Description of Map Units
Nevada Bureau of Mines and Geology
Map 127

GEOLOGY OF THE FRENCHMAN MOUNTAIN QUADRANGLE
CLARK COUNTY, NEVADA

by
S.B. Castor, J.E. Faulds, S.M. Rowland, and C.M. dePolo

The Frenchman Mountain Quadrangle contains exposures of rock units that range in age from the Middle Cambrian Chisholm Shale through Holocene alluvium. Older Cambrian and Proterozoic rocks are not exposed in the quadrangle but crop out just to the west in the Las Vegas NE Quadrangle (Matti and others, 1993). Major breaks in the stratigraphic section include the Ordovician through early Devonian (at least 100 million years), the Late Permian and part of the Early Triassic (perhaps 20 million years), and much of the Mesozoic and Cenozoic time (a break of as much as 200 million years). The Paleozoic and Mesozoic strata are conformable, and both the Ordovician/Silurian and Paleozoic/Mesozoic boundaries are disconformities. In contrast, the break between the youngest Mesozoic unit (Early Jurassic Aztec Sandstone) and the oldest Tertiary unit (basal conglomerate of the Horse Spring Formation) is marked by a slight angular unconformity. The base of the Tertiary rests on progressively younger units to the north from a position on the upper part of the Moenkopi Formation (Middle Triassic) in the southern part of the Frenchman Mountain Quadrangle to the Aztec Sandstone in the central part. However, except for local structural complexities, the dip discordance between Mesozoic and Tertiary strata is only a few degrees.

QUATERNARY

Qa  Active alluvium Active cobble, gravel, and sand deposits in washes, locally with boulders in proximal reaches; occupies channels inset up to 15 m (~35 m in Las Vegas Wash) and proximal to discharge areas of alluvial fans; anastomosing bar-and-channel surface morphology is nearly ubiquitous. These surfaces have commonly been shaped by the last major discharge event in the channel and have a distinct flood hazard potential. Deposits range from moderately sorted to poorly sorted, poorly to moderately stratified, and non-indurated to weakly cemented by salts (commonly gypsum). Clasts are angular to subrounded. Thickness of the deposits ranges from a few centimeters to ~10 m.

Qf  Landfill Sunrise landfill disturbed area. Much of this unit is cover over a decommissioned landfill, but some represents scraped and highly disturbed older units.

Qia  Intermittently active alluvium Alluvial surfaces that are intermittently active including low terraces and discharge areas of alluvial fans. Bar-and-channel surface morphology is common, although many of these surfaces have stable vegetation. Deposits range from moderately sorted to poorly sorted, poorly to moderately stratified, and non-indurated to weakly cemented by salts (commonly gypsum). Clasts are angular to subangular.

Qab  Basin alluvium of Las Vegas Valley Alluvium of the basin floor of Las Vegas Valley. Surface morphology consists of a series of shallow channels with interfluviu sandy flats. The unit consists of light brown sandy silts to silts; generally poorly to moderately stratified with thin bedding; mostly unconsolidated but locally indurated by clay and weakly cemented with gypsum and other salts.

Qa1  Young stream-terrace and fan-terrace alluvium Alluvial surfaces forming the lowest set of stream and fan terraces. A smoothed bar-and-swale surface morphology is common where clasts include cobbles; surfaces are more smoothed where clasts are pebbles. Moderately developed etching occurs on limestones and sandstones, and rock varnish is weakly to moderately well developed on small clasts. Soil development includes a 2- to 5-cm-thick eolian silt Av horizon, an incipient cambic horizon that can be up to 15 cm thick, and a stage I to II calcic horizon. Pavements are moderately well developed to well developed. Deposits are commonly weakly to moderately well indurated, poorly to moderately sorted, and are poorly to moderately stratified.

Qa2  Intermediate stream-terrace and fan-terrace alluvium (late Pleistocene) Alluvial surfaces forming an intermediate level of stream and fan terraces. Alluvial surfaces are present in the cobbly units but are smoothed from surficial reworking and eolian deposition. In pebbly deposits little or no surface may remain. Edges of deposits are commonly eroded or dissected. Pavements are well developed and rock varnish is moderately to strongly developed on silliclastic, cherty, and granodiorite rocks. Limestones and sandstones are moderately well to well etched. Soil development includes a 5- to 15-cm-thick eolian silt Av horizon overlying a reddish argillic horizon up to 80 cm thick, and a stage I to III calcic horizon or a gypsiferous horizon up to 40 cm thick at the base of the profile. Deposits are made up of sandy gravels to gravelly cobbles. Deposits are moderately well indurated, poorly to moderately sorted, and poorly to moderately stratified. Clasts are angular to subangular. Deposit thicknesses range from 0.5 to 5 m.

Qsg  Intermediate alluvium of Las Vegas Wash (late Pleistocene) Interbedded silty fine sands and gravels locally inset into the channel of Las Vegas Wash. Deposits are moderately to well stratified, non-indurated, have a badlands-erosional character, and lack surfaces and soils.

Qa3  Older stream-terrace and fan-terrace alluvium (Pleistocene) Alluvial surfaces forming the highest recognizable stream- and fan-terrace remnants. These units either lack surfaces or are erosionally stripped down to resistant calcic horizons. Areas that lack surfaces are eroded slopes or ballenas. Surfaces have moderately to well developed pavements with abundant pedogenic carbonate litter. Rock varnish is moderately well to well developed. Soils are generally truncated above calcic horizons that have stage III to IV carbonate development, overlain by an up to 20-cm-thick eolian silt cap (Av). Calcic horizons are >1 m thick, and carbonate rinds are up to 2 cm thick and are commonly micritic in character. Some buried paleosols exist. Deposits are sandy gravels to gravelly cobbles, moderately well to well indurated, poorly to moderately sorted, and poorly to moderately stratified. Clasts are angular to subangular. Deposit thicknesses range from 2 to >5 m.

QTcg  Older cemented conglomerate of Las Vegas Wash (Quaternary or late Tertiary) Sandy pebble to cobble conglomerate composed of rounded and subrounded limestone, volcanic, granitic, and gneissic clasts cemented into a sandy calcareous matrix. Moderately to well sorted, generally well stratified with large-scale fluvial cross-bedding. The deposit is a well indurated, cliff-forming unit that is generally restricted to the channel walls of Las Vegas Wash, and is 10 m to 30 m thick. The deposit represents a paleochannel along Las Vegas Wash.

QTa  Older alluvium and lag gravels (Quaternary or late Tertiary) Gravel deposits that have the highest geomorphic position of any alluvium, capping low ridges; no surfaces are preserved. Relict carbonate horizons occur locally, with up to stage IV carbonate...
development and >1-m-thick gypsic horizons with stage V salt development. Carbonate rinds on some clasts exceed 2 cm in thickness and are commonly micritic in character. The deposits are poorly stratified and consist of pebble to boulder gravels that are poorly to moderately sorted and poorly to moderately indurated. The clasts are mostly angular to subangular and have very dark surfaces. They are dominantly of Tertiary porphyry (Td) and Proterozoic metamorphic rock and granite but also include a little Tertiary limestone and local Paleozoic carbonate. These gravels, which are as much as 20 m thick, mainly overlie Tertiary deposits, commonly sandstones and conglomerates of the Muddy Creek Formation. In places, they are lag gravels resting on conglomerates in the Muddy Creek Formation.

**QTa**n Older alluvium of Nellis basin (Quaternary or late Tertiary)

Reddish brown, thin-bedded (2 to 25 cm thick), poorly to moderately sorted pebble conglomerate and lesser interbedded medium-grained sandstone. Conglomerate is generally matrix supported but includes clast-supported beds. Pebbles are subangular to subrounded. Clast compositions are dominated by Paleozoic lithologies but include sparse Proterozoic gneiss. Thickness is as much as 20 m.

**QTBl** Limestone megabreccia (?) (Quaternary or late Tertiary)

Possible landslide deposit composed primarily of anomalous west-dipping Callville Limestone but includes minor Pakoo Formation on the east (QTBlp) and possibly, near the southwest margin of the exposure, slivers of the Redwall Limestone. The margins of this deposit are generally fault-bounded and brecciated, whereas internal parts are relatively coherent. This unit may be a large landslide block derived from the high terrain of Sunrise Mountain to the south and southeast.

**TERTIARY**

Tertiary sedimentary units mapped in the Frenchman Mountain Quadrangle include the Horse Spring Formation, which is subdivided into four members following the terminology of Bohannon (1984); the informal red sandstone unit of Bohannon (1984); and the Muddy Creek Formation as designated by Longwell and others (1965) from the “Muddy Creek beds” of Stock (1921). All are considered to be of Miocene age, although tuff that lies beneath the Horse Spring Formation near Logandale has yielded a late Oligocene age (Bohannon, 1984).

**Muddy Creek Formation**

Four subunits in the Muddy Creek Formation were defined in the Frenchman Mountain Quadrangle. In the northeast part of the quadrangle, limestone, gypseous, and gypsiferous gravel subunits (Tml, Tmg, and Tmgg, respectively) compose the upper part of the Muddy Creek Formation. The most extensive subunit (Tm) consists of siltstone to conglomerate; coarse detritus in this subunit appears to have been derived from local sources.

We originally placed the limestone unit (Tml) in the Muddy Creek Formation on the basis of its stratigraphic position. On Nellis Air Force Base, this limestone lies on redbeds that have been placed in the red sandstone unit of Bohannon (1984) on the basis of an 11.6 Ma $^{40}$Ar/$^{39}$Ar date of an interbedded tuff (sample JF99-452). In addition, the limestone unit directly overlies tuffaceous marl that may be equivalent to or overlie Muddy Creek gypsite near a gas pipeline development and a northeast-trending hingeline that crosses Lake Mead Boulevard about 1 km southeast of the Muddy Creek/red sandstone contact. Our structural data support this, but the fold hinge is not shown because dips are too shallow and variable to define an exact location. Anderson further suggested that Muddy Creek conglomerate and conglomerate in the underlying red sandstone may have been deposited continuously on the north limb of a local syntectonic depocenter in this area.

**Tml Limestone** Mostly moderately resistant pale-orange limestone with light-gray to light-brownish-gray weathered surfaces; limestone is laminated to thick bedded with finely crystalline dense to porous textures. Some porous beds have cm-scale crustiform algal textures. Well-preserved ostracods have been noted in thin section, but identifiable macrofossils were not observed. The limestone is as much as 50 m thick. Friable, commonly dolomitic, pale-olive to yellowish-gray or white marl is locally exposed beneath the limestone. The limestone and marl are interbedded with or overlie gypsite along the contact with Tmg. The base of the unit also includes minor gyspum in the northwest part of the map area.

**Tmg Gypsum** Gypsum unit that caps a very gently southward-dipping plateau in the northeast part of the quadrangle and thins to the south and west; isolated remnants of this unit (many too small to be mapped) occur along Gypsum Wash north of the Paleozoic buttress that includes Gypsum Cave. The gypsite is mostly white to grayish-orange, weakly resistant rock containing white gypsum crystals, generally less than 2 mm but in places as much as 15 cm across, with variable amounts of silt and clay. The unit locally includes an upper sequence that is light greenish gray with admixed clay to fine sand. At the PABCO Gypsum Mine on the east edge of the quadrangle, gypsum ore is more than 35 m thick and averages more than 80% gyspum (L. Ordway, 1997, personal commun.). According to Papke (1987), PABCO gypsum ore also contains montmorillonite, quartz, potash feldspar, and plagioclase. Southwest of the mine the gyspse is exposed along an erosional escarpment about 3 km long; here it is 3 to 10 m thick and overlies Tm.

**Tmgg Gypsiferous gravel** Gypsiferous gravel with some moderate-orange-pink to pale-red sandy and silty layers. Clasts are mainly gray Paleozoic carbonate and chert. The upper 2 to 5 m of Tmng contains abundant gyspum and may be coeval with Tmg on the basis of topographic position. East of Gypsum Wash, this unit is interbedded with, and at least partly equivalent to, Tm.

**Tm Sandstone, siltstone, and conglomerate** Poorly to moderately sorted pale-reddish-brown and pale-red sandstone and siltstone with some interbedded pebble to boulder conglomerate. Locally, the unit is mostly coarse conglomerate. Fine-grained lithologies generally dominate in the east part of the quadrangle. Sandstone is generally fine- to medium-grained with subangular to subrounded grains, weakly indurated with calcite cement, and thinly bedded. Conglomerate generally contains subangular clasts and includes both matrix and clast-supported beds, but matrix-supported beds dominate. Bed thickness ranges from 2 to 30 cm. North of Sunrise Mountain in the Nellis Air Force Base, conglomerate gives way northward to limestone and gyspum (laccustrine facies) toward a depocenter near the north margin of the map area, here referred to as the Nellis basin. Near the Frenchman fault, Tm is dominated by thinly to moderately bedded, poorly to moderately sorted, matrix-supported, weakly indurated (calcite cement), pale-brown or reddish-brown to light-gray conglomerate containing subangular clasts of Paleozoic lithologies ranging up to 50 cm. Where composed of sandstone and siltstone, Tm is difficult to distinguish from other redbed units, such as Tht and Tr (see below) but generally has flat-lying or gently dipping (less than 20°) bedding and commonly contains some gyspum.
Volcanics of Calville Mesa

Basaltic flow rocks and associated cinders that crop out in the central east part of the Frenchman Mountain Quadrangle have been correlated with the 11.5- to 8.5-Ma volcanics of Calville Mesa (Anderson and others, 1972; Feuerbach and others, 1991) on the basis of stratigraphic position. The basalts are associated with unconsolidated tuffaceous beds (map unit Tvt) that seem to be understratified with the Muddy Creek Formation. However, it is possible that these rocks are instead related to basaltic rocks in the southeast part of the quadrangle that are 13.16 Ma (see "igneous rocks coeval with the River Mountains Volcanics" below).

Tvt Tuffaceous siltstone Nonresistant pinkish-gray tuffaceous siltstone. Includes some beds with Tvc cinders near base. Underlies Tmgg and may be coeval with part of Tm.

Tvc Mafic flows and cinders Dark gray to dark greenish-gray or grayish-red basaltic or andesitic lava, agglomerate, and cinder accumulations. The lava has phenocrysts of plagioclase, ± olivine, and ± pyroxene up to 1 mm in diameter in a fine-grained subhedral groundmass.

Red sandstone unit

The red sandstone is an informal unit of Bohannon (1984). It is generally difficult to distinguish from similar rock in other units such as the older Thumb Member of the Horse Spring Formation and the younger Muddy Creek Formation. In some areas, it was mainly distinguished from the Muddy Creek by the presence of relatively steeply dipping strata (20° or more). In a tributary of Las Vegas Wash at 36° 07' 50"N, 114° 53' 28"W an angular unconformity of about 20° between the red sandstone and the overlying Muddy Creek Formation is well exposed. The red sandstone unit crops out in two areas that may represent separate basins: (1) in the northwest part of the quadrangle, mostly on Nellis Air Force Base; and (2) in a much larger area in the southeast quarter of the quadrangle.

In the northwestern part of the quadrangle, the red sandstone unit consists of a thick (at least 600 m) sequence of mostly east-trending sedimentary rocks that accumulated in an east-tilted half graben that forms a distinct subbasin of Las Vegas Valley, as evidenced by isostatic gravity data (Langenheim and others, 1997). In the southeast quarter of the quadrangle, the red sandstone unit is estimated to be about 700 m thick, and mainly occurs in a northeast-trending basin that is about 5 km long and 3 km wide and may extend eastward for as much as 10 km (Duebendorfer and Wallin, 1991).

Tr Red sandstone undifferentiated In the northwest part of the quadrangle, Tr is chiefly composed of interbedded, moderately sorted, weakly indurated (calcite cement) pale to dark reddish-brown to purplish-brown and locally yellowish-gray to yellowish-brown mudstone, siltstone, fine- to medium-grained sandstone, and pebble conglomerate. The conglomerate is generally matrix supported and contains subangular clasts of Paleozoic lithologies (carbonate, chert, and sandstone). Medium-light-gray to dark-greenish-gray flows

Tb Basalt Medium-light-gray to dark-greenish-gray flows ± dikes with some vesicular rock and minor glassy basalt. These rocks, which include basalt and andesite on the basis of whole rock chemistry (samples C95-9 and C95-20, table 2), commonly have vesiculated tops and locally consist of glassy rock. They occur in the Lovell Wash Member (Thl) of the Horse Spring indicate an age of 11.6 Ma for this tuff (sample JF99-452, table 1). A silver-gray vitric shard tuff of similar thickness is slightly higher in the section.

In the southeast quarter of the quadrangle the red sandstone unit is mostly poorly to moderately indurated, partially calcite cemented, moderate orange-pink to pale-reddish-brown, line-grained sandstone with minor gyspum. The unit includes several tuff layers in its lower part and a thick conglomerate sequence in its upper part. Near the base of the red sandstone unit is a 1.5-m-thick bed of silver-gray, glassy, rhyolite shard tuff (C95-4, table 2). About 100 m above this tuff is a 2-m-thick white to pale-green tuffaceous sequence that mainly consists of tuffaceous sandstone with local soft sediment deformation folds. The basal 30 cm of this sequence consists of thinly bedded, line-grained rhyolite tuff (C95-3, table 2) with small crystals of quartz, sanidine, plagioclase, biotite, pyroxene, and hornblende. The sandine yielded a date of about 11.47 Ma (table 1), nearly indistinguishable from the age of the rhyolitic Ammonia Tanks Tuff, a regionally extensive high-silica rhyolite to alkali trachyte ash-flow sheet from the Timber Mountain caldera about 150 km northwest of the Frenchman Mountain Quadrangle (Sawyer and others, 1994).

Excellent outcrops of a thick sequence (at least 200 m) of well-bedded pebble to boulder conglomerate that is laterally equivalent to sandy beds in the red sandstone unit occur along the east bank of a large wash adjacent to Lake Mead Boulevard. Clasts consist of high-grade Proterozoic metamorphic rock, Tertiary basalt, white mudstone, and reddish sandstone. Bedding dips are as great as 60° to the southeast. About 75 m to the southeast in the wash is conglomerate with much gentler tilts (the maximum dip is 18° southeast) and clast lithologies similar to those noted above but additionally including abundant porphyry similar to Td (see below). The contact area in the wash, at 36° 11' 19"N, 114° 54' 00"W, is covered. R.E. Anderson (personal commun., 1999) who has noted similar relationships elsewhere suggested that this contact is gradational, and the bedding fans gradually due to tilting during deposition. We find the evidence for such a relationship to be equivocal in this area. Instead, we have mapped a contact between the red sandstone and the Muddy Creek Formation at this site and infer an angular unconformity here on the basis of clear evidence for such a relationship elsewhere. In addition, the change in clast lithology may reflect provenance in two different source areas. However, we concur that the presence of a thick conglomerate sequence in the red sandstone in this area is problematic (although Bohannon, 1984, noted local conglomerate in the unit in the Muddy Mountains) and suggests uplift during deposition.

Near the south edge of the quadrangle, the contact between the red sandstone and the underlying Horse Spring Formation is a fault that dips steeply east. In the vicinity of Lake Mead Boulevard no fault is obvious along this contact. Whether faulted or not, the contact between the red sandstone and Horse Spring Formation is commonly marked by mafic flows (Tb).

Igneous rocks coeval with the River Mountains Volcanics

In the southeast part of the quadrangle, dacitic to basaltic rocks predate the red sandstone unit. Our dates on these rocks range from about 13.2 Ma to 13.5 Ma, indicating that they correlate with the River Mountains Volcanics (Smith, 1982), which have yielded 40 Ar/ 39 Ar dates ranging from 13.0 to 13.45 Ma (Faulds and others, 1999).
Formation or separate it from the overlying red sandstone unit (Tr). Along the Thl/Tr contact east of Lava Butte at least two flows lie above light-green to white gypsum and tuff and are separated by reddish-brown sandstone and gypsum. The rocks typically contain phenocrysts of olivine and plagioclase in a fine-grained pumiceous matrix that ranges from sand to silt size. A groundmass consists of holocrystalline, intergranular, seriate flow rock with crystals of olivine as much as 4 mm long, yielded an $^{40}\text{Ar}/^{39}\text{Ar}$ age of 13.16 ± 0.18 Ma (table 1).

Td  Intrusive porphyry  Porphyry with abundant phenocrysts of white plagioclase to 5 mm, and lesser amounts of smaller black hornblende and biotite phenocrysts, in an aphanitic light-gray to light-brownish-gray matrix. It is locally altered to light gray or yellowish gray; weathered surfaces are commonly brownish gray. Td shows no clear evidence of extrusion and is therefore considered to be entirely of intrusive origin. It contains sparse inclusions of more mafic volcanic rock (probably Tta) and some narrow very fine-grained dikes or xenoliths near the top of Lava Butte.

Td occurs in the upper part of the Thumb Member of the Horse Spring Formation, forming a large mass that comprises most of Lava Butte, a narrow exposure that extends along a ridge to the north, and a similar narrow body to the south that appears to be separated from the main Lava Butte mass by a fault. The narrow masses are clearly discordant dikes; exposed contacts between them and adjacent Thumb Member sedimentary rocks are nearly vertical, and the porphyry is commonly brecciated along them. However, the western boundary of the Lava Butte mass dips shallowly east and is parallel to anomalously shallow strata in the underlying Thumb Member. Here the porphyry is strongly foliated in a narrow zone (about 10 to 50 cm thick) along the contact. The eastern contact is clearly a high-angle feature and has provisionally been mapped as a fault. The eastern contact is exposed in two places; at one of these it is a fault dipping steeply west, but at the other exposure the porphyry includes a narrow strongly foliated border similar to that along the western boundary.

The shape of the Lava Butte porphyry mass at depth is problematic because of anomalously low dips in Tt to the west and below it. It has been suggested that the contact between Thl and Tt to the west is a reverse fault (R. Bohannon, written commun., 1999), but no evidence of such a fault was observed. We interpret the Lava Butte porphyry mass as an irregular intrusion, perhaps a "Christmas tree laccolith" (see cross section B–B') that deformed surrounding parts of the Horse Spring Formation.

Although phenocryst mineralogy (plagioclase, hornblende, and biotite, without potash feldspar or quartz) is suggestive of dactitic composition, rock chemistry on a single sample from Lava Butte is that of low-silica rhyolite with somewhat elevated potash (sample C95-29, table 2). Plagioclase phenocrysts have an estimated composition of An$_{50}$, suggesting intermediate composition.

Anderson and others (1972) reported K-Ar ages of 13.8 ± 0.7 Ma and 12.0 ± 2.0 Ma (recalculated to new constants) on biotite and hornblende, respectively, from this rock unit, although Bohannon (1984) suggested that these ages were reset by alteration. Our step-heating $^{40}\text{Ar}/^{39}\text{Ar}$ ages of 13.16 ± 0.05 Ma and 13.50 ± 0.16 Ma on biotite and hornblende, respectively, from sample C95-29 (table 1) confirm the biotite date of Anderson and others (1972). Both step-heating age spectra are plateaus except for the lowest and highest temperature steps; however, the hornblende and biotite separates provided somewhat different ages (table 1). Both minerals appear unaltered in thin section, but the biotite contains abundant inclusions in comparison to the hornblende, suggesting that the older hornblende date may be more accurate. Regardless of which age is used, the dacite porphyry is probably too young to have been extruded during Thumb Member deposition, and its age is virtually indistinguishable from ages obtained on tuffs in the overlying Bitter Ridge and Lovell Wash Members of the Horse Spring Formation (table 1). The ages that we obtained on Td are similar to K-Ar (Anderson and others, 1972; Weber and Smith, 1987) and $^{40}\text{Ar}/^{39}\text{Ar}$ ages (Faure and Midgley, 1999) reported for felsic volcanic and intrusive rocks in the River Mountains to the south, suggesting that intrusions of Td in the Lava Butte area were related to magmatism in the River Mountains.

Horse Spring Formation

The Horse Spring Formation, originally defined in the Muddy Mountains by Longwell (1928), was redefined and subdivided regionally by Bohannon (1984), who also described sections in the Lava Butte area. We have used Bohannon's subdivision, but our descriptions of some units differ due to lateral variations. The Lovell Wash Member is typically white to yellowish colors and contain abundant carbonate and calcareous shale in the south part of the quadrangle but is dominated by tuff in the north part. We mapped the basal contact of the Bitter Ridge Member at the base of a thick sequence (as much as 120 m) of light-colored algal limestone with scattered carbonate nodules. This limestone is overlain by light yellow to bright yellow tuff near the top of Lava Butte. This limestone is similar to that described by Bohannon (1984) as the dominant lithology in the member in the Lava Butte area. However, the unit contains progressively less limestone to the north, where it mostly consists of sandstone. To the south, this sandstone occurs between sequences that are dominantly composed of limestone. However, to the northeast of Lake Mead Boulevard the sandstone is too thin to map at 1:24,000, and thus shaly and tuffaceous strata of the Lovell Wash Member are shown lying directly on the Thumb Member. The Thumb Member, which includes significant amounts of basal conglomerate and gypsum in the south part of the quadrangle, is largely devoid of these rock types to the north. The Rainbow Garden Member, mainly limestone in the south part of the quadrangle, thins and is replaced by calcareous sandstone to the north. The only unit with consistent lithology throughout the quadrangle is the basal conglomerate of the Rainbow Gardens Member (Trc).

Thl  Lovell Wash Member  Mostly limy or dolomitic white, light-greenish-gray, very pale-orange, pale-pink or yellowish-gray tuff, mudstone, and siltstone with minor sandstone, gypsum, carbonate beds, and tufa. This member is dominantly composed by carbonate, mudstone, and tufa in the south part of the Frenchman Mountain Quadrangle and by tuff in the eastern part of the quadrangle. Tuffs in the south part of the quadrangle range from pale-green, zeolitized rock with biotite ± hornblende to white, clay-altered material that is typified by "popcorn" weathering and is extremely sliny when wet. Lithium-rich clay (hectorite?) was noted in this unit in the Frenchman Mountain Quadrangle by Brenner-Tourtelot (1979) and Vine (1980). Clay-rich beds crop out locally along with minor amounts of finely laminated algal carbonate that resembles the "eggsilk limestone" associated with borate mineralization in the Muddy Mountains (Castor, 1993). The mudstone and sandstone are locally ripple bedded. Carbonate beds, which include both dolomite and limestone, are typically finely laminated. A light-gray tufa bed with pods and layers of dark-weathering silica (shown as -o-o-o-o- on the map) occurs near the top of the unit and is overlain by light greenish-gray tuff and gypsum. The tufa occurrences were, in part, originally mapped by Brenner-Tourtelot (1979) as "spring pots."

To the east of Lake Mead Boulevard, the Lovell Wash Member is composed mainly of very pale green to white tuff with minor dolomite. It is intruded and capped by Th. Bohannon (1984) reported a zircon fission-track age of 13.0 ± 0.8 Ma for tuff in the Lovell Wash Member. Samples collected during our mapping yielded a plagioclase $^{40}\text{Ar}/^{39}\text{Ar}$ isochron age of 13.12 ± 0.24 Ma (sample C95-50, table 1), and $^{40}\text{Ar}/^{39}\text{Ar}$ step-heating ages of 13.40 ± 0.05 Ma and 13.12 ± 0.12 Ma on biotite and hornblende, respectively (sample C95-64, table 1).
According to R.E. Anderson (personal commun., 1998), Thumb Member rocks mapped above the upper andesite flow (Tta) near the south edge of the quadrangle should be included in the overlying Bitter Ridge Member. However, we put these rocks in the upper part of Thumb Member because they are mainly light-yellowish-gray sandstone and siltstone and contain only minor amounts of limestone.

The age of the Thumb Member in the Frenchman Mountain area is poorly constrained. Relatively young ages, 11.2 to 13.8 Ma (by K/Ar, recalculated to new constants) obtained by Anderson and others (1972) are on igneous rocks that are probably intrusive, and thus represent minimum ages. Older ages, 16.0 and 17.6 Ma (by K/Ar, recalculated to new constants), are on flows within the Thumb Member, but these ages are not very accurate (± 3 Ma). Bohannon (1984) reported a 13.2 ± 0.9 Ma age on tuff in the Thumb Member, but proposed that this was an anomalously young age. He suggested a regional age range for the unit of 17.2 to possibly 13.5 Ma. Beard (1996) reported eight 40Ar/39Ar ages ranging between 16.2 Ma and 14.2 Ma in the South Virgin Mountains. The porphyry that holds up Lava Butte (Td) is considered to be intrusive into rocks of the Thumb Member on the basis of age and contact relationships. Dates on this porphyry (sample C95-29, table 1) indicate a minimum age of about 13.2 Ma for the Thumb Member in the Frenchman Mountain area. We obtained a new date of about 13.9 Ma on biotite from a tuff sample 2 km northeast of the Frenchman Mountain Quadrangle (C99-14, table 1). This is a 1-m-thick air-fall tuff that lies above siltstone and sandstone of the Thumb Member and beneath resistant limestone of the Bitter Ridge Member.

**Tta Intermediate or mafic volcanic rock** Fine-grained, pale-brown intermediate or mafic volcanic rock that contains small phenocrysts of plagioclase and biotite ± pyroxene ± altered hornblende and very fine-grained, medium- to light-gray intermediate volcanic rock with tiny plagioclase laths that form plotaxitic texture. These lithologies comprise at least two flows and may include some intrusive rock in the Thumb Member. Flows are 2 to 5 m or more thick with vesiculated tops.

**Ttb Breccia with Proterozoic detritus** Lenses and beds of breccia composed exclusively of clasts of Proterozoic rock, which is diagnostic of the Thumb Member (e.g., Rowland and others, 1990). In some areas this breccia is monolithic, but in other areas the breccia contains a variety of metamorphic and igneous lithologies including granite, amphibolite, biotite-quartz-feldspar gneiss (± garnet), alaskite, and pegmatite. The breccia is relatively resistant and generally forms steep-sided hills. As an example, the Red Needle, a prominent landmark in the southern part of the quadrangle (formerly “The Thumb” and stratigraphic namesake), consists of soft-sediment-deformed Thumb Member beds surmounted by a mass of such breccia. The breccia ranges from poorly bedded heterolithic matrix-supported debris flow deposits to clast-supported monolithic megabreccia. Some breccia clasts are large. For example, at 36° 10’ 14” N, 114° 56’ 03” W a slab of Proterozoic gneiss and pegmatite at least 15 m long was observed. Certain types of breccia predominate in specific parts of the quadrangle. In the area between Lake Mead Boulevard and the paved road to the PABCO Gypsum Mine, most breccia masses consist exclusively of coarse granite with large feldspar phenocrysts (“rapakivi granite” of some researchers). Clasts of Paleozoic rock are absent in the breccia.

**Tbc Conglomerate** Resistant to nonresistant, planar-bedded conglomerate with some sandstone interbeds; intertongues with sandstone and siltstone of Tht to the north and up section. Clasts in the conglomerate are well-rounded to subrounded pebbles to boulders and are mainly of Paleozoic and Mesozoic carbonate and sandstone, Paleozoic chert, and some quartzite (possibly Eureka Quartzite or Tapeats Sandstone). Clasts in some beds consist almost exclusively
of Mesozoic sandstone boulders. No clasts of Proterozoic rock were found. The matrix is pale- to moderate-reddish-brown carbonate-cemented, medium to granule sand. Sandstone interbeds are as much as 1 m thick, pale reddish brown, medium grained to granule, carbonate cemented, and generally contain some pebbles. The conglomerate sequence recorded a thickness of about 270 m at the southern edge of the quadrangle but pinches out 1.5 km to the north. The dashed eastern contact of the conglomerate signifies interfingerling with more typical Thumb Member sandstone.

**Trc**  Resistant basal conglomerate  Moderate to strongly resistant basal conglomerate of Rainbow Gardens Member that typically forms ridges. Clasts, mostly of Paleozoic and Mesozoic carbonate and chert with some sandstone, are generally subrounded and are pebble to cobble in size. Rare clasts of gray quartzite were also noted; these are clearly not Mesozoic sandstone and most closely resemble Lower Cambrian or Late Proterozoic quartzite such as the Johnnie Quartzite. We found no clasts of highly metamorphosed Proterozoic rock. Bohannon (1984) noted granite and gneiss clasts in this unit in southernmost Rainbow Gardens, but we did not observe these clast lithologies. The conglomerate matrix is pale-red to pale-reddish-brown, fine- to coarse-grained sand cemented by calcite. At a distance, the overall color is light brownish gray owing to the predominantly gray color of carbonate clasts. The basal Rainbow Gardens conglomerate overlies Mesozoic rocks with slight angular unconformity. It rests unconformably on Aztec Sandstone in the central part of the quadrangle and on progressively older Mesozoic units farther south. However, it lies on folded Chinle and Moenave-Kayenta rocks at 36° 12' 22"N, 114° 56' 7"W. Locally, the basal contact is marked by channels a few meters deep. In addition, the conglomerate is too thin to map at 1:24,000 in places. Bohannon (1984) reported that its upper contact shows evidence of erosion and proposed that it formed as a lag gravel on a widespread pediment surface.

**MESOZOIC**

**Ja**  Aztec Sandstone  Moderate-orange-pink to moderate-reddish-orange, fine- to medium-grained sandstone. Invariably cross-bedded in sets as much as 20 m thick. Weathers to distinctive fiery moderate orange pink to moderate reddish brown. The Aztec Sandstone, which has been correlated with the Navajo Sandstone in Utah and the Nugget Sandstone in Wyoming (Peterson and Pipirigos, 1979), is part of a regionally extensive eolian sandstone sequence that is considered to be one of the most voluminous pure quartz arenite formations in the geologic record (Blakey, 1989). Although it is generally very distinctive, forming relatively resistant outcrops with bright-orange to reddish-brown colors and large-scale cross-bedding, isolated small outcrops can be confused with other sandy redbed units. It is overlain with low angular unconformity by the basal Tertiary conglomerate of the Horse Spring Formation. The Aztec Sandstone is as much as 100 m thick in the Frenchman Mountain Quadrangle.

**Jmk**  Moenave and Kayenta Formation equivalents  Mostly nonresistant pale-red-brown to pale-brown fine sandstone, siltstone, and shale approximately 250 m thick. Characterized by abundant veiny gypsum and richly hematitic beds of grayish-red to dark-reddish-brown siltstone and shale. Minor amounts of pale-green sandstone and shale and trace amounts of gray limestone are locally present near the base, which is locally marked by resistant grayish-brown to grayish-purple chert-pebble conglomerate up to 7 m thick. The Moenave and Kayenta Formations are combined on our map. Longwell (1966) included rocks in these units in the Chinle Formation, but Wilson and Stewart (1967) proposed that strata
equivalent to the Moenave and Kayenta Formations were present in southern Nevada between the Chinle Formation and the Aztec Sandstone. Wilson and Stewart (1967) put the base of this unit beneath chert-pebble conglomerate. This conglomerate is well exposed at 36° 11′ 15″N, 114° 55′ 48″W in the Frenchman Mountain Quadrangle in the south wall of a prominent east-draining wash. The conglomerate is about 7 m thick and is overlain by interbedded brown shale and pale sandstone with minor conglomerate and thin pale-green tuff beds that are typical of the upper part of the Chinle Formation. In thin section, a sample of this rock contains about 65% of well-sorted, rounded to subrounded clasts that average about 2 mm in diameter and are composed of chert, carbonate, quartzite, and sandstone in relative order of abundance. Porphyratic to fine-grained panidiomorphic igneous clasts of intermediate composition comprise about 2% of this rock. Wilson and Stewart (1967) reported abundant volcanic clasts in this conglomerate in the Spring Mountains. Above the exposure of basal Moenave-Kayenta conglomerate in the Frenchman Mountain Quadrangle is about 30 m of reddish-brown fine-grained sandstone to shale and a few limestone beds. Here, as elsewhere, the Moenave-Kayenta equivalent may be distinguished from the underlying Chinle Formation by the absence of pale-green tuff beds.

The age of the Moenave and Kayenta Formations was originally considered to be Late Triassic on the basis of vertebrate fossils found in Arizona. However, more recent work has indicated an Early Jurassic age for the units (Peterson and Pipirigos, 1979). Marzolf (1991) placed these units above a regionally extensive basal Jurassic unconformity cut on the Chinle Formation and older rocks.

**Chinle Formation** The upper part of the Chinle Formation, which is probably correlative with the Petrified Forest Member of the Chinle as described by Wilson and Stewart (1967), consists of about 100 m of brown to light reddish-brown thin-bedded shale to fine-grained sandstone with minor interbeds of light-greenish-gray sandstone. Some very to bedded gyspum is also present. The uppermost 50 m of the formation contains thin beds of pale-yellowish-green to greenish-gray tuff. The middle part of the formation is a unit as much as 37 m thick that contains brownish-gray to yellowish-gray bentonitic ash; beds of reddish-orange to yellowish-orange, fine-grained to granule sandstone with associated conglomerate that locally contains petrified wood; light-greenish-gray, flaggy, fine-grained sandstone; and minor dark, organic-rich shale or siltstone. The base of the formation consists of a 2-m-thick sequence of dark-yellowish-brown-weathering, grayish-red to olive-gray carbonate pebble conglomerate with associated sandy limestone and limy sandstone. These rocks are the informal Spring Mountain member of Riley (1987). Altogether Tc is about 120 m thick.

We have not subdivided the Chinle Formation into the traditional Shinarump and Petrified Forest Members, although both units may be present on the basis of regional stratigraphic descriptions in Wilson and Stewart (1967). The Chinle has been proposed for group status by Lucas and Marzolf (1993), who placed five formations (including the above mentioned members upgraded to formation status) in it. At 36° 11′ 19″N, 114° 55′ 53″W, a smectite-rich bed about 5 m thick that was probably derived from tuff occurs in the Chinle just above a 12- to 32-m-thick sequence largely composed of light-colored sandstone and pebble beds (probable Shinarump Member). The smectic bed may correlate with the Blue Mesa Member of the Petrified Forest Formation of Lucas and Marzolf (1993) who reported the unit to consist of a bentonitic bed 8.5 m thick in the Valley of Fire in Clark County, Nevada. Petrified wood in the Chinle Formation has been noted at several localities in the Frenchman Mountain Quadrangle, mostly as pebbles and cobbles in the lower part of the unit, although a log segment about 50 cm in diameter was noted in the most northerly exposure in the quadrangle. We consider the base of the Chinle Formation in the Frenchman Mountain Quadrangle to lie just below the informal Spring Mountain member of Riley (1987), although Larson (1965) put this sequence in the top of the underlying Moenkopi.

**Moenkopi Formation** Four Moenkopi Formation units were mapped, largely following Larson (1965), who measured a detailed section through the unit in the Frenchman Mountain Quadrangle. The upper redbed unit ("upper red" unit of Larson, 1965) consists mainly of fine-grained clastic sediments. We mapped the gyspum-rich Schnabkaib Member directly on the Virgin Member. The middle redbed member of the Moenkopi does not appear to be present in the Frenchman Mountain Quadrangle (Larson, 1965). The Virgin Member, which is mostly marine limestone and locally fossil-rich, grades downward into the lower redbed unit. The Timpewea Member, a conglomeratic unit that is less than 10 m thick in the quadrangle (Larson, 1965), is included in our lower redbed unit ("lower red" unit of Larson, 1965).

**Upper redbed unit** Mainly varicolored shale, siltstone, and sandstone with locally abundant gyspum. Sandstone beds are commonly marked by small-scale ripples. The base is locally composed of as much as 8 m of very pale-orange to pale-red, medium-grained quartz sandstone. Most of the unit is nonresistant pale-redish-brown to pale-brown fine-grained sandstone, siltstone, and shale with veiny gyspum. It is approximately 400 m thick.

**Schnabkaib Member** Mostly gray dolomite and interbedded grayish-yellow to pale-yellowish-orange fine-grained sandstone and siltstone with abundant gyspum. Minor amounts of limestone are present. The dolomite is thin bedded, generally ripple marked, and commonly oolitic. Identifiable fossils are rare or lacking. The thickness is about 170 m.

The contact between the Schnabkaib and Virgin Formation Members is marked by a color change from resistant yellowish limestone beds of the Virgin Member, to less resistant pale-green to white gyspum and dolomite beds of the Schnabkaib. Both members contain some fine-grained clastic redbeds, but this lithology, which is generally gyspum-rich, is more common in the Schnabkaib.

**Virgin Member** Mostly gray to grayish-brown micritic limestone with interbeds of grayish-yellow to pale-olive fine-grained sandstone and siltstone with gyspum. The limestone beds commonly contain microscopic algal filaments and about 1% subrounded silt grains of quartz, feldspar, and muscovite. As a whole, this member is more resistant than Tms and contains less gyspum. The limestone is mostly yellowish gray to light gray and thin bedded. It includes beds of bioclastic limestone as much as 1 m thick, particularly near the base of the member. Minor amounts of dolomite are also present. Fossils are abundant in some beds. Although Larson (1965) reported a pectinoid mollusc and star-shape crinoid stem segments as the most widespread fossils in the unit, gastropods were the most prominent fossils noted by us. At 36° 12′ 37″N, 114° 56′ 44″W, a bed containing abundant mytiloid pelecypods was noted, and silicified gastropod and pelecypod fossils were found about 100 m to the southwest. Tmv thickness is about 150 m.

**Lower redbed unit** Mostly friable pale-red, pale-reddish-brown, and pale-brown shale to fine-grained sandstone with abundant gyspum. Thickness varies from about 100 m in the north part of the quadrangle to 250 m to the south. The base of the unit is locally marked by pebble to cobble conglomerate. The upper part of the unit, mainly gyspiferous redbeds, also contains beds of light-gray to white carbonate, mostly dolomite, that are less than 50 cm thick, commonly rippled marked, and locally contain rip-up clasts.

**PALEOZOIC**

**Kaibab Formation** The Kaibab Formation consists mostly of a resistant cherty limestone sequence that strongly resembles the main part of the underlying Toroweap Formation. This resistant limestone is probably equivalent to the Fossil Mountain Member of Sorauf and Billingsley.
The upper part of the Kaibab Formation was mapped as the Harrisburg Member (Reeside and Bassler, 1922; Sorauf and Billingsley, 1991). This unit has regional economic importance as a major source of gypsum and has been mined continuously since 1909 at Blue Diamond southwest of Las Vegas. It was described but not mapped in Clark County by Longwell and others (1965). The Harrisburg Member seems to have strong lateral variability. As a result of poor exposures, the Harrisburg Member was locally lumped with the underlying cherty limestone in the Frenchman Mountain Quadrangle. Where well exposed, it contains distinctive light-colored, sparsely fossiliferous carbonate underlain by gypsum and redbeds. An extensive Mesozoic section overlies the Kaibab Formation and is separated from it by an unconformity that was first recognized in Utah by J.W. Powell in 1876. The unconformity is not marked by obvious angular discordance but may have been a surface of some relief because Triassic deposits fill valleys eroded as much as 20 m in the Kaibab Formation (Larson, 1965).

**Pk Harrisburg Member** The upper part of the Kaibab Formation consists of 3 to 20 m of distinctive very pale-orange to light-gray, resistant, flaggy, generally fossil-poor dolomite and/or limestone with abundant chert in some beds. These carbonate beds are underlain by a gypsiferous sequence as much as 20 m thick that contains some pebble conglomerate and fine-grained clastic material.

**Pk Kaibab cherty limestone** Thick-beded to massive, cliff-forming, light-gray to light-brownish-gray limestone with abundant chert nodules that weather to dark brown. Chert nodules are as much as 25 cm in diameter. The limestone is generally medium crystalline and typically fossiliferous, with abundant crinoid stem chips and locally abundant brachiopods and rugose corals. However, the upper 20 m of the Kaibab is nonfossiliferous to poorly fossiliferous, finely crystalline to micritic, locally cross-beded, and contains only minor chert. A pinkish tint locally distinguishes Pk cherty limestone from that in Pt. The Pk cherty limestone is generally about 100 m thick, but may be as much as 170 m thick in places; it has inordinately wide map widths where it forms extensive dip slopes.

**Toroweap Formation** The Toroweap Formation is dominated by a thick sequence of fossiliferous resistant limestone that generally contains abundant chert and is similar to Pk. Above and below this are nonresistant, gypsum-rich, redbed sequences of which only the lower was mapped.

**Pt Toroweap upper unit** Thick-bedded, coarsely crystalline, cliff-forming cherty limestone similar to that in the Kaibab Formation but contains some intervals that lack chert; cherty intervals include both nodules and lenses of chert. Beds, which are typically 1 to 2 m thick, are commonly fossiliferous and contain abundant oncolites, crinoids, and brachiopod fragments, including productid brachiopods as much as 8 cm in length. In the upper part of the unit, chert-rich beds give way to about 10 m of chert-free, gray limestone. The uppermost Pt that caps this chert-free limestone typically consists of 10 to 30 m of gypsum capping by as much as 6 m of reddish- to yellowish-brown siltstone and mudstone. Overall Pt thickness ranges from 80 to 170 m. The resistant limestone and overlying gypsiferous redbed sequences are considered to be equivalent to the Brady Canyon and Woods Ranch Members, respectively, of Sorauf and Billingsley (1991).

**Pt Toroweap lower unit** Nonresistant gypsum and gypsiferous mudstone to sandstone. The upper part consists of a few meters of pale-red and pale-reddish-brown to pale-yellowish-orange, flaggy, fine-grained sandstone. Above this redbed sequence, minor pale-orange dolomite is locally exposed. The basal part of the unit is mainly pale-reddish-brown siltstone and mudstone with gypsum in beds as much as 2 m thick. Pt is typically about 40 m thick but locally thins to less than 2 m in the southwest and northwest parts of the quadrangle. It is probably equivalent to the Seligman Member of Sorauf and Billingsley (1991).

**Pc Coconino Sandstone** Nonresistant to cliff-forming, grayish-yellow to grayish-pink and locally pale-reddish-brown, cross-beded, fine- to medium-grained quartz-rich sandstone with variable amounts of calcite cement; commonly coated with dark-brown rock varnish; subrounded to subangular grains; typically consists of 90 to 95% quartz, 5 to 10% feldspar, and accessory zircon, magnetite, and hematite. The Coconino Sandstone in the Frenchman Mountain Quadrangle is similar to its counterpart on the Colorado Plateau in that it is nearly pure quartz arenite; however, it is generally not white and is cross-beded on a much finer scale as noted by Longwell (1966). It may be distinguished from the underlying pale-reddish-brown Hermitt Formation by thicker cross-bed sets and generally lighter color. In the northeast part of the quadrangle it forms prominent cliffs and is as much as 70 m thick. Elsewhere in the quadrangle it is relatively nonresistant and thinner. In the vicinity of the abandoned Sunrise Landfill near the southwest edge of the quadrangle, it is too thin (~5 m) to map at 1:24,000 scale.

**Ph Hermitt Formation** Weakly to moderately indurated, weakly calcareous, thinly bedded, well-sorted, locally cross-beded, pale-reddish-brown to moderate-orange-pink fine- to medium-grained sandstone and siltstone; locally includes very pale-orange to grayish-yellow or white sandstone and brick-red siltstone and mudstone. The reddish-brown sandstone locally contains pale-orange to white reduction spots up to 2 cm in diameter. Grains are typically subangular and consist of quartz, feldspar, and accessory muscovite, biotite, hematite, and magnetite. Ph is commonly a poorly exposed slope- or bench-forming unit. Its thickness ranges from 250 to 330 m.

**Pq Queantoweap Sandstone** Friable to moderately well indurated, weakly calcareous, fine-grained, well-sorted, white to very pale-brown, orange, or grayish-yellow, cross-beded sandstone; grains are typically subrounded and consist mainly of quartz with lesser amounts of K-spar (5 to 10%) and plagioclase, and accessory zircon and muscovite. Pq locally includes thin sequences of reddish-brown siltstone and fine-grained sandstone similar to Ph. This unit correlates with the Esplanade Sandstone of the Supai Group on the Colorado Plateau (Rowland, 1987). It ranges between 18 and 150 m thick.

**PPp Pakoon Formation** Nonresistant gypsum and light-gray to gray flaggy dolomite with minor pale-red siltstone and mudstone; typically consists of a thin upper sequence of reddish-brown to purplish-red siltstone and mudstone, thick middle sequence of bedded gypsum, and lower sequence of thinly bedded dolomite and lesser pale-grayish-brown-weathering, reddish-brown to yellowish-brown siltstone and silty dolomite. On the southeast flank of Sunrise Mountain, PPp includes a basal sequence of purplish-red mudstone and lesser gypsum beneath the lower dolomite. Dolomite layers commonly contain 5 to 10% fine-grained subangular to subrounded quartz, feldspar, and accessory muscovite and biotite. Siltstone is composed of subangular to subrounded grains of quartz, feldspar, and lesser muscovite and biotite. Dolomite beds are commonly shattered into pebble- and cobble-size fragments that are engulfed in a matrix of gypsum. Gypsum intervals typically weather into low rounded hills, whereas some of the more coherent dolomite beds form small ridges. PPp is as much as 200 m thick but is considerably thinner in places, possibly due to tectonic attenuation. The basal contact of the unit is commonly gradational with the highest sequence of interbedded limestone and calcareous cross-beded sandstone of the Calville Limestone.

**Pc Calville Limestone** Dark-gray-weathering, light-gray micritic limestone and pale-brown calcareous, locally cross-beded, fine-grained sandstone or sandy dolomite. Some limestone and sandstone beds contain chert nodules and lenses. The upper part
is about 50 m thick and is composed of light-gray micritic to finely crystalline dolomite with some cherty beds, including one bed with abundant dark-weathering chert nodules as much as 1 m in diameter. The middle part, which is lighter in color than the lower part, typically consists of alternating 1- to 3-m-thick beds of light-gray to medium- or pinkish-gray limestone, which commonly contains rounded oncinites, and thinly laminated, cross-beded sandy dolomite and calcareous fine-grained sandstone. The lower part weathers to dark grayish brown and consists of about 50 m of light-gray to pale-red cross-beded sandy limestone and dolomite with some dolomitic sandstone beds. Pc commonly includes a thin (as much as 10 m thick) lower sequence of purplish-red to reddish-brown siltstone and mudstone, as best exposed on the north flank of Frenchman Mountain. Carbonate layers generally contain 1 to 10% subrounded to subangular grains of quartz and feldspar. Some carbonate layers are fossiliferous and include abundant oncinites and fragments of brachiopods, corals, and crinoids. Sandy layers typically consist of subrounded grains of quartz (>80%), lesser K-spar and plagioclase, and accessory zircon. Some of these sandy layers are probably eolian (Rowland and others, 1990). The upper contact with the Pakoon Formation is commonly gradational and typically marked by the uppermost occurrence of interbedded calcareous fine-grained, cross-beded sandstone and light-gray limestone or dolomite. Total thickness is 200 to 275 m.

Mr Redwall Limestone Light-gray to gray and purplish-gray, pale-brown-weathering, massive to medium bedded (~1 m thick beds), medium- to coarse-grained dolomitized limestone with a fossiliferous (crinoids, brachiopods, rare nautiloids) base (Dawn Member) and a chert-rich interval (Anchor Member) about 50 m above the base. Mr locally contains crinoid-rich beds and corals. The lack of chert in the upper part contrasts with an abundance of chert in the overlying Callville Limestone. Mr is marked by a basal disconformity (Langenheim and Webster, 1979), and its pale-brown color contrasts with the underlying gray Dsc. Mr correlates with the Monte Cristo Limestone directly to the west in the Las Vegas NE Quadrangle. Average thickness is about 240 m.

Sultan Formation

Dsc Crystal Pass Member Light-gray, finely laminated to medium-bedded (1-cm- to 1-mm-thick beds) dolomite and limestone. Some beds contain stromatolitic laminae, as well as peoloids. Dsc locally has thin chert interbeds to 3 cm thick. The member typically forms a small bench between more resistant Dsvi and Mr, but the uppermost part locally forms a series of small cliffs and benches. The lower part is more massive and dolomitic than the upper part. Average thickness is about 60 m.

Dsvi Valentine and Ironside Members Medium-gray, brownish-gray-weathering, thinly laminated to thinly bedded cliff-forming sucrosic (or grainy), medium- to coarse-grained dolomite with local stromatoporoids; commonly contains vugs filled with calcite or dolomite. A distinct 1- to 2-mm-thick chert bed commonly caps the unit, especially in the Sunrise Mountain area. The middle part is cherty and forms a dark band on Frenchman Mountain. Lowermost beds are very pale-brown to locally greenish or purplish sucrosic dolomite; the base is a disconformity. Thickness is about 135 m.

En Nopah Formation Upper part consists of 10 to 15 m of light-gray to pinkish-brown, thick-bedded, very fine- to medium-grained dolomite. Some dolomite beds contain abundant stromatolites, whereas others include 5 to 15% fine-grained, subrounded quartz, feldspar, and accessory muscovite. Lower part (Dunderberg Shale Member), which typically forms a series of small ledges, consists of a basal 2 m of green calcareous shale and siltstone, an ~10-m-thick middle interval of light-gray to pinkish-gray, weathering orange brown to brown, fine- to coarse-grained vuggy detrital dolomite that locally contains glauconite pellets and rip-up clasts, and an upper unit of nonresistant olive-green to grayish-green calcareous shale and siltstone with brown dolomite interbeds. Sundberg (1979) reported a thickness of 18 m for the Dunderberg Shale Member just west of the quadrangle on Frenchman Mountain. On forms a distinct bench between more resistant Cfu and Dsvi. Total thickness averages about 45 m.

Frenchman Mountain Dolomite

Within the Grand Canyon, McKee (1945) identified an interval of dolomites that overlie the Muav Limestone, but he did not name or study this unit in detail. He referred to this interval as “undifferentiated dolomites.” Due to an absence of age-diagnostic fossils, the precise age of these rocks has been unknown. Korolev (1997) showed that these undifferentiated dolomites of the Grand Canyon are correlative with a portion of the Banded Mountain Member of the Bonanza King Formation and that they embrace the Bolaspidella, Cedaria, and Crepepkephasus trilobite zones, which collectively straddle the Middle-Upper Cambrian boundary. Korolev (1997) proposed the name Frenchman Mountain Dolomite for McKee’s “undifferentiated dolomites,” and we use that name here. In the Grand Canyon, the upper portion of these dolomites was removed by pre-Middle Devonian erosion. Thus, in Colorado Plateau sections the Frenchman Mountain Dolomite is almost certainly all Middle Cambrian. However, at Frenchman Mountain and Sunrise Mountain these dolomites are overlain by the Upper Cambrian Nopah Formation, and they probably include Upper Cambrian beds as well as Middle Cambrian. So within the quadrangle the Middle-Upper Cambrian boundary probably lies high within this interval. Directly west of the quadrangle, the Frenchman Mountain Dolomite is 371 m in thickness (Korolev, 1997). We have divided this interval into two map units.

Cfu Upper part of Frenchman Mountain Dolomite

Relatively resistant, cliff-forming, distinctive pale-orange-weathering, thickly bedded, skeletal dolomite grainstone. Fresh surfaces are light gray. Contains fossil eocrinoid columnals. Green glauconite pellets are common in the lower few meters. Some layers contain 1–2% quartz silt. Cfu correlates with the uppermost Banded Mountain Member of the Bonanza King Formation (unit Cbb-10 of Gans, 1974) in miogeoclinal sections, and with unit 24 of Rowland and others (1990). Average thickness is about 55 m.

Cfl Lower part of Frenchman Mountain Dolomite

Generally banded light- and dark-gray, moderately to thickly bedded dolomircite. Dark bands are commonly intensely burrowed; light bands typically contain fine wavy laminations that are interpreted to be cryptomicrobial, locally developed into domal stromatolites (Korolev, 1997). The base of the unit is defined by a nonresistant, bench-forming, light-gray, thinly laminated interval about 30 m thick (unit 14 of Rowland and others, 1990). Cfl contains conspicuous orange- to dark-brown chert nodules and lenses, typically 0.2 to more than 1.0 m long and 2 to 10 cm thick; no such chert lenses occur in the underlying Muav Limestone. Correlative with middle part of Banded Mountain Member of Bonanza King Formation and with units 14–23 of Rowland and others (1990). Thickness averages about 340 m.

Muav Limestone

Historically, several names have been applied to the Middle Cambrian carbonates of the Frenchman Mountain Quadrangle. In the neighboring Las Vegas NE Quadrangle, Matti and others (1993) assigned these rocks to the Bonanza King Formation. However, as summarized by Rowland and others (1990), the Frenchman-Sunrise Mountain section is cratonic with greater similarities to the Colorado Plateau sections than to miogeoclinal sections to the west and northwest. For this reason we assign the Middle Cambrian carbonates in the quadrangle to the Muav Limestone and overlying, previously unnamed dolomites. Unlike the Grand Canyon region, most of the Muav Limestone within the quadrangle has been dolomitized. The thickness of the Muav directly west of the quadrangle is 238 m (units 1–13 of Rowland and others, 1990). We have divided the Muav into two map units.
The units described below appear only in cross sections but crop out directly west of the Frenchman Mountain Quadrangle. Because they do not crop out in the Frenchman Mountain Quadrangle, descriptions of the Lyndon Limestone and all older units were partly adapted from Matti and others (1993).

**Cl** Lyndon Limestone Resistant, cliff-forming, dark-gray and orange-buff limestone. Burrow motting is common, as are large thrombolite heads with internally cotted fabrics. **Cl** correlates with the Meriwitica and Tincanebits dolomite tongues of McKee (1945), intervening shales of the Bright Angel Shale in the Grand Canyon region, and the Jangle Limestone Member of the Carrara Formation in the Spring Mountains-Death Valley region (Palmer and Rowland, 1989). Thickness directly west of the quadrangle is 30 m (Rowland and others, 1990).

**Ct** Tapeset Sandstone Highly indurated white to brown, thin- to thick-bedded, locally cross-bedded, fine- to coarse-grained quartzitic sandstone with beds of pebble conglomerate near the base; includes both silica and calcite cement, and is locally hematitic near the base (Matti and others, 1993); correlative with the Zabriskie Quartzite in the Spring Mountains-Death Valley region and with the Saline Valley Formation in the White-Inyo Mountains region (Palmer and Rowland, 1989). The thickness varies but is about 48 m directly west of the quadrangle.

**Xg** Early Proterozoic gneiss Gray, medium- to coarse-grained microcline-quartz-biotite-garnet gneiss interlayered with pink to white coarse-grained leucocratic or pegmatic gneiss (Matti and others, 1993); locally includes complexly folded layers and small boudins of hornblende-plagioclase-quartz-biotite-hypersphene gneiss. Discordant masses of fine- to coarse-grained biotite-garnet granite cut the gneiss. Mineralogy suggests granulite facies metamorphism. This unit may correlate with the Vishnu Group in the Grand Canyon (Rowland, 1987).

**See accompanying text for figures, tables, references, and a discussion of the geology of the Frenchman Mountain Quadrangle**