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GEOLOGIC MAP OF THE MANHATTAN QUADRANGLE, NYE COUNTY, NEVADA

By

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Pamphlet to accompany
GEOLOGIC QUADRANGLE MAP
GQ-1775

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DESCRIPTION OF MAP UNITS

[Phenocryst contents of most ash-flow tuffs and a few other volcanic rocks were determined by modal analyses of thin sections by F.M. Byers, Jr. Phenocryst contents are volume percent of total rock, and phenocryst minerals are listed as volume percent of total phenocrysts; Q, quartz; K, alkali feldspar (generally sanidine); P, plagioclase; B, biotite; H, hornblende; C, clinopyroxene; O, opaque-oxide minerals; M, unspecified mafic minerals. Other specific mineral names are spelled out in places. Chemical analyses are given as weight percentages on a volatile-free basis; all chemical data cited are from Shawe and Lepry (1985). In a few volcanic rocks considered in these descriptions, local hydrothermal alteration has resulted in partial or complete replacement of feldspars and mafic minerals by secondary minerals such that modal analyses of thin sections are hampered and chemical analyses of rock samples may not reflect closely the primary magmatic compositions. Modal and chemical data presented herein (recalculated on a volatile-free basis) have not been closely evaluated for possible alteration effects (for example, high SiO_2 and K_2O and low Na_2O). "Buff" as a color term means light yellowish brown; "tan" means medium yellowish brown. E.H. McKee and F.G. Poole provided valuable reviews of the map, cross sections, and description]

mf — **Manmade fill (modern)**—Chiefly mine dumps and mill tailings; includes extensive dredge tailings along the lower course of Manhattan Gulch

Qa — **Alluvium, undivided (Holocene and Pleistocene?)**—Sand, silt, and gravel, shown only in cross sections. Subdivisions of alluvium described below are based on relative age in local areas. I was unable to correlate specific units throughout the quadrangle; thus one unit may be the age equivalent of a different unit elsewhere, for example, Qa3a and Qa2b. Studies of soil characteristics of the different alluvium units, not attempted here, might clarify age relations

Qa3 — **Youngest alluvium, undivided (Holocene)**—Active alluvium in drainage courses. Characterized by braided veinlike strands of freshly deposited gravel, sand, and silt. Maximum thickness a few meters

Qa3b — **Youngest alluvium (Holocene)**—Contains abundant strands of freshly deposited sediment

Qa3a — **Youngest alluvium (Holocene)**—Slightly older than Qa3b; contains less abundant freshly deposited sediment. Qa3a commonly at higher elevation than Qa3b along sides of drainage courses. Qa3a, Qa3b, and Qa2 may merge

Qa2 — **Older alluvium, undivided (Holocene and Pleistocene?)**—Stabilized alluvium that occurs in flats, terraces, and valley-fill alluvial fans higher than Qa3, and is presently being eroded. Clasts, generally only slightly weathered, vary in size and are commonly sorted. Some strata of alluvium contain pebble-size or smaller clasts whereas other strata contain clasts to boulder size. Maximum thickness several tens of meters

Qa2b — **Older alluvium (Holocene)**—At lower level than Qa2a and only slightly eroded

Qa2a — **Older alluvium (Holocene and Pleistocene?)**—Extensively eroded older alluvium at higher elevation than Qa2b and laced with strands of active alluvium too small to map; older parts may be as old as Pleistocene. According to Ferguson (1924, p. 117), the deeper part of gravels in Manhattan Gulch is of Pleistocene age, based on fossil evidence. I am uncertain whether these gravels are equivalent to the older and deeper part of Qa2, or whether they are part of the unit mapped here as Qa1

Qa1 — **Oldest alluvium (Pleistocene?)**—Stabilized alluvium that occurs as remnants in flats and terraces higher than Qa2; presently being eroded. Oldest alluvium underlies Qa2 where alluvial fill in valleys is of considerable thickness. Locally contains boulders from a proximal source. Larger clasts (cobbles and small boulders), especially of volcanic rocks, may be significantly weathered. Maximum thickness probably many tens of meters

Qt — **Talus (Holocene)**—Steeply sloping accumulations of angular pieces of waste rock; mapped only where accumulations are well defined or where talus obscures geologic contacts such as on Ferguson Hill. Maximum thickness several meters

Ql — **Landslide (Holocene and Pleistocene?)**—Heterogeneous mixture of rock fragments and soil derived by slope failure from nearby higher bedrock and surficial materials. Maximum thickness several meters

Tb **Basalt (Miocene?)**—Dark-gray aphanitic basalt; forms a thin sill intruded along the contact between welded tuff of the Diamond King Formation and overlying lake beds of the Bald Mountain Formation, a connecting dike (3 m wide) intruded into welded tuff of the Diamond King, and a separate dike intruded across a detachment fault contact between the Bald Mountain Formation and overlying tuff of The Bald Sister. As seen in thin section, sparsely porphyritic (about 3 percent phenocrysts), with pilotaxitic groundmass of plagioclase microlites, common dark opaque iron-titanium oxide mineral, and sparse clinopyroxene in dark-brown to greenish altered (chloritized?) mesostasis. Phenocrysts (1 mm) consist of C, 37; P, 30; and Q and K, 31. Quartz and alkali feldspar are xenocrysts derived from welded tuff of the Diamond King. Present in northwest part of quadrangle about 1 km northwest of North Manhattan (site). Age unknown; likely late Miocene

Tr **Rhyolite (Miocene?)**—Light-brown, hydrothermally altered, flow-layered, autobrecciated rhyolite forms a small plug (50 by 150 m) about 2 km east of Timber Hill in southwest part of quadrangle. As seen in thin section, contains a few percent of phenocrysts, mostly biotite (altered to sericite, chlorite, and quartz), less abundant plagioclase (altered to irregular aggregates of quartz and indeterminant minerals), quartz mostly as small angular fragments less than 1 mm and uncommonly as grains as large as 7 mm, sparse fresh sanidine, and common stubby apatite crystals (rare matchstick crystals to 0.4 mm). Phenocrysts are set in a microcrystalline groundmass consisting mostly of quartz and alkali feldspar. Buff, aphanitic, hydrothermally altered, vertically flow layered rhyolite forms a second small oval-shaped plug (65 by 100 m) 300 m southeast of the Jumbo mine and 3 km south of Manhattan. Sparse quartz phenocrysts mostly less than 1 mm and rarely to 4 mm, and rare clay-altered alkali feldspar phenocrysts to 8 mm, are set in a groundmass replaced by microcrystalline quartz, alkali feldspar, and sericite. Age unknown; likely late Miocene

Tbr **Breccia dikes and sill (Miocene?)**—Dark-gray to dark-reddish-brown matrix contains fragments (to 2 cm) of granite and minor amounts of schist, silicified limestone, argillite, and other Paleozoic rock types; hydrothermally altered. Matrix is extremely fine grained and probably consists of microscopic quartz and alkali feldspar. As seen in thin sections, abundant quartz xenocrysts, commonly ragged, fragmental, and strained (biaxial, small 2V), crowd the matrix. Minor unaltered muscovite is ubiquitous; altered biotite (to muscovite or sericite, quartz, and an iron mineral) occurs locally. Feldspars altered to sericite, quartz, calcite, and microcrystalline alkali feldspar(?). Zircon and apatite are common accessories. Pyrite cubes and irregular blebs (now iron-oxide minerals) are scattered throughout matrix and replaced minerals; cubes are especially abundant in quartz-sericite-(calcite) schist fragments. Several small dikes a meter or so thick trending mostly north-northwest, and a small sill-like body, intrude limestone of the Toquima Formation near south margin of quadrangle 4 km south of Manhattan. Age unknown; possibly late Miocene

Ta **Andesite and latite dikes and plugs (Miocene and Oligocene)**—Several small crystal-poor, porphyritic andesite and latite dikes and plugs intrude Cretaceous granite and Cambrian quartzite in southeast corner of quadrangle. A dark-olive-brown andesite dike less than 100 m long in granite contains abundant streaks of pulverized granite; the andesite has 3 percent crystals (1 mm) that consist of P, 16; H, 60; and C, 24. A light-brown, hydrothermally altered, flow-layered andesite plug less than 50 m in diameter in quartzite contains 8 percent phenocrysts (1–2.5 mm) that consist of P, 59; B, 17; and O, 24 (limonite after pyrite) in a groundmass of aligned microlites. A pale-grayish-brown andesite dike about 100 m long in granite contains about 8 percent phenocrysts (1–2 mm) that consist of P, 77 (clay altered); and B, 23. Biotite K-Ar age of this dike is 24.2±0.8 Ma (rock sample locality A; Shawe and others, 1986)

Tf **Dacite of Ferguson Hill (Miocene and Oligocene)**—Light gray, flow layered, crystal poor; forms two flow domes and associated dikes emplaced into the volcanics of the Manhattan caldera. Light buff gray where hydrothermally altered. Modal analyses of seven thin sections indicate 7–21 percent phenocrysts (1–5 mm) that consist of P, 64–78; K, 7–24; B, 9–14; O, 1–4; and pyroboles, 0–2, set in a granophyric matrix. Biotite is conspicuous in hand specimens. The flow domes, crudely oval shaped and about 1.5 km long, form two conspicuous hills about 5 km north-northwest of Manhattan. Biotite K-Ar ages of 23.5±0.8 Ma and 25.5±0.9 Ma (determined for large satellitic dike, 1.8 km long, northwest of the flow domes; rock sample localities **B** and **C**, respectively; Shawe and others, 1986)

g — **Glass lenses scattered throughout** Tf **flow domes**—Dark gray, conformable with flow layers, and less than 100 m long

Tuff of The Bald Sister (upper Oligocene)—Poorly consolidated to welded ash-flow tuffs characterized by abundant small pumice and lithic fragments. The upper part of the formation (**Tbsu**) is mostly welded tuffs and some interlayered poorly consolidated tuffs. These overlie the main part of the formation (**Tbsl**), which consists of poorly consolidated tuffs. A thin discontinuous basal unit (**Tbsg**) consists of tuff that contains numerous boulders of granite. The tuff of The Bald Sister, previously correlated with the tuff of Peavine Creek in the Toiyabe Range about 20 km west of Manhattan (Shawe, 1987), is here considered to be unrelated to the tuff of Peavine Creek on the basis of detailed petrographic studies. The tuff of The Bald Sister is named for one of three peaks in the core of the Manhattan caldera about 5 km northeast of Manhattan, where maximum remnant thickness of the formation is exposed. Total exposed thickness about 250 m

Tbsu — **Upper member**—Mostly light-brown and light-pinkish- to light-greenish-brown, crystal-poor, rhyolitic, welded ash-flow tuff; contains abundant pale-pinkish-buff to tan, flattened pumice lapilli (to 2 cm) and rounded volcanic lithic fragments (to 1 cm). Minor interlayered, less consolidated ash-flow tuff. Modal analyses of five thin sections of welded tuff indicate 5–8 percent phenocrysts (1–3 mm) that consist of Q, 0–13; K, 28–61; P, 31–60; B, 2–5; O, 0.3–4; and pyroboles, 1–4. Six chemical analyses indicate the following averages: SiO_2, 72.8; Al_2O_3, 14.4; K_2O, 4.5; Na_2O, 3.8; CaO, 1.1; Fe_2O_3, 2.1; FeO, 0.07; MgO, 0.62; TiO_2, 0.35; and P_2O_5, 0.10. Conformably overlies the lower member (**Tbsl**) on The Bald Sister and The Bald Brother about 5 km northeast of Manhattan, on hill 8705 in northeast corner of quadrangle, and on hill 7586 near north-central margin of quadrangle. Top of unit has been eroded away; remnant thickness about 80 m

Tbsl — **Lower member**—Pale-greenish-gray to pale-greenish-buff, poorly consolidated, crystal-poor rhyolitic ash-flow tuff; contains abundant nonflattened pumice fragments and lithic fragments, mostly less than 1 cm. Modal analyses of four thin sections indicate 10–17 percent phenocrysts made up of Q, 7–13; K, 6–12; P, 63–80; B, 5–13; and O, 0–2. A modal analysis of an andesite lithic in tuff from northwest part of quadrangle indicates 29 percent phenocrysts (1–3 mm) in a microlitic groundmass; phenocrysts are 97 percent plagioclase and the remainder are pseudomorphs of clinopyroxene. Texture and composition are typical of the Crone Gulch Andesite (**Tca**) described below. The relation is significant because it shows that at least part of the Crone Gulch is older than the tuff of The Bald Sister. (The Crone Gulch intruded the tuff of The Bald Sister locally, and thus is younger than part of the tuff of The Bald Sister.) Nine chemical analyses average the following: SiO_2, 72.2; Al_2O_3, 14.9; K_2O, 4.3; Na_2O, 2.7; CaO, 2.2; Fe_3O_4, 1.8; FeO, 0.37; MgO, 0.65; TiO_2, 0.38; and P_2O_5, 0.12. This average is similar to that of the upper member of the tuff of The Bald Sister, although significantly lower in Na_2O content and significantly higher in CaO content. The lower member conformably overlies the Bald Mountain Formation except locally in the central peaks northeast of Manhattan where lenses of tuff charged with granite boulders (**Tbsg**) mark the lower contact, and on and north of Ferguson Hill northwest of Manhattan where a low-angle detachment fault marks the base of the formation. Biotite K-Ar ages of 24.6±0.8 Ma and 24.8±0.8 Ma (rock sample localities **D** and **E**, respectively; Shawe and others, 1986). Thickness 110–170 m

Tbsg — **Granite-boulder tuff**—Pale-greenish-gray tuff matrix containing numerous boulders and cobbles of coarse-grained granite of the Belmont pluton (not described here) and porphyritic granite (**Kbgp**) and lesser amounts of rhyolite, limestone, chert, schist, argillite, slate, and quartzite. A boulder of dark-gray diorite was observed in **Tbsg** on the northwest spur of Bald Mountain. In places granite boulders have strongly indurated tuff rinds, typical of clasts in eruptive megabreccias associated with the Manhattan caldera (Shawe and Snyder, 1988). Modal data from a thin section of the tuff matrix indicate about 4 percent phenocrysts (1–3 mm) made up of Q, 3; K, 6; P, 74; B, 1; O, 5; and mafic pseudomorphs, 11. About one-third of the matrix consists of small lithic fragments, mostly argillite. The diorite boulder mentioned above is a metamorphosed holocrystalline (grain size 1–3 mm) rock made up of the following percentages of minerals: mafic minerals (altered biotite and pyrobole), 15; plagioclase (partly altered, in places sausseritized), 28; orthoclase (probably recrystallized from primary feldspar), 9; phlogopite (as patches surrounding altered mafic minerals, and throughout the rock), 35; zoisite, 8; apatite, 3; and calcite, 2. Granite-boulder tuff forms thin lenses no more than a few meters thick at the base of the tuff of The Bald Sister around the central peaks in the Manhattan caldera

Tca **Crone Gulch Andesite (upper Oligocene)**—Olive-brown to light-greenish-gray, olive- to brown-weathering, locally vesicular porphyritic andesite. Four modal analyses indicate 22–27 percent phenocrysts in a microlitic groundmass; phenocrysts (to 6 mm) consist of 94–100 percent plagioclase and 0–6 percent mafic minerals, mostly clinopyroxene. A mode of a hydrothermally altered vesicular andesite indicates 31 percent phenocrysts (to 4 mm) consisting of P, 72; and aggregates of chlorite and serpentine, 28. Chemical analyses of seven unaltered samples average SiO_2, 57.6; Al_2O_3, 18.1; K_2O, 2.4; Na_2O, 3.3; CaO, 7.1; Fe_2O_3, 4.9; FeO, 1.8; MgO, 2.9; TiO_2, 1.0; and P_2O_5, 0.34. Chemical analysis of the hydrothermally altered andesite indicates SiO_2, 59.5; Al_2O_3, 18.7; K_2O, 3.6; Na_2O, 5.2; CaO, 1.7; Fe_2O_3, 5.2; FeO, 1.9; MgO, 2.3; TiO_2, 1.2; and P_2O_5, 0.38. Forms an east-trending stock about 3 km long and 1 km wide south of Diamond King Hill, numerous thick (to greater than 100 m) sills on and near Bald Mountain, and many small dikes and plugs throughout quadrangle. Plagioclase K-Ar age 22.6±1.4 Ma (rock sample locality F; Shawe and others, 1986). Probably about the same age as the 24.6±0.8-Ma tuff of The Bald Sister

Tra **Rhyolite and andesite plug (Oligocene)**—Composite intrusion of light-gray to light-greenish-gray, light-brown-weathering porphyritic rhyolite and greenish-gray, dark-olive-brown-weathering aphanitic andesite. Andesite forms large blobs a few meters across enclosed in rhyolite. The rhyolite is a crystal-rich (25 percent) rock with commonly fragmental phenocrysts (1–3 mm) set in a microcrystalline matrix (of quartz and feldspar?) that contains minute fragments of crystals. Phenocrysts consist of Q, 37; K, 28; P, 9; M (altered to chlorite and calcite), 12; O, 1. Calcite (13 percent) is scattered as small irregular patches throughout altered feldspars, mafic minerals, and matrix. Andesite is aphanitic (microlitic and holocrystalline as seen in thin section); most crystals are less than 0.5 mm; uncommon crystals are 1.5 mm or more in length. Consists of Q, 6; K, 6; P, 55; O, 5; calcite (irregular small scattered patches), 5; and chlorite, 23. Quartz and chlorite fill interstices among plagioclase laths. The plug, 30–40 m in diameter, intrudes volcaniclastic lake beds of the Bald Mountain Formation (Tbml) on southwest flank of Bald Mountain. Thus the plug is younger than the Bald Mountain Formation and is about the same age as the Crone Gulch Andesite

Bald Mountain Formation (upper Oligocene)—Predominantly tuffaceous siltstone and sandstone lakebeds (Tbml) interlayered conformably with lacustrine and fluvial sandstone and fluvial conglomerate (Tbms), and locally tuff (Tbmt). Widespread in north half of quadrangle. Thickness 15–200 m

Tbml **Tuffaceous siltstone and sandstone lakebeds**—Buff, light-gray, light-greenish-gray, and greenish-gray, interlayered, laminated to thin-bedded, lacustrine volcanic siltstone and sandstone. Modal analyses of four fine- to coarse-grained sandstone samples indicate a groundmass of devitrified shards in a cryptocrystalline matrix (45–77 percent of rock) in which are embedded detrital grains consisting of the following percentages of components: lithic fragments (mostly granite, rhyolite, and intermediate volcanics), 1–8; Q, 22–33; K (both sanidine and feldspar derived from granite), 52–58; P, 14–18; and O and other mafic minerals, 2 or less. Two chemical analyses indicate SiO_2, 80.4, 81.1; Al_2O_3, 8.3, 10.7; K_2O, 3.5, 3.7; Na_2O, 1.8, 3.0; CaO, 4.3, 0.18; Fe_2O_3, 0.77, 0.74 ; FeO, 0.17, 0.20; MgO, 0.15, 0.08; TiO_2, 0.12, 0.15; P_2O_5, 0.05, 0.02; and MnO, 0.11, 0.03. Exposed on the central peaks of the Manhattan caldera and on hill 8705 in northeast part of quadrangle, and in scattered patches in northwest part of quadrangle. A thin lens of light-gray algal limestone (a meter or so thick) is interbedded in volcanic siltstone southwest of hill 7586 in north-central part of quadrangle. A layer of densely welded ash-flow tuff 1–2 m thick, identical to that in the upper member of the Diamond King Formation (Tdu), lies a few meters above the base of the Bald Mountain lakebeds at the west base of hill 7586 in north-central part of quadrangle. Aggregate thickness of lakebeds is 15–200 m

Tbms **Sandstone**—Buff, light-greenish-gray, and greenish-gray, coarse-grained tuffaceous sandstone and fluvial cobble and boulder conglomerate. Unit is mostly coarse-grained sandstone, evenly bedded and with low-angle crossbeds. Locally, a basal conglomerate is channelled into the underlying ash-flow tuff layer of the Diamond King Formation. Two modal analyses of sandstone indicate a rock composed of 74–78 percent groundmass of a cryptocrystalline mosaic of altered shards and pumice fragments that contain detrital grains consisting of lithic fragments, 7; Q, 8–20; K, 38–55; P, 22–49; B, 1–3; and O, 0–4. A chemical analysis of a sample of coarse-grained sandstone shows SiO_2, 77.9; Al_2O_3, 12.2; K_2O, 5.4; Na_2O, 2.6; CaO, 0.71; Fe_2O_3, 0.96; FeO, 0.11; MgO, 0.19; TiO_2, 0.17; P_2O_5, 0.05; and MnO, 0.04. A channel-fill sandstone-conglomerate unit on the northeast flank of hill 8705 in northeast part of quadrangle contains fragments of Diamond King ash-flow tuff as large as 0.7 m in diameter, as well as smaller boulders, cobbles, and pebbles of Diamond King tuff, other welded tuff, ash-fall tuff, rhyolite, andesite, granite, schist, and slate. Units of coarse-grained sandstone and conglomerate 0–70 m thick are interlayered within and underlie the lakebeds of Tbml. Unconformably overlies the Diamond King Formation

Tbmt **Ash tuff**—Buff, pale-greenish-buff, and pale-greenish-gray, massive, moderately crystal-rich ash-fall and ash-flow tuff that contains abundant pumice and lithic fragments mostly less than 1 cm. Four modal analyses indicate 52–72 percent argillized groundmass in which relict shard forms are evident, 8–34 percent pumice and lithic fragments, and 13–19 percent phenocrysts. Phenocrysts consist of the following percentages of minerals: Q, 5–13; K, 2–12; P, 67–82; O, 1–3; and M, mostly B, 4–12. Forms layers as much as 80 m thick at and near base of formation, and thin layers a meter or so thick (not mapped separately) interlayered in lakebeds, north of Ferguson Hill in northwest part of quadrangle and in east-central part of quadrangle

Diamond King Formation (upper Oligocene)—Interlayered, partially to densely welded ash-flow tuff and volcanic sandstone. Consists of upper (Tdu), middle (Tdm), and lower (Tdl) members, and associated volcanic sandstone units (Tdus, Tdms). Thickness 100–230 m

Tdu **Upper member**—Light-pinkish-buff to light-gray, moderately welded, crystal-rich rhyolitic ash-flow tuff. Characterized by abundant smoky quartz dipyramids. Four modal analyses indicate 24–30 percent phenocrysts (1–3 mm) that consist of Q, 34–42; K, 33–47; P, 12–30; and B, O, and pyroboles, generally less than 1 percent each. Allanite and zircon are common accessories. Three chemical analyses indicate SiO_2, 75.9–78.6; Al_2O_3, 10.9–12.7; K_2O, 4.6–5.6; Na_2O, 1.9–3.4; CaO, 1.2–1.3; Fe_2O_3, 0.18–1.4; FeO, 0.04–0.09; MgO, 0.02–0.16; TiO_2, 0.08–0.12; and P_2O_5, 0.03–0.06. Member appears to lie conformably on Tdm at a generally well defined contact; in places this contact is marked by a layer of volcanic sandstone as much as 15 m thick, and thinner sandstone layers occur within the member locally, indicating cooling breaks. In one place on Diamond King Hill, Tdu cuts down through Tdm and lies directly on the Round Rock Formation. Widely distributed in north part of quadrangle. Thickness 35–115 m

Tdus **Sandstone units**—Light-greenish-gray and light-greenish-buff, fine- to coarse-grained, pebbly, quartz-rich tuffaceous sandstone. Pumice fragments (less than 1 cm) locally abundant. Laminated to coarsely layered and evenly layered; low-angle crossbeds in places. May be in part a surge deposit, and in part water laid. Compositionally similar to ash-flow tuffs of the Diamond King Formation; proportions of component minerals may vary in adjacent layers. Forms local layers within and at base of **Tdu**. Thickness 0–15 m

Tdm **Middle member**—Light-pinkish-brown, gray, and buff, moderately welded, crystal-rich rhyolitic ash-flow tuff. Characterized by abundant smoky quartz dipyramids. Contains minor lithic fragments and locally moderately abundant rounded to flattened pumice fragments, mostly less than 1 cm. Four modal analyses indicate 22–31 percent phenocrysts (1–3 mm) that consist of Q, 36–44; K, 43–53; P, 10–19; and B, O, and pyrobole pseudomorphs, each 1 percent or less. Allanite and zircon are characteristic accessory minerals. Three chemical analyses indicate the following percentages: SiO_2, 76.6–79.7; Al_2O_3, 12.0–12.6; K_2O, 4.4–4.8; Na_2O, 2.0–3.5; CaO, 0.60–0.74; Fe_2O_3, 0.86–1.1; FeO, 0.08–0.16; MgO, 0.11–0.12; TiO_2, 0.05–0.11; and P_2O_5, 0.03–0.05. Appears to overlie unconformably and transgressively the lower member (**Tdl**), the upper unit of the upper member of the Round Rock Formation (**Tru3**), and the middle unit of the upper member of the Round Rock Formation (**Tru2**). Thickness 0–125 m

Tdms **Sandstone units**—Similar to that in **Tdu**. Forms layers and lenses as much as 20 m thick within and at base of **Tdm**

Tdl **Lower member**—Light-buff to light-pinkish-buff, generally slightly welded, lithic ash-flow tuff. Contains small lithic fragments (to 1 cm) and abundant (about 30 percent of groundmass) small whitish to light-brown pumice fragments (to 1 cm). Moderately crystal rich (10–15 percent); phenocrysts, 1–3 mm in size, consist of Q, about 40; K, 45; P, 10–20; and M (B and O), trace. Two chemical analyses indicate SiO_2, 76–79; Al_2O_3, 11.2–12.6; K_2O, 4.7–4.8; Na_2O, 2.4–2.6; CaO, 1.0–2.6; Fe_2O_3, 0.7–0.8; FeO, 0.3; MgO, 0.5; and TiO_2, 0.1–0.2. Thickness 0–70 m where member lies unconformably above **Tru2** in northwest part of quadrangle. (Description based on character of the unit in the Round Mountain quadrangle just to the north; Shawe, 1995)

Round Rock Formation (upper Oligocene)—Interlayered, lithic-rich ash-flow tuff (poorly to densely welded) and minor ash-fall tuff, megabreccia, and tuff breccia, erupted from the Manhattan caldera and deposited mostly as intracaldera facies. Minor sandstone is present. Consists of an upper member that is divided into three units which contain several subunits of megabreccia, vitrophyre, and densely welded tuff, a middle member of megabreccia, and a lower member that contains units of megabreccia and densely welded tuff. On the basis of geophysical modeling (Shawe and Snyder, 1988, plate 1), inferred total thickness within quadrangle ranges between about 700 and 1,400 m

Upper member—Mostly poorly consolidated ash-flow and ash-fall tuff divided into three stratigraphic units, an upper unit (**Tru3**), a middle unit (**Tru2**), and a lower unit (**Tru1**), distinguished in the field primarily on the basis of color. Within the upper member the lower unit is everywhere present, but the middle and upper units are absent locally. Biotite K-Ar age 25.0±0.8 Ma (rock sample locality **G**; Shawe and others, 1986). Thickness 120–250 m

Tru3 **Upper unit of upper member**—Greenish-buff, partially welded, crystal-poor to moderately crystal-rich, rhyodacitic, lithic-pumice intracaldera ash-flow tuff, locally significant amounts of tuffaceous sandstone, and minor ash-fall tuff. Contains layers and lenses of megabreccia locally. Ash-flow tuff (six modes) contains 3–27 percent phenocrysts (0.5–2 mm) that consist of Q, 2–16; K, 2–14; P, 62–93; B, 1–11; O, 1–3; and altered pyroboles, 0–3. Three chemical analyses indicate SiO_2, 71.5; Al_2O_3, 15.1; K_2O, 4.2; Na_2O, 3.1; CaO, 2.0; Fe_2O_3, 2.0; FeO, 0.39; MgO, 0.67; TiO_2, 0.34; and P_2O_5, 0.12. Present in central and northeast parts of quadrangle where it overlies **Tru2** and **Tru1**. Thickness 0–140 m

Trus **Eruptive megabreccia unit of Silver Creek**—Small to large (10 m) clasts of mostly Cretaceous granite of the Belmont pluton of the granite of Shoshone Mountain [nonporphyritic coarse-grained granite (not described here), porphyritic granite (**Kbgp**), and aplite (not described here)] in a matrix of comminuted granite and rhyolitic to rhyodacitic volcanic ash. Locally contains minor clasts of dark-gray limestone, quartzite, schist, and slate as large as 0.3 m. Present only in northeast corner of quadrangle where it occurs as probable outflow, at and near the top of the upper unit (Tru3), from a vent area at the margin of the Manhattan caldera just to the east in the Belmont West quadrangle. Thickness 0–50 m

Trur **Rhyolite megabreccia**—Light-gray, buff-weathering rhyolite occurring as rounded and polished to angular clasts (to 5 m) in a buff to greenish-buff ash matrix similar to ash-flow material of the upper unit (Tru3). Two modal analyses of rhyolite indicate a granophyric groundmass that contains 12–13 percent phenocrysts (1–4 mm) that consist of Q, 17–19; K, 31–47; P, 21–39; B, 9–10; and H, 1–3. A mode of the tuff matrix of the rhyolite megabreccia indicates about 7 percent phenocrysts (1–4 mm) made up of Q, 3; K, 10; P, 63; B, 23; and O, 0.5. Present only in northeast corner of quadrangle where it is in the approximate stratigraphic position of the locally missing middle unit (Tru2). Thickness 0–10 m

Tru2 **Middle unit of upper member**—Pinkish-brown, lavender, and light-brownish-gray, partially welded, crystal-poor, rhyodacitic, lithic-pumice intracaldera ash-flow tuff. Contains a few layers of ash-fall tuff locally, a lens of megabreccia (Trub) near center of quadrangle, and lenses of vitrophyre (Truv) and layers of densely welded ash-flow tuff (Truw) in northwest corner of quadrangle. Ash-flow tuff (seven modes) contains 3–11 percent phenocrysts (0.5–2 mm) that consist of Q, 1–30; K, 0–15; P, 54–94; B, 0–10; and O, 1–4. One chemical analysis indicates SiO_2, 72.6; Al_2O_3, 14.2; K_2O, 4.4; Na_2O, 4.4; CaO, 1.0; Fe_2O_3, 2.2; FeO, 0.0; MgO, 0.46; TiO_2, 0.22; and P_2O_5, 0.08. Present in northwest, north-central, and central parts of quadrangle and absent in most of northeast part of quadrangle. Thickness 0–120 m

Trub **Breccia**—Buff ash-flow tuff similar to that of the enclosing Tru2; contains abundant fragments and small blocks of dark-gray Paleozoic rocks, mostly siliceous argillite. Forms a lens about 0.5 km long and about 10 m thick near center of quadrangle

Truv **Vitrophyre**—Black, dark brown weathering, crystal poor; characterized by abundant small (less than 1 cm) brown lithic fragments and extremely flattened, black pumice lapilli (2 cm and less long). A modal analysis indicates about 8 percent pumice (two-thirds pale brown and one-third dark brown to black in hand specimen) and 12 percent phenocrysts that consist of Q, 11; K, 16; P, 61; and M (mostly O and B, and minor C, orthopyroxene, and H), 12. Lenses and layers of vitrophyre as much as 700 m long and only a few meters thick are found in northwest corner of quadrangle

Truw **Welded tuff**—Light-brown, crystal-poor, densely welded ash-flow tuff characterized by abundant flattened, brown pumice lapilli (to 2 cm) and common small (less than 1 cm) lithic fragments. A modal analysis indicates about 9 percent phenocrysts that consist of Q, 18; K, 21; P, 50; and M (mostly B, altered pyroboles, and minor O), 12. Forms a medial layer a few tens of meters thick and less in northwest part of quadrangle

Tru1 **Lower unit of upper member**—Buff, partially welded, crystal-poor, rhyodacitic, lithic-pumice intracaldera ash-flow tuff. Locally contains minor thin layers of ash-fall tuff. Ash-flow tuff (eight modes) contains 2–10 percent phenocrysts (0.5–2 mm) that consist of Q, 1–20; K, 2–21; P, 56–88; B, 0–8; and O, 0–2. Three chemical analyses indicate SiO_2, 71.5; Al_2O_3, 15.1; K_2O, 4.2; Na_2O, 3.1; CaO, 2.0; Fe_2O_3, 2.0; FeO, 0.39; MgO, 0.67; TiO_2, 0.34; and P_2O_5, 0.12. Unit is present in the lower part of the upper member, in north and central parts of quadrangle. Thickness 35–120 m

Trp **Rhyolite plug and dikes**—Light-pinkish-gray, locally autobrecciated rhyolite that forms an inferred plug (300 by 400 m) and associated dikes as much as 60 m wide on hill 7425, 3 km northwest of Manhattan. Lacks compaction foliation of welded tuff. Inferred to have formed late in the emplacement of the middle member of the Round Rock Formation (described below) by irruption of rhyolitic magma that was the source of the earlier reddish-brown rhyolite and rhyolitic welded ash-flow tuff of Trm. May be transitional into rhyolitic welded tuff erupted during a late stage of formation of Trm

Trm **Middle (megabreccia) member**—A layer of eruptive megabreccia, mostly intracaldera, lying conformably between the upper and lower members. Member consists of clasts of reddish-brown to reddish-gray, welded, rhyolitic ash-flow tuff, and rhyolite flow rock, gray andesite lava, and composite rhyolite-andesite clasts, mostly no more than 10 m in size, rarely to about 50 m, in generally sparse to locally abundant buff ash-flow tuff matrix, similar to ash-flow tuff of the upper and lower members. In places appears to consist entirely of rhyolite clasts, and in other places to consist entirely of andesite clasts. Locally, andesite clasts occur in the upper part and rhyolite clasts in the lower part. Within the areas of **Trm** on the map, the label "**r**" indicates rhyolite clasts and "**a**" indicates andesite clasts. The label "**r/a**" indicates rhyolite clasts predominant over andesite clasts, and "**a/r**" indicates andesite clasts predominant over rhyolite clasts. Where ash-flow matrix is virtually absent from much of the middle member, fragments ranging in size from a millimeter to 10 m of gray andesite are contained in reddish-brown rhyolite, or conversely, large to small fragments of rhyolite are contained in andesite. Rhyolite clasts are predominantly ash-flow tuff; other types are tuff breccia, lava, and autobrecciated lava. Andesite clasts are mostly lava with minor amounts of tuff breccia. Compositional gradation exists between andesite and rhyolite so that rocks of intermediate composition such as rhyodacite, latite, and quartz latite also are present. Modal analyses of four moderately to densely welded, crystal-rich rhyolite or quartz-latite ash-flow tuffs indicate 18–36 percent phenocrysts of Q, 19–37; K, 16–40; P, 21–54; B, 1.5–9; and O, 0.5–2. An autobrecciated rhyolite lava contains about 36 percent phenocrysts of Q, 16; K, 30; P, 42; and M (B, H, and O), 11. Rhyolite ash-flow tuff breccia, based on two modes, contains about 33–40 percent hornblende andesite lithic fragments in a rhyolite groundmass containing 13 and 8 percent phenocrysts of Q, 47 and 18; K, 21 and 8; P, 27 and 49; and M (H, B, and O), 6 and 28. A modal analysis of a rhyodacite lava indicates about 8 percent phenocrysts of K, 12; P, 69; B, 16; and other M, 3, in a felted microlitic groundmass. A latite tuff breccia that contains about 57 percent lithic fragments, mostly hornblende andesite and lesser amounts of felsic volcanic types and flow-layered glass, contains about 12 percent phenocrysts of K, 35; P, 45; B, 6; and O (including oxyhornblende?), 14. Modal analyses of five andesite lavas indicate 5–16 percent phenocrysts of P, 38–80; H, 12–60; B, 0–3; and O, 0.3–8, in a pilotaxitic-seriate groundmass. Three chemical analyses of rhyolite ash-flow tuffs indicate a range of SiO_2, 69.6–73.6; Al_2O_3, 14.0–15.8; K_2O, 3.9–5.2; Na_2O, 2.9–3.8; CaO, 1.2–2.4; Fe_2O_3, 1.8–2.5; FeO, 0.20–0.59; MgO, 0.36–0.61; TiO_2, 0.23–0.35; P_2O_5, 0.07–0.12; and MnO, 0.03–0.05. A chemical analysis of a latite lava indicates SiO_2, 67.3; Al_2O_3, 16.1; K_2O, 2.3; Na_2O, 4.5; CaO, 3.1; Fe_2O_3, 3.2; FeO, 0.54; MgO, 1.7; TiO_2, 0.54; P_2O_5, 0.23; and MnO, 0.03. A chemical analysis of an andesite lava indicates SiO_2, 59.1; Al_2O_3, 18.5; K_2O, 2.3; Na_2O, 5.0; CaO, 4.2; Fe_2O_3, 5.8; FeO, 0.71; MgO, 3.2; TiO_2, 0.73; P_2O_5, 0.31; and MnO, 0.04. Member is widely distributed along south margin of the Manhattan caldera east, north, and northwest of Manhattan, and in northwest and north-central parts of quadrangle. Varies in thickness between about 15 m to probably more than 150 m near its inferred source, a composite rhyolite-andesite volcano 3 km northwest of Manhattan formed at the time of deposition of the middle member of the Round Rock Formation. A 10-m-thick layer of flow-laminated andesite lava occurs about 0.9 km southwest of hill 7425 where it lies dipping steeply southwest, off the flank of the inferred composite rhyolite-andesite volcano

Trl **Lower member**—Pale-greenish-gray, light-gray, light-brownish-gray, buff, and pinkish-buff, poorly to moderately welded, rhyolitic to latitic, lithic-pumice intracaldera ash-flow tuff; contains thin to thick layers and lenses of strongly welded tuff (**Trlw**) and megabreccia (megabreccia of Sloppy Gulch, **Trls**). Lithic-pumice tuff contains sparse to abundant fragments of chert, slate, schist, granite, pumice, rhyolite, and other volcanics. Weathers locally to a popcorn surface indicative of the presence of swelling clay. Modal analyses of three samples of partially to moderately welded rhyolitic ash-flow tuff indicate a content of 5–14 percent lithic fragments and 4–25 percent phenocrysts. Phenocrysts (1.5–3 mm) consist of Q, 14–34; K, 11–13; P, 43–73; B, 3–11; and other M, 0–1.5. Present in north-central, northwest, west-central, and central parts of quadrangle within the Manhattan caldera; maximum exposed thickness about 250 m; total thickness based on geophysical modelling (Shawe and Snyder, 1988, plate 1) about 400–1,100 m

Trlw **Welded tuff**—Densely welded, light-brownish-gray to light-brown, rhyolitic intracaldera ash-flow tuff characterized by a basal black, dark-brown-weathering vitrophyre interlayered in less-welded ash-flow tuffs of the lower member. Three modal analyses indicate a content of 0–10 percent lithic fragments and 6–9 percent phenocrysts. Phenocrysts (0.5–2 mm) consist of Q, 0–3; K, 26–30; P, 64–67; M (including B, O, and C), 4–6. A chemical analysis of a black vitrophyre from the unit indicates SiO_2, 74.6; Al_2O_3, 14.3; K_2O, 4.4; Na_2O, 3.6; CaO, 1.6; Fe_2O_3, 1.4; FeO, 0.26; MgO, 0.24; TiO_2, 0.16; P_2O_5, 0.05; and MnO, 0.08. Trlw is interlayered within Trl in north-central and central parts of quadrangle; thickness 10–60 m; basal vitrophyre in north-central part of quadrangle is about 10 m thick

Trls **Eruptive(?) megabreccia of Sloppy Gulch**—Large blocks (to 300 m) of mostly Paleozoic rocks, including limestone, jasperoid, calc-silicate-mineralized limestone, slate, chert, siliceous argillite, quartzite, conglomerate, sandstone, siltstone, and schist, and lesser amounts of Cretaceous granite and Tertiary volcanic types, in ash-flow tuff matrix similar to that in the main part of the lower member (Trl). Unit exhibits aspects (immense clasts of rocks exposed in caldera walls; localization at caldera structural margin) generally interpreted as a result of caldera wall collapse. However, the megabreccia of Sloppy Gulch contains small to immense clasts of rocks that themselves consist of healed breccia unlike any exposed in the Manhattan caldera wall rocks, and some clasts of rocks unknown in the wall rocks (Shawe and Snyder, 1988), leading to the inference that the clasts were derived from depth and hence were erupted to their present level in the Manhattan caldera structural margin. A modal analysis of one sample of the ash matrix of the megabreccia indicates about 1.5 percent lithic fragments and 14 percent phenocrysts of Q, 14; K, 18; P, 57; B, 8; and O, 2. A mode of a large (100 m) orangish-buff, crystal-poor (5 percent) rhyolite tuff-breccia block in the Sloppy Gulch unit indicates Q, 12; K, 60; P, 19; and O, 9.

The rhyolite tuff breccia is unlike other volcanic rocks recognized in or near the Manhattan caldera. Common blocks of the reddish-brown rhyolite and less abundant clasts of the gray andesite of the middle member of the Round Rock Formation (Trm) are found throughout much of the area of the Sloppy Gulch unit where it is exposed along the south margin of the Manhattan caldera from the west-central to southeast parts of the quadrangle (indicated on the map by an underlined Trm symbol). Whether or not these blocks were incorporated into Trls during explosive emplacement of Trm is unknown. Where Trls is interlayered with Trm about 3 km northwest of Manhattan, clasts of Trm probably were emplaced into Trls during eruption of Trm; layers are as thick as 100 m.

The Sloppy Gulch unit has as much as 200 m of vertical exposure where it is interpreted to be vent facies along the south margin of the Manhattan caldera; where it is considered to be outflow in southeast part of quadrangle it may be as much as 70 m thick. An outcrop of Trls (60 by 180 m) lies on granite 4 km south-southeast of Manhattan

Ks **Syenite plug (Cretaceous?)**—Syenite and minor shonkinite form a 40- by 60-m complex plug of irregularly textured rock. Syenite, showing abrupt textural changes from coarse grained to fine grained, consists of 50–75 percent orthoclase (crystals to 10 mm) and lesser amounts of sodic amphibole (crystals to 3 mm, of varied pleochroism: pale green, yellowish brown, green, or bluish green), plagioclase (crystals to 10 mm), sphene, opaque-oxide minerals, apatite, and calcite. Mosaic to mortar structure (crystals to less than 0.1 mm) is common locally in the feldspars; parts of the rock are strongly foliated such that aligned feldspar lensoids (less than 1–5 mm) impart a pronounced directional fabric. Amphibole forms small sheaves and sunbursts of elongate crystals, commonly interstitial to feldspars, or concentrated along fractures. Sphene and opaque-oxide minerals form ragged to subhedral patches mostly in proximity to amphibole. Apatite is scattered as euhedral crystals, and calcite forms small sparse replacements throughout the rock. Shonkinite is texturally similar to syenite, and irregularly distributed. One modal analysis indicates the following percentages of minerals: orthoclase, 28; plagioclase, 8; soda amphibole, 53; sphene, 7; opaque-oxide minerals, 4; and apatite, 0.3. The plug is emplaced into limestone of the Ordovician Zanzibar Formation and bows up a nearby plate of the Cambrian Harkless Formation that tectonically overlies the Zanzibar about 2.5 km south of Manhattan. Age of the syenite plug is unknown; because the plug is locally foliated (compare with the foliated Cretaceous granite of Pipe Spring, described below), and because its intrusion deformed the plate of the Cambrian Harkless Formation that was emplaced probably in Late Cretaceous time, the age of the plug is inferred to be Cretaceous

Granite of Pipe Spring (Late Cretaceous)—Coarse-grained granite (**Kpg**) that crops out along south edge of quadrangle and forms the north edge of a pluton about 10 by 13 km in exposed extent. A few small plugs and irregular apophyses of granite intrude Paleozoic sedimentary rocks at and near north and northwest margins of pluton. Late-phase aplite (**Kpa**) occurs as satellitic sills and dikes in adjacent Paleozoic rocks and as dikes and irregular intrusions in the granite

Kpa **Aplite**—Pale-buff, pale-gray, and white, fine-grained aplite forms numerous dikes and sills, and small lenses and plugs, in Paleozoic sedimentary rocks, and dikes and abundant irregular and diffuse bodies ranging in size from a few meters to several hundred meters in the granite pluton, especially near its margin. In the sedimentary rocks, dikes are as much as a few meters wide and sills rarely more than 15 m thick. In the granite pluton, dikes commonly are a meter or less wide, but the irregular, diffuse bodies range in length from a few meters to several hundred meters. Aplitic bodies at the contact of the pluton with sedimentary rocks may constitute chilled margins of the large granite body; aplitic bodies within the pluton may represent late intrusions or metasomatically recrystallized parts of the granite. The aplites are mostly mosaic-textured rocks of grain size less than 1 mm. Some aplite dikes contain local pockets of pegmatitic material. Modal analysis of an aplite collected at the contact of the pluton indicates Q, 35; orthoclase, 11; microcline, 16; P, 29; and muscovite, 10. A mosaic of constituent grains contains scattered clots of poikilitic muscovite (to 3 mm) enclosing quartz grains. A sample of a porphyritic aplite body within the pluton contains Q, 40; orthoclase, 14; microcline, 12; P, 32; and 2 percent other minerals (B, O, and muscovite). Plagioclase (to 4 mm) and quartz (to 3 mm) constitute sparse phenocrysts in the mosaic groundmass. Some aplite dikes are extremely differentiated. A sample of a dike in granite in southeast corner of quadrangle contains Q, 71; orthoclase, microcline, and plagioclase combined, 2; and sericite (including 1 percent muscovite—crystals more than 0.2 mm long), 26. The sericite and muscovite have replaced feldspars. A mode of a sample of slightly foliated aplite from a dikelike segment of an apophysis of the granite north of the pluton indicates Q, 6; orthoclase, 15; microcline, 70; and P, 9. Thin aplite dikes intruded into calc-silicate-mineralized limestone of the Toquima Formation about 3 km east of Manhattan consist almost entirely of albite. A few very fine grained, slightly foliated, light-buff to white "sills" mapped as aplite were shown by thin-section studies to be layers of sericite-quartz schist. Most of the aplite dikes in granite are in southeast corner of quadrangle where they trend generally northerly. A biotite K-Ar age of an aplite dike in the Pipe Spring pluton about 200 m east of the Manhattan quadrangle is 76.1±2.7 Ma (Shawe and others, 1987)

Kpg **Granite**—Pale gray to pale buff, coarse grained, foliated. Foliation, defined primarily by aligned biotite and muscovite flakes, is most conspicuous in areas in which aplite is sparse. Foliation is generally conformable with the outward dipping contact of the pluton, which in most places parallels bedding in the invaded Paleozoic sedimentary rocks. Grain size is mostly about 2–8 mm; in a few places scattered phenocrysts as large as 1–2 cm are evident. A modal analysis of a sample of granite collected near the margin of the Pipe Spring pluton indicates Q, 40; orthoclase, 9; microcline, 13; P, 31; B, 4; muscovite, 2; and O, 1. Muscovite replaces biotite and the cores of some plagioclase crystals, as ragged to sharply formed crystals. Sparse zircon, apatite, and opaque-oxide minerals are accessories. Whole-rock isochron Rb-Sr age 80.2±2.4 Ma (John and Robinson, 1989), and whole-rock-biotite isochron Rb-Sr age 80.1±1.0 Ma (Shawe and others, 1986). Muscovite K-Ar age 78.9±1.8 Ma and biotite K-Ar age 75.0±2.6 Ma. (All ages except the whole-rock isochron age determined on material from rock sample locality H). The ages of biotites from granite and aplite of the Pipe Spring pluton are younger than the 80-Ma age of emplacement of the pluton, and they suggest a post-emplacement episode of doming, and metamorphism of the pluton

Granite of Shoshone Mountain (Late Cretaceous)—Two-mica, mostly coarse-grained granite that forms two large oval-shaped plutons, the Round Mountain and Belmont plutons. Only a small part of the Belmont pluton (**Kbgp**) crops out in northeast corner of quadrangle

Belmont pluton

Kbgp **Porphyritic granite**—Light-gray, coarse-grained porphyritic granite. Phenocrysts (about 15 percent of rock) of orthoclase and (or) microcline 2–10 cm long are conspicuous. Groundmass of the granite (grain size 1–10 mm) is hypidiomorphic granular but locally shows mortar structure, especially where foliated; contains the following: Q, 31; K (varying from mostly orthoclase to mostly microcline), 37; P (including minor myrmekite locally), 27; B, 3; muscovite, 1; and O, 1. Muscovite occurs commonly as partial replacements of biotite and plagioclase. Zircon and apatite are common accessory minerals. A chemical analysis of a sample of porphyritic granite contains SiO_2, 71; Al_2O_3, 16.0; K_2O, 4.4; Na_2O, 4.0; CaO, 1.6; Fe_2O_3, 0.76; FeO, 0.69; MgO, 0.33; and TiO_2, 0.30. Age of the Belmont pluton, based on two Rb-Sr whole-rock isochrons, is 84.5±2.3 Ma and 84.8±4.4 Ma (John and Robinson, 1989). Seven biotite and muscovite K-Ar ages of 80–82 Ma for the Belmont pluton (see John and Robinson, 1989, for references), although not precise enough to be distinguished from the Rb-Sr whole-rock isochrons, likely reflect a post-emplacement episode of doming, metamorphism, and mineralization of the pluton as indicated by the geologic relations. (From "Description of map units" in the Round Mountain quadrangle north of the Manhattan quadrangle, Shawe, 1995)

Pzu **Paleozoic rocks, undivided**—Marine sedimentary rocks. Shown only in cross sections

(Pd) **Diablo Formation (Permian)**—Heterogeneous sedimentary rocks made up of interlayered olive-brown argillite, siltstone, sandstone, and conglomerate. Conglomerate fragments (to 4 cm) tend to be angular and lensoid, and consist of black and gray chert, fine-grained quartzite, slate (or argillite), gray limestone and dolomite, and some fine-grained volcanics. A thin section of sandstone shows tightly packed lensoid grains averaging about 1 by 3 mm in size and consisting of argillite, carbonate, chert, quartzite, siltite, sandstone, volcanic rocks (mostly intermediate lavas), and rare granitoids. Rocks of the Diablo Formation occur only as fragments enclosed within the megabreccia of Sloppy Gulch (**Trls**), where they commonly are internally brecciated. One large slab of the Diablo, about 100 m long and 40 m thick, is found in megabreccia 2 km north-northwest of Manhattan. Most other fragments, scattered throughout the megabreccia unit, are only a few meters and less in size. The Diablo in the Manhattan quadrangle is similar to that mapped by Ferguson and Cathcart (1954) in the Toiyabe Range 20 km northwest of Manhattan, and to that mapped and described by Poole and Wardlaw (1978) in the Toquima Range 12 km southwest of Manhattan

Toquima Formation (Upper and Middle Ordovician)—Generally thin-bedded, interlayered marine argillite, siliceous argillite, limy argillite, argillaceous limestone, limestone, siltstone (or siltite), and quartzite (mostly massive), as well as jasperized and (or) metamorphosed equivalents. Strongly deformed, probably in several episodes from late Paleozoic to Late Cretaceous time. Commonly sheared, tightly folded, and brecciated; quartz is veined, silicified, and iron stained as a result of hydrothermal alteration. Exposed in south part of quadrangle. Forms a thrust plate overlain by thrust plate of the Cambrian Harkless Formation and underlain by a thrust plate of the Ordovician Zanzibar Formation. Original thickness uncertain because of extreme deformation; probably several hundred meters thick. Correlative with part of the Ordovician Palmetto Formation of southern Nevada (for example, Ferguson, 1924; McKee, 1968) and with the Middle and Upper Ordovician parts of the Vinini Formation in the northern Toquima Range (McKee, 1976). Because of the interlayered character of lithologies in the formation, map units will be described as lithologic types rather than as stratigraphic units. The lithologic types distinguished are limestone (**Otl**), jasperized limestone (**Otlj**), calc-silicate-mineralized limestone (**Otlc**), argillite (**Ota**), quartzite (**Otq**), and dolostone (**Otd**)

Ot **Toquima Formation, undivided**—Shown only in cross sections

Otl **Limestone**—Medium gray to light gray, thin bedded to laminated, commonly silty or argillaceous. Thin layers of dark-gray to brown argillite, limy argillite, and siliceous argillite or siltite are interlayered with limestone in places. Some limestone is slightly fetid. Silicified limestone (jasperoid or jasperized limestone, **Otlj**) and calc-silicate-mineralized limestone (**Otlc**) are described below. A thin section of thinly laminated limestone shows that laminae (less than 1 mm), bounded by graphite-filled shears, consist of aligned lensoid grains of calcite as much as 0.2 mm long and 0.05 mm wide. The rock is about 20 percent quartz as scattered, minute (0.05 mm), rounded to angular grains. Where abundant, quartz grains tend to form mosaic aggregates. Another thin section, of thin-bedded and laminated limestone (laminae 1–5 mm), shows aligned lensoid crystals of calcite (to 1 mm; length-width ratio 2:1 to 3:1). The calcite exhibits crudely aligned shear lamellae, subparallel with laminae. Calcite laminae are bounded by shears marked by strung-out grains of quartz (less than 0.1 mm), iron oxide, and graphite(?). Locally, quartz grains are aggregated as mosaic lensoids (to 10 by 5 mm). Units are several tens of meters thick, but original thickness impossible to determine because of extreme deformation. The post-quartzite units of limestone are correlative with the Upper Ordovician parts of the Ely Springs Dolostone and Hanson Creek Formation of central and southern Nevada (F.G. Poole and R.J. Ross, Jr., oral commun., 1970)

Otlj **Jasperized limestone**—Dark brown to dark gray; reflects widespread hydrothermal alteration and silicification. Especially common in faulted, fractured, and brecciated zones, and in many places contains anomalously high amounts of metals (Shawe, 1988). Certain limestone beds seem to be preferentially jasperized. Masses of jasperoid, either fault or bedding controlled, may measure as much as several hundred meters across

Otlc **Calc-silicate-mineralized limestone**—Buff to pale greenish buff; contains tremolite, actinolite, or diopside; abundant where the Toquima Formation is exposed about 3 km east of Manhattan, and in scattered localities elsewhere. Tremolite schist is the most common calc-silicate-mineralized form of metamorphosed limestone. As seen in thin sections, generally aligned lensoids (to 1 cm long) of tremolite crystals or sheafs of crystals, mostly less than 1 mm long, occur with lesser, irregular amounts of quartz and calcite. Small (mostly less than 0.1 mm) oxidized cubes of pyrite are scattered throughout the schist. At one locality 2 km southwest of Manhattan, recrystallized limestone contains sparse scapolite. Idocrase occurs with tremolite in calc-silicate-mineralized limestone 6.5 km east of Manhattan near east margin of quadrangle

Ota **Argillite**—Gray to dark gray, somewhat phyllitic or fissile, commonly silicified. Locally contains thin beds of quartzite, siltite, or limestone, and thin beds that are siliceous, silty, or limy. A thin section of a "micro-foliated" argillite shows microscopic quartz grains as aligned lensoids separated by interstitial clay(?), graphite, and sparse sericite. Crisscrossed by small (1 mm–1 cm) veinlets of quartz. Graptolite bearing in places near layers of quartzite. Graptolites (fossil localities labelled **1**, and identified by W.B.N. Berry and R.J. Ross, Jr.) include *Climacograptus scharenbergi* Lapworth, *Climacograptus* sp. (*C. eximius* Ruedemann?), *Climacograptus caudatus* Lapworth, *Climacograptus bicornis* (J. Hall), *Climacograptus bicornis* var. *tridentatus* Lapworth, *Climacograptus bicornis* var. *peltifer* Lapworth, *Dicellograptus sextens* J. Hall, *Dicellograptus sextens* var. *exilis*, *Dicellograptus intortus* Lapworth, *Dicranograptus ramosus* (J. Hall), *Dicranograptus spinifer* Lapworth, *Dicranograptus contortus* Ruedemann, *Diplograptus multidens* Elles and Wood, *Glyptograptus euglyphus* (Lapworth), *Glyptograptus teretiusculus* (Hisinger), *Hallograptus mucronatus* (J. Hall), *Orthograptus calcaratus* var. *acutus* Elles and Wood?, *Orthograptus quadrimucronatus* (J. Hall), *Retiograptus*? sp., *Cryptograptus tricornis* (Carruthers), and *Glossograptus hincksii* (Hopkinson). These graptolites belong to Berry's (1960) zones 11–14, of

Mohawkian (late Middle Ordovician) age. Argillite units in the formation may have had original thicknesses as great as 100 m

Otq **Quartzite**—Gray and light gray, in places brown to buff weathering, fine grained, in part medium grained, massive to laminated; some beds are siltite; locally bleached white or very pale buff. In places interlayers consist of gray quartz-tremolite schist. Quartz grains in quartzite are closely packed and mosaic textured, mostly less than 0.5 mm in size. Minor sericite-muscovite clusters are scattered throughout the rock or form interstitial screens or patches among quartz grains. Sparse detrital opaque-oxide grains and a trace of zircon grains are present. Minute (less than 0.1 mm) cubes of pyrite as well as black specks and laminae of graphite are scattered throughout the rock. A thin section of quartz-tremolite schist shows interlensing clusters of quartz and tremolite-(actinolite) crystals separated by anastomosing graphite-filled shears. Sparse cubes of oxidized pyrite are scattered throughout the rock. A rare layer a few centimeters thick of quartzite-pebble conglomerate is interlayered in quartzite near the top of Black Mammoth Hill 2 km west of Manhattan. Subrounded to subangular, light-gray, pure quartzite pebbles about 5 cm long are embedded in gray, finer grained matrix of sericitic quartzite. Layers of quartzite range from a few to about 100 m thick. Represents Ordovician transitional facies; correlative with the Middle Ordovician Eureka Quartzite (part) of eastern and southern Nevada (F.G. Poole and R.J. Ross, Jr., oral commun., 1970) and part of the Vinini Formation of the northern Toquima Range (McKee, 1976)

Otd **Dolostone**—Light-gray, fine-grained, thin-bedded, laminated dolostone; interlayered with limestone; present in southwest corner of quadrangle as a layer several meters thick

Zanzibar Formation (Middle Ordovician)—Generally thin- to medium-bedded, interlayered marine limestone, cherty limestone, argillaceous limestone, argillite, limy argillite, siliceous argillite, and siltstone. Near granite contacts, limestone has been metamorphosed to marble and calc-silicate-mineralized limestone. Locally elsewhere, limestone has been jasperized and argillite has been metamorphosed to schist. An incomplete section about 40 m thick at the south base of Black Mammoth Hill consists of a lower part of gray argillite and minor interlayered thin-bedded limestone, 3 m of tightly folded gray argillite that contains 1–2 cm layers of limestone, 7 m of olive-brown argillite, 5 m of dark-grayish-brown strongly silicified argillite or limestone, 8 m of tightly folded dark-gray thin-bedded silty limestone, 3 m of gray thin-bedded limestone and silicified limestone, and 15 m of light-gray thin-bedded laminated limestone. Locally strongly sheared, folded, and brecciated as a result of thrust faulting, and quartz veined and iron mineralized as a result of hydrothermal alteration. Forms a thrust plate overlain by a thrust plate of the Toquima Formation and underlain by a thrust plate of Cambrian(?) siltite, a thrust plate of the Cambrian Gold Hill Formation, and the Mayflower Schist. Exposed in south part of quadrangle. Original thickness uncertain because of extreme deformation; probably several hundred meters. Age is Whiterockian (early Middle Ordovician), based on fossil identifications by W.B.N. Berry, R.J. Ross, Jr., and J.W. Huddle of samples from near the Manhattan quadrangle (one fossil locality in quadrangle, labelled 2) and in the Toiyabe Range west of the Toquima Range. Correlative with part of the Palmetto Formation in southern Nevada (for example, Ferguson and Cathcart, 1954) and part of the Antelope Valley Limestone (Ross, 1970). Because of the interlayered character of the rock types, they are described below as lithologic units rather than as stratigraphic units. The units described are limestone (**Ozl**), jasperized limestone (**Ozlj**), dolostone (**Ozd**), and argillite (**Oza**)

Oz **Zanzibar Formation, undivided**—Shown only in cross sections

Ozl **Limestone**—Light gray to dark gray, in places brownish gray weathering, medium bedded to laminated (laminae due mostly to tectonic shearing related to thrust faulting). Locally argillaceous, silty, and (or) silicified. Parts contain interlayered nodular to layered chert in beds a few centimeters thick. A thin section of laminated limestone shows calcite as lensoid to equidimensional crystals mostly about 0.05–1 mm in size, concentrated in layers according to size. The lensoids are subparallel to anastomosing laminae of graphite. Sparse rounded grains of quartz and opaque-oxide minerals scattered throughout are probably detrital. Muscovite as elongate disoriented crystals to about 0.3 mm long is sparsely scattered throughout the rock. A similar though severely deformed limestone as seen in thin section shows tightly folded laminae defined by streaks and bands of graphite dust.

Calc-silicate-mineralized limestone (not mapped) has replaced limestone beds generally near granite contacts; it is a light-greenish-gray and light-gray to dark-gray, generally hard and dense rock. Calc-silicate minerals present include tremolite-actinolite, diopside, and epidote, none everywhere present. Potassium feldspar occurs along with diopside in some rocks. An unusual calc-silicate rock was found as a layer, thickness undetermined, in limestone 3.2 km due south of east edge of Manhattan and 100 m from the contact of the Pipe Spring pluton (**Kpg**). A modal analysis indicates about 39 percent quartz, 37 percent epidote, 11 percent biotite, and 13 percent fluorite. A trace of opaque-oxide minerals is present. Fluorite forms layers 1 mm thick of interconnected crystals and as isolated patches interstitial to quartz and epidote. The fluorite layers parallel well-developed compositional layering in the rock. Quartz occurs as mosaic grains to 0.25 mm in size; some oval grains occur isolated in fluorite. Epidote is intergrown with quartz as generally anhedral crystals; some subhedral to euhedral crystals occur in fluorite. Biotite forms interstitial patches in quartz and epidote.

In addition to calc-silicate-mineralized limestone near igneous contacts, some limestone has been bleached and marbleized. In places the sugary-white marble contains abundant pale-gray tremolite prisms (to 2 mm). Limestone units may be as thick as several tens of meters, but original thickness is impossible to determine because of extreme deformation

Ozlj **Jasperized limestone**—Dark gray, commonly stained with yellowish-brown to reddish-brown iron oxide. Forms replacements of beds, or irregular masses that grade along bedding from unaltered limestone. Commonly brecciated and fault controlled. As seen in thin section, jasperoid consists of mosaic quartz grains mostly 0.01–0.1 mm in size. Segments of graphitic layers, disrupted by brecciation, can be seen scattered throughout the rock. Limonite after pyrite is common as grains, cubes, and dust. Masses of jasperoid that are bedding controlled are as much as several hundred meters long

Ozd **Dolostone**—Medium-gray, dense dolostone, locally brecciated and quartz and calcite veined. Dolomite grains, mostly less than 0.1 mm, in places greater than 1 mm, form a mosaic, partly replaced by tremolite. Scattered oxidized pyrite cubes are evident in thin section. Forms a thin thrust sliver enclosed within the Toquima Formation on Salisbury Peak 2 km east of Manhattan

Oza **Argillite**—Gray to dark-gray, noncalcareous to limy, locally faintly laminated or phyllitic argillite or shale. In places silicified and iron mineralized to form jasperoid. Microcrystalline groundmass consists of quartz, clay, sericite, and calcite in varied proportions, commonly with iron oxide (altered from pyrite) and graphite streaked along bedding or fissility layers. In places, incipient schistosity is evident where foliation may be either parallel with or transverse to bedding; folia are characterized by coarser (but less than 0.1 mm) oriented sericite and (or) chloritoid along with mosaic quartz and (or) calcite and some iron oxide (from pyrite). Locally, strongly deformed bedding laminae are evident in massive-appearing argillite that nevertheless exhibits throughgoing fissility. Uncommon pale-buff boudins of fine-grained quartz-sericite rock (originally siltstone?) occur in strongly deformed argillite. Argillite units may be as thick as about 150 m; original thickness unknown

Ꞓst **Siltite (Cambrian?)**—Medium-gray, schistose, brown-weathering arkosic siltite. As seen in thin section, well-foliated schist of granular quartz, orthoclase, and minor calcite as grains (mostly less than 0.1 mm) showing mosaic texture where in mutual contact; foliation parallel to bedding defined by faint compositional layering and moderately aligned tremolite and sericite (some elongate muscovite crystals to 0.5 mm). Abundant small, well-rounded (oval-shaped), detrital zircon grains concentrated in a few bedding layers; rare detrital thorite(?). Sparse tiny apatite crystals and pyrite cubes scattered throughout. Exposed in a small thrust window underlying the Zanzibar and Harkless Formations 2 km south of Manhattan. On the basis of lithology, probably of Cambrian age, but of unknown correlation. Thickness unknown

Gold Hill Formation (Lower Cambrian)—Phyllitic schist and quartzite deposited as shale and sandstone in a marine environment and subsequently metamorphosed. Forms a thrust plate overlying the Mayflower Schist and underlying thrust plates of the Toquima and Zanzibar Formations and probably a thrust plate of Cambrian(?) siltite. Forms an antiform beneath upbowed thrust plates of the Ordovician formations, extending for about 8 km east-southeastward from Gold Hill at Manhattan; its internal structure here, however, is an overturned syncline verging north-northeastward. Also exposed along north margin of the Pipe Spring pluton. Total thickness not exposed; exposed thickness uncertain because of strong internal deformation and thrust fault truncation; original thickness probably at least 1 km. Age in part Early Cambrian, based on fossil evidence (*Olenellus gilberti* Meek) from similar looking rocks in the Toiyabe Range 25 km northwest of Manhattan (Ferguson and Cathcart, 1954). Because of the interlayered character of rock types in the Gold Hill Formation, they are described below as lithologic units rather than as stratigraphic units. Units are schist (**Єgs**), interlayered schist and quartzite (**Єgsq**), interlayered quartzite and schist (**Єgqs**), quartzite (**Єgq**), limestone (**Єgl**), calc-silicate-mineralized limestone (**Єglc**), and dolostone (**Єgd**)

Єg **Gold Hill Formation, undivided**—Shown only in cross sections

Єgs **Schist**—Light- to medium-gray, light-olive-brown- to buff-weathering, phyllitic argillite to mica schist. Contains minor thin (generally less than 1 m), interlayered, brownish-gray quartzite and limestone beds. Thin sections show that the phyllitic argillite consists of a finely laminated assemblage of fine-grained (mostly less than 0.05 mm) quartz-sericite-clay that contains local streaks and films of graphite and scattered specks of iron oxide (after pyrite). As seen in thin sections, the schist consists of a finely laminated, fine-grained (mostly less than 0.1 mm) quartz-mica assemblage with varied amounts of other metamorphic minerals. Sericite (muscovite in coarser varieties), chloritoid, and (or) biotite may be accompanied by tremolite-actinolite, garnet, calcite, and (or) zoisite. Opaque-oxide minerals include rounded detrital minerals, recrystallized iron-titanium oxides, pyrite, or limonite that is irregularly distributed throughout the rock. Sparse apatite and sphene, and rare tourmaline, are probably metamorphic minerals. Streaks and films of graphite are seen along some folia. One schist sample exhibits millimeter-thick, compositionally varied layers; one type of layer (relatively coarse grained) contains quartz, biotite, garnet, sphene, and opaque oxides; another (medium grained) contains quartz, actinolite, zoisite, sphene, and opaque-oxide minerals; a third (fine grained) contains quartz, biotite, zoisite, and opaque-oxide minerals. Most of the western two-thirds of the Gold Hill overturned syncline, which extends east-southeast from Manhattan, is mapped as schist (**Єgs**). Most of the eastern one-third of the Gold Hill in this structure is mapped as interlayered schist and quartzite (**Єgsq** and **Єgqs**, described below) because of uncertainty as to the position, abundance, and thickness of quartzite layers in the sequence. Schist units are as much as several hundred meters thick. Host to stockwork-disseminated gold deposits in west part of the Manhattan district

Єgsq **Interlayered schist and quartzite**—Interlayered schist (**Єgs**) and quartzite (**Єgq**) units of uncertain thickness; schist predominates over quartzite

Єgqs **Interlayered quartzite and schist**—Interlayered quartzite (**Єgq**) and schist (**Єgs**) units of uncertain thickness; quartzite predominates over schist

Єgq **Quartzite**—Whitish buff, buff, and light olive brown, in places dark brown weathering, mostly fine grained, in minor part coarse grained, thin bedded (and commonly schistose) to massive. Minor interlayers of thin mica schist, siltite, and limestone. Unweathered quartzite is generally light gray and contains sparse pyrite. Quartzite in the overturned syncline that extends east-southeastward from Manhattan is generally thin bedded, "dirty" (contains unidentified, dark dustlike material), and darker colored; that bordering the Pipe Spring pluton farther south is more massive, "cleaner," and lighter colored (almost white in places). Thin, randomly oriented quartz veinlets are common in quartzite. As seen in thin sections, the "dirty" quartzite is mostly fine grained (0.05–0.5 mm) and laminated; predominant quartz grains show granular mosaic texture. In places the quartzite contains grains as large as 1–5 mm that are surrounded by a groundmass of fine-grained mosaic quartz grains. Sparse grains of feldspar (mostly albite) are seen in some quartzites. Muscovite (and sericite), biotite, calcite, and tremolite-actinolite in minor amounts are interstitial or in seams that parallel folia and bedding. Apatite and tourmaline appear to be metamorphic minerals; in places apatite is abundant and forms clusters of tiny grains, or large disrupted elongate crystals that parallel folia. Rounded detrital zircons are common, concentrated in some bedding layers; thorite(?) is a rare detrital. As seen in thin section, "clean" nearly pure white quartzite from near the Pipe Spring pluton consists almost entirely of mosaic-textured, mutually interpenetrating quartz grains 1–3 mm across. Minor muscovite as flakes less than 1 mm across occurs within and interstitial to quartz grains. Quartzite units in the area extending east-southeastward from Manhattan are as much as about 150 m thick; quartzite at the margin of the Pipe Spring pluton is probably at least 200 m thick

€gl **Limestone**—Buff and light brownish gray to gray, massive to thin bedded to laminated. Forms layers a few meters to 100 m thick interlayered in schist (€gs), schist-quartzite (€gsq), and quartzite-schist (€gqs) units. Contains vein and replacement deposits of native gold, and arsenic, antimony, and mercury minerals in east part of the Manhattan district

€glc **Calc-silicate-mineralized limestone**—Pinkish buff, pale greenish gray, and nearly white; hard and dense. Commonly shows bedding characteristics of original limestone; in places structureless. As seen in one thin section, abundant diopside forms aggregates of granular crystals (less than 1 mm) as well as large (to 8 mm) sievelike crystals that enclose tremolite, sericite, zoisite, and sphene crystals. Sericite forms 1-mm patches that enclose small sphene and zoisite crystals. Tremolite also is concentrated in thin layers in the rock. A second thin section shows quartz grains (mostly less than 0.2 mm) as a mosaic-textured groundmass that contains interstitial calcite and diopside, and scattered crystals of tremolite (to 0.5 mm) and sphene and pyrite (less than 0.1 mm). Some calc-silicate-mineralized limestone consists entirely of idocrase and calcite. Mapped only in southwest corner of map area

€gd **Dolostone**—Brownish-gray, brown-weathering, dense dolomitized limestone. As seen in thin section, granular mosaic-texture dolomite grains (mostly less than 0.5 mm) constitute the bulk of the rock. Grains show a slight tendency locally toward rhombohedral forms. Thin veinlets of dolomite traverse parts of the rock. Sparse scattered blebs of quartz are present, and iron oxide, probably altered from pyrite, occurs irregularly. Recognized only in the White Caps Limestone Member (of Gold Hill Formation) as mapped by Ferguson (1924, p. 19) 1 km east of the White Caps mine and 3 km east-southeast of Manhattan

Mayflower Schist (Cambrian?)—Mostly knotted schist (€ms) with minor interlayered quartzite (€mq), and limestone (€ml). Extremely deformed by shearing and isoclinal folding. Underlies other thrust plates at thrust fault contacts in south part of quadrangle. Entire formation nowhere exposed; original thickness unknown but it is probably several hundred meters to a kilometer or more thick. Considered by Ferguson (1924) to be Ordovician(?) in age, but here considered to be Cambrian(?) on the basis of lithologic similarity to known Cambrian rocks

€ms **Schist**—Gray, dark-gray, dark-greenish-gray, and dark-olive-gray, brown- to olive-weathering, knotted schist. Well-developed foliation glistens in incident sunlight. Thin sections show well-developed foliation manifested by abundant chloritoid, biotite, and sericite (or muscovite) flakes (to 0.5 mm long) embedded in a granular mosaic of quartz grains (mostly 0.1–0.25 mm). The schist is characterized by abundant knots (to about 5 mm) of quartz and chloritoid, or quartz, chloritoid, and sericite, generally oval shaped and aligned in schistosity. Sparse tremolite-actinolite is present in some rocks. Sparse to abundant graphite, strung out along schistosity, helps define foliation. In places knots of sericite, chloritoid, and quartz are only incipiently developed, as graphitic laminae extend through the knots with only slight deflection. Schist is the predominant rock type in the Mayflower Schist

Ꞓmq **Quartzite**—Dark-gray, dark-grayish-brown- to buff-weathering, thin-bedded silty quartzite, interlayered in knotted schist (Ꞓms). Forms a layer several tens(?) of meters thick on southwest flank of hill 8043, 1 km east of Manhattan. The quartzite appears to be interlayered as a stratigraphic unit in knotted schist; possibly it was tectonically emplaced into its present position. A thin (1.5 m) layer of light-gray, olive-gray-weathering schistose siltite (not mapped) is interlayered in knotted schist, 2.3 km southeast of Manhattan. As seen in thin section, the rock consists of predominant mosaic quartz grains (mostly 0.02 mm, some to 0.1 mm). Biotite flakes (to 0.3 mm) form clusters and streaks, and sericite aggregates form lensoids (to 3 mm), along foliations in the quartz. Sparse tiny apatite crystals are present, and opaque-oxide minerals and limonite dust are irregularly distributed in the rock

Ꞓml **Limestone**—Gray, thin-bedded limestone in a layer a few meters thick crops out in the knotted schist (Ꞓms) about 3 km southeast of Manhattan. A second thin (2–3 m) layer 1 km to the southwest and 0.5 km north of the margin of the Pipe Spring pluton is a dark-gray, speckled calc-silicate-mineralized limestone. As seen in thin section, a cryptocrystalline groundmass of quartz, with abundant specks of graphite, contains abundant diopside crystals (to 2 mm) cored with sheaves and sunbursts of tremolite. Mosaic quartz grains (to 0.3 mm) are interstitial to diopside aggregates, and opaque masses of graphite are concentrated at edges of metacrysts

Harkless Formation (Lower Cambrian)—Phyllitic schist and silicified argillite, with minor siltstone, sandstone, limestone, and dolostone deposited as marine sediments and subsequently metamorphosed. Forms a thrust plate overlying thrust plates of the Toquima and Zanzibar Formations in southwest part of map area. Broken internally by minor thrust faults (some not mapped), and overlain locally by minor remnants of the Toquima and Gold Hill Formations in an even higher thrust plate. Full thickness not exposed; exposed thickness uncertain because of internal deformation and truncation by thrust faults. A partial measured section about 475 m thick is interrupted by a thrust fault 200 m above its base. The Harkless Formation is of Early Cambrian age, based on presence of *Salterella* (identification by E.L. Yochelson of the U.S. Geological Survey) collected by F.G. Poole from several localities near and just west of west-central edge of map area (two fossil localities in quadrangle, labelled 3). Lithologically similar to and of the same age as the Harkless Formation in southwestern Nevada and southeastern California (for example, Stewart, 1966; McKee and Moiola, 1962). Because of the interlayered character of rock types in the formation, they are described below as lithologic units rather than as stratigraphic units. Units are schist (Ꞓhs), siliceous argillite (Ꞓha), limestone (Ꞓhl), siltstone (Ꞓhst), and sandstone (Ꞓhss)

Ꞓh **Harkless Formation, undivided**—Shown only in cross sections

Ꞓhs **Schist**—Medium-gray, olive-gray-weathering, thinly laminated micaceous schist. Contains minor thin layers of siliceous and (or) silty argillite; some layers are "thin-platy" phyllitic argillite, pencil slate, or knotted schist. Within certain beds, compositional layers may appear extremely deformed, even isoclinally folded. Thin sections show that micaceous schist consists of aligned sheafs of sericite and chlorite that define anastomosing shears that bound lensoids of mosaic quartz grains (mostly 0.01–0.1 mm). Graphite, commonly as strings of minute grains or as films along folia, varies from sparse to abundant from layer to layer. Apatite forms sparse tiny metacrysts. A thin section of a micaceous schist collected a few meters from the contact of the Pipe Spring pluton shows sieve-like flakes of muscovite (to 1 mm) enclosing granular-mosaic quartz grains (to 0.2 mm). In some thin laminae, biotite is intergrown with and molded around quartz. Other layers are dominated by sheafs of chlorite aligned with foliation. Knotted schist contains lensoid knots (as long as 1 cm) made up of microcrystalline sericite, quartz, and graphite, surrounded by well-foliated sericite-chlorite-quartz schist. In some places knots in the schist consist of rectangular "shadow" crystals, showing square cross sections, that are aggregates of microcrystalline sericite (concentrated in rims), quartz (concentrated in cores), and minor hematite. Individual mapped units of micaceous schist range in thickness from a few meters to as much as 300 m

€ha **Siliceous argillite**—Medium-gray to dark-gray, olive-gray- to brown-weathering, platy to phyllitic and commonly silicified argillite. Contains minor thin layers of schistose argillite or micaceous schist. Locally within certain beds, compositional layers are seen to be strongly deformed, and transgressed by rock cleavage that parallels the general stratigraphic layering of units. As seen in thin sections, siliceous argillite consists of a microcrystalline aggregate of mosaic quartz grains and aligned sericite and clay(?) crystals, incipiently schistose and compositionally layered. In some layers graphite "dust" is abundant enough to impart a black color to the rock. Scattered patches and dusty streaks of iron oxide are common throughout. Individual mapped units of siliceous argillite range from a few meters to about 200 m thick

€hl **Limestone**—Medium gray, grayish brown weathering, and laminated. Thin interlayered beds of micaceous schist and siliceous argillite are found in places. As seen in thin section, the limestone consists mostly of calcite as grains and irregularly aligned lensoids (mostly less than 0.05 mm) separated by anastomosing shears, commonly marked by streaks and films of graphite. Grain-size variations may characterize different laminae. Quartz is sparse and occurs as scattered grains along bedding. Sparse knots of coarse calcite (to 1 cm) contain curved muscovite flakes (to 2.5 mm), quartz (to 1 mm), and irregular iron-oxide patches (to 1 mm). Limestone layers range from a few meters to 25 m thick. The thickest layer, mapped for a length of 2 km, lies south of Manhattan Gulch near west edge of quadrangle

€hst **Siltstone**—Interlayered gray, dark-brown-weathering siltstone, and lesser dolostone and argillite, evenly bedded in beds 1–5 cm thick. As seen in thin section, siltstone is made up mostly of mosaic quartz grains (less than 0.05 mm) bounded by anastomosing shears parallel to compositional layering. Granular calcite, or dolomite, or abundant orangish-brown biotite mark some layers. Graphite "dust" is streaked along shears, and blebs and cubes of iron oxide after pyrite are scattered throughout. Zircon is a sparse detrital mineral. Siltstone was mapped as a layer about 40 m thick and 1.5 km long south of Manhattan Gulch near west-central edge of quadrangle. Elsewhere, siltstone occurs only as small patches (thrust remnants) and thin layers in southwest part of quadrangle

€hss **Sandstone**—Gray, weathering to light reddish gray, buff, and light brown, fine to coarse grained, in places limy or quartzitic. A thin section of limy sandstone shows mostly rounded quartz grains (0.3–1 mm), not everywhere in contact, with margins slightly corroded. Interstices are filled with calcite charged with iron-oxide dust. Oxidized pyrite forms common framboids and sparse cubes (to 0.2 mm) centered in quartz interstices and grown into the quartz grains. Zircon and apatite crystals are sparse within quartz grains. In some sandstones, well-rounded coarse quartz grains show faceted quartz overgrowths. Mapped as layers a few meters thick only near Nevada Highway 377 at west-central edge of quadrangle

SUMMARY OF GEOLOGIC EVENTS

Cambrian marine clastic and minor carbonate rocks in the Manhattan quadrangle (Harkless Formation, **Ꞓh**; Gold Hill Formation, **Ꞓg**; siltite unit, **Ꞓst**; and Mayflower Schist, **Ꞓms**) were deposited as part of a westward-thickening wedge on the continental shelf at what was then the western edge of the North American continent (Stewart, 1980). Ordovician marine rocks were deposited probably as transitional facies rocks intermediate in character between predominantly carbonate (eastern) facies sediments on the continental shelf and siliceous (western) facies sediments in a western ocean basin, perhaps in deeper parts of the inner continental rise. Rocks of the Toquima Formation (**Ot**) are more siliceous than those of the slightly older Zanzibar Formation (**Oz**), and they may have been deposited in deeper water than were the Zanzibar strata.

The only upper Paleozoic rocks known in the quadrangle are the clastic rocks of the Permian Diablo Formation (**Pd**), present only as clasts in the Tertiary megabreccia of Sloppy Gulch (**Trls**) of the Round Rock Formation. Because I believe the clasts in the megabreccia were derived from the subsurface, I interpret that upper Paleozoic rocks underlie the Cambrian and Ordovician rocks, perhaps beneath much of the quadrangle. This interpretation requires that the Cambrian and Ordovician rocks are allochthonous and were emplaced in post-Diablo time.

On the basis of regional data (for example, Roberts and others, 1958; Stewart, 1980; Kleinhampl and Ziony, 1985), I surmise that the area underwent significant periodic compressional deformation starting in the late Paleozoic and continuing through the Mesozoic. Poole and Wardlaw (1978) reported pre-Permian deformation of Lower Cambrian argillite and post-Triassic thrusting of eugeoclinal Cambrian and Ordovician rocks 12 km southwest of Manhattan. The present configuration of the thrust plates of Cambrian and Ordovician rocks reflects such deformation. A lower plate composed of the Mayflower Schist is overlain on a strongly folded thrust fault by a plate composed of the Gold Hill Formation, in turn overlain by a plate composed of Cambrian(?) siltite, in turn overlain by a plate composed of the Zanzibar Formation, in turn overlain by a plate composed of the Toquima Formation, and it overlain by a plate composed of the Harkless Formation. Small thrust remnants of Cambrian and Ordovician rocks above the Harkless indicate a yet higher thrust plate, mostly removed by erosion. And finally, a higher thrust plate of the Harkless overlies a plate of the Zanzibar Formation overlying the Harkless at the west-central edge of the quadrangle. Minor thrust faults are evident locally within the thrust plates. Deformation both of the thrust faults and internally in the plates themselves appears to diminish upward, suggesting that emplacement of the plates was successively from the base upward.

Subsurface reconstructions of the Paleozoic rocks shown in the cross sections are speculative. However, they are reasonably based on the arrangement of rock units indicated by the surface mapping, and on superposition of thrust plates and style of deformation determined from mapping in nearby areas. Consistency from cross section to cross section tends to corroborate the interpretations.

Rocks of the Toquima and Zanzibar Formations are equivalent in age to part of the Vinini Formation farther north in the Toquima Range (McKee, 1976). In addition, the Toquima Formation is lithologically similar to the Vinini, although the Toquima in the Manhattan quadrangle contains no pillow basalts, and probably more limestone than the Vinini. The Toquima, and probably also the Zanzibar, thus constitute a part of, or are transitional to, the western facies rocks of the Roberts Mountains allochthon, and the thrust faults underlying the plates of Toquima and Zanzibar rocks therefore should be considered equivalents of the Roberts Mountains thrust fault system, of Early Mississippian age (for a discussion of the Roberts Mountains thrust, see Poole and others, 1992). In contrast to my interpretation, F.G. Poole (oral commun., 1970) considers the Toquima and Zanzibar Formations to be Ordovician transitional facies beneath the east-directed Roberts Mountains allochthon in central Nevada.

Thrust plates that underlie the thrust plates of Ordovician rocks in the Manhattan quadrangle are predominantly clastic rocks of Cambrian age; they occupy the same structural position as do shale and limestone units of Ordovician age in the northern Toquima Range (McKee, 1976). The Ordovician rocks in the northern Toquima Range were interpreted by McKee (1976) to have been thrust from west to east before emplacement of the Roberts Mountains allochthon but not earlier than Middle Devonian time. Whether or not the rocks that underlie the thrust plates of Ordovician rocks in the northern Toquima Range and in the Manhattan quadrangle were emplaced at the same time is not known.

If a plate of Permian rocks underlies the Manhattan quadrangle, as I speculated above, then the Roberts Mountains allochthon and underlying plates of Cambrian rocks in the southern Toquima Range probably were emplaced together as a separate allochthon, in their present juxtaposition, no earlier than Permian time.

Thrust faulting that emplaced rocks of the Harkless Formation above the Zanzibar and Toquima Formations, and in turn the Toquima, Zanzibar, and Gold Hill Formations above the Harkless, took place before intrusion of the Late Cretaceous granite of Pipe Spring (Kpg), inasmuch as the thrust faults are intruded by aplite bodies (Kpa) associated with the pluton. However, aplites emplaced as sills along thrust faults within the Harkless locally are boudinaged, and sheared and foliated parallel to the thrust surfaces, suggesting that thrust deformation had not ceased entirely at the time of aplite intrusion.

The north-northeast-verging overturned syncline in strata of the Gold Hill Formation east-southeast of Manhattan, together with northward-overturned minor isoclinal drag folds in many of the sedimentary units, suggest that a significant episode of north-directed compression caused folding and thrust faulting. Moreover, the likely source of thrust plates of the Harkless Formation in the quadrangle lies to the south-southwest in southwestern Nevada and southeastern California, implying their transport to the north-northeast. Such orientation of compression is at variance with most of the regional evidence that has indicated east-directed (uncommonly, west-directed) compression throughout much of the late Paleozoic to Mesozoic deformation in the Basin-Range province (for example, Roberts and others, 1958; Stewart, 1980). Moreover, in the Round Mountain quadrangle just north of the Manhattan quadrangle, Paleozoic rocks are deformed as though compression was east directed (Shawe, 1995). Lineations (rodding as a result of rotation of mineral grains between shear surfaces?) evident in the metamorphosed Paleozoic rocks in the Manhattan quadrangle are oriented predominantly east-west, subparallel to predominant fold axes there. However, lineations interpreted to be stretch lineations in such rocks in the Round Mountain quadrangle, also predominantly east-west in orientation, are nearly normal to fold axes there. Detailed studies of the polyphase deformations that have affected the rocks in the southern Toquima Range should be carried out to resolve the ambiguities and to clarify the tectonic history of the area.

The Late Cretaceous Belmont pluton (Kbgp) was emplaced at about 85 Ma, and invaded by aplites, domed, and mineralized at about 80 Ma (see Shawe, 1995, for a fuller discussion of the history of the Belmont pluton).

The Late Cretaceous granite of Pipe Spring (Kpg) was emplaced during waning stages of compressional deformation, as seen by concordance of foliation in the granite and in satellitic bodies of aplite (Kpa) with that in adjacent wallrocks. The pluton probably was emplaced as a thick lensoid sill intruded along a major deep-seated thrust break, suggested by general concordance of contact attitudes with strata in the adjacent wallrocks. Local irregularities of intrusion reflect complexities of the folded and faulted sedimentary rocks. Subsequent doming of the pluton warped the wallrocks upward and outward. Age data indicate emplacement of the granite of Pipe Spring at about 80 Ma and foliation and doming at perhaps as late as 76 Ma. A granodiorite dike satellitic to the pluton in the Belmont West quadrangle just east of the Manhattan quadrangle was emplaced at about 76 Ma (Shawe and others, 1987). Some aplites in the Manhattan quadrangle were intruded at about 75 Ma. Mineralization associated with the pluton occurred at about 75 Ma (Shawe, 1988).

The syenite plug (Ks) south of Manhattan was emplaced in Late Cretaceous(?) time near the close of the granitic episode that saw intrusion of the Pipe Spring pluton and associated aplites. The plug and some of the late aplite dikes may be late alkalic differentiation products of the granitic magma that produced the earlier intrusions.

Eruption of silicic intracaldera ash-flow tuffs of the Round Rock Formation (Trl, Tru) and collapse of the Manhattan caldera occurred at about 25 Ma. Average chemical composition of the upper member (Tru) varies from 73.9 percent SiO_2 and 13.6 percent Al_2O_3 in its lower part to 71.5 percent SiO_2 and 15.1 percent Al_2O_3 in its upper part, suggesting eruption of the upper member from a differentiated magma chamber. Emplacement of megabreccia units (Trlm, Trm, Trus) occurred throughout the history of caldera development (see Shawe and Snyder, 1988, for details). In the later phases of deposition of the middle (megabreccia) member (Trm) of the Round Rock Formation, a rhyolite plug and associated dikes (Trp) were intruded into the core of a composite (andesite-rhyolite) volcano northwest of Manhattan, which was the source, during catastrophic explosive eruptions, of the materials in the middle member.

Deposition of silicic ash-flow tuff (Tdl, Tdm, Tdu) and sandstone units (Tdls, Tdms) of the Diamond King Formation followed shortly after emplacement of the Round Rock

Formation. The Manhattan caldera then became a basin that received tuffaceous lake sediments and some fluvial deposits of the Bald Mountain Formation (**Tbm**). Shortly thereafter, at about 25 Ma, the area was covered by rhyolitic ash flows of the tuff of The Bald Sister (**Tbsl**, **Tbsu**). Perhaps at about the same time, the Bald Mountain Formation and locally The Bald Sister were intruded by extensive sills and small dikes and plugs of the Crone Gulch Andesite (**Tca**) that stemmed from an andesite stock northeast of Manhattan. The Crone Gulch yields questionable K-Ar ages; geologic relations indicate that it was intruded at about 25 Ma. Inflation at depth of a magma chamber that was the source of the Crone Gulch Andesite may have caused resurgence of the Manhattan caldera such that the core was lifted somewhat as a piston while peripheral ash-flow tuff layers sagged inward (see Shawe and Snyder, 1988, for a fuller discussion).

Two dacite flow domes (**Tf**) were emplaced in the Manhattan caldera near its west margin at about 25 Ma. A low-angle fault exposed near the plugs appears generally to dip inward toward the eastern plug, and in places near the plug the fault is characterized by considerable breccia. I infer that the low-angle (detachment) fault resulted from lateral pressure during emplacement of the flow dome as the dome expanded outward near the surface (see cross sections *D–D'* and *F–F'*). The western plug appears to have intruded through the low-angle fault, and hence it is inferred to be younger than the fault. Time of formation of the low-angle detachment is thus placed at about 25 Ma, a timing appropriate to coincide with emplacement of the eastern flow dome.

Possibly at about the time of intrusion of the Crone Gulch Andesite, a small composite rhyolite-andesite plug (**Tra**) was intruded into the volcanics of the Manhattan caldera on the southwest flank of Bald Mountain. At about 24 Ma, small andesite and latite plugs and dikes (**Ta**) were intruded into the granite of Pipe Spring and into adjacent Paleozoic rocks in the southeast corner of the Manhattan quadrangle.

Two small rhyolite plugs were intruded into Paleozoic rocks 3–4 km south of Manhattan. Their ages are unknown; they may be 35–40 Ma, the age of a thermal event recognized in the vicinity, or they may be about 16 Ma, the age of gold mineralization in the Manhattan district (Shawe and others, 1986; Shawe, 1988). Because significant erosion has occurred south of the caldera since 35–40 Ma, and because the flow-layered and nearly aphanitic character of the plugs suggests shallow emplacement, I believe it likely that they are younger rather than older.

Several small breccia dikes occur just south of the western of the two rhyolite plugs south of Manhattan. Their age is not known but it may be as young as late Miocene. Proximity to one of the rhyolite plugs suggests a possible genetic relationship.

Two narrow dikes and a sill of basalt are intruded into the Bald Mountain Formation, the tuff of The Bald Sister, and the low-angle (detachment) fault separating the formations. They may be as young as late Miocene or younger in age.

A major southeast-striking fault, here named the Manhattan fault, forms the southwest margin of the Manhattan caldera and extends southeastward through the Manhattan gold district. Its orientation suggests a possible relation to the Walker Lane zone of right-slip deformation farther south. The fault is subparallel to the alignment of gold deposits in the district, and it may have been a principal control on localization of the deposits. Such control is particularly evident in the east part of the district, where the fault intersects limestone units in the Gold Hill Formation and may have served as a "feeder" to deposits formed in those units. Age of the fault is uncertain. The fault may predate the caldera and may have localized a segment of the caldera margin during caldera collapse. The fault could not be traced southeastward into granite of the Pipe Spring pluton, suggesting its possible pre-granite age.

Evidence for the time of initiation of extensional Basin-Range faulting, uplift of the Toquima Range, and alluviation of Big Smoky Valley on the west side of the Toquima Range is lacking in the Manhattan quadrangle. On the basis of regional evidence (for example, Stewart, 1980, p. 110), the initiation was probably some time during the early Miocene. The common occurrence of two or three levels of Quaternary alluvium in many places in the quadrangle indicates that uplift of the range was sporadic.

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