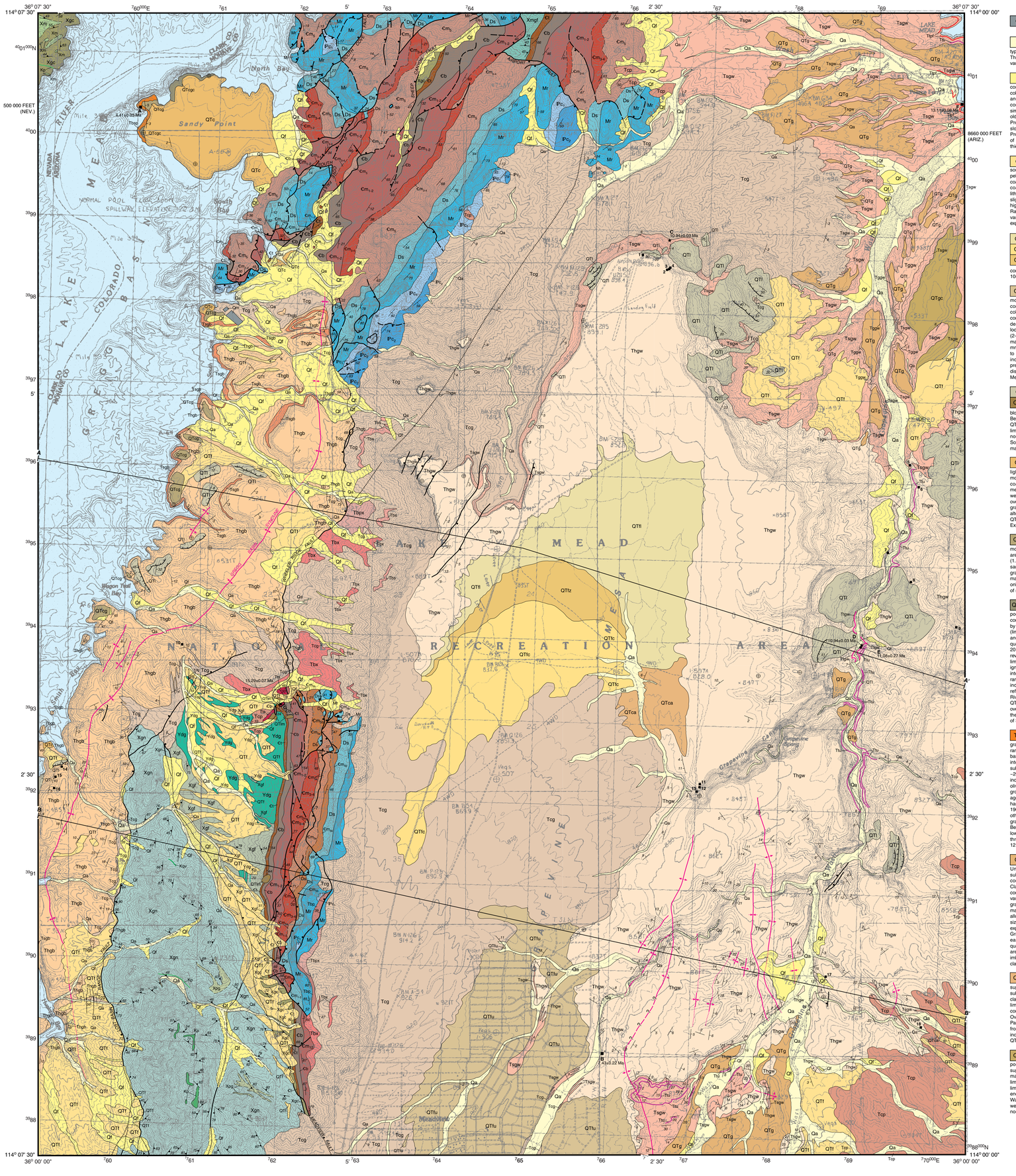

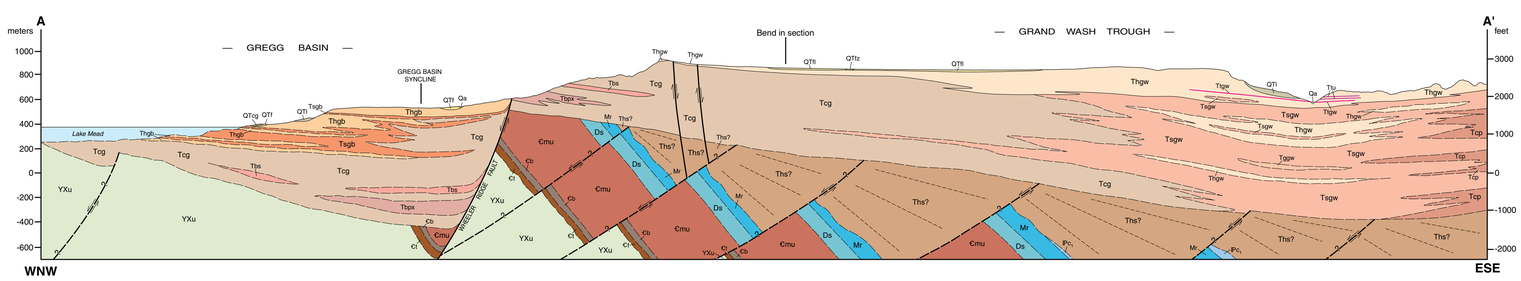

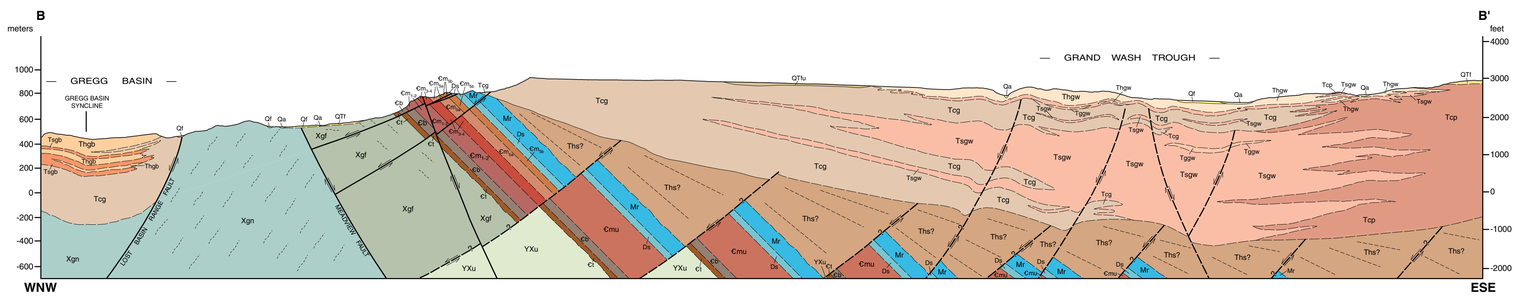

Qm **Manmade materials** (parking lot).

Qa **Alluvial deposits (Holocene)** Gray to light-brown or light-reddish-brown, unconsolidated, poorly sorted and typically subangular to angular gravel, pebbles, sand, and silt. Thin (~3 cm) to medium bedded. Incised into all older rock units; variable thickness up to ~10 m.

Qf **Alluvial fan and pediment deposits (Holocene to late Pleistocene?)** Gray to brown, poorly consolidated, poorly sorted subangular to angular pebble to cobble, clast-supported conglomerate with subordinate lenses and thin beds of matrix-supported pebble and cobble conglomerate and coarse-grained sandstone. Lithologically similar to QTf where clasts are locally derived from dissected older conglomerate (Qf, QTcg, and Tcg). Thgw, Thgb, and various Proterozoic units. Bedding ranges up to 1.5 m thick. On steeper slopes, uppermost beds are overlain by minor colluvium. Probably post-extensional because the deposits cover exposures of the Grand Wash and Lost Basin Range faults. Up to 15(?) m thick.

QTf **Older alluvial fan and pediment deposits (Pleistocene to Pliocene?)** Gray to brown, poorly sorted, poorly to moderately consolidated, subangular to angular pebble to cobble clast-supported conglomerate with medium- to coarse-grained sand matrix and subordinate lenses and beds of coarse-grained sandstone; beds generally up to 2 m thick; lithologically similar to Qf with clasts of local derivation; occurs as slightly to strongly dissected erosional remnants less much as 3 m higher than nearby Qf and Qa; appears to be cut by Lost Basin Range fault. Some upper surfaces contain clasts with rock varnish and thin calcrete crusts suggesting relatively long exposure. Up to 15(?) m thick.

QTfl **Colluvium and alluvial fan deposits (Holocene to Pliocene?)** Brown to light-brown, unconsolidated pebbles, sand, silt, and clay on Grapevine Mesa dominated by limestone (**QTfl**) or granite (**QTfc**) pebbles derived from nearby exposures of Thgw or Tcg. **QTfz** is a transition between QTfl and QTfc and contains clasts of both granite and Tertiary limestone. Up to 10(?) m thick.

QTfu **Alluvial fan deposits, undifferentiated (Holocene to late Miocene?)** Brown to pinkish-brown, poorly to moderately consolidated, moderately to poorly sorted conglomerate containing subrounded to angular pebbles, cobbles, and boulders in sand matrix. Very similar in composition to the much coarser and older Tcg from which it was derived on Grapevine Mesa but generally finer-grained and locally contains abundant cement and secondary calcite veins (2-3 mm thick). Clasts are generally dominated by pebbles of mafic rocks averaging 2-10 cm long and individual feldspars 1-10 mm in length. Thickness of fining-upward bedding ranges from 3 to 50 cm (5-10 cm average); planar cross-beds in one location indicate an easterly flow direction; pebble imbrication predominantly indicates north to east flow directions. Difficult to distinguish from Tcg where limestone is absent on Grapevine Mesa. Exact age unknown. Up to 6(?) m thick.

QTl **QTlm** **Landslide and talus deposits (Holocene to Pliocene?)** Slump blocks and unconsolidated rubbly debris composed of angular cobbles and boulders derived from Thgw and Tsgw (**QTl**) and Cmu (**QTlm**); blocks range up to ~250 m length and are up to ~50 m thick. Bedding attitudes in individual landslip blocks are locally shown. QTl deposits mainly occur near steep slopes, where a thin cap of limestone (Thgw and Thgb) is underlain by poorly consolidated non-resistant siltstone and sandstone (Tsgw and Tsgb). Some deposits consist of multiple landslides, which were not mapped separately.

QTc **Chemehuevi Formation (Pleistocene to Pliocene)** The Chemehuevi Formation (Longwell, 1936) is a light-tan or buff, poorly consolidated to unconsolidated, moderately to well-sorted, subrounded to subangular medium- to coarse-grained quartz arenite and siltstone with common medium-scale cross-bedding. Exposed in two areas in the western part of the quadrangle at Sandy Point and South Bay; overlain by younger fans and pediments (Qf) at South Bay; grades laterally into QTcg. Longwell (1936) noted >120 m of alternating large-scale cross-bedded and vaguely bedded siltstone within QTc, extending below the surface of Lake Mead at Sandy Point. Exposed thickness is as much as ~25 m.

QTcg **Unconsolidated Colorado River gravels (Pleistocene to Pliocene)** Unconsolidated, moderately to well-sorted, clast-supported conglomerate. Clasts are composed of well rounded to rounded pebbles and cobbles (1.5-20 cm in length) of resistant Paleozoic limestone, chert, sandstone (~30%), quartzite (~30%), and ~10% Proterozoic granite, gneiss and pegmatitic quartz. Fine to coarse sand matrix. Clasts are commonly coated with rock varnish. Crops out only as erosional remnants (usually <2 m thick) exposed on tops of small hills near Lake Mead in western part of quadrangle.

QTgc **Cemented Colorado River gravels (Pleistocene? to early Pliocene)** Light-gray to brown, moderately to poorly sorted, subrounded to well rounded, clast-supported conglomerate with coarse sand matrix and moderately indurated by calcite. Clast lithologies match resistant Paleozoic units (limestone, sandstone, quartzite, and chert), Proterozoic granite and gneiss, and Cretaceous and/or Proterozoic pegmatitic quartz. Clasts generally range in length from a few millimeters to 20 cm. Pebble counts on upper and lower beds, respectively, revealed 34 and 48% quartzite and sandstone, 21 and 25% limestone, 37 and 15% chert, 3 and 2% quartz, and 5 and 10% igneous and metamorphic rocks (Lucchitta,1966). Subordinate interbeds and lenses of coarse-grained cross-bedded sandstone range from ~20 cm to 2 m thick. Cross-bedding and imbrication indicate an easterly and southerly flow direction probably reflecting a meander in the generally west-flowing Colorado River. The 4.4 Ma basalt of Sandy Point (Tbsp) is intercalated in QTcgc. An erosional surface above the cemented river gravels is overlain by QTc and QTcg, respectively. Exposed thickness of the basalt and gravels both range up to >12 m on the west face of Sandy Point.

Tbsp **Basalt of Sandy Point (early Pliocene)** Porphyritic olivine basalt that interfingers with Colorado River gravels (QTcg and QTcgc); locally columnar jointed with spacing ranging from 10 cm to 2 m; flows up to 25 m thick; vesicular at base; no layering or paleosols observed indicating only one flow; intercalated with QTcgc, QTcg, and QTc. Contains 15-20% subhedral to anhedral olivine phenocrysts ranging in length from ~200 µm to 800 µm (~480 µm average). Accessory minerals include alkali feldspar and opaque oxides. Petrographically like olivine along crystal partings, hematite, and titanomagnetite. A groundmass concentrate from the basalt yielded an $^{40}Ar/^{39}Ar$ age of 4.41±0.03 Ma (M. Kunk, written commun., 1998). Tbsp has been correlated with basalts in Grand Wash Bay (Lucchitta, 1966), which have yielded a 3.8±0.11 Ma K-Ar age (Damon and others, 1978). The basalt lies only ~110 m above the current grade of the Colorado River (before the filling of Lake Mead). Because it overlies some lenses within QTcgc (exposed only at lower lake level), the basalt of Sandy Point indicates that a through-going Colorado River had developed by ~4.4 Ma. Up to 12 m thick on the western side of Sandy Point.

QTg **Pediment, stream, and alluvial fan deposits of Grapevine Wash (Pleistocene to Pliocene?)** Unconsolidated to poorly consolidated, moderately to subrounded, poorly sorted pebble to cobble clast-supported conglomerate and subordinate sandstone lenses and beds. Clasts range in length from a few millimeters to 75 cm and consist of various lithologic types including Tertiary limestone, varnished basalt, granite, late Paleozoic limestone, and gray fine-grained Paleozoic quartzite. Medium- to coarse-grained sand matrix. Exposed in most basal part of the quadrangle as dissected alluvial fan remnants and terraces up to 10 m thick with clast sizes ranging in length from 5 to 50 cm (15-30 cm average). Also exposed as a thin veneer in the central to northern part of Grapevine Wash. Basalt cobbles may be derived from either early Miocene lavas at Iron Mountain (15 km south of the quadrangle) or possibly late Miocene lavas in Grand Canyon area to the east. West of Pearce Ferry, QTg deposits have clast imbrication indicating an easterly flow direction and contain more clasts of granite and less of Thgw and basalt. Up to ~10 m thick.

QTga **Calcrete conglomerate (Holocene to late Miocene?)** White to pinkish tan fine-grained, matrix-supported conglomerate. Clasts consist of poorly sorted subrounded to subangular pebbles and cobbles. Subrounded clasts commonly consist of white chert, basalt, and Paleozoic limestone and dolostone, whereas subangular clasts are commonly derived from Thgw and various Proterozoic rocks. Overlies Thgw on Grapevine Mesa west of Grapevine Canyon. Paleozoic limestone and dolostone clasts were probably derived from the Grand Wash Cliffs to the east of the map area before incision of Grapevine Wash. Also caps fanglomerates (Tcp and QTf) near the Grand Wash Cliffs. Up to ~5 (?) m thick.

QTgc **Alluvial fan of Grapevine Wash (Pleistocene? to Miocene?)** Well indexed, thick to massive beds of poorly sorted, moderately rounded to subangular clast-supported conglomerate containing a coarse-grained sand matrix cemented by calcite; clast types include Paleozoic limestone, chert, and sandstone, Proterozoic gneiss, and Tertiary limestone; crops out as an elongate exposure at the northern end of Grapevine Wash near the present course of Grapevine Wash but ~80 m above the wash; rare cross-bedding indicates a westerly flow direction; clast imbrication indicates a westerly and northerly flow direction. Exposed thickness is as much as 12 m.

ROCKS OF THE GRAND WASH TROUGH

All Tertiary strata exposed within the Grand Wash trough are informally grouped into the rocks of the Grand Wash trough (after Bohannon, 1984). These strata primarily consist of basinal sedimentary rocks locally intercalated with thin volcanic units (Lucchitta, 1966). The rocks of the Grand Wash Trough include Thgw, Thgb, Tsgw, Tsgb, Tggw, Tbgw, Ttu, Tptf, Tcg, Tbs, Tbp, Tbx,Tbpx, Tcp, and Ths.

The Hualapai Limestone

A prominent limestone deposit crops out in the Grapevine Wash area, along the flanks of Grapevine Mesa, and in the Gregg Basin. This unit was previously included in the Hualapai Limestone Member of the Muddy Creek Formation (Longwell, 1928, 1936), Hualapai Limestone facies of the Muddy Creek complex (Lucchitta, 1966), and upper member of the "rocks of the Grand Wash trough" (Bohannon, 1984). On the basis of common usage, we refer to this unit as the Hualapai Limestone and consider it as the upper most formation within the rocks of the Grand Wash trough. The Hualapai Limestone in the Grapevine Wash area is very similar in composition and texture to that in the Gregg Basin, and the limestone in each area occupies the same stratigraphic position. The upper part of the limestone was probably once continuous between the Grapevine Wash area and Gregg Basin. However, we divide the Hualapai Limestone into two members (Grapevine Wash [Thgw] and Gregg Basin members [Thgb]) due to minor differences in overall composition and the possibility that these two basins were isolated from one another for part of their history.The age of the Hualapai Limestone in the Grand Wash trough is bracketed between ~11 and 7 Ma on the basis of geochemical correlations and $^{40}Ar/^{39}Ar$ dates of interbedded tephras (see discussion in text). Thgw and Thgb overlap in age with the Muddy Creek Formation. The depositional environment was likely a warm shallow lake with a significant amount of evaporation (Wallace, 1999). $\delta^{13}C$ and $\delta^{18}O$ isotopic data indicate a non-marine origin for the CO_2 and a source water derived from high altitudes (Faulds and others, 1997, 2001c; Wallace, 1999). Blair (1978), Blair and Armstrong (1979), and Bradbury and Blair (1979) previously made erroneous interpretations of the Hualapai Limestone as a saline marine-estuarine deposit. The Hualapai Limestone reflects the last interior-drainage deposits that accumulated immediately prior to arrival of the Colorado River within the Grand Wash trough.

Thgw **Hualapai Limestone, Grapevine Wash area (late Miocene)** White to pinkish-tan, vuggy, thin to massive bedded, pelleted packstone, wackestone, and calcareous mudstone commonly with thin wavy lenticular laminations. Pelmicrite dominates and commonly contains oncolites ranging up to 6 mm in diameter with nuclei ranging from micrite intraclasts (commonly pelleted), algal filaments, and rip-up clasts of algal laminations. Travertine, including flowstone and tufa, is also relatively common, particularly in transitional areas where silty limestone and/or siltstone interbeds are more common within the limestone. Bedding is commonly massive but is thin near transition to Tggw; both lenticular (or "eggshell") and planar laminations are common. Thgw is a resistant ridge former that caps Grapevine Mesa; exposed surfaces commonly contain sharp microkarren; weathers brown to pinkish color in Grapevine Wash due to silty coating from erosion of fine silt laminations and interbeds. Diagenetic features include commonly neomorphosed (recrystallized) micrite to microspar and vugs typically partially filled with secondary fibrous, blocky, and dentate calcite. Pelleted micrite is commonly partially replaced with cloudy neomorphosed calcite crystals containing ghost structures. Common filling of primary vugs and fenestral porosity occurred in up to three stages, as evidenced by: (1) rims of small blocky calcite containing inclusions of oxide-rich minerals in the vugs, in addition to the replacement of the micrite substrate by neomorphosed calcite; (2) clear blocky or radiaxial fibrous calcite with oxide-rich inclusion 'laminations' (Blair and Armstrong, 1979); and (3) latest stage large clear blocky calcite crystals. Locally, chalcedony is found as a final vug-filling material within 5 m of intercalated tuffs, which may indicate that silica-rich fluids were derived from the devitrification of the tuffs. Locally contains abundant white secondary calcite veins up to a few cm thick oriented oblique and perpendicular to bedding. Contacts are generally gradational and interfingering but are locally sharp; commonly interfingers and grades laterally with sandstone-siltstone in Tsgw and Tsgb (e.g., Grapevine Wash on the east side of quadrangle); locally sharp transitions occur with Tsgw (e.g., north end of Airport Point where siltstone grades into clean limestone in <10 m); grades laterally and interfingers with conglomerate (Tcp) near the Grand Wash Cliffs on the eastern margin of the map area. Thgw dips ~3-5° to the east and is locally folded and faulted; teepee structures up to 2 m in height are locally common in the southeastern and southwestern parts of the quadrangle; compaction deformation and stylolites common in thin section. Thin fine-grained ash-falls (few centimeters to 2 m thick), such as Tgw, are locally intercalated in Thgw. Many tephras are reworked or consist of devitrified volcanic glass altered to clay minerals. At least the upper part of the exposed section onlaps the Grand Wash fault and therefore postdates movement on the fault. Exposed thickness of Thgw is as much as ~300 m in the Grapevine Wash area.

Thgb **Hualapai Limestone in Gregg basin (late Miocene)** White to pinkish-tan pelleted packstone, wackestone, and calcareous mudstone; pelmicrite dominates; very similar in texture to Thgw but locally contains thick lenses (up to ~12 m) of interbedded siltstone, the thicker deposits of which are mapped as Tsgb lenses. Thgb has generally undergone less neomorphism than Thgw and contains only a minor amount of wavy laminations (or "eggshell" texture). Thgb and Tsgb record ~275 m of throw on the Wheeler Ridge fault. Thgb locally rests directly on YXu, as evidenced by exposures on the west side of Hualapai Wash ~3 km south of the map area. Exposed thickness is as much as 170 m.

Sandstone and Siltstone

The sandstone-siltstone units (Tsgw and Tsgb) in the Grand Wash trough interfinger with and grade into both the overlying Hualapai Limestone and underlying fanglomerate facies. In the lower Grapevine Wash area, the sandstone-siltstone unit envelops a 20 m thick lens of primary silty gypsum (Tggw). The exposed thicknesses of the sandstone-siltstone facies in the Grapevine Wash area and Gregg Basin are 120 and 95 m, respectively. The unexposed thickness of these deposits may be much greater. The depositional environment of the sandstone-siltstone facies was probably a highly evaporative interior continental playa, as evidenced by the intercalated gypsum, thin bedding, and mudcracks. The lack of fluvial textures (such as cross-beds or ripple marks), local abundance of gypsum rinds, interfingering and bordering fanglomerate facies, and intercalated gypsum unit (Tggw) rule out a significant fluvial contribution.

Tsgw **Tsgb** **Sandstone and siltstone, Grapevine Mesa area and Gregg Basin (late to middle Miocene)** Pale reddish-brown to brown, thin- to medium-bedded, moderately sorted, weakly to moderately indurated sandstone and siltstone facies in the Grapevine Wash area (Tsgw) and Gregg Basin (Tsgb). Grains are generally subrounded, consist of quartz, feldspars, micas, and mafic minerals, and are locally cemented by calcite. Characterized by alternating beds of fine- to medium-grained sandstone, siltstone, and mudstone with subordinate lenses and minor interbeds of pebble conglomerate with coarse sand matrix; clasts mostly composed of granite or individual angular to subrounded grains of quartz, feldspar, and mafic minerals. Root or stem traces and burrows are common. Planar cross-bedding and mudcracks are rare. Lenses of primary and/or secondary(?) gypsum locally common with individual laths 1-2 cm long oriented perpendicular to bedding. This unit was previously referred to as the sandstone and siltstone facies of either the Muddy Creek Formation (Longwell, 1936) or Muddy Creek complex (Lucchitta, 1966). Both upper and lower contacts are gradational and distinguished by >50% siltstone or sandstone. Upper part grades into beds and lenses of calcareous mudstone-wackestone and silty-sandy limestone; more calcareous near upper contact, where secondary calcite veins are locally common. Lower contact with fanglomerate (Tcg and Tcp) is gradational with lenses of concentrated subangular to subrounded pebbles. The exposed part of the sandstone-siltstone facies within the quadrangle is bracketed between ~13 and 11 Ma. Ash-fall tuffs in the Pearce Ferry area intercalated within Tsgw yielded three fission-track ages ranging from 10.8 to 11.6 Ma (Bohannon, 1984) and an $^{40}Ar/^{39}Ar$ maximum eruptive age of ~13.1 Ma (Faulds and others, 2001b). The reddish matrix in these units suggests derivation from non-resistant Pennsylvanian-Permian redbeds, which crop out extensively to the east on the Colorado Plateau and to the north of the Grand Wash trough. Exposed thickness is as much as 120 m; probably was much more extensive before erosion by the Colorado River.

Tggw **Gypsum (late to middle Miocene)** Brown to pinkish brown very fine-grained silty gypsum of primary and secondary origin; crops out near the northern end of Grapevine Wash. Subordinate interbeds of reddish brown gypsiferous siltstone and fine- to medium-grained sandstone locally comprise up to 40% of the section and grade laterally into and interfinger with more gypsiferous beds. Brown silt concentrated in irregular clumps, with average diameter of 150 µm, comprises approximately 15% of the most gypsiferous beds. Four distinct types of gypsum crystals were observed in individual beds; from smallest to largest: 1) clear and cloudy gypsum with lengths of 10-20 µm, irregular boundaries, apparent ghost structures, and minor silt inclusions which imply neomorphism; 2) clear dentate gypsum ranging from 20 µm to 60 µm in length with both irregular and straight boundaries and interpreted as the first stage of vug-filling; 3) clear blocky and lath-shaped single gypsum crystals ranging from 40 µm to 1 mm and interpreted as late-stage vug-fill; and 4) clear laths >400 µm in length that fill cracks cutting the minor sandstone and siltstone interbeds and probably represent the latest stage of diagenesis. Beds range from 2 to 150 cm thick. White and clear secondary gypsum lenses and veins are 1 mm to 7 cm thick. The presence of sandstone and siltstone implies periodic shallow water and evaporative conditions (margins of or intermittent shallow lake fed by streams and/or groundwater) and later diagenesis. Similar to Tsgw, Tggw is bracketed between ~13 and 11 Ma by nearby dated tephras. Thickness is as much as 20 m.

Tephras

Several tephras are interbedded with the sedimentary rocks of the Grand Wash trough (Ttgw, Ttpf, and Ttu). The tephras represent ash-fall tuffs derived from distant volcanic eruptions. The ash-fall deposits were only mapped locally, mainly in the Pearce Ferry and Grapevine Wash areas. Two tephras in the Pearce Ferry area have previously yielded three zircon fission-track ages ranging from 10.8±0.8 Ma to 11.6±1.2 Ma (Bohannon, 1984). In this study, five new age estimates were obtained on three additional tephras (i.e., not dated by Bohannon, 1984) utilizing geochemical correlations (i.e., tephrochronology, see Perkins and others, 1995) and $^{40}Ar/^{39}Ar$ geochronology. These dates range from ~13.1 to 7.4 Ma.

Ttgw **Tephra in Grapevine Wash area (late Miocene)** Gray very fine-grained, sparsely porphyritic nonwelded tuff intercalated within lowermost part of Thgw and upper part of Tsgw; contains approximately 1-2% very fine-grained phenocrysts of ~35% quartz (~50-100 µm in length), ~35% titanomagnetite (10-25 µm in length), ~10% plagioclase (50-100 µm in length), ~5% sanidine (50-100 µm in length), and ~5% brown biotite (~150 µm in length). Green anhedral chlorite locally occurs as an accessory mineral around glass. Groundmass consists entirely of glass shards that locally display a foliation parallel to contacts. Locally grades laterally into dark gray weakly indurated lenses 2-5 cm thick in the upper 0.5 m of the unit. The best exposure is located 0.6 km north of Grapevine Canyon in Grapevine Wash (at sample location E); commonly underlain by red silt and sand (10-20 cm thick); includes calcareous zones near upper contact where overlain by Thgw. Glass geochemistry of two samples (e.g., Perkins and others, 1995, 1998) indicate a correlation with a 10.94±0.03 Ma tuff in the Bruneau-Jarbidge volcanic field near Trapper Creek in southernmost Idaho (M. Perkins, personal communication, 1999). Ttgw is probably more widespread but was only mapped locally because of limited exposure.Thickness ranges from ~1 m to 2 m.

Ttu **Tephras, undifferentiated (late to middle Miocene)** White to tan and blue-gray very fine- to fine-grained undifferentiated ash-fall tuffs intercalated within Thgw and Tsgw. Commonly reworked and altered to clay minerals. Thicknesses of mapped tuffs range from ~30 cm to 1 m.

Ttpf **Tephra in Pearce Ferry area (middle Miocene)** White fine- to medium-grained biotite ash-fall tuff with laminations consisting of 1 to 10 mm of brown mud. Contains ~5% phenocrysts of which ~40% are quartz, ~30% plagioclase, ~20% sanidine, and ~10% greenish-brown biotite. Groundmass consists of volcanic glass shards (~100-250 µm in length) preferentially oriented parallel to bedding. Tptf is intercalated with Tsgw near or at the shore of Lake Mead in the Pearce Ferry area. Tptf yielded an $^{40}Ar/^{39}Ar$ age of 13.11±0.08 Ma on sanidine, but this should be considered a maximum eruptive age for this unit (M. Heizler, written communication, 1999). Two tephras a few meters stratigraphically above Ttpf in the Pearce Ferry area have yielded three zircon fission-track ages ranging from 10.8±0.8 Ma and 11.6±1.2 Ma (Bohannon, 1984). Thickness is ~1 to 2 m.

Conglomerate

Conglomerate (Tcg and Tcp) is the thickest exposed unit (at least 250 m) within the rocks of the Grand Wash Trough. On the basis of clast lithology, two members of conglomerate were distinguished in the Grand Wash trough. Conglomerate to the west of Grapevine Wash (Tcg) generally contains clasts of Proterozoic rock, including the distinctive ~1.45 Ga megacrystic Gold Butte Granite derived from the South Virgin Mountains to the west (Lucchitta, 1966). In contrast, on the east side of Grapevine Wash, clast lithologies are typically dominated by Paleozoic limestones and dolostones derived from the Grand Wash Cliffs to the east (Tcp). Subordinate lenses of unstratified megabreccia (Tbs, Tbx, Tbpx, and Tbpx) and tuffaceous rocks (Tts) are intercalated within mainly the lower part of the conglomerate on the west side of Grapevine Mesa. The overlying sandstone-siltstone and limestone units grade into and interfinger with the conglomerate. The conglomerate has previously been referred to as the Gregg's breccia by Lee (1908), the conglomerate and breccia units of the Muddy Creek Formation (Longwell, 1936), and conglomerate-breccia facies of the Muddy Creek complex (Lucchitta, 1966). The poor sorting, angularity and size of clasts, both matrix- and clast-supported beds, and intercalated lenses of sandstone suggest that the conglomerate originated as debris-flow and sheetflood deposits on alluvial fans. $^{40}Ar/^{39}Ar$ dates and geochemical correlations of tuffs in the Tts and sandstone-siltstone units (Tsgw) bracket the age of the conglomerate between ~15.3 and 11 Ma.

Tcg **Conglomerate (late to middle Miocene)** Brown, pinkish, and light gray poorly sorted, moderately to poorly consolidated conglomerate. The matrix of the conglomerate and interbedded lenses of sandstone consist of coarse- to medium-grained, poorly to moderately sorted, subangular grains of quartz, feldspars, and micas. Angular to subangular clasts of the conglomerate range in size from pebbles to large boulders (>5 m) and generally increase in size to both the east and west of the Grapevine Wash area. Bedding thickness ranges up to ~2 m; includes both matrix- and clast-supported beds; weakly to moderately cemented by calcite. Clasts derived from the ~1.45 Ga Gold Butte Granite and pebble imbrication indicate provenance from the Gold Butte block in the South Virgin Mountains 6-15 km to the west (Lucchitta, 1966). The clasts derived from the Gold Butte Granite consist of a rapakivi-type granite and are coarsely porphyritic, euhedral to subhedral perthite-biotite granite with a medium- to coarse-grained groundmass of potash feldspar, quartz, plagioclase, and biotite. The perthite is mantled by oligoclase and albite and clumps of biotite aggregates undergone less neomorphism than Thgw and contains only a minor amount of wavy laminations (or "eggshell" texture). Thgb and Tsgb record ~275 m of throw on the Wheeler Ridge fault. Thgb locally rests directly on YXu, as evidenced by exposures on the west side of Hualapai Wash ~3 km south of the map area. Exposed thickness is as much as 170 m.

Tbs **Breccia (late to middle Miocene)** Reddish brown and gray, moderately to well indurated clast-supported breccia intercalated within Tcg; commonly clast-supported containing <10% silt and mud matrix; clasts range in size from boulders >3 m in length to mm-scale angular mineral fragments of the same rock type; calcite cement; clast types include granite and gneiss (**Tbx**) and Paleozoic limestones and dolostones (**Tbp**) or a combination of both Paleozoic and Proterozoic rocks (**Tbpx**); crackle breccia common but subordinate jigsaw breccia (cf., Yarnold and Lombard, 1989) lenses also found. Lenses of angular clast conglomerates containing 10-15% coarse-grained sand to silt matrix were locally distinguished as a sedimentary breccia (**Tbs**). Bedding thickness of Tbs ranges from ~0.75 to 2 m. Tbs contains subordinate jigsaw and crackle breccia and typically forms small resistant ledges, whereas unstratified deposits such as Tbx are commonly slope formers. These units crop out only on west flank of Grapevine Mesa. Tbp, Tbx, and Tbpx probably originated as large rock-avalanche deposits derived from both the South Virgin Mountains to the west and the nearby walls of a large east-trending paleocanyon cut into Paleozoic strata. Tbs deposits may be the distal portion of rock-avalanche deposits. Thickness ranges from ~2 to 80 m.

Tcp **Paleozoic clast fanglomerate (late to middle Miocene)** White to pinkish-brown, poorly sorted clast- and matrix-supported, pebble to cobble and boulder conglomerate; contains a sandy to micritic matrix; grades laterally into and interfingers with Thgw near the Grand Wash Cliffs. Clast lithology consists mainly of locally-derived Paleozoic strata. Previously named a sub-facies of the conglomerate-breccia facies of the Muddy Creek complex by Lucchitta (1966). Tcp generally crops out from <30 m to ~2 km west of the Grand Wash Cliffs, which lie directly east of the map area, but locally includes an uppermost alluvial fan deposit up to 5 km west of the Grand Wash Cliffs. Tcp is locally capped by calcrete. Calcrete (QTca) that contains clasts of Paleozoic limestone and dolostone west of Grapevine Wash may be remnants of alluvial fan progradation associated with Tcp deposits. About 17 km northeast of the quadrangle at Nevershine Mesa, a basalt flow interbedded with this conglomerate (Lucchitta and others, 1986) has yielded an 8.8 Ma $^{40}Ar/^{39}Ar$ age (Faulds and others, 2001b). Exposed thickness ranges up to 120 m but is probably more extensive in the subsurface.

Tts **Nonwelded tuffs and volcaniclastic sedimentary rocks (middle Miocene)** Light gray nonwelded tuffs containing 17% phenocrysts (consisting of 35% quartz, 20% biotite, 15% augite, 12% plagioclase, 12% sanidine, and 5% titanomagnetite) and medium gray to white fine- to coarse-grained, thinly bedded, weakly indurated volcaniclastic sandstone; underlies Tcg and is possibly the oldest dateable Tertiary unit in the Grand Wash trough south of Lake Mead. White irregular shaped pumice fragments (1-7 mm in length) constitute ~30% of some nonwelded tuffs. Sanidine from a nonwelded tuff in Tts has yielded an $^{40}Ar/^{39}Ar$ age of 15.29±0.07 Ma. Exposed thickness is ~2-10 m, but may be much thicker in subsurface.

Ths **Horse Spring Formation (middle to early Miocene)** The Horse Spring Formation crops out from Las Vegas on the west to the northern Grand Wash trough (i.e. north of Lake Mead) on the east (Longwell, 1928; Bohannon, 1984; Beard, 1996). In the Grand Wash trough, only the Rainbow Gardens Member of the Horse Spring Formation has been observed, although the Thumb Member probably exists in the subsurface (Beard, 1996). The Rainbow Gardens Member consists of a basal conglomerate and overlying carbonate rocks. The Thumb Member includes sandstone, conglomerate, siltstone, rock-avalanche deposits (e.g., megabreccia), gypsum, and carbonate rocks. The Horse Spring Formation was not identified in the quadrangle but is inferred in the subsurface (cross sections A-A' and B-B'). The middle Miocene tuffaceous rocks (Tts) and breccia deposits (Tbs, Tbp, Tbx, Tbpx) may correlate with the Horse Spring Formation.

CRETACEOUS (?) ROCKS

Kp **Pegmatite (Late Cretaceous?)** Medium to coarse-grained unfoliated granite and pegmatite mainly consisting of potassium feldspar, quartz, muscovite, hornblende, and biotite. Granite dominates in the southwestern part of the quadrangle, but these bodies typically grade into pegmatite. Age is uncertain; clearly cuts Ydg, but no bodies were found cutting Paleozoic strata; may be related to peraluminous Late Cretaceous, two-mica granites in the region (e.g., Blacet, 1975).

Kqv **Quartz vein (Late Cretaceous?)** Coarse-grained quartz vein probably related to Kp. Several small veins and veinlets were not mapped.

PALEOZOIC ROCKS

IPc$_2$ **Upper member of the Callville Limestone (Pennsylvanian)** Thick to medium bedded, slope forming, light gray limestone and pinkish gray sandy limestone, with local beds of yellowish gray sandy limestone. Basal bed is cross-bedded sandy limestone ~2 m thick that usually weathers to form a conspicuous dark brown horizon. Total thickness ~100 m.

IPc$_1$ **Lower member of the Callville Limestone (Pennsylvanian)** Thick bedded, slope forming, very light gray limestone. Abundant orange to reddish brown chert stringers occur near the top of the unit. Total thickness ~150 m.

Mr **Redwall Limestone (Mississippian)** Thickly bedded yellowish gray limestone and dolostone overlain by a conspicuous horizon of interbedded gray dolostone and dark brown chert; generally fossiliferous; in turn overlain by medium bedded light gray to yellowish gray sandy dolostone. This formation is a very prominent cliff-former, commonly holding up ridge crests in the area. Total thickness is ~150 m.

Ds **Sultan Limestone (Middle Devonian)** Prominent cliff-forming olive gray dolostone, commonly including abundant silicified stromatolites or vugs, overlain by less resistant, well bedded olive gray to light gray dolostone. Well-sorted, well-rounded pale pink to white quartz-arenite beds or pinkish gray sandy dolostone beds are locally found below the olive gray dolostone. These may belong to the Mountain Spring Formation. Total thickness is ~140 m.

Cmu **Muav Limestone, undifferentiated (Late to Middle Cambrian)** The middle Cambrian Muav Limestone (see Rowland and others, 1990) is the thickest and most prominent Cambrian unit within the cratonal stratigraphic section of the Grand Canyon region. Within the miogeocline of southern and central Nevada, the Bonanza King Formation is the equivalent of the largely cratonal Muav Limestone. Because the Meadview North Quadrangle contains a relatively thin cratonal section of Paleozoic sedimentary rocks, we refer to the middle Cambrian carbonates here as the Muav Limestone. The Muav Limestone was subdivided into three units.

Cm$_3$ **Cm$_{3a}$** **Cm$_{3b}$** **Muav Limestone, Unit 5 (Late Cambrian)** Equivalent to the upper part of the Banded Mountain Member or the Bonanza King Formation, although the beds equivalent to the uppermost Banded Mountain Member have been erosionally removed and are marked by the sub-Devonian unconformity. Forms prominent bench. Light gray, burrow-mottled dolomite overlain by medium gray burrow-mottled dolomite and interbeds of light gray to white crystalgal dolomite. Total thickness is ~300 m.

Cm$_{2-3}$ **Muav Limestone, Units 3 and 4 (Late to Middle Cambrian)** Equivalent to the lower part of the Banded Mountain Member of the Bonanza King Formation. Unit 3 is a dark gray, cliff forming, burrow-mottled dolomite with some orange overprint on silt-rich portions. Unit 4 is slightly less resistant, dark to medium gray dolostone with interbeds of light gray to white crystalgal dolomite. A prominent horizon of brown chert lenses occurs ~10 m above the base of Unit 4. Total thickness is ~80 m.

Cm$_{1-2}$ **Muav Limestone, Units 1 and 2 (Middle Cambrian)** Equivalent to the Papoose Lake Member of the Bonanza King Formation. Prominent cliff-forming light gray limestone overlain by medium gray, bedded, burrow-mottled limestone and dolostone with an orange overprint, particularly on silt-rich burrows and along some bedding planes. The top of Unit 2 is marked by a recessive orange buff, cross-bedded carbonate grainstone. Total thickness is ~200 m.

Cb **Bright Angel Formation (Middle Cambrian)** Shale and subordinate limestone. The basal parts consist of green and reddish brown shale containing worm burrows, oscillation ripples, and local cross-beds. The upper part consists of a light brown and dark gray oncolitic silty limestone, which is overlain by green shale with worm burrows. Approximate thickness ranges from 20 to 40 m.

Ct **Tapeats Sandstone (Early Cambrian)** Highly indurated pale brown to pale reddish-brown thin to thick bedded, locally cross-bedded fine- to coarse-grained sandstone; includes both silica and calcite cement. Unconformably overlies Early Proterozoic gneiss and Middle Proterozoic gabbro-diabase in the southwestern part of the quadrangle. Thickness ranges from 20 to 40 m.

PROTEROZOIC ROCKS

Ydg **Gabbro and diabase (Middle Proterozoic)** Gray to greenish-gray, medium- to coarse-grained generally unfoliated gabbro and diabase consisting of 55-60% plagioclase; lesser hornblende, augite, and hypersthene; minor magnetite (2-3%) and quartz (1%); and traces of zircon. Gabbro locally has a weak foliation. Hornblende and pyroxene are locally altered to chlorite and biotite. A similar unit in the South Virgin Mountains may be related to the Gold Butte Granite (K. Howard, written commun., 1999).

Xpg **Pegmatitic gneiss (Early Proterozoic)** Moderately foliated pegmatitic gneiss consisting mainly of coarse-grained potassium feldspar, quartz, biotite, and accessory garnet; probably similar in age to Xgn; many small bodies within Xgn were not mapped.

Xgf **Granitic gneiss (Early Proterozoic)** Reddish-brown, fine- to medium-grained weakly to moderately foliated granite very similar in composition to Xgc, but decidedly finer grained than Xgc. Locally includes small bodies of garnet gneiss.

Xgc **Megacrystic-granitic gneiss (Early Proterozoic)** Pale brown to reddish-brown, coarse-grained (megacrystic) weakly to moderately foliated gneiss; consists mainly of potassium feldspar, plagioclase, quartz, hornblende, and biotite; potassium feldspar grains are up to 5 cm long; typically highly fractured and