U. S. DEPARTMENT OF THE INTERIOR
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PRELIMINARY GEOLOGIC MAP OF THE MOHAVE MOUNTAINS AREA MOHAVE COUNTY, WESTERN ARIZONA

by

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INTRODUCTION

The Mohave Mountains area surrounds Lake Havasu City, Arizona, in the Basin and Range physiographic province (fig. 1). The Mohave Mountains and the Aubrey Hills form two northwest-trending ranges adjacent to Lake Havasu (elevation 448 ft; 132 m) on the Colorado River (fig. 2). The low Buck Mountains lie northeast the Mohave Mountains in the alluviated valley of Dutch Flat. Lowlands at Standard Wash separate the Mohave Mountains from the Bill Williams Mountains to the southeast. The highest point in the area is Crossman Peak in the Mohave Mountains, at an elevation of 5148 ft (1519 m). Arizona State Highway 95 is now rerouted in the northwest part of the area from its position portrayed on the base map, and now also extends south through the southern edge of the map area (fig. 2).

Geologic mapping was begun in 1980 as part of a program to assess the mineral resource potential of Federal lands under the jurisdiction of the U.S. Bureau of Land Management (Light and others, 1983). Mapping responsibilities were as follows: Proterozoic and Mesozoic rocks--K.A. Howard; dikes--J.K. Nakata; Miocene section--J.E. Nielson; and surficial deposits--H.G. Wilshire.

Earlier the geology of the area was known only from reconnaissance (Wilson and Moore, 1959). The present series of invesitigations has resulted in reports on the crystalline rocks and structure (Howard and others, 1982a), dikes (Nakata, 1982), Tertiary stratigraphy (Pike and Hansen, 1982; Nielson, 1986; Nielson and Beratan, 1990), surficial deposits (Wilshire and others, 1983), tectonics (Howard and John, 1987; Beratan and others, 1990), geophysics (Simpson and others, 1986), mineralization (Light and McDonnell, 1983; Light and others, 1983); field guides (Nielson, 1986; Howard and others, 1987), and geochronology (Nakata and others, 1990).

GEOLOGY

The area lies within a terrane characterized by major low-angle normal faults (commonly called detachment faults) of Miocene age (Davis and others, 1980; Carr, in press; Howard and John, 1987; John, 1987; Davis and Lister, 1988; Davis, 1988). The Whipple Mountains detachment fault is exposed 2 mi (3 km) southwest of the mapped area, and the probably equivelent Chemehuevi detachment fault is exposed 5 mi (8 km) northwest of the mapped area. Both dip gently toward the Mohave Mountains area and project beneath it at shallow depth.

Proterozoic metamorphic and igneous rocks, Cretaceous plutons, and Tertiary dikes underlie the map area. Tertiary volcanic and sedimentary rocks overlie the Proterozoic rocks. Tilting to the southwest in the Miocene along northeast-dipping normal faults resulted in steep to overturned dips of lower Miocene strata and the Proterozoic-Tertiary nonconformity. Consequently the map view restores to cross-sectional views before the tilting, in which deeper crustal levels in any tilted block are encountered to the northeast. The faulting is inferred to relate to down-to-northeast motion on the the deeper Whipple Mountains-Chemehuevi fault (Howard and John, 1987). Upper Miocene to Quaternary deposits overlie the deformed rocks.

The largest of the tilted fault blocks is the Crossman block, centered in the map area (Crossman plate of Howard and others, 1982a). Other large tilt blocks are the Bill Williams, Buck, and Tumarion blocks (fig 3). Smaller tilt blocks or slices occur in the Standard Wash, Aubrey Hills, and Boulder mine areas.

Proterozoic and Mesozoic Rocks

Granite gneisses are the predominant Early Proterozoic rocks in the map area. The gneisses are like those widely exposed elsewhere in the eastern Mojave Desert region (Wooden and Miller, 1990), consisting partly of supracrustal rocks and largely of metaplutonic rocks (Howard and others, 1982a). Scattered amphibolite bodies (Xga) help to outline large folds in the gneiss terrane. Fold axes plunge to the southwest and restore to northeast plunge if Tertiary tilting is removed (Howard and others, 1982a).

Amphibolite is associated with white garnet-bearing gneissic pegmatite (Xgp) in the northwestern part of the Crossman block, serving as a marker for fault separation to a block in the Boulder mine area; the same assemblage also crops out along strike to the northeast in the Buck block, as well as farther southeast in the Crossman block.

Remnant metasedimentary rocks (Xgs) and fine-grained biotite granite gneiss (Xgb) and younger foliated monzogranite (Xgp) crop out in the northern part of the area in structurally high positions of the pre-Tertiary crustal section. Augen gneiss (Xap, Xag, and Xagd) occurs in structurally intermediate levels of the section, and becomes more foliated and more mafic with paleodepth. Dating by the uranium-lead (U-Pb) method indicates an Early Proterozoic age (1642 Ma) for an augen gneiss body in the Bill Williams Mountains (Wooden and Miller, 1990; Table 1, no. 36). Howard and others (1982a) earlier had grouped the augen gneiss with Middle Proteozoic(?) granitoids of Standard Wash which it resembles. The augen gneiss commonly coincides with aeromagnetic highs (Simpson and others, 1986). The deepest rocks in the exposed crustal section are dominated by garnet-spotted leucocratic gneiss (Xgl) in which pervasive garnets, now mostly retrograded, suggest high-grade metamorphism.

Granite and quartz monzodiorite in Standard Wash (Ysg, Ysqm) are tenatively correlated with rocks of Middle Proterozoic age (about 1400 Ma) described by Anderson and Bender (1989). An aeromagnetic high is associated with the quartz monzodiorite (Simpson and others, 1986). The granite is seen to intrude older gneiss just south of the map area in the southern Aubrey Hills. The Standard Wash granitoids are not mapped in the Crossman, Bill Williams, or Buck blocks.

Swarms of Middle Proterozoic ophitic diabase dikes intrude the gneiss and granitoids (see cross sections; Nakata, 1982; Howard, in press). The dikes (Yd) are similar to diabase dikes that occur widely in Arizona and southeastern California and are interpreted to have an age of about 1100-1200 Ma (Wrucke and Shride, 1972; Hendricks and Lucchitta, 1974; Davis and others, 1980; Howard and others, 1982a; 1982b; Fitzgibbon, 1988). The dikes cut older folds and fabrics without deflection. Their generally northwest strikes and steep dips restore to subhorizontal when Tertiary tilting defined by the dip of lowest Tertiary strata is removed. Hence the dikes are intrerpreted as originally horizontal sheets. They are mapped to paleodepths of as great as 14 kilometers below the Proterozoic-Tertiary nonconformity. Original depths of emplacement below the Proterozoic ground surface must have been even greater.

Cooling ages obtained on Proterozoic rocks by the fission-track (zircon) and potassium-argon (K-Ar) methods range from 46 to 1372 Ma (Table 1; Nakata and others, in press). The numerical ages tend to young downward (northeastward) in the pre-Tertiary structural sections, and are consistent with younger cooling at deeper levels. Study by the $^{40}Ar/^{39}Ar$ technique supports this interpretation (Foster and others, 1990).

Mineralized quartz veins in the Mohave Mountains contain sulfides and precious metals (Light and others, 1983). The veins cut the Proterozoic diabase and are cut by Tertiary dikes, and have a minimum age of mid-Cretaceous as determined by isotopic dating: Medium-grained white mica in altered gneiss associated with the veins yielded K-Ar ages of 90 to 102 Ma; numerical cooling ages on fine-grained white mica and zircon are 52 to 78 Ma (Table 1, nos. 30-32; Nakata and others, 1990).

The Mohave Mountains and adjacent ranges are near the northeastern limit of the Cretaceous magmatic arc (Burchfiel and Davis, 1981; John, 1981; John and Wooden, in press). Granitic plutons of known and inferred Cretaceous age are widespread to the west but are rare to the northeast. Cretaceous rocks in the Mohave Mountains area may be apophyses of the deeper batholithic terrane exposed to the west in the Chemehuevi Mountains (John, 1987b). This interpretation is based on a hypothesis of Howard and John (1987) that the northern Mohave Mountains represent the displaced upper plate to rocks exposed in the Chemehuevi Mountains. Granodiorite and porphyritic granite (Kgb, Kpg) in the north part of the map area are correlated to Late Cretaceous rocks of the Chemehuevi Mountains Plutonic Suite (John, 1987b, 1988; John and Mukasa, 1990; John and Wooden, in press).

Rocks in the Mohave Mountains area that may be either Cretaceous or Tertiary in age include a northeast-striking rhyolite dike dated by K-Ar on biotite at 62 Ma (Table 1, no. 28, unit TYd), northeast-striking dikes of lamprophyre and quartz porphyry (TKl, TKqp), and small stocks of granite and diorite (TKg, TKd) that yielded middle Tertiary numerical K-Ar ages on biotite and hornblende (Table 1, nos. 26, 27). Northeast-striking dikes of Laramide (Late Cretaceous to early Tertiary) age are widespread in Arizona (Rehrig and Heidrick 1976).

Cenozoic Rocks

The lowest stratified Tertiary unit (Tac) is arkosic conglomerate and sandstone, locally redbed, which is assigned an Oligocene or early Miocene age. It nonconformably overlies deeply oxidized Proterozoic rocks, and forms the base of a heterogeneous, dominantly volcanic section of otherwise early and middle Miocene age (fig. 4; Pike and Hansen, 1982; Nielson, 1986; Nielson and Beratan, 1990; Beratan and others, 1990). The volcanic rocks consist of mafic and silicic lava flows, volcaniclastic flows and breccias, air-fall tuff, and tuff breccia. The Peach Springs Tuff of Young and Brennan (1974), a regional ash-flow tuff, occurs high in the lower Miocene part of the section. The sedimentary rocks include arkosic conglomerate and conglomeratic sandstones derived from Proterozoic sources, sandstone and sedimentary breccia derived solely from reworked volcanic rocks, and fanglomerate, sandstone, and claystone from mixed sources. The lower part of the Tertiary section is intruded by silicic and mafic dikes that may be feeders for some of the flows.

The dikes are part of a dense swarm of northeast-dipping Tertiary dikes that pervades the pre-Tertiary basement of the Crossman block (see cross sections). This Mohave Mountains dike swarm forms about 15 percent of the rock volume in the Crossman block (Nakata, 1982), and accounts for a northeast-southwest crustal dilation of 2-3 km that occurred during regional tectonic extension. The K-Ar ages considered most reliable as intrusive ages for the swarm range from 19.2 ± 0.5 to 21.5 ± 0.5 Ma (Table 1, nos. 21-25).

The Tertiary strata below the Peach Springs Tuff correlate broadly with the sedimentary and volcanic rocks of Fox Wash described by Sherrod (1988) from the Bill Williams Mountains. Dating by the K-Ar method indicates that the age of the volcanic rocks in this section is about 19 to 22 Ma (Table 1, nos. 8-11, 13; Nielson and Beratan, 1990; Nakata and others, 1990). The Peach Springs Tuff is dated from Kingman, Arizona, at 18.5 + 0.2 Ma (Nielson and others, 1990). The steeply dipping to overturned oldest part of the Tertiary section is overlain succesively by units of early Miocene to middle Miocene age having progressively shallower dips, in places without obvious unconformities between strata. Therefore the stratified units were deposited during tilting, and they likely record sedimentary influxes that relate to the tilting and faulting. Conglomerates low in the section are largely roundstone. Higher units include lacustrine strata deposited in closed structural basins. Fanglomerates and landslide megabreccias occur high in the section.

North of Lake Havasu City a gently dipping latite flow (Tadf) dated by K-Ar at 19.9 ± 0.5 Ma overlies more steeply tilted flows and strata (Tfts) from which an indistinguishable age of 19.2 ± 0.5 Ma was obtained. The 30° and greater angular unconformity between the latite flow and underlying strata records the tilting of the Crossman block (Nielson and Beratan, 1988), so the age of tilting can be interpreted as near 19.5 Ma. Stratal dips suggest that tilting of other blocks ranged from mostly before, to mostly after, deposition of the 18.5-Ma Peach Springs Tuff.

A middle Miocene fanglomerate unit (Tfg) represents the first of two distinct periods of post-detachment alluviation. Capping it are rhyolite and olivine basalt flows (Tr, Tob) that have been dated at 12.2 to 8.6 Ma (Suneson and Lucchitta, 1983; Nakata and others, 1990). They and the underlying fanglomerate are relatively undeformed compared to older strata, but in the southeast part of the area they are faulted and are tilted gently southwest, the same direction as older steeper tilts.

The Bouse Formation of late Miocene and Pliocene age was deposited mostly in quiet water along the valley that was later to be followed by the Colorado River. A sandy subaerial facies of the Bouse was deposited in the northern part of the Mohave Mountains area; a similar facies was mapped south of the Whipple Mountains by Dickey and others (1980).

Undeformed upper Miocene to Quaternary piedmont sedimentary deposits record a second period of alluviation. These deposits are fanglomerates composed of unsorted to poorly sorted coarse, angular to subangular clastic debris derived from the exposed pre-Tertiary and Tertiary rocks. The fanglomerates interfinger with river-laid sand and gravel along the Colorado River to the west of the study area. The bulk of the fanglomerate deposits are at least as old as Pleistocene, and probably formed a series of large, coalescing depositional fans (unit QTs1). The depositional surface later was nearly completely dissected, with levels of erosion generally below the soil profile, on the west side of the mountains where drainages flow directly into the Coloroado River. Dissection, planation, and reworking is largely responsible for a series of inset terraces and washes veneered by succesively younger parts of the piedmont unit. Soils are progressivly less well developed on younger units (Wilshire and others, 1983).

Tertiary Structure

Structural relations in the Crossman block indicate that it was tilted as a largely coherent block. The lower part of the Tertiary section dips steeply to overturned. The tilt persists at deeper structural levels in the block, as shown by the consistent steep orientations of rotated Proterozoic diabase sheets, subparallel to the lower Tertiary section. The Tertiary Mohave Mountains dike swarm maintains a moderate northeast dip all across the block and is unbroken by faults except in a few places.

The evidence for tilting of the Crossman block implies that it exposes a cross section that represents progressively greater crustal depths from southwest to northeast. This section represents 10 to 15 km of crustal thickness if the Crossman block is unbroken and tilted at least 75° (Howard and John, 1987). Amphibolite bodies within the block trace cryptic Proterozoic folds that argue against much internal disruption of the block by Tertiary faulting, except where faults are mapped. The Crossman block may have been translated 40 km from Chemehuevi Valley, where the western Whipple Mountains below the Whipple Mountains detachment fault exposes a footwall of similar dike swarms and Proterozoic gneisses (Davis and others, 1980, 1982; Carr and others, 1980; Dickey and others, 1980; Howard and others, 1982a; Davis, 1988; Lister and Davis, 1989).

The Whipple Mountains-Chemehuevi detachment fault projects beneath the Crossman block and is inferred to juxtapose it against deeper mid-crustal mylonitic gneisses (see cross sections). In the eastern Chemehuevi Mountains and eastern Whipple Mountains the footwall of the detachment exposes mylonitic gneisses derived from Proterozoic to Tertiary protoliths and mylonitized in the Cretaceous and Tertiary (Davis and others, 1982; Anderson and Rowley, 1981; Anderson and others, 1988; Davis, 1988; John and Mukasa, 1990).

An abrupt northeast termination of the Crossman block at its originally deep end is proposed on cross section AA' in order to help explain a steep gravity gradient at this position. The gravity gradient led Simpson and others (1986) to model a steep boundary between denser rocks underlying the exposed Crossman block against less dense (undiked?) bedrock to the northeast, under a thin sedimentary cover. The gravity model requires a greater density contrast (0.12 to 0.15 g/cc) between bedrock terranes than would be expected from the largely granitic bedrock exposed in the region and from density measurements of rocks in the Crossman block (Simpson and others, 1986). Hence the interpretation portrayed on cross section AA' must be considered tentative and uncertain.

A curving family of northwest-striking faults including the Wing fault cut the northwest part of the Crossman block. These faults are steep, they cut the Mohave Mountains dike swarm, and they appear to have significant pre-dike swarm displacements of gneiss units. Based on the generalized crustal section inferred for unbroken parts of the Crossman block, each fault of the Wing-fault family appears to attenuate crustal section, juxtaposing originally shallower rocks against originally deeper rocks to the north. Chloritized rock is present on the "deep" northeast side of the Wing fault but not on the "shallow" side, a pattern reminiscent of chloritized footwalls of low-angle normal faults in the region. Based on the resemblances to low-angle normal faults in the region, the steep Wing fault perhaps was rotated from an originally smaller dip.

The Boulder mine and Standard Wash areas expose numerous fault slices in synformal arrays structurally over the Crossman, Bill Williams, and Tumarion blocks. The faults in the Aubrey Hills and the Boulder mine area mostly dip at low angles, and those in the Standard Wash area are inferred to also. Fault traces concave to the northeast in the Standard Wash area are consistent with synformal shapes and low northeast dips for the faults. Cross sections BB' and CC' interpret a shallow depth to the underlying footwall of the Whipple Mountains detachment fault. The depth is consistent not only with the geology but with the depth to a seismic-velocity increase interpreted as the base of the highly faulted allochthons (McCarthy and others, 1987; John and others, 1987).

The southeast-dipping Powell Peak fault bounds the Tumarion block against higher blocks of the Boulder Mine area, and the southeast-dipping Crossman Peak fault similarly bounds the exposed Crossman block against higher blocks of the Standard Wash area. Measured striae on the latter fault strike northeast in a direction parallel to the direction of extension and regional fault slips, including slip on the deeper Whipple Mountains and Chemehuevi detachment faults (Davis and others, 1980; John, 1987a; Howard and John, 1987).

Cross sections BB' and CC' portray the Powell Peak and Crossman Peak faults as bottoming at shallow depth, so that the Crossman block is connected at depth below the Standard Wash area and the Boulder mine area with the Bill Williams and Tumarion blocks. This interpretation is based on 1) the alinement of Tertiary strata in the three big upended blocks 2) the moderate (30-40°) dip of the exposed Powell Peak and Crossman Peak faults, and 3) the synformal array of higher blocks in the Boulder Mine and Standard Wash areas (Howard and others, 1982a; Howard and John, 1987). An alternate interpretation is that the Crossman Peak and Powell Peak faults are syndepositional transfer faults, and that the Crossman block does not intervene between the Standard Wash area and the Aubrey Hills as portrayed on the cross sections. This latter interpretation is based on stratigraphic coherence in the Tertiary section of the Aubrey Hills and Standard Wash areas, and stratigraphic contrasts to the Crossman block (Nielson and Beratan, 1990; Beratan and others, 1990).

Relatively mild tilting and step faulting in upper Miocene strata (northeast part of cross section BB') may postdate active extension accomodated on the Whipple Mountains and Crossman Peak faults. The late Miocene tilting may relate to rebound of the detachment faults and later adjustments of tilted blocks following the end of movement on the master fault.

DESCRIPTION OF MAP UNITS

STRATIFIED DEPOSITS AND ROCKS

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 the 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 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. The units are subdivided on the basis of geomorphic expression. Units 4, 3, and 2 are pediment terraces developed mainly on deposits of unit 1 (QTs1) and have no or only thin veneers of new deposits. Divided into:

Qs4 **Unit 4 (Holocene)**--Equivalent to units Q4 and Q3b 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 m to 1 m above active channels. Deposits sustain more varied vegetation than active channels. No soil development

Qs3 **Unit 3 (Holocene)**--Equivalent to unit Q3a of Bull (1974). Fill of inactive channels, 1 m to 4 m above local active channels. Sand, pebbles, cobbles, and boulders; commonly with 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 much as 2 cm thick, nonargillic B horizon up to 24 cm thick, thin carbonate pebble coatings at surface and ranging to 1.5 m depth

Qs2 **Unit 2 (Pleistocene)**--Locally divided into:

Qs2b **Subunit B**--Equivalent to unit Q2b of Bull (1974). Moderately dissected surfaces 1 to 17 m above adjacent drainages with well-developed varnished pavement, inset into subunit A or into the substrate of subunit A. Substrate of coarse to medium, poorly to moderately sorted, bedded to massive gravel as much as 4 m thick; in sharp contact with underlying unit QTsl or older sedimentary deposits. Diversified vegetation community restricted mainly to drainages. Vesicular A soil horizon 1 to 7 cm thick, nonargillic B horizon ranges to 25 cm thick, argillic Bt and Btk horizons as much as 50 cm thick, Bk and Bkm calcic horizons as much as 130 cm thick

Qs2a **Subunit A**--Equivalent to unit Q2a 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 Qs2b with well-developed varnished pavement. Substrate of coarse to medium, poorly sorted, generally massive gravel up to about 4 m thick, in sharp contact with underlying finer-grained unit QTs1 or older sedimentary deposits. Diversified vegetation community in drainages. Where present soil horizons include: vesicular A horizon up to 6 cm thick, nonargillic B horizon as much as 35 cm thick, argillic Bt and Btk horizons up to 100 cm thick, and Bk and Bkm calcic horizons as much as 150 cm thick

QTs1 **Unit 1 (Pleistocene, Pliocene, and late Miocene?)**--Equivalent to unit Q1 of Bull (1974). Dissected surfaces with no relic 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 much as 5 cm thick, nonargillic B horizon up to 20 cm thick, argillic Bt and Btk as much as 55 cm thick, and Bk and Bkm calcic horizons up to 200 cm thick. Petrocalcic zone commonly drapes over ridges underlain by unit QTs1. Underlies deposits related to younger erosional surfaces at depths of a few m 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 the Mohave Mountains a subaerial facies is present composed dominantly of reddish sandstone and thin interbedded gravels

Tob **Olivine basalt (late Miocene)**--In southeast 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 the potassium-argon (K-Ar) method on the Mohave Springs Mesa flow is 8.6 ± 0.3 Ma (Suneson and Lucchitta, 1983) and on the Black Mountain flow is 11.1 ± 0.3 Ma (table 1, no. 1). Vent for the Mohave Springs Mesa flow is identified by Suneson and Lucchitta (1983) in the Castaneda Hills southeast of the map area. Flows 20 to 160 m thick. Queried steeply dipping patch (foliation measured on vesicular layering) east 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, Ysq, and Xgl. Underlies unit QTs1. Probably a landslide deposit derived from the 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 southeast 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 the olivine basalt (Tob) and overlies the fanglomerate (Tfg) and older units. Correlative with silicic volcanic rocks of Suneson and Lucchitta (1983) in the Castaneda Hills, which have K-Ar ages that range from 10.3 to 15.1 Ma, and with the rhyolite and the silicic volcaniclastic rocks of Sherrod (1988) in the Monkey's Head quadrangle. In map area as much as 150 m thick

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 the clast population changes abruptly from dominantly volcanic rocks to dominantly granitic gneiss as matrix changes from purplish to reddish. Attitude typically is sub-horizontal but locally dips reach 35°. Overlies older Tertiary deposits with angular unconformity. Underlies the rhyolite (Tr) and olivine basalt (Tob) units. Correlative with the Osborne Wash Formation of Davis and others (1980). Highly variable in thickness

Tmbx **Megabreccia (middle Miocene)**--Exposed only in the Aubrey Hills, near Lake Havasu. Megabreccia derived from white mylonitic two-mica granite gneiss and from dikes of dark gabbro--rocks typical of the footwall of the Whipple Mountains detachment fault in the western Whipple Mountains, 20 km to the west (G.A. Davis, oral commun., 1985). Includes undeformed blocks hundreds of meters across. Striae along base of deposit and drag folds in underlying sedimentary rocks suggest that the deposit is a landslide that was emplaced from the southeast direction. In places the base of the deposit is marked by load casts and intervening injections consisting of the breccia mixed with sand or shale from the substrate. Correlated with the megabreccia deposit of the northern Whipple Mountains (Dunn, 1986). The unit overlies the 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 the arkose of Keenans Camp of Suneson (1980). Overlies the Peach Springs Tuff of Young and Brennan (1974). Divided into:

Tys **Sedimentary and interbedded pyroclastic rocks--**Mapped in the northwest and southeast parts of the 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 the 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 the megabreccia unit (Tmbx). Dips range from 12° to 90°. Overlies the Peach Springs Tuff. Thickness highly variable, up to 1400 m

Tyb **Basalt, tuff and sandstone--**In the 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 the arkose of Keenans Camp of Suneson (1980). The unit generally dips 35° to the southwest, but locally near faults dips as much as 50° to the north. Queried outcrops 2 km east of Pittsburg Point (sec. 23, T. 13N., R. 20W) are fine-grained andesite. Basalt occurs as stacks of flows up to 12 m thick. Thickness 100-120 m

Tyc **Conglomerate, sandstone, and tuff--**In the Aubrey Hills. Buff to white pebble conglomerate and medium-grained sandstone, and laterally persistent beds of white waterlaid tuff. Local limestone interbeds occur in the sandstone. Conglomerate clasts are predominantly rounded pebbles of mixed volcanic and plutonic rocks; volcanic types include pebbles of the Peach Springs Tuff. Sandstones are crudely layered and commonly have large-scale low angle cross-bedding. Unit resembles sedimentary parts of the basalt, tuff, and sandstone unit (Tyb), but has a larger proportion of poorly sorted fanglomerate. Grades to the southeast into the 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 the map area. Thickness up to 200 m

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

Tbt **Basalt and tuff (middle or early Miocene)**--East of Lake Havasu City, and in the northwest part of the map area. Comprises basalt and tuff of uncertain stratigraphic position relative to the Peach Springs Tuff of Young and Brennan (1974). On the 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 the tuff and basalt flows (Tfot) and to a lesser degree the stratigraphically higher basalt, tuff, and sandstone (Tyb); overlies the rhyolite tuff, flows, and domes (Tfr). In the northwest part of the map area includes an olivine basalt flow with numerical K-Ar age of 14.6 Ma (whole-rock; table 1, no. 3); the flow dips steeply in conformity with underlying rocks of unit Tfl, and it underlies rocks of the sedimentary and pyroclastic rocks (Tys); similar basalts nearby occur both underlying and overlying the 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 the age of the Peach Springs Tuff: basal pyroxene-plagioclase-biotite latite flow (SiO_2, 59.5%; K_2O, 11.2%)--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 up to 130 m

Tps **Peach Springs Tuff of Young and Brennan (1974) (early Miocene)**--Welded crystal-lithic ashflow 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 the base. Extensively exposed in northern Mohave Mountains and Aubrey Hills, where the tuff commonly is partly to highly silicified and contains zones of secondary brecciation. Unit dips 30° to 60° southwest. Age of the 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 the unit are more variable (Glazner and others, 1986; table 1, nos. 4, 7). Thickness in map area ranges up to 100 m

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

Tfr **Rhyolite tuff, flows, and domes**--In the Aubrey Hills and east and north of Lake Havasu City. White stratified airfall tuff, interbedded flows and domes, and intrusions of plagioclase-biotite ± hornblende rhyolite. Attitudes highly variable. In the area northeast 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. The dips probably reflect both tectonic and considerable local original dips of deposits. In the Aubrey Hills the unit comprises dominantly flows with vitrophyric bases, monolithologic avalanche breccia, and minor tuff, all of biotite rhyolite; dips are 35° to 45°to the southwest. Interfingers toward the 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 the arkose of Keenans Camp of Suneson (1980). Underlies the Peach Springs Tuff of Young and Brennan (1974). Consists of:

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

Tfos **Tuff, sandstone, and basalt**--In the 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 the exception of basalt flows the unit represents a depositional environment similar to lacustrine parts of the unit Tys, but predates the Peach Springs Tuff. Unit interfingers to the west and northwest with basal flows of unit Tfob, which it underlies, and to the north with upper parts of the unit Tfot, which it overlies. Thickness up to 750 m

Tfot **Tuff and basalt flows**--In the 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 up to 5 m diameter. Clasts are mostly porphyritic granite, gneiss, amphibolite, and schist, more rarely, andesite. The contacts between tuff or conglomerate and basalt flows contain peperite and the flow bases are pervasively altered, indicating extrusion of flows over saturated sediments. Dips range from 30° to 80°. Underlies the Peach Springs Tuff north of Lake Havasu City and underlies units Tfob and Tfos in the 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_20 that resemble latite and trachyte, and may be due to metasomatic additions of these components. The 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. 8); basaltic andesite flow north of Lake Havasu City, 21.5 Ma (whole-rock; W.A. Rehrig, oral commun., 1982). Sedimentary deposits including arkosic fanglomerate 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 the 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 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 the andesitic and dacitic flows, dikes, and sills (Tadf)

Tfll **Andesitic to latitic sills and flows--**In the Aubrey Hills and Standard Wash. Tan to brown bodies of altered orthopyroxene-bearing andesite, latite, or dacite that form prominent ridges. Sills assimilated sedimentary beds like those of unit Tflf. Feeder dikes for sills or flows are locally prominent. Dips range up to 60°. Maximum thickness about 200 m in Standard Wash; much less in Aubrey Hills

Tflt **Tuff breccia--**In the Aubrey Hills and Standard Wash. Pinkish 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 the Aubrey Hills and Standard Wash. Fluvial and lacustrine sedimentary rocks include conglomerate with boulders as coarse as several meters, mixed arkosic-volcanic conglomerate, and yellow-green volcaniclastic siltstone and sandstone, commonly with pumiceous 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 the unit are intruded and partly to wholly assimilated by mafic flows of unit Tfls; this relation is best exposed at south end of the 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 the 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 up to 10 mm long, 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); if high K_20 (3%) 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 the Aubrey Hills and Standard Wash. Interbedded sandstone, conglomerate, and "turkey-track" or "jackstraw" andesite(?) porphyry. Thin bed of limestone caps the unit in the 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 State 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)--Shown only on cross sections. Divided into:

Tdm **Diorite and fine-grained mafic dikes (middle? and early Miocene)**- In the 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 the approximately 20-Ma age inferred for the older leucocratic dikes (Tdl). Small dikes north of Lake Havasu City cut the andesitic and dacitic flows, dikes, and sills (Tadf)

Tdap **Andesite porphyry dikes (early Miocene)**--Trachytic-textured dark-gray andesitic dikes having alined tabular plagioclase phenocrysts, like "jackstraw" or "turkey-track" lava flows (Tflp). Generally cut the 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 the probable Miocene intrusive age of unit

Tda **Andesitic dikes (early Miocene)**--Gray to black, dark brown-weathering, hornblende andesite, diabase and microdiorite, generally having 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 the andesite porphyry (unit Tap--relations in Standard Wash area, unmapped). Where in contact, most dikes of this unit cut the leucocratic dikes (Tdl). Potassium-argon hornblende, plagioclase, and whole-rock numerical ages of 29 to 78 Ma on the unit (table 1, nos. 17-20) conflict with the probable early Miocene geologic age and may reflect excess argon. Most dikes dip northeast at moderate angles. Dikes are 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 the west side of the 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 the central part of the map area, 3 km north of Crossman Peak. Biotite-hornblende granodiorite and biotite-hornblende quartz diorite. Granodiorite is characterized by stubby hornblende phenocrysts as large as 1 cm; idiomorphic texture in margin of body suggests hypabyssal intrusion; contains epidote of possibly magmatic origin; may be a coarser grained equivalent of the leucocratic dikes unit (Tdl); modal composition is indicated in Figure 5. Associated quartz diorite appears to merge into a northwest-trending dike of the andesitic dikes unit (Tda); K-Ar age on biotite from the 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 the same as andesite dikes of unit Tda. Basalt (Miocene?) occurs in the Bill Williams Mountains. Felsite and aplite occur 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 the 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 the Bill Williams Mountains cuts and has chilled margins against metamorphic fabric of the 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 occurs in the southeast Mohave Mountains 3 km northwest of Black Mountain

TKqp **Quartz porphyry dikes (Tertiary or Cretaceous)**--Near the northwest corner of the map area. Granodiorite porphyry having phenocrysts of sphene, hornblende, biotite, alkali feldspar, prominent quartz, and plagioclase. Cuts the 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 the 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 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 out crop the biotite granodiorite unit (Kbg). Intrudes and is closely associated with the 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. The unit also includes a small intrusion in the 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 the Late Cretaceous Chemehuevi Mountains Plutonic Suite (John, 1987a, 1988; John and Mukasa, 1990; John and Wooden, in press) mapped 10 km west of the map area

Kbg **Biotite granodiorite (Late Cretaceous)**--In the northwest part of the 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 the map area on Powell Peak, near where a K-Ar age on biotite of 72.0 Ma was obtained (Nakata and others, in press). Resembles the biotite granodiorite unit of the Late Cretaceous Chemehuevi Mountains Plutonic Suite (John, 1987, 1988; John and Mukasa, 1990; John and Wooden, in press) mapped 10 km west of the map area

Yd **Ophitic diabase dikes (Middle Proterozoic)**--Shown only on cross sections. 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 and olive-brown or locally dark purplish brown. Dikes are 1 to 20 m thick, averaging 3.7 m where measured by Nakata (1982) in the Mohave Mountains. Most dikes dip steeply, subparallel to nonconformably overlying Tertiary strata where present in the same fault blocks, indicating that the dikes were subhorizontal prior to Tertiary tilting. Intrudes the coarse-grained granite unit (Ysg) and older rocks, and is intruded by biotite granodiorite (Kgd) and granite (TKg), and younger rocks. Correlative with Middle Proterozoic diabase intrusions and extrusions in Death Valley, the eastern Mojave Desert, Grand Canyon, and southern Arizona that are thought to be about 1100 Ma in age (Fitzgibbon and Howard, 1987; Fitzgibbon, 1988)

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

Ysg **Coarse-grained granite**--Red-weathering coarse-grained monzogranite characterized by coarse tabular gray to cream-colored 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, the Parker Dam granite of Anderson (1983) and Anderson and Bender (1989), dated by the uranium-lead method at 1401 Ma. Also resembles the porphyritic granite subunit of the augen gneiss unit (Xap). Grades to and locally cuts the 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, varies 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 orrelated with, the Bowmans Wash pluton of Anderson and Bender (1989) dated by the uranium-lead method at 1407 Ma

METAMORPHIC ROCKS

Augen gneiss (Early Proterozoic)--Coarse-grained to medium-grained biotite orthogneiss characterized by augen of alkali feldspar. Occurs in several bodies. Garnet occurs in small bodies north of the 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 the Bill William Mountains that yielded a U-Pb age (zircon) of 1642 Ma (table 1, no. 36; Wooden and Miller, 1990). The unit tends to be least metamorphosed and most felsic where closest to the Proterozoic-Tertiary nonconformity. Bodies southeast of Lake Havasu City and in the Bill Williams Mountains are accordingly divided into gradational lithotypes varying subtly in degree of metamorphic fabric development and in modal mineralogy (fig. 6). The gradational variation is interpreted as reflecting a paleodepth profile before Tertiary tilting. Divided into:

Xap **Porphyritic granite unit--**The 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 the northwest part of the map area (Howard and others, 1982a, fig. 8 photo). Small body of syenogranite in the 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 the 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 the Bill Williams Mountains. Cut by the ophitic diabase dikes (Yd). Cut in Fall Springs Wash (Mohave Mountains) by undeformed veins of aplite and pegmatite, and in the Bill Williams Mountains by veins of garnet-bearing pegmatite resembling the 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 the Buck Mountains unit includes unmapped other kinds of gneiss; quartz in the augen gneiss is bluish or purplish and occurs 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 the following units also includes rocks characteristic of the 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 the rock may have been metamorphosed to high grade

Xgp **Pegmatite and monzogranite**--In the northwestern part of the map area the unit consists of medium-grained light-colored foliated monzogranite and associated pegmatite; the 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 the 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, containing cummingtonite rimmed by hornblende, pseudomorphs consisting of hornblende, clinozoisite, white mica, and cummingtonite, and rarely augite. Small unmapped bodies occur throughout most of the gneiss units. K-Ar numerical age of 1372 Ma on hornblende in the 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-grained 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 the spotted leucocratic gneiss unit (Xgl). Resembles the gneiss of Virginia May mine in the Turtle Mountains, California, 50 km southwest of the 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 the metasedimentary rocks unit (Xgs)

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Table 1. K-Ar and fission-track (FT) numerical ages (Nakata and others, in press) and a U-Pb age (map no. 36) determined by Wooden and Miller (1990).
Asterisk indicates ages that are considered unlikely to represent crystallization age.

Map no.	Map unit	Sample no.	Latitude (34 o)	Longitude (114 o)	Rock type	Method	Material dated	Age, Ma	
1	Tob	P81MH-8A	30.7'	4.5'	basalt	K-Ar	whole rock	11.1 +/- 0.3	
2	Tr	JP82MH-23	27.7'	3.5'	tuff	K-Ar	sanidine	12.7 +/- 0.6	
3	Tbt	H81MH-18	40.9'	18.7'	basalt	K-Ar	whole rock	14.6 +/- 0.4	
4	Tps	JP80MH-192	37.8'	20.7'	tuff	K-Ar	sanidine	17.6 +/- 0.4	*
4	Tps	P81MH-2	37.8'	20.7'	tuff	K-Ar	sanidine	18.0 +/- 0.5	
5	Tadf	JP81MH-388B	33.8'	19.5'	tuff	K-Ar	plagioclase	17.9 +/- 0.5	
6	Tadf	JP81MH-378	35.4'	21.1'	latite	K-Ar	biotite	19.9 +/- 0.5	
7	Tps	JP81MH-159	30.7'	5.2'	tuff	K-Ar	biotite	18.7 +/- 0.7	
8	Tfts	JP81MH-14A	29.7'	14.6'	basalt	K-Ar	whole rock	17.9 +/- 0.7	
9	Tfts	JP81MH-296	35.5'	22.0'	rhyolite	K-Ar	biotite	19.2 +/- 0.5	
		"			"	K-Ar	hornblende	16.3 +/- 0.4	*
10	Tfts	JP80MH-223	37.5'	20.0'	perlite	K-Ar	biotite	19.1 +/- 0.6	
		"			"	K-Ar	hornblende	17.2 +/- 0.7	*
11	Tfts	JP80MH-139	28.2'	12.0'	perlite	K-Ar	biotite	20.5 +/- 1.6	
		"			"	K-Ar	hornblende	18.8 +/- 0.5	
12	Tfts	JP81MH-361	38.0'	18.6'	volcanic breccia	K-Ar	biotite	48.0 +/- 1.2	*
13	Tap	JP80MH-187	37.8'	20.5'	latite porphry	K-Ar	whole rock	19.8 +/- 0.6	
14	Tdr	P81MH-1	36.5'	21.2'	rhyolite	K-Ar	plagioclase	15.1 +/- 0.4	
15	Tdm	JN81MH90-2	33.7'	6.3'	diorite	K-Ar	hornblende	22.6 +/- 0.7	
						"	"	26.9 +/- 0.7	*
15	Tdm	JN81MH90-2A	33.7'	6.3'	diorite	K-Ar	hornblende	21.7 +/- 0.7	
16	Tdap	BLM-139-8	34.5'	8.8'	andesite	K-Ar	plagioclase	42.7 +/- 1.1	*
17	Tda	BLM-163-35	35.8'	11.3'	andesite	K-Ar	whole rock	78.1 +/- 2.0	*
18	Tda	BLM163A	35.3'	11.6'	andesite	K-Ar	whole rock	42.9 +/- 1.1	*
19	Tda	P81MH-15B	33.0'	11.6'	microdiorite	K-Ar	whole rock	42.0 +/- 1.3	*
20	Tda	H83MH-66	33.6'	5.8'	microdiorite	K-Ar	hornblende	29.2 +/- 0.7	*
21	Tdl	BLM-190-8	32.4'	14.5'	dacite	K-Ar	whole rock	18.4 +/- 0.5	*
		" "			"	"	" (acid)	11.3 +/- 0.3	*
22	Tdl	H81MH-5	36.3'	15.5'	dacite	K-Ar	biotite	19.8 +/- 0.5	
23	Tdl	H81MH-39	32.5'	12.4'	dacite	K-Ar	biotite	19.2 +/- 0.5	
24	Tdl	H82MH-15	36.2'	11.0'	dacite	K-Ar	biotite	20.8 +/- 0.5	
25	Tgd	H82MH-57B	34.2'	9.1'	quartz diorite	K-Ar	biotite	21.5 +/- 0.5	
26	TKg	H80MH-310	37.4'	16.6'	granite	K-Ar	biotite	18.1 +/- 0.5	
		"			"	FT	zircon	16.6 +/- 1.7	*
27	TKd	H80MH-311	37.7'	16.7'	diorite	K-Ar	hornblende	32.0 +/- 1.0	*
28	TPd	P81MH-20	32.4'	9.8'	rhyolite	K-Ar	biotite	62.3 +/- 1.6	
29	TPd	G81BW-167	23.6'	5.2'	microdiorite	K-Ar	hornblende	332 +/- 16	*
30	Xag	P81MH-21B	31.2'	14.1'	altered gneiss	K-Ar	sericite	54.9 +/- 1.4	*
30	Xag	P81MH-21C	31.2'	14.1'	altered gneiss	K-Ar	sericite	65.0 +/- 1.6	*
		"			"	FT	zircon	78.0 +/- 9.0	*
30	Xag	P81MH-21A	31.2'	14.1'	altered gneiss	K-Ar	white mica	91.4 +/- 2.3	
30	Xag	P81MH-21D	31.2'	14.1'	altered gneiss	K-Ar	white mica	89.7 +/- 2.2	
31	Xgl	K81MH-36	32.1'	10.2'	altered gneiss	K-Ar	white mica	92.0 +/- 2.3	
32	Xgb	K81MH-62A	34.9'	17.1'	altered rock	K-Ar	white mica	102 +/- 3	
33	Ysqn	P81MH-9	28.0'	9.1'	granodiorite	FT	zircon	46.4 +/- 5.4	*
34	Xag	H81BW-25	24.3'	7.2'	gneiss	K-Ar	biotite	130 +/- 4	*
		"			"	FT	zircon	81.7 +/- 8.7	*
35	Xag	P81MH-22	29.2'	13.8'	gneiss	K-Ar	biotite	111 +/- 3	*
36	Xag	H81BW-174	24.0'	7.9'	augen gneiss	U-Pb	zircon	1640	
37	Xagd	H82MH-16	36.2'	11.1'	gneiss	K-Ar	biotite	49 +/- 11	*
38	Xagd	P81MH-6	37.2'	17.3'	augen gneiss	K-Ar	biotite	66.7 +/- 1.7	*
		"			"	FT	zircon	22.6 +/- 1.9	*
39	Xagd	P81BK-12	41.6'	8.8'	augen gneiss	K-Ar	biotite	120 +/- 3	*
40	Xagd	H87MH-29	33.0'	13.6'	augen gneiss	K-Ar	biotite	188 +/- 5	*
41	Xagd	H81BK-7A	39.6'	9.5'	gneiss	K-Ar	biotite	264 +/- 7	*
		"			"	FT	zircon	81.6 +/- 8.6	*
42	Xgp	P81MH-10	38.4'	21.5'	granite	K-Ar	biotite	597 +/- 11	*
43	Xga	P81BK-13	41.8'	8.9'	amphibolite	K-Ar	hornblende	1372 +/- 41	*
44	Xga	H83MH-67	33.5'	5.9'	amphibolite	K-Ar	hornblende	104 +/- 3	*
45	Xgl	H87MH-30	33.2'	12.6'	leucogneiss	K-Ar	biotite	116 +/- 3	*

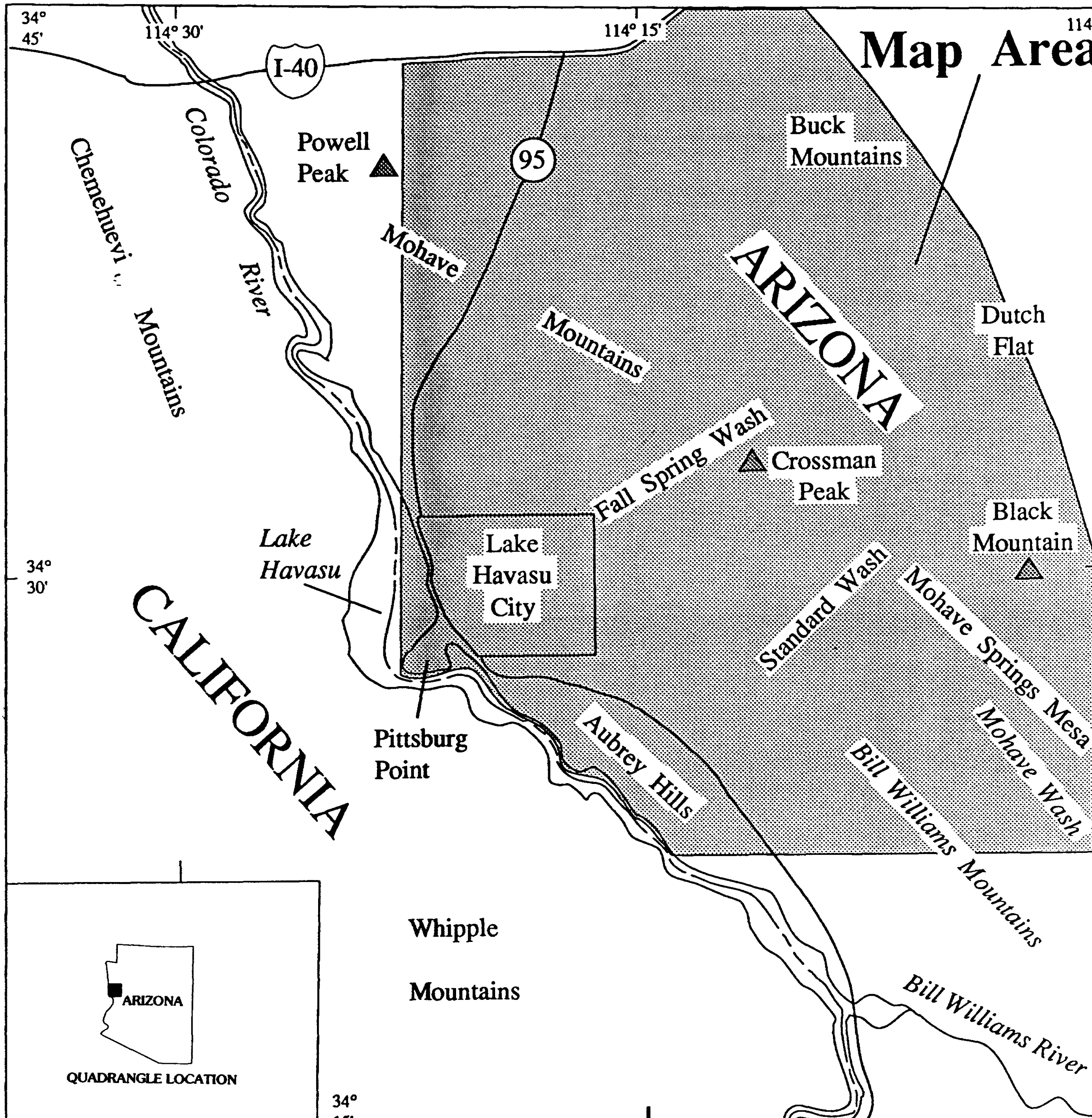


Figure 1. Location map.

Figure 2. Index map of geographic features.

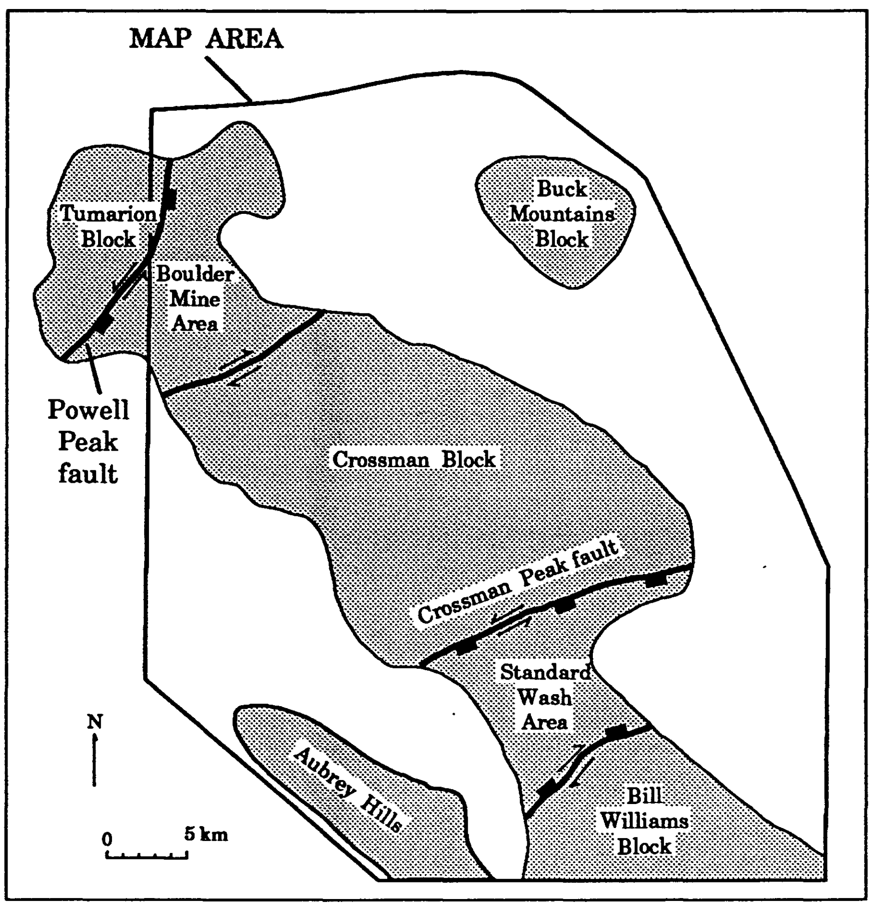


Figure 3. Generalized tectonic map showing tilt blocks and major faults.

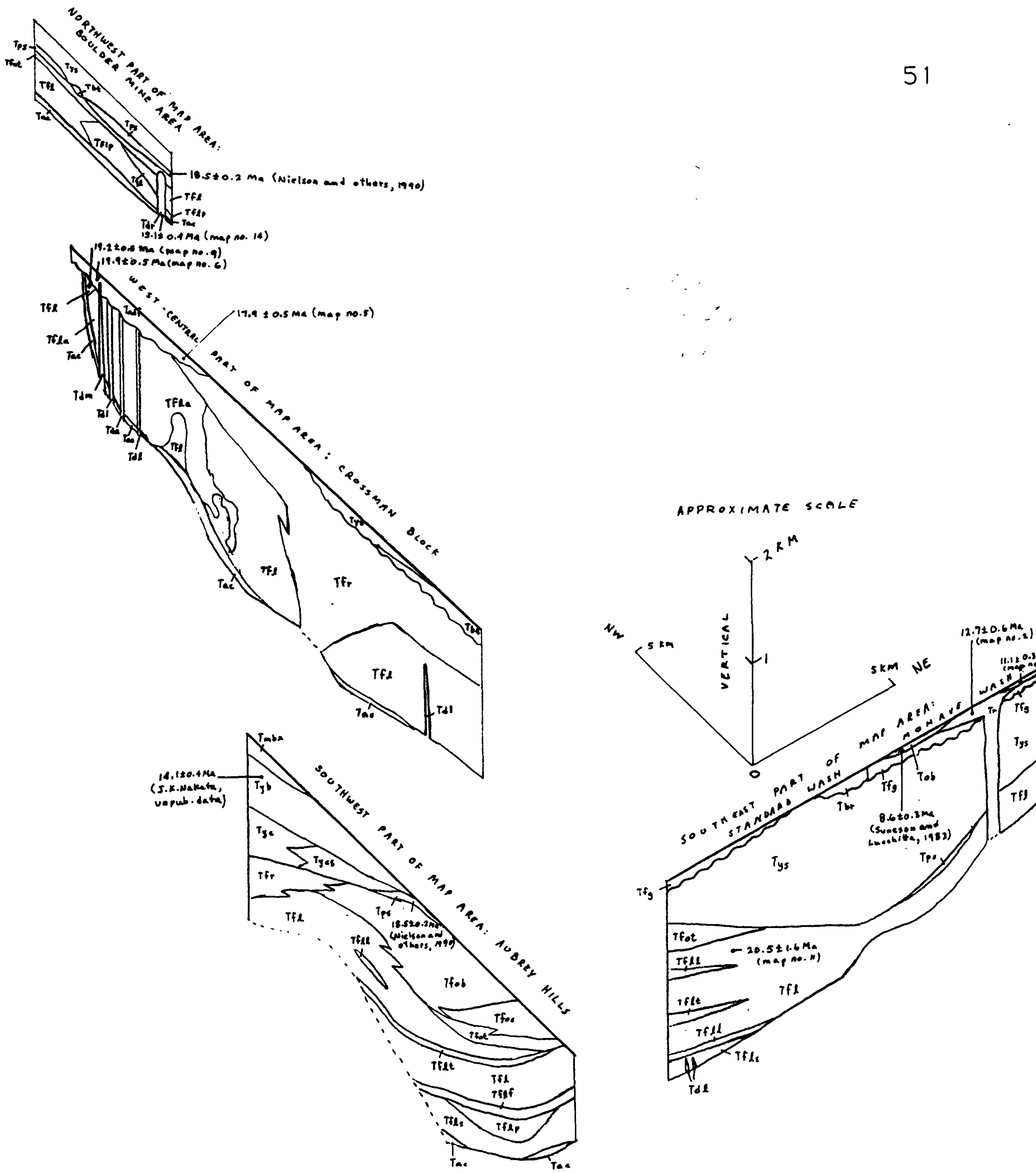
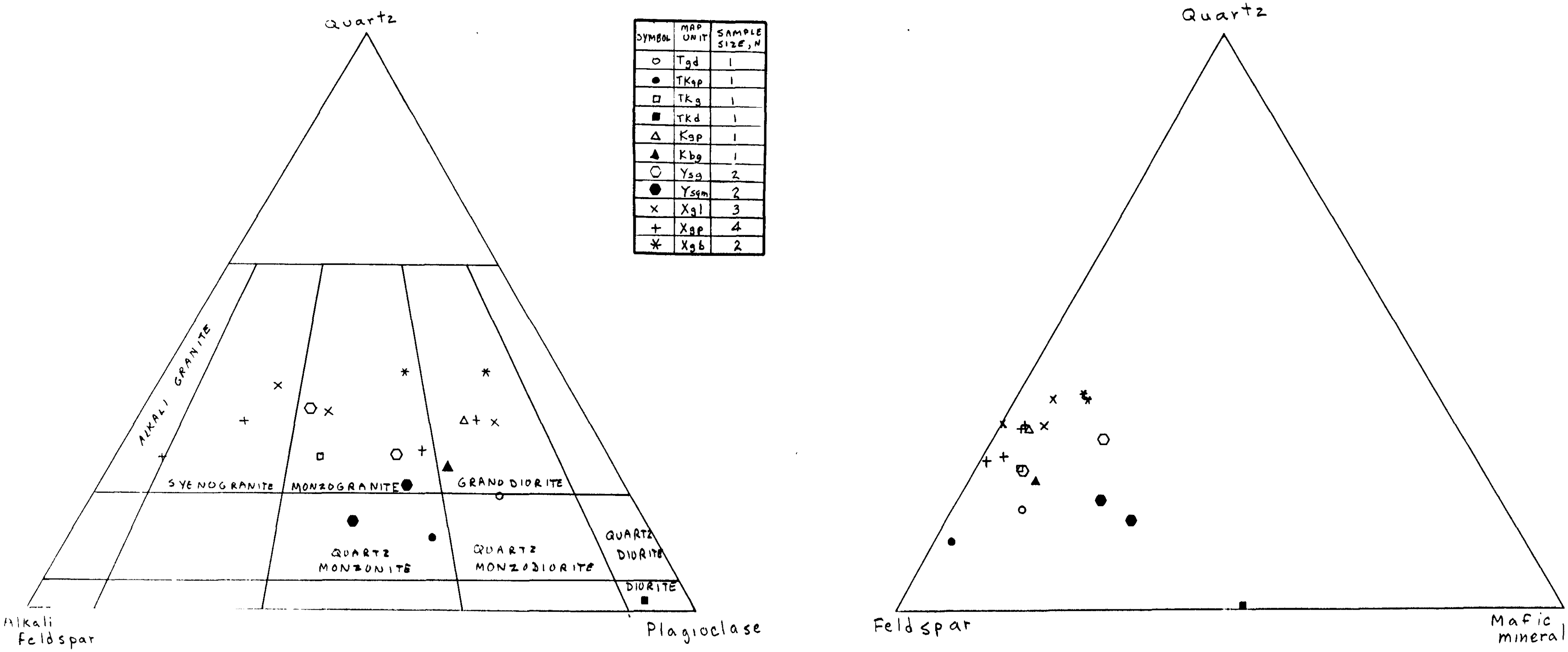


Figure 4. Interpretive stratigraphic cross sections showing relationships among subdivided Tertiary units that pre-date the Bouse Formation. Markedly angular unconformities in the sections are shown by wavy lines.



SYMBOL	MAP UNIT	SAMPLE SIZE, N
○	Tgd	1
●	TKgp	1
□	Tkg	1
■	TKd	1
△	Kgp	1
▲	Kbg	1
⬡	Ysg	2
⬢	Ysgm	2
×	Xgl	3
+	Xgp	4
✳	Xgb	2

Figure 5. Modal composition of plutonic rock units, based on an average of 1000 points counted on stained slabs. See Figure 6 For the augen gneiss unit. IUGS classification (Strekeisen, 1973).

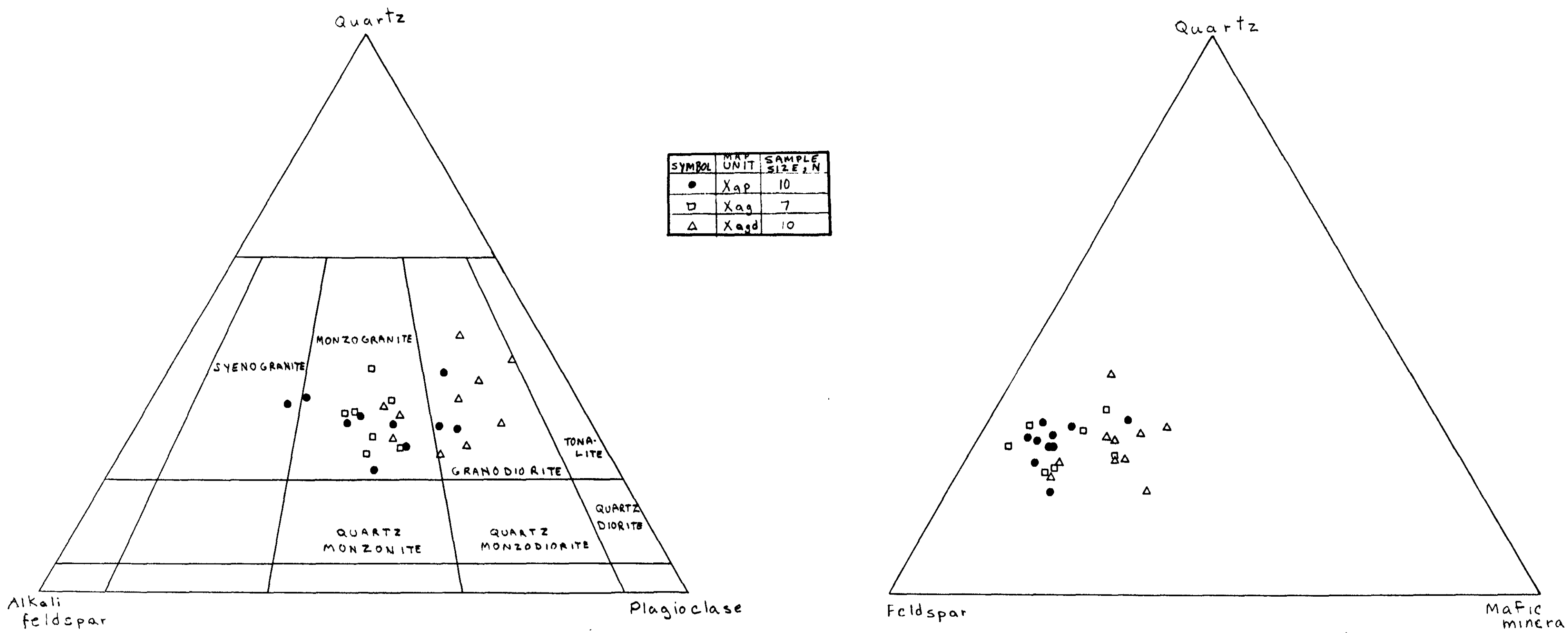
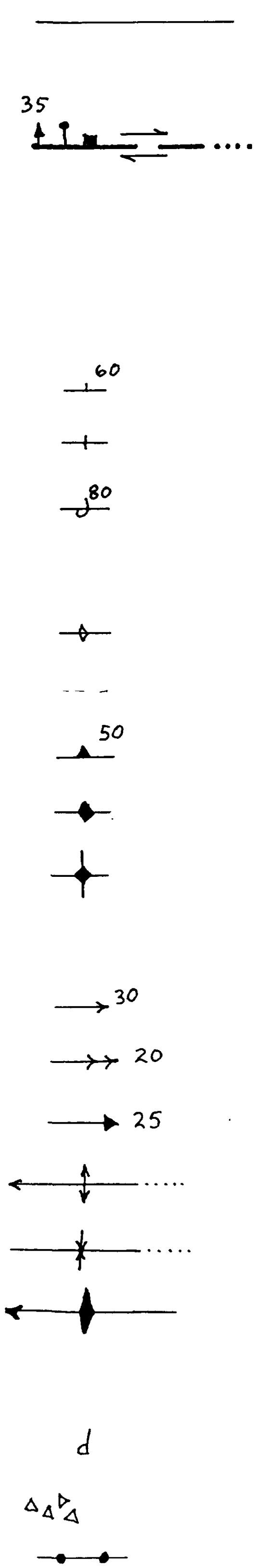


Figure 6. Modal composition of the augen gneiss unit, based on an average of 1000 points counted on stained slabs. IUGS classification (Streckeisen, 1973)

SYMBOLS



Contact

Fault--Showing 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

Inclined

Vertical

Overturned

Strike and dip of igneous foliation

Vertical

Strike and dip of metamorphic foliation

Inclined

Vertical

Horizontal

Trend and plunge of lineation--May be combined with foliation symbol

Mineral lineation

Mylontic lineation

Fold axis

Anticline--Showing plunge. Dotted where concealed

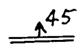
Syncline--Dotted where concealed

Antiform--Showing plunge. Defined by gneissic foliation and map patterns of metamorphic rock units

Disturbed ground--Urbanized area

Brecciated rock--Tectonic breccia

Quartz vein

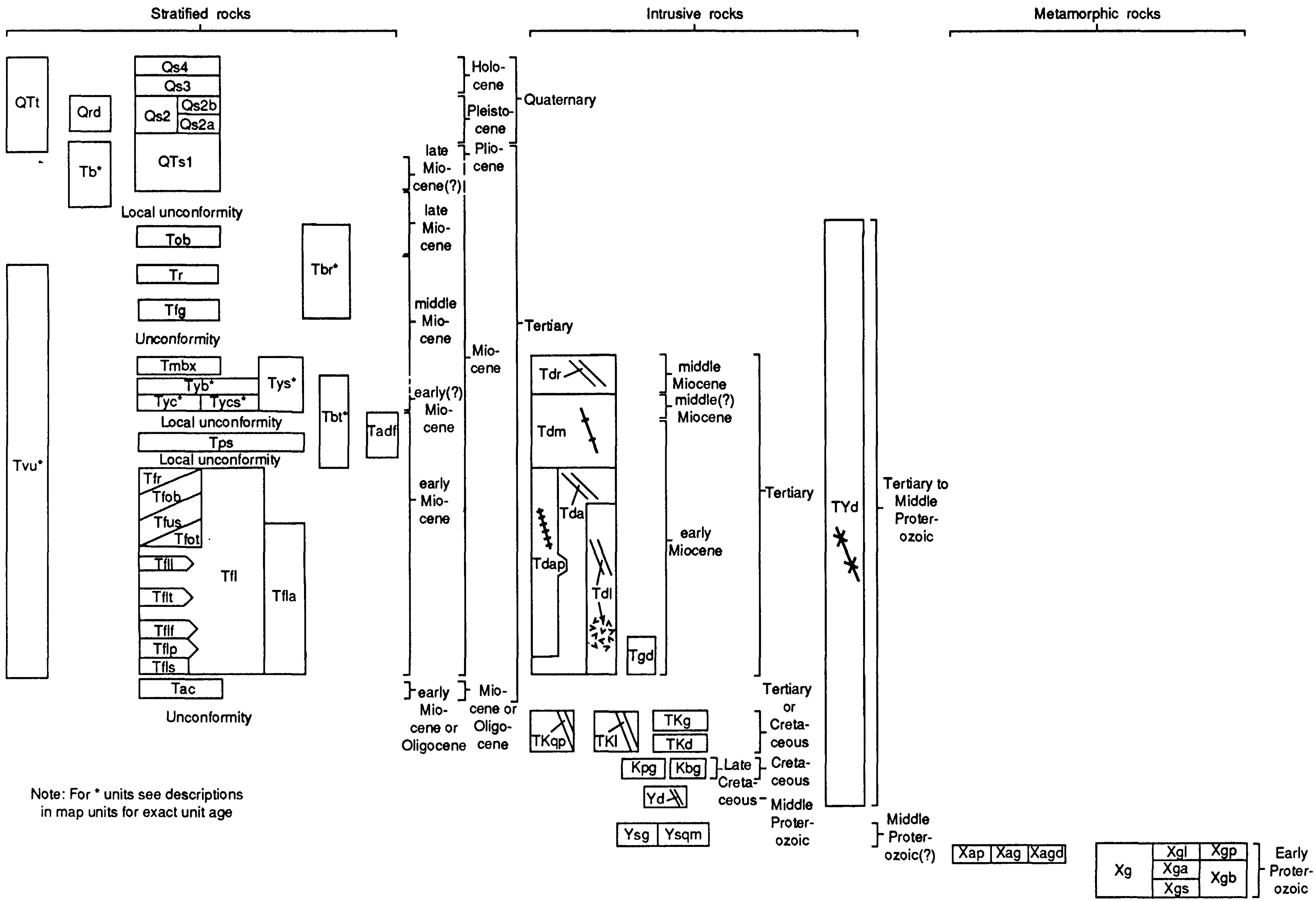
 **Dip of dike**

3 △ **Locality of dated sample(s)**--Listed in Table 1

Note on Numerical Ages in Table 1

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

CORRELATION OF MAP UNITS



Note: For * units see descriptions in map units for exact unit age