains) by undeformed veins of aplite and pegmatite and in Bill Williams Mountains by veins of garnet-bearing pegmatite resembling spotted leucocratic gneiss unit (Xgl)

Xagd **Granodiorite augen gneiss unit**—Medium- to coarse-grained augen gneiss and equigranular gneiss of granodiorite and lesser monzogranite composition. Contains hornblende in some areas, subordinate to biotite. Rare biotite-rich enclaves are oriented parallel to foliation. Cut by isoclinally folded garnet-bearing pegmatite dikes and by veins and blobs of purplish or bluish quartz. Also cut by ophitic diabase dikes (Yd). In Buck Mountains unit includes unmapped other kinds of gneiss; quartz in augen gneiss is bluish or purplish and present as discrete eyes. Near Fall Springs Wash (Mohave Mountains) locally includes hornblende granodiorite augen gneiss containing plagioclase augen

Xg **Gneiss, undivided (Early Proterozoic)**—Unit is divided according to dominant rock type but, as mapped, each of following units also includes rocks characteristic of other units:

Xgl **Spotted leucocratic gneiss**—Light-medium-gray, medium-grained granite gneiss and locally pegmatitic gneiss. Quartz is gray to lavender. Color index 0 to 10. Garnet and dark spots (commonly garnet-cored spots of chlorite, brown to green biotite, phlogopite, epidote, and amphibole, representing pseudomorphs after garnet and possibly pyroxene) commonly form feathery or plumose trains several centimeters long in outcrop. Granulitic texture and pervasive retrograded garnets suggest rock may have been metamorphosed to high grade

Xgp **Pegmatite and monzogranite**—In northwestern part of map area, unit consists of medium-grained, light-colored foliated monzogranite and associated pegmatite; monzogranite contains biotite, biotite and muscovite, or biotite and garnet, and yielded a K-Ar numerical age on biotite (interpreted as a cooling age) of 597 Ma (table 1, No. 42). Elsewhere unit consists of white garnet-bearing gneissic pegmatite (±muscovite) commonly associated with amphibolite; locally exhibits granophyric igneous texture

Xga **Amphibolite**—Color index 25 to 60. Locally exhibits relic gabbroic textures; contains cummingtonite rimmed by hornblende, pseudomorphs consisting of hornblende, clinozoisite, white mica, and cummingtonite, and rarely augite. Small unmapped bodies present throughout most gneiss units. K-Ar numerical age of 1372 Ma on hornblende in Buck Mountains (table 1, No. 43) is interpreted as a cooling age

Xgs **Metasedimentary rocks**—Dark-gray feldspathic quartzite, garnet quartzite, metaconglomerate(?), and aluminous schist and gneiss. Mineral assemblages include (a) biotite, K-feldspar, sillimanite, garnet, and muscovite; (b) garnet, cordierite, sillimanite, and biotite; (c) biotite, muscovite, plagioclase, and K-feldspar, (d) K-feldspar, muscovite, biotite, and garnet; and (e) plagioclase, garnet, and biotite. Most muscovite is replacing sillimanite. Garnet is locally chloritized. Metaconglomerate(?) contains pebblelike aggregates of sillimanite, sericite, and quartz

Xgb **Biotite gneiss**—Fine- to medium-grained, medium-gray biotite granitic gneiss. Mostly of monzogranite composition; alkali-felspar commonly more abundant than plagioclase. Color index about 9. Locally contains garnet. In places layered or veined by dark-bordered veins a few centimeters thick of leucocratic gneiss (ptygmatically folded). Cut by pegmatite associated with spotted leucocratic gneiss unit (Xgl). Resembles gneiss of Virginia May Mine in Turtle Mountains, Calif., 50 km southwest of map area (pictured by Howard and others, 1982b, fig. 3). Probably largely orthogneiss but also includes probable paragneiss where quartz-rich, aluminous, or associated with metasedimentary rocks unit (Xgs)

*Some ages listed in table 1 record cooling younger than age of rock (especially for Proterozoic rocks); other ages are anomalously older than probable rock age (especially for dikes) and may result from excess argon (Nakata and others, 1990). Description of Map Units mentions ages that are believed to reflect crystallization age of sampled rock units.

Contact

Fault—May show dip. Dashed where inferred, dotted where concealed. Bar and ball on downthrown side. Teeth on upper plate of low-angle normal fault. Arrows show strike sense of displacement

Strike and dip of bedding
- 60 **Inclined**
- **Vertical**
- 80 **Overturned**

Strike and dip of igneous foliation
- 60 **Inclined**
- **Vertical**

Strike and dip of metamorphic foliation
- 50 **Inclined—**Degree of dip is unavailable for several localities
- **Vertical**
- **Horizontal**

Trend and plunge of lineation—May be combined with foliation symbol
- 30 **Mineral lineation**
- 20 **Mylonitic lineation**
- 25 **Fold axis**

Anticline—May show plunge. Dotted where concealed

Syncline—Dotted where concealed

Antiform—Showing plunge. Defined by gneissic foliation and metamorphic rock unit

Brecciated rock—Tectonic breccia

Quartz vein

45 **Dip of dike**

△ 3 **Locality of dated sample(s)**—Listed in table 1

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