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Preliminary Geologic Map of the Eastern and Northern Parts of the Topock 7.5-minute Quadrangle Arizona and California

by

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Geology mapped by J.E. Nielson (1981, 1982, 1990) assisted by V.L. Hansen (1981); K.A. Howard and B.E. John (1980, 1981, 1989, 1990).

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DESCRIPTION OF MAP UNITS

SEDIMENTARY AND VOLCANIC ROCKS AND DEPOSITS

d **Disturbed materials (Holocene)**--In northwest corner of map area. Manmade levees in Topock Marsh

Qs **Windblown sand (Holocene)**--In northern third of map area. Loose, medium to coarse sand. Locally pebbly where mixed with lag of alluvium on terraces above Sacramento Wash

Alluvial units--Sandy and gravelly deposits of local streams and fans. Subdivided into four units. From youngest to oldest, these units correspond to units mapped in the adjacent Mohave Mountains area to the east as Qs4, Qs3, Qs2, and QTs1 (Howard and others, 1990; in press)

Qy **Youngest alluvium (Holocene)**--In modern washes and alluvial aprons. Angular to subangular, poorly to moderately sorted, unconsolidated sand and gravel. Composed of material derived from Proterozoic and Mesozoic rocks and Tertiary volcanic rocks. Deposits mostly undissected to slightly dissected

Qya **Younger alluvium (Holocene)**--Forms surfaces of undissected fans. Surface small-scale relief commonly expressed as bar-and-swale landforms. Angular to subangular, poorly to moderately sorted, unconsolidated sandy gravel. Derived locally from Proterozoic and Cretaceous rocks and Tertiary volcanic rocks

Qoa **Older alluvium (Pleistocene)**--Scattered throughout the map area. Isolated deposits that are dissected by modern streams. Consists of angular to subangular, moderately sorted poorly consolidated sand and gravel. Generally forms terraces surfaced by desert pavement of varnished stones. May locally include deposits as young as Holocene. Forms thin veneers above oldest alluvium unit on terraces

Qo **Oldest alluvium (Pleistocene)**--In northern third of map area and southern end of map area. Deeply dissected deposits up to tens of meters thick. Angular to subangular, poorly sorted cobble and boulder gravel and pebbly sandstone. Clasts mostly locally derived. Overlies and interfingers with river sand and gravel (units Qrs and Qrg). In southwestern corner of south end of map area, surface of deposits appears graded to high-standing deposits of river gravel (Qrg). On terraces south and north of Sacramento Wash in north part of the map area, forms a capping deposit (above Qrg and Qrs) containing cobbles and boulders of basalt derived from the Black Mountains and gneiss types derived from the Hualapai Mountains. Sparse rounded clasts of exotic quartzite and limestone on interfluves near Sacramento Wash may either be part of the deposit or a result of post-depositional colluvial mixing with river gravel (Qrg). Northwest of Powell siding in northeast part of the area, includes well-sorted gravel containing subrounded clasts of basalt and gneiss, interpreted as a fluvial deposit from ancestral Sacramento Wash. In the northeast part of the map area south of Powell siding, basal part overlying Bouse Formation is calcareous pebbly sandstone 8 m thick. Pleistocene age inferred; may include deposits as old as Pliocene

River deposits of the modern and ancestral Colorado River

Qrf **Floodplain silt and sand (Holocene)**--In northwestern part of the map area. Unconsolidated silt, mud, and sand in the modern floodplain of the Colorado River. Backwater from the 1938 closure of Parker Dam accounts for much of a 20th-century rise of 5-8 m in the average river stage near Topock (Metzger and Loeltz, 1973); this documented rise in level suggests that the river bed and the upper few meters of the floodplain unit have aggraded historically

Gravel and sand (Pleistocene)--Deposits of the ancestral Colorado River. Mammoth fossils (*Mammuthus meridionalis*) found at Topock (at Arizona abutment of Santa Fe Railway Colorado River bridge) and north of map area at Golden Shores suggest deposition of part of them unit during the Irvingtonian (Pleistocene) land-mammel age (Agenbroad and others, 1992). Equivalent to units B, D, and E of Metzger and Loeltz (1973) and in part with the Chemehuevi Formation of Longwell (1936). Divided lithologically into:

Qrg **Gravel**--In northwestern and southern parts of the map area. Well sorted deposits of sand and gravel. Pebbles and cobbles are well-rounded, mostly consisting of far-traveled clasts, including quartzite and lesser amounts of limestone and chert; other clasts consist of more locally derived gneissic and volcanic rocks. At west side of map area west of Topock Bay, includes rounded boulders of gneiss as large as 0.9 m in diameter (Metzger and Loeltz, 1973, fig. 11). Occurrence of unit at elevations as high as ~80 m above present river indicates ancestral river-bed level. Most occurences overlie unit Qrs, but according to Metzger and Loeltz (1973) some occurrences (including the boulder gravel described above) underlie deposits assigned to unit Qrs

Qrs **Sand (Pleistocene)**--In northwestern part of map area. Pinkish to tan and buff, weakly to moderately consolidated sand, silt, and clay, containing interbeds of well-sorted rounded-pebble gravel. Locally contains concretions and gypsum crystals. Gravel and sand cross-bedded. Rests on locally derived, well indurated undeformed fanglomerate of unit Qo and on river gravel (Qrg). Near Topock, about 0.5 km south of west end of map area, unit contains charcoal, and an internal paleosol with root casts. Contains abundant trace fossils 0.3 km north of northwest part of map area. Generally interfingers with and underlies Qrg and Qo, but stratigraphic relations with these units are uncertain in some areas. Lithologically indistinct from parts of Bouse Formation. At Park Moabi 0.9 km west of northwest part of map area, pinkish sands assigned to Qrs overlie the Bouse unconformably.

Tb **Bouse Formation (Pliocene)**--Bedded green clay, tan siliceous claystone, and tan to pinkish sandstone, with minor green nodules and yellowish-brown and white concretions. North of Powell Peak in sec. 19, T. 16 N., R. 20 W., basal white marl 3-4 m thick overlies pre-Tertiary rocks and dips 15° north. Drilled thickness of the Bouse between overlying gravels and underlying fanglomerate in two wells in north-central part of map area is 77 m (sec. 11, T. 16 N., R. 20 1/2 W) and 57 m (sec.14, T. 16 N., R. 20 1/2 W) (Metzger and Loeltz, 1973).

Tst **Sedimentary rock and tuff (middle and early? Miocene)**--In southeastern part of map area. Well-bedded sandstone, poorly sorted sandy conglomerate, and interbeds of tuff. Conglomerate pebbles and rarer cobbles include angular to subangular volcanic rocks of mafic and intermediate composition, and locally, rounded boulders derived from Peach Springs Tuff. About 1.5 km northwest of Yucca Mine (SW corner sec. 8, T. 15 N., R. 20 W.), unit is coarsely-bedded to massive sandstone, pebbly sandstone, conglomeratic sandstone, and cobble to boulder conglomerate, probably deposited as mud flows and debris flows on irregular erosional surface. In lower part of unit, subangular to subrounded clasts are predominantly derived from basalt, pumice, and Peach Springs Tuff; upper part contains a greater proportion of gneiss and granite clasts. Sandy matrix is at least 50% pumice, and also contains quartz grains and feldspar crystals. Layers in lower part vary from coarse sandstone to matrix-supported conglomerate, with clast sizes coarsening upward; many large blocks are oriented with long axes vertical. Some clast-supported pebbleconglomerate is entirely volcaniclastic, composed largely of fragments of oxidized and fresh basalt mixed with light-colored pumice, probably reworked from lapilli tuff deposits. Northeast of Yucca Mine, a thick lens of massive matrix-supported conglomerate, possibly a lahar deposit, consists of subrounded boulders of Peach Springs Tuff more than 1 m across and large cobbles and boulders of basalt and other volcanic rock types. This lens is overlain by well-bedded coarse sandstone and conglomeratic sandstone, mostly volcaniclastic. Above, in upper part of unit, matrix contains abundant rounded quartz sand in addition to dominant volcanic grains; gneiss and granite clasts may be as abundant as volcanic rock types and the content of basement clasts larger than 10 cm is greater than in lower part of the unit. Thin beds of airfall tuff are interbedded in the upper part. Thickness, 60-80 m

Tp **Peach Springs Tuff of Young and Brennan (1974) (early Miocene)**--In southern part of the map area. A single flow and cooling unit of welded rhyolite ashflow tuff. Phenocrysts are dominantly sanidine (commonly adularescent blue), and lesser quartz, plagioclase, biotite, hornblende, and sphene. Basal vitrophyre present locally. Forms resistant pinkish ridges, cliffs, and rock slopes

Lower volcanic sequence (early Miocene)--Includes subvolcanic intrusions. Divided into:

Tvm **Mafic intrusive rocks**--Sills and dikes hosted by the other units of lower volcanic sequence. Unmapped similar intrusions also occur in other Miocene volcanic units, especially Tvi. Extrusive equivalents high in the pre-Peach Springs Tuff section are included in basalt and tuff (Tvbt) and volcanic and intrusive rocks (Tvi) units

Tvbt **Basalt and tuff**--Basalt flows and light-colored silicic tuff. The basalt is extrusive equivalent of mafic intrusive rocks (Tvm) unit, and the tuff is equivalent to tuff mapped separately as Tvt. Basaltic flows have intersertal to holocrystalline groundmass rich in plagioclase; some glassy samples show seriate size distribution of groundmass plagioclase. All flows contain plagioclase phenocrysts and most flows also have sparse large glomerocrysts of intergrown pyroxene grains. Olivine present as rare small grains, most of them altered to red clay. Red clay also forms veinlike masses within groundmass. Underlies Peach Springs Tuff

Tvt **Tuff**--Light-colored silicic airfall tuff and tuff breccia. Massive to thinly bedded, locally coarse-grained. Silicified zones are ubiquitous. Underlies Peach Springs Tuff

Tvi **Volcanic and intrusive rocks**--Tuff, sedimentary rocks, and lava flows (equivalent to Tvt, Tvts, Tvf, and Tvbt), intruded by abundant mafic sills and dikes (equivalent to Tvm). Tuff is replaced by jasper near abundant intrusions at the Yucca mine and 1 km to the northwest

Tvts **Tuff and sedimentary rock**--Buff-colored air-fall and ashflow tuff, conglomerate, and sandstone. Thin basal red conglomerate and siltstone conformably overlie lava flows unit (Tvf). Bulk of unit consists of tuffaceous conglomerate hundreds of meters thick that intertongues with pumice-rich silicic welded tuff. Clast imbrication in tuff locally suggests ash-flow transport to the southwest. Replacement jasper is abundant in SE 1/4 NW 1/4 sec. 18, T. 15 N, R. 20 W.

Tvf **Lava flows**--Mafic and intermediate flows. Largely basalt and basaltic andesite, and lesser andesite, dacite, and latite; predominantly porphyritic. Some light colored intermediate flows have felted feldspar-rich groundmass and abundant magnetite grains, sparse plagioclase phenocrysts, and rare black pyroxene phenocrysts. Locally these flows have trachytic texture. Other flows and flow breccia have very fine-grained plagioclase-rich groundmass that also contains apatite and magnetite, and phenocrysts of plagioclase, hornblende (locally oxyhornblende), and biotite. Plagioclase phenocrysts may be very large (up to 6.5 mm), but mafic minerals are smaller (hornblende 2 mm or less, biotite in yet smaller dispersed flakes). Hornblende grains may contain abundant needles of apatite. Massive flows are characterized by euhedral phenocrysts, but phenocrysts in flow breccia show incipient fragmentation. Darker flows consist of andesite or latite with plagioclase-rich groundmass, locally abundant, large (1 to 3 mm length) plagioclase phenocrysts, and smaller phenocrysts of dark green pyroxene. Pyroxene phenocrysts are sparse or absent. Tabular plagioclase phenocrysts locally are aligned so that weathered outcrops display "jackstraw" texture. Mafic minerals are partly altered to red clay. Rests unconformably on pre-Tertiary rocks. Overlain conformably by the tuff and sedimentary rocks (Tvts) unit

Tva **Volcanic agglomerate**--Small isolated exposure in the central part of the area (N 1/2 sec. 26, T. 16 N., R. 20 1/2 W.). Red, andesitic or latitic, matrix-supported breccia. Lahar deposit. Similar rock near Topock Gorge west of map area forms basal part of Tertiary section resting unconformably on pre-Tertiary rocks

INTRUSIVE AND METAMORPHIC ROCKS

Tdl **Light-colored dikes (Miocene)**--Leucocratic dacitic dikes mostly 2.5 to 15 m thick. Plagioclase and rare rounded quartz phenocrysts, about 1 mm in diameter. Cuts biotite granodiorite (Kcb) and older units. East-striking dike in west-central part of map area cuts a Miocene fault (just west of map area) related to Gold Dome fault zone. Cuts dikes of biotite lamprophyre (TKl) unit

Tdm **Mafic dikes (Miocene)**-- Dikes of mafic rocks, including lamprophyre, that intrude pre-Tertiary host rocks. Locally vesicular. Locally with trachytic texture. Some unmapped dikes intrude Miocene faults in the Gold Dome and other fault zones. Thickness of mapped and unmapped dikes ranges from 0.4 to 3 m, averages 1 m.

TYd **Dark dikes (Tertiary to Proterozoic)**--In central part of map area. Mapped largely from air photographs. Includes dark lamprophyre dikes that cut biotite granodiorite (Kcb) unit

TKq **Quartz porphyry (Tertiary or Cretaceous)**--Microgranite. In central part of map area, forms small stocks or irregular bodies elongate east-west. In east-central part of map area includes a northeast-striking dike. Rock is light-colored. Phenocrysts (as much as 35 percent) of quartz and commonly biotite, sphene, plagioclase, and orthoclase in very fine-grained (0.05-0.01 mm) groundmass. Cuts biotite granodiorite (Kbg) and older units

TKf **Fine-grained granite (Tertiary or Cretaceous)**--Forms two small stocks in central part of map area. Fine-grained, very light-gray, equigranular biotite granite. Cuts Proterozoic gneiss (Xg)

TKl **Biotite lamprophyre (Tertiary or Cretaceous)**--In east-central part of map area. Steeply northwest-dipping lamprophyre dikes, typically 1 to 1.5 m thick, cut Powell Peak Pluton and its host rocks. One moderately (55°) east-southeast-dipping quartz- and plagioclase-bearing dike cuts Borrow Pit plutonic body and is in turn cut by a dike of the leucocratic dike (Tdl) unit. Dikes commonly occur as families of closely-spaced parallel dikes. Dark rock containing 1- to 4-mm hornblende and bronze-colored (locally poikilitic) biotite phenocrysts in fine-grained (0.2 mm) matrix. Locally spherulitic, exhibits elongate amygdules, and has finer-grained chilled margins. Age relative to 90° of Miocene tilting is unknown; if pre-tilt, the 75° west-northwest dip exhibited by most dikes would restore to vertical, east-northeast strike

Chemehuevi Mountains Plutonic Suite

Kcb **Biotite granodiorite (Late Cretaceous)**--Forms Powell Peak Pluton in the east part of the area, a small outlier 1 km west of Powell Peak, and a pluton here called the Borrow Pit body 3.5 km northwest of Powell Peak. Light-gray, medium-grained (2-3 mm), equigranular granodiorite to locally monzogranite. Rarely contains K-feldspar phenocrysts 5 mm across. Feldspars white. Color index 5-9 percent, mostly 6-7 percent. Contains abundant accessory sphene and sparse allanite. Contains small amount of hornblende in some northwestern exposures of Powell Peak Pluton and western exposures of Borrow Pit body. Hypidiomorphic granular. Plagioclase shows oscillatory zoning. Small outlier 1 km west of Powell Peak is fine-grained porphyrytic, with interstitial quartz and rare quartz phenocrysts 2 mm across. SiO_2 content of sample H80Mh-287 reported by John and Wooden (1990) is 68 percent. Margins show no evidence of chilling, but locally adjacent rocks (KYq) exhibit hornfels recrystallization. Locally interleaved with adjacent gneisses or extends many apophyses into gneisses. Veins, alteration, and intrusive breccia originating from the Borrow Pit body affect the diorite of Topock (Kt), indicating that the diorite of Topock is older. Powell Peak Pluton shows chilled fine-grained porphyritic textures against the hornblende-biotite granodiorite (Kch). Also intrudes the diorite (Kwd). Southeast of Powell Peak, has thin, gently east-southeast-dipping mylonitic gneiss zone exhibiting northeast-trending lineation. K-Ar age of biotite from small body 1 km west of Powell Peak (sample H81MH-154) is 72.0 $\pm$ 1.8 Ma (Nakata and others, 1990). Correlated with biotite granodiorite unit (John, 1987b, John and Wooden, 1990) of Chemehuevi Mountains Plutonic Suite in the Chemehuevi Mountains, dated as Late Cretaceous (~70 Ma) by John and Mukasa (1990)

Kch **Hornblende-biotite granodiorite (Late Cretaceous)**--Forms a small body bordering the Powell Peak pluton 1 km south of Powell Peak. Gray, medium-grained, equigranular hornblende-biotite granodiorite; contains accessory sphene. Color index ~25 percent. Mafic minerals clotted in anhedral masses. Alined mafic minerals define vague igneous foliation. Intruded by biotite granodiorite (Kcb) unit. Here considered to be a border phase of Powell Peak Pluton and broadly correlative with Chemehuevi Mountains Plutonic Suite

Whale Mountain sequence(?) of John (1987b)

Kwd **Diorite (Cretaceous?)**--In the northeastern part of map area. Medium-grained (2-5 mm), equigranular biotite-hornblende diorite to quartz diorite. Color index

15-35 percent. Subhedral to euhedral bronze-colored biotite and black hornblende. Contains abundant inclusions and screens of gneiss and amphibolite. Primary foliation parallels steep southern intrusive contact against the older KYg unit. Also cuts diabase unit (Yd). Intruded by biotite granodiorite (Kcb) unit. Biotite date of 82 Ma by $^{40}Ar/^{39}Ar$ (D.A. Foster, written commun., 1994--sample BJ89MH-3) is interpreted as a minimum age of intrusion. Resembles and is tentatively correlated with rocks of Whale Mountain sequence of John (1987b; John and Wooden, 1990) in the Chemehuevi Mountains

Kt **Diorite of Topock (Cretaceous?)**--Forms small (1-km) pluton and satellite bodies in west-central part of the area and beyond map area to the west and south. Dark gray, fine-grained (0.2-0.3 mm) biotite-hornblende microdiorite to micro-quartz diorite. Color index 10-30 percent. Biotite is conspicuous in outcrop, locally poikilitic. In thin section, plagioclase laths show trachytic texture. Silica content (one analyzed sample, just west of map area) 57 percent; percentages of other oxides indicates chemical dissimilarity from analyses of Whale Mountain sequence of John (1987b) published by John and Wooden (1990). Intrudes Proterozoic gneiss and granite, and is intruded by biotite granodiorite (Kcb) unit (Borrow Pit body) and abundant Tertiary dikes

KYg **Granite (Cretaceous? to Middle Proterozoic?)**--North of Powell Peak in northeastern part of map area. Biotite to hornblende-biotite monzogranite. Equigranular; grain size 2-4 mm. Mafic crystals appear ragged. Color index about 5 percent. Intruded by diorite (Kwd) and biotite granodiorite (Kcb) units; intrudes or is gradational with quartz monzodiorite (KYq) unit. May be any age from Late Cretaceous to Middle Proterozoic

KYq **Quartz monzodiorite (Cretaceous? to Middle Proterozoic?)**--North of Powell Peak in northeastern part of map area. Equigranular hornblende-biotite quartz monzodiorite to tonalite. Grain size dominantly 2-3 mm with subequant horblende as long as 4 mm. Feldspar gray to pale purplish. Color index 15-20 percent. Mafic minerals appear ragged or clotted in hand specimen. Hornblende is rimmed by biotite. Hypidomorphic granular in thin section. Intruded by diorite (Kwd) and biotite granodiorite (Kcb). May be any age from Late Cretaceous to Middle Proterozoic

Yd **Diabase (Middle Proterozoic)**--Intrusive sheets averaging 3 m thick. Margins commonly sheared. Very dark gray rock, with ophitic texture; white plagioclase laths 2-5 mm long set in a black groundmass mostly of uralitic amphibole (secondary after pyroxene). Most sheets are steep, strike northwest, and restore to subhorizontal orientation before Miocene tilting (John and Howard, 1994). In thickest (45 m) sheet the plagioclase grains are locally concentrated in patches near the southwest side inferred to be the original top, and are as long as 10 mm (NW 1/4 sec. 25, T 16 N, R 20 1/2 W). Correlated with diabase widely distributed across Arizona and southeastern California dated about 1.1 Ga (Howard, 1991; Hammond, 1991)

Yg **Coarse-grained granite (Middle Proterozoic)**--In west-central part of map area. Coarse-grained, gray to red biotite-hornblende monzogranite and lesser medium-grained granite and quartz monzodiorite. Sphene-bearing. Mafic minerals recrystallized (hornfelsed?). Cut by diabase sheets and younger dikes, and by diorite of Topock (Kt)

Xag **Augen gneiss (Early Proterozoic)**--Forms large dike-like pluton in central part of map area and two small bodies in southern part of map area. Medium-gray to brownish; locally dark gray. Coarse-grained. Hornblende-biotite granodiorite to quartz monzodiorite in composition. Color index 14-25; or greater where margin of main pluton is locally dioritic and fine-grained (chilled) against older gneissic pegmatite. Contains cross-cutting pegmatite dikes. Contains inclusions of biotite gneiss, amphibolite, and leucocratic gneiss. Apophyses and dikes of augen gneiss from the large pluton cut across the foliation of adjacent leucocratic gneiss in the gneiss (Xg) unit. Biotite K-Ar age 863 $\pm$ 22 Ma and zircon fission-track age 73.8 $\pm$ 7.5 Ma (sample H81MH-155) considered as cooling (minimum) ages (Nakata and others, 1990). Resembles rocks dated as 1.64 Ga by U-Pb in the Bill Williams Mountains by Wooden and Miller (1990)

Xg **Gneiss (Early Proterozoic)**--Heterogeneous. Includes layered to massive, fine-grained, gray biotite granite gneiss, amphibolite, and mafic gneiss, all cut by younger leucocratic granite gneiss, gray biotite granite gneiss, and pegmatite. Unit locally subdivided according to dominant rock type; subunit boundaries gradational, approximately located, and cannot be used to estimate fault separations; subdivided into:

Xgl **Leucocratic gneiss**--Very light-gray medium-grained leucocratic granite gneiss and cross-cutting pegmatite. Both lithotypes commonly spotted with large (as wide as 1.5 cm) garnets or chlorite pseudomorphs after garnet

Xgp **Pegmatite and granite gneiss**--In the southeastern part of map area. Medium-grained, medium-gray, poorly foliated, massive biotite ($\pm$ garnet) monzogranite to granodiorite gneiss (metamorphic texture; color index 6 percent) and cross-cutting garnet-bearing white pegmatite. Pegmatite is cut by diabase (Yd) unit and probably by augen gneiss (Xag) unit

Xga **Amphibolite**--Two mapped patches in the central part of the area. Smaller amphibolite bodies are common within the other mapped gneiss units. Foliated hornblende-plagioclase rock

Xgs **Mixed granite gneiss and metasedimentary rocks**--Two patches, in the central and southern parts of the area. Granite gneiss and lesser seams or layers of supracrustal biotite schist, garnet-biotite gneiss, and black feldspathic biotite quartzite

Contact--Showing dip. Younger (Y) and older (O) units indicate where some intrusive relations were observed

Fault--Showing dip. Dashed where inferred, dotted where concealed. Sense of lateral slip shown by arrows. Bar and ball on downthrown side. Boxes on upper-plate of low-angle normal fault

Mylonite

Syncline

Anticline--Showing direction of plunge

Strike and dip of bedding

Strike of vertical bedding

Horizontal bedding

Strike and dip of magmatic foliation

Strike of vertical magmatic foliation

Strike and dip of metamorphic foliation

Strike of vertical metamorphic foliation

Trend and plunge of mylonitic lineation--Combined with foliation symbol

Locality of dated sample

Line of vertical section

INTRODUCTION

This map covers a structurally complex area between larger areas that were mapped by John (1987b) and by Howard and others (1990, in press) (Fig. 1). The map area lies along the Colorado River and in the northwestern Mohave Mountains of Arizona, just east and northeast of the Chemhuevi Mountains of California. Field guides to parts of the area and its environs were presented by Nielson (1986), Howard and others (1987), John and Howard (1994), and Howard and others (1994).

LATE CENOZOIC STRUCTURAL FRAMEWORK

The area lies within the 100-km wide Colorado River extensional corridor. Extreme crustal extension along this corridor dominates the late Cenozoic deformational history of the eastern Mojave and western Sonoran Deserts (Howard and John, 1987) (Fig. 1). Large-scale Miocene extension of the upper and middle crust in the corridor was accomplished along northeast-dipping brittle low-angle normal faults, often called detachment faults. These faults cut gently down-section in the northeast direction of tectonic transport from a breakaway 50 km west of the Topock quadrangle (Howard and John, 1987). Detachment faults are exposed around domal core complexes in the central part of the corridor, including the Chemehuevi Mountains immediately west of the area of this map (John, 1987a, b). Transport direction of the upper plate of each fault, where known, was to the northeast. Cumulative slip on the fault system increases to the northeast across the corridor and totals an estimated 40-75 km (stretching factor ß=1.7 to 4) (Howard and John, 1987; Hillhouse and Wells, 1991). Regional field relations indicate that the basal detachment fault(s) cut initially to depths of 10 to 15 km, based on the paleothickness of the Crossman block in the Mohave Mountains (Fig. 1), a hanging-wall block above the regionally developed Chemehuevi and Whipple detachment faults. The fault system is rooted 30-50 km east of the Topock quadrangle under the little-deformed Hualapai Mountains and Colorado Plateaus (Howard and John, 1987; Howard and others, 1990). Miocene extension in this region therefore occurred along an east-rooted, asymmetric shear system in the upper and middle crust (Howard and John, 1987).

Tilted Fault Blocks

Tectonic extension of Miocene age in the Colorado River extensional corridor produced tilting, detachment faulting, and structural disruption in the map area. The affected rocks include Miocene volcanic and sedimentary deposits and their basement substrate of Proterozoic and Cretaceous intrusive and metamorphic rocks. The Devils Elbow Fault and the deeper, younger Chemehuevi Detachment Fault project eastward below the map area from exposures in Topock Gorge and the Chemehuevi Mountains (John, 1987a,b). Two adjacent tilted fault blocks called the Jackpot and Tumarion blocks (John and Howard, 1994) lie above the Devils Elbow fault in the map area (Fig. 1). The blocks are separated by a northeast-striking system of steep transfer faults, the Gold Dome Fault zone (John and Howard, 1994). A structurally higher low-angle fault on the east side of the map area, the Powell Peak Fault, superposes yet higher structural slices (Boulder Mine and Yucca Mine area) over the Tumarion block (Howard and others, 1982, in press).

All the major fault blocks in the map area are probably steeply tilted (about 90°) to the southwest. The amount of tilting is deduced from the steep southwest to locally-overturned dips of nonconformably overlying early Miocene rocks in nearby areas, and on the persistently near-vertical dip and northwest strike of Proterozoic diabase sheets that intrude basement gneisses (John and Howard, 1994). The diabase sheets elsewhere across southern California and Arizona were shown to restore mostly to subhorizontal orientations because they tend to lie parallel to overlying strata of Proterozoic to Tertiary age (Howard, 1991). Measured attitudes of diabase sheets in the map area are approximately parallel to structurally intact basal Tertiary strata deposited on the basement blocks at the south end of the map area and in adjacent areas to the west and east. Like the basal strata, therefore, the diabase sheets were subhorizontal before tilting in the Miocene. The uniform orientations of the diabase sheets indicate that the basement blocks were tilted to the southwest approximately 90°. Because of the vertical tilting, the fault blocks expose natural cross sections of plutons and dike swarms.

Miocene Folds

The Topock quadrangle is one of several areas in the southern Basin and Range province that displays plunging folds where layered cover rocks are folded above fault offsets in deeper unstratified rocks (Howard and John, 1991, 1997). John and Howard (1994) and Howard and John (1997) interpreted these folds as forced (draped) above growing faults at the edges of basement blocks as the blocks tilted and segmented above deeper detachments during the progress of tectonic extension.

The relatively thin cover of Miocene sedimentary and volcanic rocks drapes over and around fractured and tilted basement rocks at the south corner of the Tumarion block (Howard and John, 1997). The result is a complexly faulted south-plunging anticline in the Miocene rocks at this corner. The folding of cover units contrasts with the homoclinal tilt of underlying basement shown by the uniform orientation of diabase sheets. The folded cover rocks include massive volcanic flows that lack internal angular unconformities. Depositional contacts in the lower part of the cover sequence are commonly sheared. Bedding-parallel faults attenuate the fold limb that overlies the Powell Peak fault, indicating that flexural slip helped accommodate folding.

A second style of folding is recorded by two gently-plunging southeast-striking synclines in the Miocene rocks in the southeast part of the map area. The southern syncline lies in the hanging-wall of a down-to-the-northeast normal fault. The southwest-facing limb of this syncline can be viewed as the cap of a tilted domino-like block. The northeast-facing limb probably resulted from normal drag on the underlying fault.

Timing of Extension

Crustal stretching in the region began about 23 Ma, based on K-Ar ages of the oldest volcanic units in the synextensional Tertiary basins (Brooks and Martin, 1985; Howard and John, 1987; Spencer and Reynolds, 1991; Nielson, 1993; Howard and others, 1993), crystallization ages of the oldest synextensional plutons in the lower plate of core complexes (Wright and others, 1986; Foster and others, 1990), and the oldest $^{40}Ar/^{39}Ar$ cooling ages related directly to denudation of footwall rocks (Foster and others, 1990; John and Foster, 1993). The period of rapid extension that led to formation of the metamorphic core complexes and adjacent basins in this region ceased by about 13-14 Ma, based on the age of untilted volcanic rocks and on thermochronology in the basement rocks (Howard and John, 1987; Davis and Lister, 1988; Richard and others, 1990; Foster and others, 1990, 1991; Spencer and Reynolds, 1991; Simpson and others, 1991; John and Foster, 1993).

PROTEROZOIC ROCKS

Early Proterozoic gneisses in the area form a complex assemblage dominated by metamorphosed granitic rocks, which enclose small bodies of amphibolite and metasedimentary gneiss. Except for younger augen gneiss, the rock units are probably 1.7 Ga or older based on regional geochronology (Wooden and Miller, 1990; Chamberlain and Bowring, 1990; Bryant and Wooden, 1991; Wooden and Dewitt, 1991). The augen gneiss resembles rocks dated as 1.64 Ga in the Bill Williams Mountains by Wooden and Miller (1990). The augen gneiss forms an elongate pluton. If 90° of Tertiary tilting is considered, the mapped exposure of this pluton represents the cross section of a thick dike-like body that deepens toward the northeast.

The Early Proterozoic metamorphic rocks are intruded by granite tentatively assigned to the Middle Proterozoic based on similarity to other granites in the region that are dated as 1.4 Ga (Anderson and Bender, 1989). The granite in turn is intruded by younger diabase sheets correlated with 1.1-Ga diabase elsewhere in Arizona and California based on lithologic similarity and common original horizontal orientation (Howard, 1991).

MESOZOIC PLUTONS

Rocks younger than Middle Proterozic and older than late Mesozoic are absent from the map area, but elsewhere in the region a sequence of shallow marine Cambrian to Permian strata are preserved that indicate tectonic stability through Paleozoic time (Stone and others, 1983). Late Mesozoic plutonism and orogeny are known from many adjacent regions, and are recorded in the quadrangle by Cretaceous or probable Cretaceous granitoid plutons. These plutons include (1) diorite tentatively correlated with the Whale Mountain sequence of John (1987b), (2) the undated distinctive diorite of Topock, and (3) younger biotite granodiorite correlated with the Chemehuevi Mountains Plutonic Suite of Late Cretaceous age that crops out in the Chemehuevi Mountains to the west (John, 1987b; John and Wooden, 1990; John and Mukasa, 1990). In the map area the biotite granodiorite forms the Powell Peak Pluton in the Tumarion structural block and the Borrow Pit body in the Jackpot structural block. Both of these two plutons are elongate-upward bodies when 90° of Tertiary tilting is considered. By restoring Tertiary northeastward movement along the underlying detachment faults (John, 1987a), the two plutons occupy cupola positions above the beheaded, authochthonous, sill-shaped Chemehuevi Mountains Plutonic Suite exposed in the Chemehuevi Mountains (John, 1988).

A swarm of northeast-striking biotite lamprophyre dikes (TKl) of Cretaceous or Tertiary age cuts the Powell Peak pluton. If the dikes pre-date tilting of the Tumarion structural block, their restored, pre-tilt orientation becomes vertical and still strikes northeast. This orientation matches that of Laramide (Late Cretaceous- to early Tertiary-age) dikes in many parts of Arizona (Rehrig and Heidrick, 1976). Irregular bodies and dikes of quartz porphyry (TKq) and of fine-grained granite (TKf) in the area are also assigned an age of either Cretaceous or Tertiary.

MIOCENE ROCKS RELATED TO TECTONIC EXTENSION

Volcanic and sedimentary rocks of Miocene age lie nonconformably upon and commonly are faulted against the pre-Tertiary crystalline rocks. The deformed Tertiary rocks are divided into three major lithologic sequences, from oldest to youngest, (1) a lower volcanic sequence, (2) the Peach Springs Tuff of Young and Brennan (1974), and (3) a upper unit of sedimentary rock and tuff. In adjacent areas to the west and south, clastic deposition in the upper unit was controlled largely by the development of syntectonic hanging-wall structures above the developing detachment faults (Miller and John, 1988; 1993; John and Howard, 1994).

The Miocene section is fragmentary but its stratigraphic thickness in the map area is estimated to be on the order of 1 km. Most of the faulted Tertiary volcanic rocks in the region around the Chemehuevi and Mohave Mountains are between 14 and 22 Ma in age (Howard and John, 1987; Nielson and Beratan, 1990; Nakata and others, 1990; Nielson, 1993; Nielson and Beratan, 1995).

The lower volcanic sequence broadly correlates with flows in the nearby Mohave Mountains that yielded an age (by the K-Ar method on whole-rock) of 19.8$\pm$0.6 Ma (Nakata and others, 1990). The sequence is well exposed in the southeast part of the map area. Volcanic units vary laterally. They include andesitic to dacitic lahar agglomerate low in the section (and present here in a structurally isolated patch). Mafic and intermediate-composition flows lie at intermediate levels, and are overlain by a sequence of tuffs that interfinger abruptly with tuffaceous conglomerate and sandstone. The highest rocks consist of silicic tuff and basalt flows; dikes and sills cogenetic with these flows invade parts of the volcanic section.

The overlying Peach Springs Tuff is a regionally widespread ash-flow that Nielson and others (1990) dated at 18.5 $\pm$ 0.2 Ma using $^{40}Ar/^{39}Ar$ methods. The distinctive unit crops out prominently and forms an important stratigraphic marker.

The overlying unit of sedimentary rocks and tuff is mostly conglomerate and is greater than 80 m thick. Correlative rocks in nearby areas include landslide breccia, sandstone, and rare interbedded basalt flows in a sequence up to 2 km thick (Miller and John, 1988, 1993; Nielson and Beratan, 1990; Nielson, 1993; John and Howard, 1994; Howard and others, in press). These rocks were deposited during extensional deformation (Miller and John, 1988, 1993). In Topock Gorge just west of the map area, they unconformably overlie the Peach Springs Tuff with an angular discordance as great as 13° (John and Howard, 1994).

POST-EXTENSION DEPOSITS

Undefomed sedimentary deposits ranging in age from late Miocene to Holocene unconformably overlie the synextensional sequences. These units include alluvial-fan deposits, the Bouse Formation, ancient and modern river deposits of the Colorado River, and windblown sands. The oldest unit is locally-derived alluvial-fan deposits, present only in the subsurface, beneath the Bouse Formation (Metzger and Loeltz, 1973).

The Pliocene Bouse Formation was described in the area by Metzger and Loeltz (1973). The Bouse in the map area consists of a basal white marl 3-4 m thick and overlying deposits, at least 15 m in exposed thickness, of interbedded green and yellow clay and silt, and pink sand. Subsurface thicknesses of 57 and 77 m for the formation were recorded in two drill holes south of Sacramento Wash (respectively NE1/4SW1/4NW1/4 sec. 14, and SE1/4SW1/4SW1/4 sec. 11, T.16 N, R. 20 1/2)(Metzger and Loeltz, 1973). The Bouse Formation is widely considered to record deposition in a brackish lake or estuary of the proto-Gulf of California, and to include deltas deposited by the earliest throughgoing Colorado River prior to 3.4-4 Ma (Buising, 1990).

Overlying the Bouse Formation are locally derived piedmont gravels, and also Pleistocene gravel and sand deposited by the ancestral Colorado River. These ancestral river deposits include interbedded pinkish sand, gypsiferous clay, silt, and clast-supported cross-bedded gravel containing well rounded cobbles and pebbles of quartzite, limestone, and other rock types derived from distant sources. Mammoth remains assigned to *Mammuths meridionalis* found close to the map area suggest an age of 0.3-1.5 Ma for parts of the gravel and sand unit (Agenbroad and others, 1992; L. Agenbroad, pers. commun., 1994). The sand subunit (Qrg) locally resembles the Bouse Formation. Upper, mostly fine-grained parts of the gravel and sand unit (subunits D and E of Metzger and Loeltz, 1973) were considered by Metzger and others (1973) to be equivelent to the Chemehuevi Formation of Longwell (1936), which previously had been called the Chemehuevis gravel by Lee (1908). The Chemehuevi Formation extends discontinuously from Lake Mead to Yuma Arizona, a distance of over 550 km. Bell and others (1978) interpreted the age of the Chemehuevi Formation elsewhere as 0.1-0.2(?) Ma, based on normal paleomagnetic polarity, degree of soil development on underlying alluvial-fan deposits, and Th-U and Pa -U dating of a fossil tusk and overlying soils. River gravel (Qrg) mostly overlies the sand subunit and caps terraces as high as 80 m above the present Colorado River within the map area. The river gravel in turn is capped by locally derived alluvial deposits.

The four mapped units of locally derived alluvium of the piedmont resemble those of the adjacent Mohave Mountains area on the east discussed by Wilshire and Reneau (1992). The oldest alluvium (Qo) is highly dissected and mostly overlies the river gravels (Qrg). In the northeastern part of the map area, deposits mapped as the oldest alluvium include well-sorted fluvial gravels derived from nearby mountain ranges and deposited along an ancestral Sacramento Wash.

Younger units of alluvium generally form thin veneers on the oldest alluvium (Wilshire and Reneau, 1992). These younger units of alluvium, as well as windblown sand and river floodplain deposits, are little dissected or not dissected, in contrast to the older units.

QUATERNARY FAULTING AND FOLDING

Faults and folding locally affect the sand (Qrs) and oldest alluvium (Qo) units. A vertical, down-to-the-west fault cuts Qrs immediately south of the map area in a roadcut along highway I-40. This fault projects northward into the northwest part of the map area near a gas pipeline measuring station at El Paso Gas main office. A gentle scarp 4.4 m high, which slopes 12° west in an an otherwise flat terrace, tracks the northward projection of this fault within the map area. The scarp cuts a boulder-strewn surface underlain by unit Qo, stratigraphically above Qrs. The north to northwest strike of this fault is paralleled by another fault in unit Qrs just north of the quadrangle. The Needles graben cuts old alluvial materials a few km north of the quadrangle and strikes northwest.

The sand (Qrs) unit exhibits southwestward dips of 10-12° along the north side of Sacramento Wash near the north-central border of the map area. Metzger and Loeltz (1973, p. 14) sketched and described the dipping beds in detail and concluded that they record structural adjustment during deposition of fluvial beds. Additional warping of Pleistocene or late Neogene age may be recorded where the basal white marl of the Bouse Formation dips 15° north over pre-Tertiary rocks in sec. 19, T. 16 N., R. 20 W.

MINERALIZATION AND MINERAL EXPLORATION

Quartz veins of post-Cretaceous age cut unmapped mafic dikes which in turn cut the northeastern exposures of the Cretaceous Powell Peak Pluton and its Proterozoic wall rocks. Chrysocolla and pyrite occur in one of these veins, along an unmapped vertical fault striking west-northwest, and the vein has been prospected along a shaft (shown on the base map) 3 m deep (NW 1/4 sec. 30, T.16 N., R.20 W.).

Alteration and silicification of Miocene sedimentary and volcanic rocks in association with intrusion by Miocene mafic rocks produced jasper and barite in the Yucca Mine area and nearby in SE 1/4 NW 1/4 sec. 18, T. 15 N, R. 20 W in the southeast part of the map area.

A prospect pit indicates mineral-exploration activity in the basal marl of the late Neogene Bouse Formation in the northeast part of the map area (sec. 19, T. 16 N., R. 20 W.). Borrow pits exploit gravel of the oldest alluvium unit (Pleistocene) in the central part of the area.

REFERENCES CITED

Agenbroad, L.D., Mead, J.I., and Reynolds, R.E., 1992, Mammoths in the Colorado River corridor, in Reynolds, R.E., compiler, Old routes to the Colorado: Redlands, California, San Bernardino County Museum Association Special Publication 92-2, p. 104-106.

Anderson, J.L., and Bender, E. E., 1989, Nature and origin of Proterozoic A-type granitic magmatism in the southwestern United States: Lithos, v. 23, p. 19-52.

Bell, J.W., Ku, T-L, and Kukla, G.J., 1978, The Chemehuevi Formation of Nevada, Arizona, and California: An examination of its distribution, facies, and ages: Geological Society of America Abstracts with Programs, v. 10, p. 45.

Bryant, Bruce and Wooden, J.L., 1991, Proterozoic geology of the Poachie Range and vicinity, west-central Arizona, *in* Karlstrom, K.E., editor, Proterozoic geology of Arizona: Arizona Geological Society Digest, v. 19, p. 85-96.

Buising, A.V., 1990, The Bouse Formation and bracketing units, southeastern California and western Arizona: Implications for the evolution of the proto-Gulf of California and the lower Colorado River: Journal of Geophysical Research, v. 95, p. 20,111-20,132.

Brooks, W.E., and Martin, R.F., 1985, Discordant isotopic ages and potassium metasomatism in volcanic rocks, Yavapai County, Arizona: Geological Society of America Abstracts with Programs, v. 17, page 344.

Chamberlain, K.R. and Bowring, S.A., 1990, Proterozoic geochronologic and isotopic boundary in NW Arizona: Journal of Geology, v. 98, p. 399-416.

Davis, G.A., and Lister, G.S., 1988, Detachment faulting in continental extension: Perspectives from the southwestern U.S. Cordillera: Geological Society of America Special Paper 218, p. 133-159.

Foster, D.A., Harrison, T.M., Miller, C.F., and Howard, K.A., 1990, $^{40}Ar/^{39}Ar$ thermochronology of the eastern Mojave Desert, California, and adjacent western Arizona: with implications for the evolution of metamorphic core complexes: Journal of Geophysical Research, vol. 95, B1, p. 20,005-20,024.

Foster, D.A., Miller, DS., and Miller, C.F., 1991, Tertiary extension in the Old Woman Mountains area, California: Evidence from apatite fission track analysis: Tectonics, v. 10, no. 5, p. 875-886.

Hammond, J.G., 1991, Middle Proterozoic diabase intrusions in the southwestern U.S.A. as indicators of limited extensional tectonisms, *in* Gower, C.F., Rivers, T., and Ryan, B., editors, Mid-Proterozic Laurentia-Baltica: Geological Association of Canada, Special Paper 38, p. 517-531.

Hillhouse, J.W., and Wells, R.E., 1991, Magnetic fabric, flow directions, and source area of the lower Miocene Peach Springs tuff in Arizona, California, and Nevada: Journal of Geophysical Research, v. 96, no. B7, 12,443-12, 460.

Howard, K.A., 1991, Intrusion of horizontal dikes: tectonic significance of Middle Proterozoic diabase sheets widespread in the upper crust throughout the southwestern US: Journal of Geophysical Research, v. 96, no. B7, 12,461-12,478.

Howard, K.A., and John, B.E., 1987, Crustal extension along a rooted system of imbricate low-angle faults: Colorado River extensional corridor, California and Arizona, in Coward, M.P., Dewey, J.F., and Hancock, P.L., eds., Continental Extensional Tectonics; Geological Society of London Special Paper No. 28, p. 299-311.

Howard, K.A., and John, B.E., 1991, Disharmonic drape folds associated with upper-crustal extension in the southern Basin and Range (abs): Geological Society of America Abstracts with Programs, v. 23, no. 2, p. 36.

Howard, K.A. and John, B.E., 1997, Fault-related folding during extension: Plunging basement-cored folds in the Basin and Range, Geology, v. 25, p. 223-226.

Howard, K.A., Christiansen, P.P., and John, B.E., 1993, Cenozoic stratigraphy of northern Chemehuevi Valley and flanking Stepladder Mountains and Sawtooth Range, southeastern Calif., in Sherrod, D.R. and Nielson, J.E., eds., Tertiary stratigraphy of highly extended terranes, California, Arizona, and Nevada: U.S. Geological Survey Bulletin 2053, p. 95-97.

Howard, K.A., Goodge, J., and John, B.E., 1982, Detached crystalline rocks of the Mohave, Buck and Bill Williams Mountains, western Arizona, in Frost, E.G., and Martin, eds., Mesozoic-Cenozoic tectonic evolution of the Colorado River region, California, Arizona, and Nevada: San Diego, Cordilleran Publishers, p. 377-392.

Howard, K.A., John, B.E., Davis, G.A., Anderson, J.L., and Gans, P.B., 1994, A guide to Miocene extension and magmatism in the lower Colorado River region, Nevada, Arizona, and California: U.S. Geological Survey Open-File Report 94-246, 54 p.

Howard K.A., John, B.E., and Miller, C.F., 1987, Metamorphic core complexes, Mesozoic ductile thrusts, and Cenozoic detachments: Old Woman Mountains - Chemehuevi Mountains transect, California and Arizona, *in* Davis, G.H. and Vandendolder, E.M., eds., Geologic diversity of Arizona and its margins: Excursions to choice areas: Arizona Bureau of Geology and Mineral Technology Special paper 5, p. 365-382.

Howard, K.A., Nielson, J.E., Wilshire, H.G., Nakata, J.K., Goodge, J.W., Reneau, S.L., John, B.E., and Hansen, V.L., 1990, Preliminary geologic map of the Mohave Mountains area, Mojave County, western Arizona: U.S. Geological Survey Open-File Report 90-684, scale 1:48,000.

Howard, K.A., Nielson, J.E., Wilshire, H.G., Nakata, J.K., Goodge, J.W., Reneau, S.L., John, B.E., and Hansen, V.L., in press, Geologic map of the Mohave Mountains area, Mohave County, Arizona: U.S. Geological Survey Misc. Investigations Map I-2308 , scale 1:48,000

John, B.E., 1987a, Geometry and evolution of a mid-crustal extensional fault system: Chemehuevi Mountains southeastern California, in Coward, M.P., Dewey, J.F., and Hancock, P.L., eds., Continental Extensional Tectonics; Geological Society of London Special Paper No. 28, p. 312-339.

John, B.E., 1987b, Geologic map of the Chemehuevi Mountains area, San Bernardino County, California, and Mohave County, Arizona: U.S. Geological Survey Open-File Report 87-666, (1:24, 000 with explanation).

John, B.E., 1988, Structural reconstruction and zonation of a tilted mid-crustal magma chamber: the felsic Chemehuevi Mountains plutonic suite: Geology, v. 16, p. 613-617.

John, B.E, and Foster, D.A., 1993, Structural and thermal constraints on the initiation angle of detachment faulting in the southern Basin and Range: the Chemehuevi Mountains case study: Geological Society of America Bulletin, v. 105, p. 1091-1108.

John, B.E. and Howard, K.A., 1994, Drape folds in the highly attenuated Colorado River extensional corridor, California and Arizona, *in* McGill, S.F. and Ross, T.M., editors, Geological investigations of an active margin: Geological Society of America Cordilleran

Section Guidebook, 27th Annual Meeting, San Bernardino, California, March 21-23, 1994: San Bernardino County Museum Association, p. 94-106.

John, B.E., and Mukasa, S.B., 1990, Footwall rocks to the mid-Tertiary Chemehuevi detachment fault: a window into the Late Cretaceous middle crust: Journal of Geophysical Research, v. 95, B1, p.463-485.

John, B.E., and Wooden, J.L., 1990, Petrology and geochemistry of the metaluminous to peraluminous Chemehuevi Mountains plutonic suite, southeastern California, *in* Anderson, J.L., ed., The Nature and Origin of Cordilleran Magmatism, Geological Society of America Memoir 174, pages 71-98.

Lee, W.T., 1908, Geologic reconnaissance of a part of western Arizona: U.S. Geological Survey Bulletin 352, 96 p.

Longwell, C.R., 1936, Geology of the Boulder Reservoir floor, Arizona-Nevada: Geological Society of America Bulletin, v. 47, p. 1393-1476.

Metzger, D.G., and Loeltz, O.J., 1973, Geohydrology of the Needles area, Arizona, California and Nevada: U.S. Geological Survey Professional Paper 486-J, 54 p.

Metzger, D.G., Loeltz, O.J., and Irelna, B., 1973, Geohydrology of the Parker-Blythe-Cibola area, Arizona and California: U.S. Geological Survey Professional Paper 486-G, 130 p.

Miller, J.M.G., and John, B.E., 1988, Detached strata in a Tertiary low-angle normal fault terrane, southeastern California: A sedimentary record of unroofing, breaching and continued slip: Geology, v. 16, p. 645-648.

Miller, J.M.G., and John, B.E., 1993, Tertiary stratigraphy of the Chemehuevi Mountains, southeastern Calif. and western Ariz., *in* Sherrod, D.R., and Nielson, J.E., eds., Tertiary stratigraphy of highly extended terranes, California, Arizona and Nevada: U.S. Geological Survey Bulletin 2053, p. 119-121.

Nakata, J.K., Pernokas, M.A., Howard, K.A, Nielson, J.E., and Shannon, J., 1990, K-Ar and fission track ages (dates) of volcanic, intrusive, altered and metamorphic rocks in the Mohave Mountains area, west-central Arizona: Isochron/West, no. 56, p. 8-20.Nielson, J.E., 1986, Miocene stratigraphy of the Mojave Mountains, Arizona, and correlation with adjacent ranges, *in* Cenozoic stratigraphy, structure and mineralization in the Mojave Desert: Geological Society of America, Cordilleran Section, 82nd Ann. Mtg., Los Angeles, CA, March 25-28, 1986, Guidebook and Volume, Field Trip numbers 5 and 6, p. 15-24.

Nielson, J.E., 1986, Miocene stratigraphy of the Mojave Mountains, Arizona, and correlation with adjacent ranges, *in* Cenozoic stratigraphy, structure and mineralization in the Mojave Desert: Geological Society of America, Cordilleran Section, 82nd Ann. Mtg., Los Angeles, CA, March 25-28, 1986, Guidebook and Volume, Field Trip numbers 5 and 6, p. 15-24.

Nielson, J.E., 1993, Stratigraphic and structural correlation of Tertiary strata of the Mohave Mountains and Aubrey Hills, Ariz., in Sherrod, D.R., and Nielson, J.E., eds., Tertiary stratigraphy of highly extended terranes, California, Arizona and Nevada: U.S. Geological Survey Bulletin 2053, p. 133-138.

Nielson, J.E., and Beratan, K.K., 1990, Tertiary basin development and tectonic implications, Whipple detachment system, Colorado River extensional corridor, California and Arizona: Journal of Geophysical Research, v. 95, p. 599-614.

Nielson, J.E., and Beratan, K.K., 1995, Stratigraphic and structural synthesis of a Miocene extensional terrane, southeast California and west-central Arizona: Geological Society of America Bulletin, v. 107, p. 241-252.

Nielson, J.E., Lux, D.R., Dalrymple, G.B., and Glazner, 1990, A.F., Age of the Peach Springs Tuff, southeastern California and western Arizona: Journal of Geophysical Research, v. 95, p. 571-580.

Rehrig, W.A. and Heidrick, T.L., 1976, Regional tectonic stress during the Laramide and late Tertiary intrusive periods, Basin and Range province, Arizona: Arizona Geological Society Digest, v. 10, p. 205-228.

Richard, S.M., Fryxell, J.E., and Sutter, J.F., 1990, Tertiary structure and thermal history of the Harquahala Mountains, west-central Arizona: Implications for denudation by a major detachment system: Journal of Geophysical Research, v. 95, B12, p. 19,973-19987.

Simpson, C., Sweitzer, J., and Howard, K.A, 1991, A reinterpretation of the timing, position, and significance of part of the Sacramento Mountains detachment fault, southeastern California: Geological Society of America Bulletin, v. 103, p.751-761.

Spencer, J.E., and Reynolds, S.J., 1991, Tectonics of mid-Tertiary extension along a transect through west central Arizona: Tectonics, v. 10, p. 1204-1221.

Stone, Paul, Howard, K.A., and Hamilton, Warren, 1983, Correlation of Paleozoic strata of the southeastern Mojave Desert region, California and Arizona: Geological Society of America Bulletin, v. 94, p. 1135-1147.

Wilshire, H.G. and Reneau, S.L., 1992, Geomorphic surfaces and underlying deposits of the Mohave Mountains piedmont, lower Colorado River, Arizona: Zietschrift fur Geomorphologie, v. 36, p. 207-226.

Wooden, J.L. and Dewitt, Ed, 1991, Pb isotopic evidence for the boundary between the Early Proterozoic Mojave and central Arizona crustal provinces in western Arizona, *in* Karlstrom, K.E., editor, Proterozoic geology of Arizona: Arizona Geological Society Digest, v. 19, p. 27-50

Wooden, J.L. and Miller, D.M., 1990, Chronologic and isotopic framework for Early Proterozoic crustal evolution in the eastern Mojave Desert Region, SE California: Journal of Geophysical Research, v. 95, p. 20,133-20,146.

Wright, J.E., Anderson, J.L., and Davis, G.A., 1986, Timing of plutonism, mylonitization, and decompression in a metamorphic core complex, Whipple Mountains, California. Geological Society of America Abstracts with Programs, v. 18, p. 201.

Young, R.A. and Brennan, W.J., 1974, Peach Springs Tuff: It's bearing on the structural evolution of the Colorado Plateau and development of Cenozoic drainage in Mohave County, Arizona: Geological Society of America Bulletin, v. 85, p. 83-90.

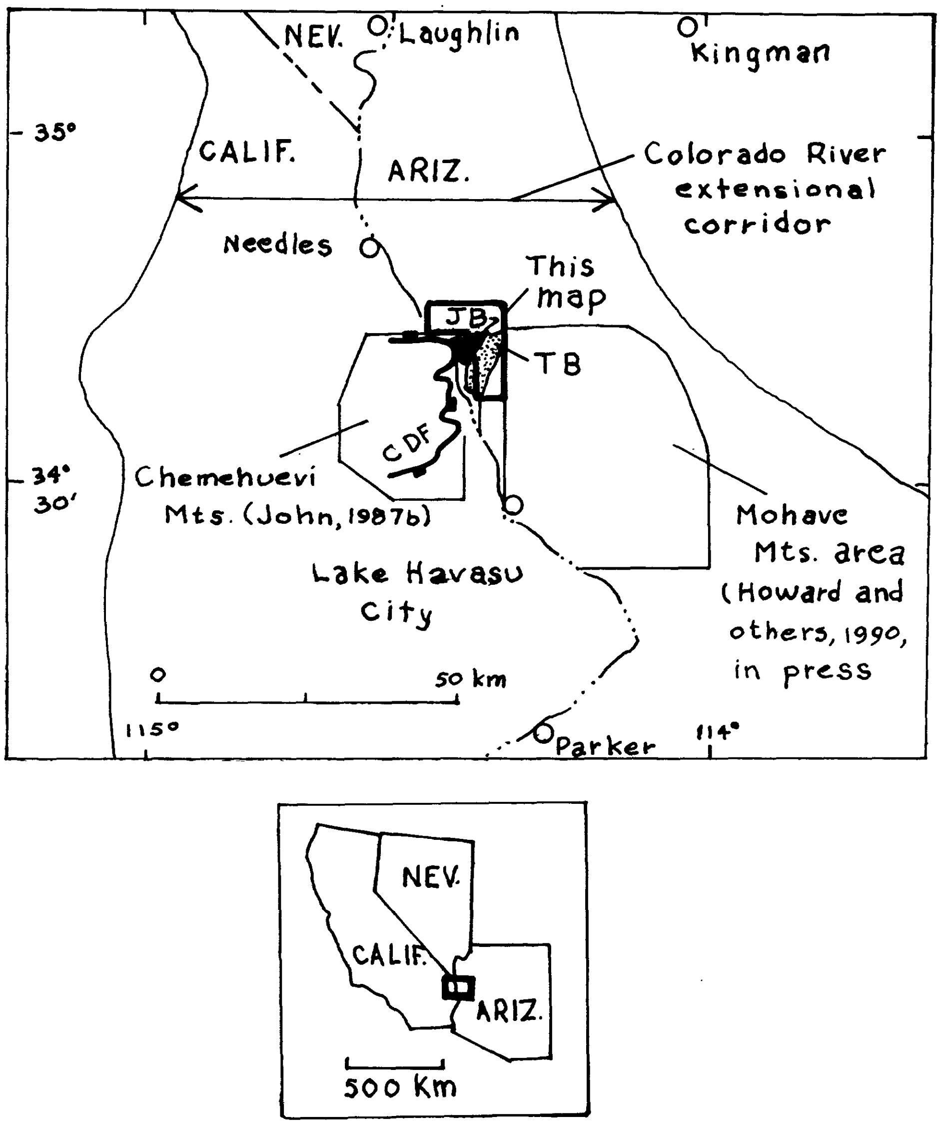

Figure 1. Index map showing the map area in relation to adjacent geologic maps and the Colorado River extensional corridor. Major structural features in and near the map area include the Chemehuevi Detachment Fault (CDF), Jackpot fault block (JB, in black), and Tumarion fault block (TB, in stipple).

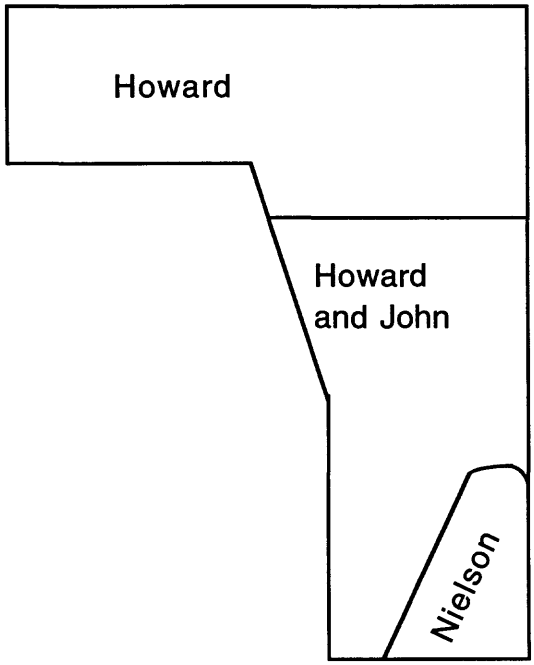

Figure 2. Map showing mapping responsibilities.

CORRELATION OF UNITS