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Geology of the southern San Mateo Mountains, Socorro and Sierra counties, New Mexico

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GEOLOGY OF THE SOUTHERN SAN MATEO MOUNTAINS, SOCORRO AND SIERRA COUNTIES, NEW MEXICO

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ABSTRACT—The San Mateo Mountains of Socorro and Sierra Counties, south-central New Mexico, are bounded by the Monticello graben to the west and the Mulligen Gulch and San Marcial basin to the east. The oldest rocks exposed in the southern San Mateo Mountains are Proterozoic and Paleozoic rocks exposed east of the Nogal Canyon fault at Bell Hill; Paleozoic limestones also are found south of Vicks Peak. The Datil Group contains all late Eocene-early Oligocene volcanic strata up to the 31.8 to 29.4 Ma regional hiatus in volcanism and includes the Rock Springs and Red Rock Ranch formations, Hells Mesa Tuff, and La Jencia Tuff. The southern San Mateo Mountains is dominated by the Nogal Canyon caldera (28.4 Ma). The estimated diameter of the caldera is 25 km, and Lynch (2003) estimated the total volume of the Vicks Peak Tuff as 1816 km³. Re-interpretation of past studies and recent re-mapping by the author in the southern San Mateo Mountains has refined understanding of the Nogal Canyon caldera. The Vicks Peak Tuff (28.4 Ma) and associated rhyolite and quartz latite flows and domes erupted from this caldera. The Vicks Peak Tuff is >490 m thick and is locally overlain by >550 m of rhyolite. Stratigraphic relationships indicate that the eruption of the Vicks Peak Tuff was followed by intrusion of the granite of Kelley Canyon and eruption of the rhyolite of Alamosa Canyon, within <0.42 Ma (Lynch, 2003). The Springtime Canyon Formation overlies the Vicks Peak Tuff east of Vicks Peak and consists of rhyolite, quartz latite and latite flows and associated tuffs erupted along the eastern caldera boundary, probably during this time period, but radioisotopic dating is required. Rhyolite dikes and small rhyolite domes that could be related to the caldera were erupted along the southern and northern boundaries of the caldera. The northern boundary of the caldera is partially concealed by the formation of the Mt. Withington caldera and the eruption of the Vicks Peak Tuff and younger rhyolites. The caldera was offset locally by younger normal faults (i.e. Rock Springs, Priest, Indian Peaks, Rhyolite, Dark Canyon, and Bell Mountain faults). The San Jose mining district is within the Nogal Canyon caldera and could be associated with the formation of the caldera. The San Mateo Mountains mining district is south of the Nogal Canyon caldera.

INTRODUCTION

The San Mateo Mountains in southern Socorro and northern Sierra Counties is approximately 64 km long north-south and the name is derived from St. Matthew (“Mateo” in Spanish), one of the disciples of Jesus. Seven high peaks in the range exceed 3,000 m in elevation (Vicks Peak, 3,287 m, San Mateo Mountain, 3,092 m, San Mateo Peak, 3,090 m, West Blue Mountain, 3,287 m, Blue Mountain, 3,142 m, Apache Kid Peak, 3,063 m, Mt. Withington, 3,083 m). The San Mateo Mountains are bounded by the Monticello graben to the west and the Mulligen Gulch and San Marcial basin to the east (Fig. 2). The Nogal Canyon caldera (28.4 Ma) and pre-caldera volcanic and volcanoclastic rocks are exposed in the southern San Mateo Mountains (Fig. 2). The Vicks Peak Tuff and associated rhyolite and quartz latite flows and domes erupted from the caldera and were subsequently intruded by granitic stocks (Lynch, 2003; McLemore, 2010).

Even though geologic mapping in the San Mateo Mountains is not completed, the available data indicates that the overall geologic history of the range is similar to that found throughout southern New Mexico. The San Mateo Mountains lie in a tectonically active and structurally complex area of the southwestern U.S. and are part of the Mogollon-Datil volcanic field, which is a late Eocene-Oligocene volcanic province that extends from west-central New Mexico southward into Chihuahua, Mexico (Fig. 1; McDowell and Claubaugh, 1979; McIntosh et al., 1991, 1992a, b; Chapin et al., 2004). In the southwestern U.S., Tertiary volcanic activity began about 40-36 Ma with the eruption of andesitic lavas and breccias, followed by episodic bimodal silicic and basaltic andesite volcanism during ~36 to 24 Ma (Cather et al., 1987; Marvin et al., 1988; McIntosh et al., 1992a, b). Approximately 25 high- and low-silica rhyolite ignimbrites (ash-flow

tuffs) were erupted and emplaced throughout the Mogollon-Datil volcanic field during the second event; source calderas have been

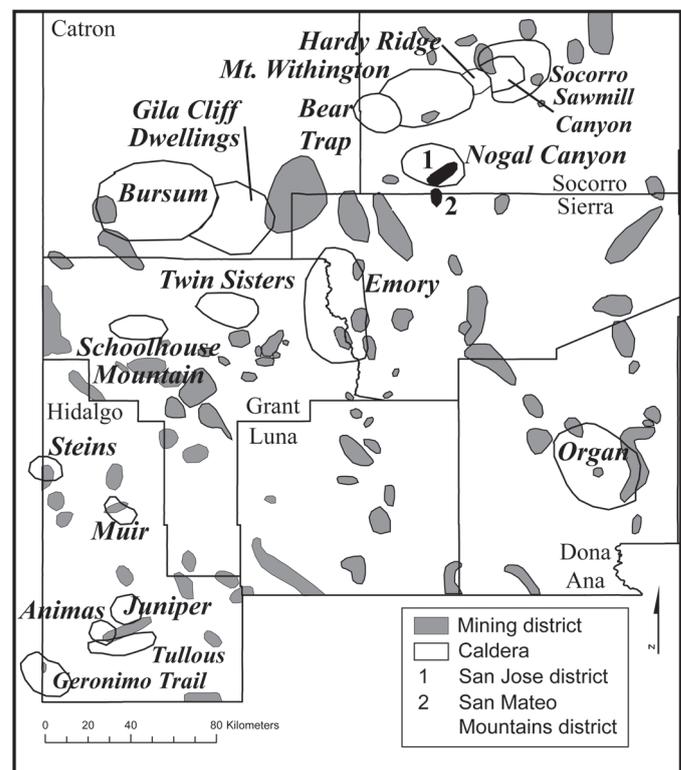


FIGURE 1. Calderas and mining districts in the Datil-Mogollon volcanic field, southwestern New Mexico (calderas from Chapin et al., 2004; mining districts from New Mexico Mines Database).

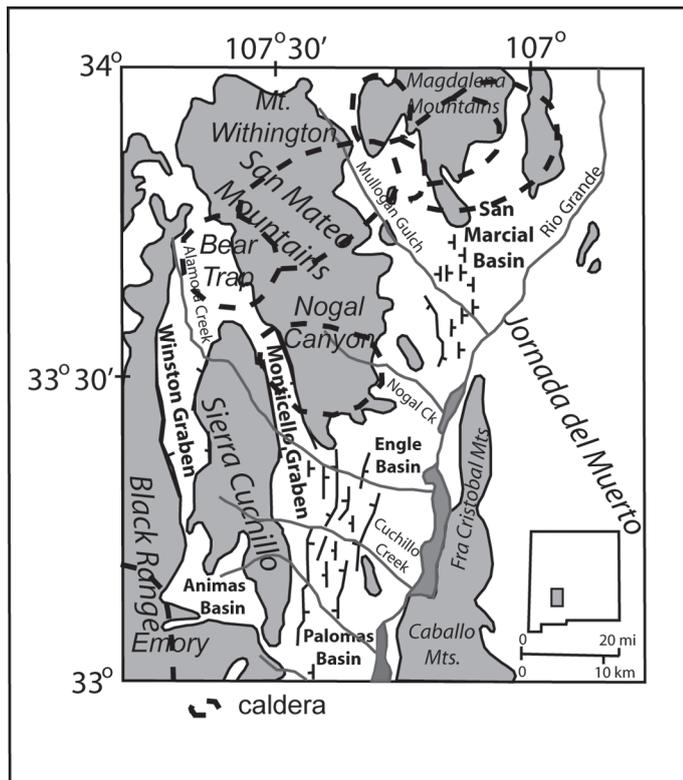


FIGURE 2. Tectonic features in the southern San Mateo Mountains, Socorro and Sierra Counties, New Mexico.

identified for many of the ignimbrites (McIntosh et al., 1992a, b; Chapin et al., 2004). Subsequent faulting, hydrothermal alteration, and volcanism have offset, altered, and covered portions of the volcanic rocks, which creates difficulties for regional correlations.

The purpose of this report is to 1) describe the geologic history and stratigraphy of the southern San Mateo Mountains and the Nugal Canyon caldera and 2) provide preliminary regional correlations of the volcanic rocks.

PREVIOUS WORK

The earliest geologic studies in the San Mateo Mountains were by Lasky (1932), Harley (1934), Willard (1957), Dane and Bachman (1961) and Weber (1963). Kottowski (1960) and Kelly and Furlow (1965) mapped and examined the Paleozoic stratigraphic section at Bell Hill (formerly Buck Mountain), north of Nugal Canyon. Furlow (1965) and Farkas (1969) described the complex nature of the volcanic stratigraphy in the southern San Mateo Mountains, but did not recognize the presence of the Nugal Canyon caldera. Deal (1973) defined the Mt. Withington caldera in the northern San Mateo Mountains and Deal and Rhodes (1976) were the first to propose the Nugal Canyon caldera in the southern San Mateo Mountains. Hermann (1986) mapped the southern margin of the Nugal Canyon caldera. Lynch (2003) mapped the northwestern portion of the Vicks Peak area. McLemore (2010, 2012a, b, this guidebook) mapped the western

San Mateo Mountains. Atwood (1982) mapped the area north-east of the Nugal Canyon caldera. Davis (1988) and Smith (1992) mapped the Luna Park and Aragon Hill areas in the southern San Mateo Mountains.

Regional mapping included Osburn (1984), who compiled a geologic map of Socorro County. Harrison et al. (1986) mapped the T or C 1:100,000-scale quadrangle. The geology of the central and northern San Mateo Mountains (north of East Red Canyon) has been described by Ferguson (1986, 1987, 1990, 1991), Ferguson and Osburn (1993), and Ferguson et al. (2007). Mineral investigations in the San Jose and San Mateo Mountains mining districts include Lasky (1932), Berry et al. (1982), Attwood (1982), McLemore (1983), Neubert (1983), North (1983), Cox (1985), Foruria (1984), Hahman (1993) and Korzeb et al. (1995).

METHOD OF STUDY

Recent re-mapping of the geology in the southern San Mateo Mountains (parts of the Vicks Peak, Steel Hill, Black Hill, Monticello, and Montoya Butte 7.5-minute quadrangles) was by the author at a scale of approximately 1:24,000, using the USGS topographic maps as a base. Areas of anomalous structural complexity, hydrothermal alteration, anomalous coloration, and mineralization were examined, sampled, and mapped at a scale of approximately 1:12,000. A geologic map was compiled in ARCMAP@ using U.S. Geological Survey topographic maps as the map base. Descriptions of the stratigraphy and lithology of the pre-caldera volcanic rocks are from Farkas (1969), Hermann (1984), Lynch (2003) and other cited references. Mapping is on-going and the geologic map and description of the mineral resources will be released in a future report. Ages are from Chapin et al. (2004), unless otherwise noted.

STRATIGRAPHY

Proterozoic and Paleozoic Rocks

The oldest rocks exposed in the southern San Mateo Mountains are Proterozoic rocks exposed east of the Nugal Canyon fault at Bell Hill (Steel Hill quadrangle), also known on earlier maps as Buck Mountain (Fig. 3; Atwood, 1982; McLemore, 2012c, this guidebook). The granite is brown to orange, coarse to medium grained and consists of quartz, K-feldspar, plagioclase, muscovite, and magnetite. Epidote coats some of the fractures and replaces some muscovite and feldspar. Brown to orange, coarse- to medium-grained, slightly foliated gneiss is intermingled with the granite locally. The granite and gneiss are intruded in places by thin (less than 1 m wide), simple pegmatites (quartz, feldspar, muscovite) and white quartz veins.

Unconformably overlying the Proterozoic rocks is a tan to brownish-black coarse-grained sandstone to conglomerate that includes interbeds of greenish-black and olive-gray shaly limestone, dark brown hematitic sandstone, and white quartz sandstone. The conglomerate contains clasts of the Proterozoic granite and gneiss. These sedimentary rocks resemble the basal Cambrian-Ordovician Bliss Formation in the Caballo Moun-

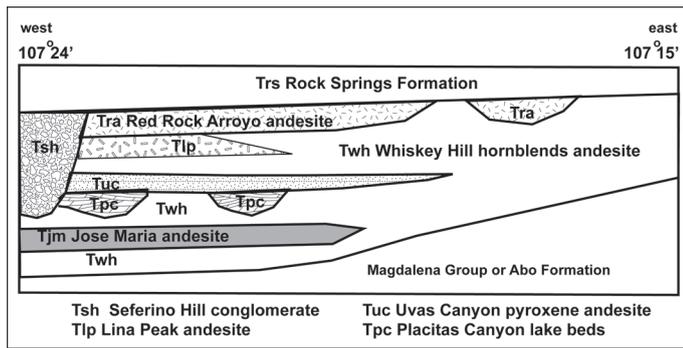


FIGURE 4. Diagrammatic stratigraphic section of the Red Rock Ranch Formation (Trr, Datil Group; from Farkas, 1969). Contacts are mostly unconformable.

andesite, 5) Luna Park andesite, 6) Red Rock Arroyo andesite, 7) Red Rock Arroyo vesicular andesite, and 8) Seferino Hill conglomerate. Hermann (1986) described five units within the Red Rock Ranch Formation (oldest to youngest): 1) volcanoclastic member, 2) shale member, 3) Garcia Falls andesite, 4) upper andesite member, and 5) Luna Peak andesite member. The Whiskey Hill hornblende andesite of Farkas (1969) is correlative to the volcanoclastic member and Garcia Falls andesite of Hermann (1986) and is light gray, speckled porphyritic andesite, with phenocrysts of biotite and amphibole. The Jose Maria andesite consists of 9-12 m thick red to red-brown, microcrystalline andesite, found in the vicinity of the Jose Maria well. The Placitas Canyon laminated lake beds (shale member of Hermann, 1986) consist of red to yellow tuffaceous to black fissile shale in the Placitas Canyon, and contain a fossil leaf flora dominated by conifers that broadly resembles the more famous (and geologically younger) Florissant flora from Colorado (Farkas, 1969; Meyer, 1986, 2012, this guidebook). The Uvas Canyon pyroxene andesite (upper andesite member of Hermann, 1986) locally crops out west of Red Rock Arroyo and consists of 7-12 m of grayish black to dark gray andesite flows with large phenocrysts of plagioclase and augite. The Luna Peak andesite is gray and consists of large euhedral plagioclase phenocrysts. The Red Rock Arroyo andesite and vesicular andesite are grayish blue to grayish purple with a pilotaxitic groundmass of plagioclase, magnetite, and amphibole. The Seferino Hill conglomerate is well indurated, red boulder, volcanoclastic conglomerate with interbeds of coarse-grained, cross bedded sandstones and is found at Seferino Hill and Questa Blanca Canyon.

Hells Mesa Tuff

The Hells Mesa Tuff is a white to pink to gray, welded to partially welded, crystal-rich quartz latite to rhyolite ash flow tuff that erupted from the Socorro caldera near Socorro at 32.0 Ma (Chapin et al., 2004). It consists of 20-30% sanidine, quartz, plagioclase, and biotite phenocrysts and 5% lithic fragments in a groundmass of pumice, sanidine, quartz, plagioclase, biotite, zircon, and orthopyroxene. In the Questa de Trujillo area (Optional stop after lunch, Day 2) the tuff is 37 m thick.

Rock Springs Formation

The Rock Springs Formation was named by Farkas (1969) after the Rock Spring Canyon in sections 13, 14, and 26, T9S, R6W, where the most complete stratigraphic section is found. The Rock Springs Formation consists of more than 914 m of interbedded andesite and latite flows, flow breccias, and tuffs. The formation is divided into seven units by Farkas (1969) (Fig. 5, oldest to youngest): 1) lower Luna Park tuff, 2) lower latite flows, 3) upper Luna Park tuff, 4) variegated breccia, 5) upper latite tuff, 6) upper andesite flows, and 7) volcanic agglomerate. Hermann (1986) divides the Rock Springs Formation into 13 members (oldest to youngest): 1) lower Luna Park tuff, 2) lower andesite member, 3) Luna Park latite, 4) Shipman Canyon andesite, 5) Luna andesite, 6) Hump Mountain andesite, 7) Shipman Spring tuff, 8) andesite flow, 9) pyroxene andesite, 10) Priest Mine andesite, 11) upper andesite, 12) volcanoclastic sediment, and 13) zeolitic andesite. Future mapping by the author will attempt to map and correlate these units. The Hells Mesa and La Jencia tuffs are interbedded within the Rock Springs Formation and provide some age control.

La Jencia Tuff

The La Jencia Tuff is a light brown to light red-brown, moderately- to well-welded tuff that erupted from the Sawmill caldera at 28.7 Ma (Chapin et al., 2004). It consists of sanidine, biotite, and quartz in a groundmass of sanidine, plagioclase, quartz, biotite, pyroxene, and opaque minerals.

Volcanic Rocks Associated with the Nogal Canyon Caldera

Vicks Peak Tuff (Tvp)

The predominant lithology in the southern San Mateo Mountains is the Vicks Peak Tuff that erupted from the Nogal Canyon caldera at 28.4 Ma (Lynch, 2003; Chapin et al., 2004). The rhyolitic ash flow tuff is moderately to densely welded, phenocrysts poor and locally exhibits columnar jointing or multiple fractures.

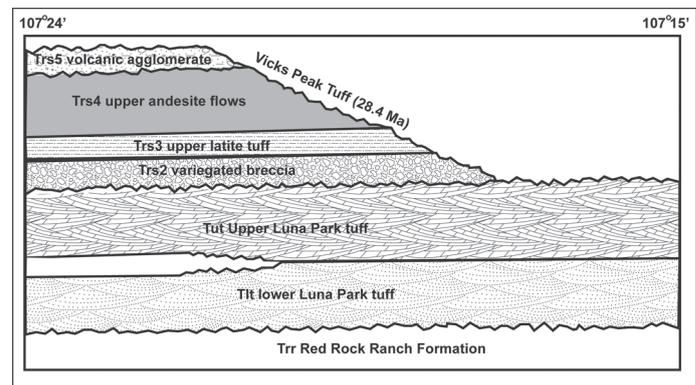


FIGURE 5. Diagrammatic stratigraphic section of the Rock Springs Formation (Trs, Datil Group; from Farkas, 1969). Flat contacts are gradational; other contacts are unconformable. The Luna Park tuff is correlated to the Farris Ranch Tuff, 35.6 Ma by McIntosh et al. (1992a, b).

The Vicks Peak Tuff varies in color throughout the San Mateo Mountains from light gray to pinkish gray to brown gray to pale red purple to gray to white. Phenocrysts include tabular to euhedral sanidine (1-3 mm, 1-10%), biotite (trace-1%), and trace quartz that are in a devitrified welded ash and pumice matrix with local rock fragments of andesite and rhyolite. Abundant flattened pumice and gas cavities can be found locally at the top of individual flows, and feldspar and quartz crystals are commonly found in the gas cavities (vapor phase alteration). In the western portion of the quadrangle, the ash flow tuff contains abundant spherulites.

Typically, the lower part of the Vicks Peak Tuff is highly jointed, densely welded and devitrified and consists of lesser amounts of phenocrysts (1% sanidine, 5% pumice) and rare lithic fragments (Hermann, 1986; Lynch, 2003). The middle portion of the Vicks Peak Tuff generally is cliff-forming, columnar jointed, densely welded, and devitrified tuff and consists of more phenocrysts (5% sanidine, 10% pumice) and locally contains more lithic fragments. Locally, the middle portion of the ash flow tuff contains abundant spherulites. A 1-3 m thick, vitrophyre is locally present at the base of the lower and middle units.

The upper portion of the Vicks Peak Tuff consists of a non-welded to welded to poorly-welded, tan to pink-gray to reddish brown, medium- to coarse-grained rhyolitic tuff. The tuff is relatively crystal-rich and contains as much as 10% sanidine phenocrysts (1-5 mm long), quartz, and magnetite with trace amounts of biotite, plagioclase, and zircon. Pumice and gas cavities are locally common with rare rock fragments. The upper tuff is typically altered where faulted. Farkas (1969) considered this unit as part of the Indian Creek Rhyolite, whereas Cox (1985) considered this tuff as the tuff of Milliken Park (although Cox, 1985, interpreted this unit as younger than the Springtime Canyon Formation). Lynch (2003) and Hermann (1986) considered this tuff as the upper part of the Vicks Peak Tuff.

The thickness of the Vicks Peak Tuff is uncertain because a complete section of the unit is not exposed. The Vicks Peak Tuff is more than 690 m thick inside the caldera boundary in the northeastern portion of Montoya Butte quadrangle (Lynch, 2003; McLemore, 2010) and ranges in thickness from 5 to 200 m west of the caldera boundary (Maldonado, 1974, 1980; McLemore, 2010). Hermann (1986) estimated the total thickness to be 1,200 m at Vicks Peak.

The tuff unconformably lies on top of the lahar and andesite of Monticello Box north of Cañada Alamosa at Black Mountain and rests on top of latite of Montoya Butte south of the Cañada Alamosa (Fig. 10; McLemore, 2012a). In the southern San Mateo Mountains, the Vicks Peak Tuff lies on top of andesites of the Red Rock Ranch and Rock Springs formations. Exposures of the Vicks Peak Tuff have been found in the Joyita Hills (northeast of Socorro), northern Jornada del Muerto, and the Magdalena, Lemitar, Bear, Datil, and Gallinas Mountains (Osburn and Chapin, 1983). Lynch (2003) estimated the total volume of the Vicks Peak Tuff to be 1,816 km³.

Rhyolite of Alamosa Canyon (Tac)

The rhyolite of Alamosa Canyon is exposed in the western San

Mateo Mountains, west of Vicks Peak. The rhyolite of Alamosa Canyon (Tac) was named by Maldonado (1974, 1980, 2012) and was called rhyolite lavas by Lynch (2003) and Ferguson et al. (2007). These lava flows overlie the Vicks Peak Tuff and locally form rhyolite dome complexes that conceal local fault zones. Locally, the unit forms cliffs and mesa tops. A basal vitrophyre (1-3 m thick) typically forms the contact between the Vicks Peak Tuff and the lava flows. Thin (1-3 m thick), moderately- to poorly-welded, phenocryst-poor (1-10%) ignimbrites are interbedded with the lava flows, especially in areas of rhyolite domes. These ignimbrites contain phenocrysts of tabular sanidine, plagioclase, and trace biotite and quartz. The rhyolite flows can be difficult to distinguish from the Vicks Peak Tuff because of their similar composition. The rhyolite lava flows commonly have undulatory flow banding, rounded quartz phenocrysts (<5%, except in gas cavities), and locally contorted and overturned folds. The tops of the rhyolite flows commonly contain abundant gas cavities that can be filled with clear, smoky, and amethystine quartz, anorthoclase, magnetite, titanite, and pseudobrookite (Maldonado, 1974; McLemore, 2010). The rhyolite of Alamosa Canyon is as much as 60 m thick inside the caldera (Lynch, 2003) and 50-220 m thick west of the caldera boundary (McLemore, 2010). Lynch (2003) determined that the age of the rhyolite of Alamosa Canyon is 28.4 Ma (⁴⁰Ar/³⁹Ar dating) and is indistinguishable from the age of the Vicks Peak Tuff. A sample collected in the southern portion of the Montoya Butte quadrangle, west of Vicks Peak (MONT-104), was dated as 28.4±0.04 Ma by ⁴⁰Ar/³⁹Ar (McLemore, 2010).

Springtime Canyon Formation

The Springtime Canyon Formation overlies the Vicks Peak Tuff and consists of rhyolite, quartz latite and latite flows and associated tuffs erupted along the eastern boundary, probably contemporaneously with the rhyolite of Alamosa Canyon, but dating is required. The Springtime Canyon Formation is exposed in the eastern San Mateo Mountains. Furlow (1965) named the rhyolitic rocks overlying the Vicks Peak Tuff north of Springtime Canyon, the Indian Creek Tuff-Vitrophyre. Farkas (1969) called it the Indian Creek Rhyolite. Deal and Rhodes (1976) suggested that these rocks are quartz latite rather than rhyolite and that the name Indian Creek Rhyolite be abandoned. This apparent confusion results from complex faulting, hydrothermal alteration, and similarity of the lower portion of the Springtime Canyon Formation with the Vicks Peak Tuff.

Observations by this author suggest that some of the lower lava flows of the Springtime Canyon Formation at Steel Hill are rhyolite lava flows similar to the rhyolite at Alamosa Canyon found west of Vicks Peak (McLemore, 2010). The Springtime Canyon flows gradually become quartz latite (using the older terminology) towards the upper portions of the unit. The thickest portion of the Springtime Canyon Formation is north of Springtime Canyon (Furlow, 1965), suggesting the eruptive center of the unit is buried in this area.

The lower unit of the Springtime Canyon Formation in the Nogal and Springtime Canyons area is a light brown-gray to black, glassy vitrophyre. This vitrophyre is 3-9 m thick. The vit-

rophyre is overlain by gray to dark brown porphyritic lava that contains 20% feldspar, 5% biotite, and 3-5% quartz as phenocrysts and feldspar, quartz, and trace biotite, zircon, and magnetite in the groundmass. Many flows contain clots, streaks, and stringers of rhyolite similar to the Vicks Peak Tuff.

Rhyolite of San Juan Peak

The rhyolite of San Juan Peak consists of peralkaline rhyolite dikes, plugs, lavas, and ash flow tuffs and is mapped in the San Juan Peak area (Atwood, 1982). It consists of quartz, sanidine, plagioclase, riebeckite, and magnetite (Atwood, 1982). The lavas and ash flow tuff cap San Juan Peak, overlying Vicks Peak Tuff.

Turkey Springs Tuff

The Turkey Springs Tuff erupted from the Bear Trap Canyon caldera in the northern San Mateo Mountains and is exposed in small outcrops in the Vicks Peak area (Hermann, 1986), in drainages in the northern and northwestern portion of the Montoya Butte quadrangle (north of Cañada Alamosa, McLemore; 2010, 2012a, b) and in the northern San Mateo Mountains (Ferguson, 1986, 1987, 1990, 1991; Ferguson and Osburn, 1993; Lynch, 2003; Ferguson et al., 2007). The Turkey Springs Tuff typically is a gray to pinkish gray, phenocryst-poor (3-8%), poorly- to moderately-welded ignimbrite. A more phenocryst-rich phase (up to 20%) is present locally. Phenocrysts include tabular sanidine (1-3 mm, 5-10%), euhedral to subhedral quartz (1-3 mm, 0-10%), and trace plagioclase, biotite, magnetite/hematite, and titanite in a devitrified groundmass of ash and pumice. Rock fragments of rhyolite and andesite are common locally. Elongate pumice fragments (1-3 cm) are locally common. The Turkey Springs Tuff is as much as 60 m thick in the Montoya Butte quadrangle and 70-105 m thick elsewhere in the San Mateo Mountains (Lynch, 2003). Lynch (2003) determined that the Turkey Springs Tuff is 24.4 Ma ($^{40}\text{Ar}/^{39}\text{Ar}$ dating) and a sample collected by McLemore (2010) near Monticello Box was 24.5 ± 0.04 Ma.

Younger volcanic and volcanoclastic rocks

Rhyolite dikes and small rhyolite domes and lava flows erupted along the southern and northern Nogal Canyon caldera and could be the latest eruptions of the caldera (Farkas, 1969; Hermann, 1986; Davis, 1988). Younger andesite to dacite flows are found throughout the southern San Mateo Mountains (Farkas, 1969; Maldonado, 1974, 1980; Hermann, 1986). The andesite to dacite flows are fine grained to aphanitic, dense to vesicular, gray to brown-gray flows that consist of pyroxene, hornblende, biotite, and iron-oxide minerals. They are less than 2 m thick. Volcanoclastic sedimentary rocks are exposed locally in the San Mateo Mountains, and consist of well-cemented, massive to thin bedded, volcanoclastic conglomerate, sandstone and siltstone.

Basalt and associated scoria flows are found interbedded with sediments along the southern Cañada Alamosa (lower box) near San Mateo Canyon (McLemore et al., 2012, this guidebook). These basalt flows are up to 24 m thick, black to dark gray, fine

grained, locally porphyritic, dense to vesicular, and exhibit local pillow-like structures. The basalt consists of phenocrysts of plagioclase, pyroxene, and trace olivine (altered to iddingsite), magnetite, calcite, and iron oxides in a fine-grained groundmass. These basalt flows were thought to be similar in age to the Winston and Hillsboro basalt flows, based upon appearance and composition (Maldonado, 1974, 1980, 2012; McLemore, 2010). However, $^{40}\text{Ar}/^{39}\text{Ar}$ dates indicate that these basalts are 18-19 Ma and much older than previously thought and correlates with the Hayner Ranch Formation (Mack et al., 1998; Koning, 2012, this guidebook). Mapping and geochronology of rocks elsewhere in the southern San Mateo Mountains are required to determine if rocks of similar age are found there.

Quaternary-Tertiary Santa Fe Group (QTsf, Pleistocene to Miocene)

Since formation of the Nogal Canyon caldera and eruption of rhyolite lavas during the Miocene, large amounts of detritus were shed into the Alamosa and San Marcial basins and Monticello graben from the San Mateo Mountains. This detritus was derived largely from erosion of rhyolite ash-flow tuffs and rhyolite and andesite flows from the San Mateo Mountains. Over time, this erosion resulted in deposits that may be as much as 400 m thick in places in the Monticello graben (McLemore, 2012d, this guidebook). These piedmont deposits consist of reddish-brown, pale-brown, tan, and orange, poorly-sorted, poorly consolidated, inter-tonguing beds of massive conglomerates and thin, massive to cross-bedded, fine-grained sandstones, siltstones, and clay beds. Organic material is rare and, if present, consists predominantly of plant roots. Graded bedding and cross-bedding are common in thin lenses (several meters thick). The deposits eroded from the San Mateo Mountains are thicker and more extensive than deposits eroded from the Sierra Cuchillo. These sedimentary units have been correlated to the Gila Conglomerate (Myers et al., 1994) or the Winston Formation (Hillard, 1967, 1969), but are better correlated with the Palomas, Rincon Valley, and Hayner Ranch formations of the Santa Fe Group (Harley, 1934; Heyl et al. 1983; Lozinsky, 1986; Maxwell and Oakman, 1990; McCraw and Love, 2012, this guidebook; Koning, 2012; this guidebook). The piedmont deposits typically are incised, so that younger deposits are inset into them (McCraw and Williams, 2012, this guidebook).

Quaternary alluvium, floodplain, and colluvium

Colluvium deposits, including minor landslide deposits, are found in local areas of the southern San Mateo Mountains where thin veneers of unconsolidated gravel, sand, and silt cover the volcanic bedrock. Floodplain deposits consist of unconsolidated, moderately sorted, fine- to coarse-grained sand, silt, and clay, are several meters thick, and are cut by the active streams. The youngest deposits in the area are unconsolidated alluvium deposited by the active streams, which are found in the active arroyos and stream channels and consist of volcanic rocks, predominantly rhyolite and granite (McCraw and Williams, 2012). The larger streams meander and cut as much as 600 m into the

older Quaternary-Tertiary sediments; Alamosa Creek is the only stream that flows all year. The smaller streams are ephemeral and cut into volcanic bedrock or in broad valleys cut into the older Quaternary-Tertiary sediments.

INTRUSIVE ROCKS

Mafic Dikes

Fine-grained to aphanitic mafic dikes, up to 1-2 m wide, intrude the Rock Springs and Red Rock Ranch formations. Lithologies range from basalt to andesite to dacite. The dikes are fine grained to aphanitic to locally porphyritic, dense to locally amygdaloidal, black to dark to greenish gray to reddish brown and consist of plagioclase, pyroxene, biotite, and hornblende in a fine-grained groundmass. Many are altered, form saddles in between hill tops, and the groundmass consists of calcite, chlorite, and locally epidote. These dikes are believed to be older than the Vicks Peak Tuff, rhyolite of Alamosa Canyon, and granite of Kelly Canyon, because the dikes do not intrude the Vicks Peak Tuff, rhyolite of Alamosa Canyon, and granite of Kelly Canyon and are chemically distinct from these younger rhyolites (McLemore, 2010). Mapping is required to determine if there are any preferred orientations.

Granite of Kelly Canyon

Several irregular to elongated stocks of pink to gray granite intruded the Vicks Peak Tuff in Kelly and San Mateo Canyons. Lynch (2003) and Ferguson et al. (2007) called these stocks granite porphyry stocks and McLemore (2010) called these rocks the granite of Kelly Canyon. The granite is holocrystalline to porphyritic and consists of K-feldspar (2-15 mm, 25-35%) in a finer-grained groundmass of sanidine (20-30%), quartz (20-30%), plagioclase (20-30%), and trace biotite and magnetite. The chemical composition of the granite of Kelly Canyon is nearly identical to the chemical composition of the Vicks Peak Tuff and rhyolite of Alamosa Canyon (McLemore, 2010). Lynch (2003) determined that the age of the granite of Kelly Canyon is 28.3 Ma ($^{40}\text{Ar}/^{39}\text{Ar}$ dating), which is indistinguishable from the age of the Vicks Peak Tuff.

Rhyolite Dikes and Domes

Rhyolite dikes, up to 1-2 m wide, and rhyolite domes intruded the Rock Springs and Red Rock Ranch formations. The rhyolite dikes and domes are pink to reddish-brown, fine-grained to porphyritic, and consist of plagioclase, sanidine, and quartz in a fine-grained matrix. Mapping is required to determine if there are any preferred orientations.

STRUCTURE

Numerous normal faults cut the volcanic rocks in the southern San Mateo Mountains (Fig. 6); most of them have vertical to steep dips and trend north-northeast. Faults typically are brecciated, silicified, and exhibit local gouge zones of clay, calcite, and quartz. Fractures and joints locally parallel the fault traces. Many canyons and drainages are offset by or follow faults. Some, but not all dikes, follow faults; whereas most hydrothermal veins follow faults or dikes. The dikes and hydrothermal veins have variable directions.

The predominant structure in the southern San Mateo Mountains is the Nogal Canyon caldera (Fig. 6), which is an apparent resurgent caldera (Lynch, 2003). Evidence for resurgent is high-altitude peaks found within the caldera that are composed of Vicks Peak Tuff and related rhyolites (Vicks Peak, San Mateo Mountain, San Mateo Peak, West Blue Mountain, Blue Mountain, Apache Kid Peak). Re-interpretation of past studies and recent mapping by the author in the southern San Mateo Mountains has refined the boundaries of the caldera. The Vicks Peak Tuff (28.4 Ma) and associated rhyolite and quartz latite flows and domes erupted from this caldera and these rocks were subsequently intruded by granitic stocks. Deal and Rhodes (1976) defined the boundaries of the Nogal Canyon caldera based upon reconnaissance mapping of a relatively thick section of the Vicks Peak Tuff (>500 m) within the caldera as compared to thinner outflow sequences of the Vicks Peak Tuff (100-200 m; Osburn and

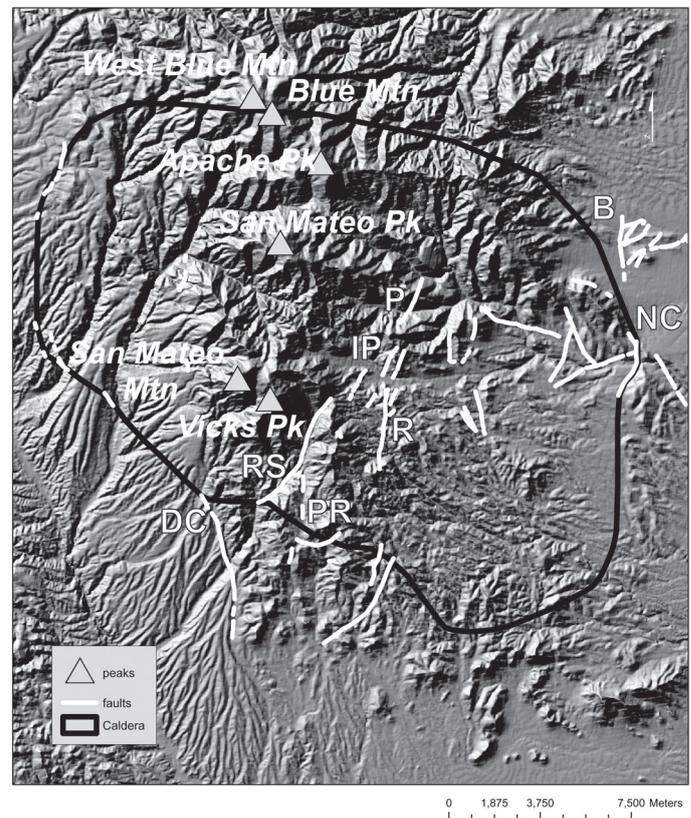


FIGURE 6. Boundaries of the Nogal Canyon caldera, modified from Deal and Rhodes (1976) by geologic mapping (Hermann, 1986; Lynch, 2003; the author, 2005-2012). Names of faults: NC=Nogal Canyon, B=Bell, RS=Rock Springs, PR=Priest, P=Pankey, IP=Indian Peak, R=Rhyolite, DC=Dark Canyon.

Chapin, 1983; McIntosh et al., 1992a, b). The southern margin of the Noyal Canyon caldera was defined by a series of small rhyolite stocks and complex faulting (Fig. 6; Deal and Rhodes, 1976). The northeastern margin was defined by a thick sequence of latite and rhyolite flows of the Springtime Canyon Formation. Some of the northern parts of the caldera remain unmapped. Detailed mapping by Hermann (1986) confirmed the southern margin of the Noyal Canyon caldera, as evidenced by rhyolite intrusions along the southern portion of the Rock Springs fault (Fig. 6). Lynch (2003) recognized that the northern boundary of the Noyal Canyon caldera is north of his mapped area near East and West Red Canyon. McLemore (2010, 2012a) mapped the western boundary of the Noyal Canyon caldera in Kelley and San Mateo Canyons in the Monticello graben (Fig. 6). The eastern margin of the Noyal Canyon caldera is in part defined by the Noyal Canyon fault (Fig. 6; Farkas, 1969).

The Noyal Canyon caldera is offset locally by younger normal faults (i.e., Rock Springs, Priest, Indian Peaks, Rhyolite, Dark Canyon, Bell Mountain faults). The Rock Springs fault is curved south of Vicks Peak and merges into the north-trending Priest fault. The northeast-trending Indian Peak fault is exposed in the northwest portion of the mapped area (Fig. 6) and continues north to Indian Peak (Forureu, 1984; Hahman, 1993), where silicified rhyolite is exposed along the fault (see Day 2 road log, fig. 2.11, this guidebook). The displacement is unknown. Quartz-alunite alteration is associated with the northern portion of the fault.

The Rhyolite fault extends from south of the Rhyolite mine, northward to Springtime Canyon, strikes N0° to 20°E and dips 70-90°NW, and has an estimated stratigraphic displacement of more than 110 m downthrown to the west (Forureu, 1984). The Rhyolite, Milliken, and Taylor mines are along the Rhyolite fault, and the fault is exposed for nearly 8 km (Forureu, 1984). The fault is well exposed in scattered silicified outcrops and brecciated zones. The Milliken shaft at Stop 1 is on the Rhyolite fault (McLemore, 2012f).

The Pankey fault strikes north-northeast and dips 80°east to vertical (Forureu, 1984). In Springtime Canyon, the fault is a zone of jointed, brecciated, and silicified rhyolite (Lasky, 1934). The Pankey mine is along the fault in Springtime Canyon and was the predominant gold-silver producing mine in the San Jose district (McLemore, 2012e).

The Noyal fault is in the eastern San Mateo Mountains and places Vicks Peak Tuff against Red Rock Ranch Formation andesites and Magdalena Group limestones (Farkas, 1969; McLemore, unpublished mapping, 2011-2012). The eastern edge of the Noyal Canyon caldera may be in part the Noyal Canyon fault (Fig. 6; Lynch, 2003; McLemore, unpublished mapping, 2011-2012). The Vicks Peak south and west of the fault is >250 m thick and is <100 m east of the Noyal Canyon fault.

The north-trending Bell Mountain fault (Buck Mountain fault of Furlow, 1965) separates andesites and andesite breccias of the Rock Springs Formation from the fault blocks of Paleozoic and Proterozoic rocks (McLemore, 2012c, this guidebook). The southern portion of the fault is terminated by the Noyal Canyon fault (Fig. 6).

The north-trending Dark Canyon fault is a younger normal fault associated with the formation of the Monticello graben to the west and separates Quaternary sedimentary rocks from volcanic rocks of the Rock Springs Formation (Hermann, 1986; McLemore, 2012d). Displacement along the Dark Canyon fault is as much as 1,300 m (Hermann, 1986; Lynch, 2003).

SUMMARY OF THE MINERAL DEPOSITS

It is beyond the scope of this paper to describe the mineral deposits; future reports will describe and evaluate the mineral resources in these districts in detail. Mining districts are common along the ring fractures of many calderas in New Mexico and elsewhere (Fig. 1; McLemore, 1983; Lovering and Heyl, 1989; Elston, 1994; Korzeb et al., 1995; McLemore, 1996), and two mining districts are found within and south of the Noyal Canyon caldera in the San Mateo Mountains: the San Jose and San Mateo Mountains mining districts. Volcanic-epithermal vein, volcanogenic uranium, placer gold, and placer tin deposits and associated hydrothermal alteration are found in these districts. The history of the mining districts and mineral production are in McLemore (2012e, this guidebook).

These districts are characterized by intense acid-sulfate alteration (also known as advanced argillic alteration), which produces the multiple shades of white, red, yellow, orange, purple, green, brown, and black found throughout the southern San Mateo Mountains, especially along faults (Forureu, 1984; Cox, 1985; Davis, 1988; Hahman, 1993; McLemore, 2012f). This type of alteration typically forms a zoned halo surrounding the mineral deposit and is an attractive target for prospecting, especially for volcanic-epithermal gold-silver veins, porphyry copper and molybdenum deposits, and volcanogenic beryllium deposits, to name a few types of associated mineral deposits. A modern analog for the formation of this alteration would be a geothermal system, such as the Norris Geyser Basin in Yellowstone National Park (Muffler et al., 1971; Henley and Ellis, 1983; Kharaka et al., 2000; Rodgers et al., 2002).

PRELIMINARY CONCLUSIONS

The oldest rocks in the southern San Mateo Mountains are Proterozoic metamorphic and granitic rocks that are overlain by Paleozoic sedimentary rocks. Andesitic flows and breccias of the Rock Springs and Red Rock Ranch formations were erupted at approximately 40-30 Ma. Ash flow tuffs from regional calderas also were erupted during this time period (Hells Mesa, La Jencia Tuffs). The eruption of Vicks Peak Tuff and collapse of the Noyal Canyon caldera followed at 28.4 Ma, together with the intrusion of granite of Kelly Canyon and the eruption of Alamosa Canyon rhyolite (Fig. 7). An early stage of hydrothermal mineralization and alteration occurred in the Milliken Park and Springtime Canyon areas during or after collapse and doming of the Noyal Canyon caldera. The Springtime Canyon Formation and younger rhyolites were erupted after the Vicks Peak Tuff. Eruption of additional volcanic rocks, including the peralkaline

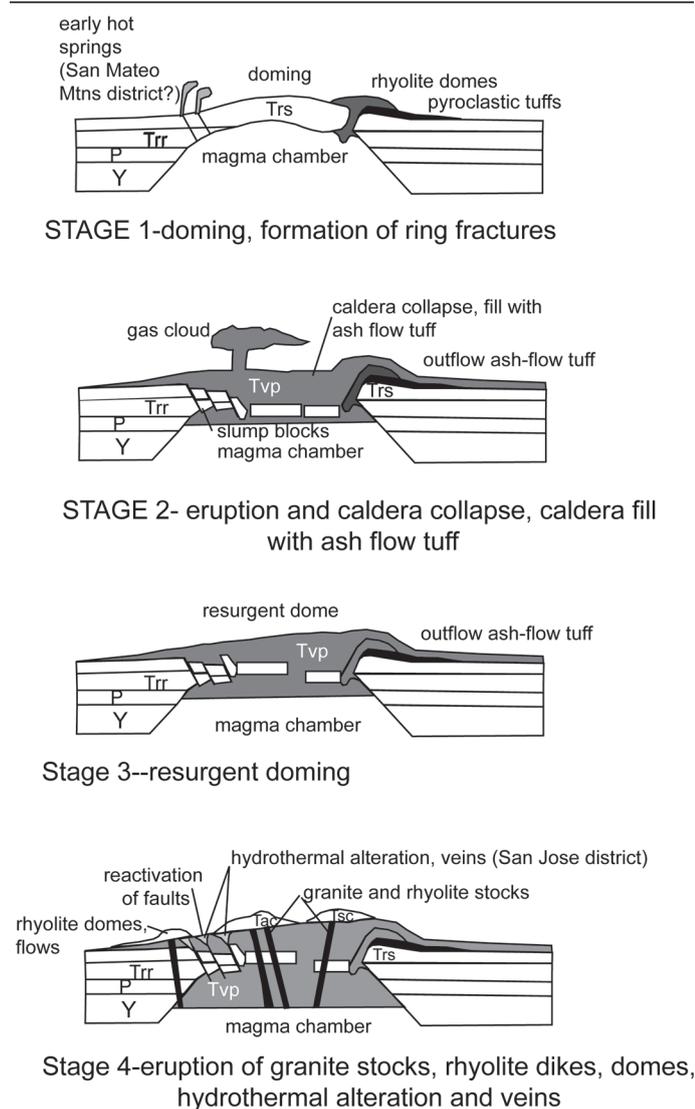


FIGURE 7. Formation of the Nogal Canyon caldera. Stratigraphic symbols defined in Figure 3. In part modified from Elston (1994) and Lynch (2003). Stage 1—magma collects at the top of the magma chamber, causing doming and formation of ring fractures. The magma expands and erupts along the ring fractures. Stage 2—magma continues to erupt and the rocks overlying the magma chamber collapse into the void produced by the erupted magma. Magma fills the crater. Stage 3—magma refills the magma chamber and doming begins again. Stage 4—additional eruption occurs and is followed by intrusion of granite and rhyolite stocks. Subsequent Basin and Range tectonic activity reactivates or offsets portions of the caldera.

rhyolite at San Juan Peak followed. The Turkey Springs Tuff at 24.4 Ma represents some of the last volcanic activity. Basin and Range faulting and late stage of hydrothermal mineralization and alteration followed. Alkali basalts were erupted in the Monticello graben at 18-19 Ma onto older sedimentary rocks of the Santa Fe Group (McLemore et al., 2012). Deposition of Santa Fe Group and younger sedimentary deposits followed.

Figure 8 summarizes the preliminary regional correlations between the rocks in the southern San Mateo Mountains and the Sierra Cuchillo.

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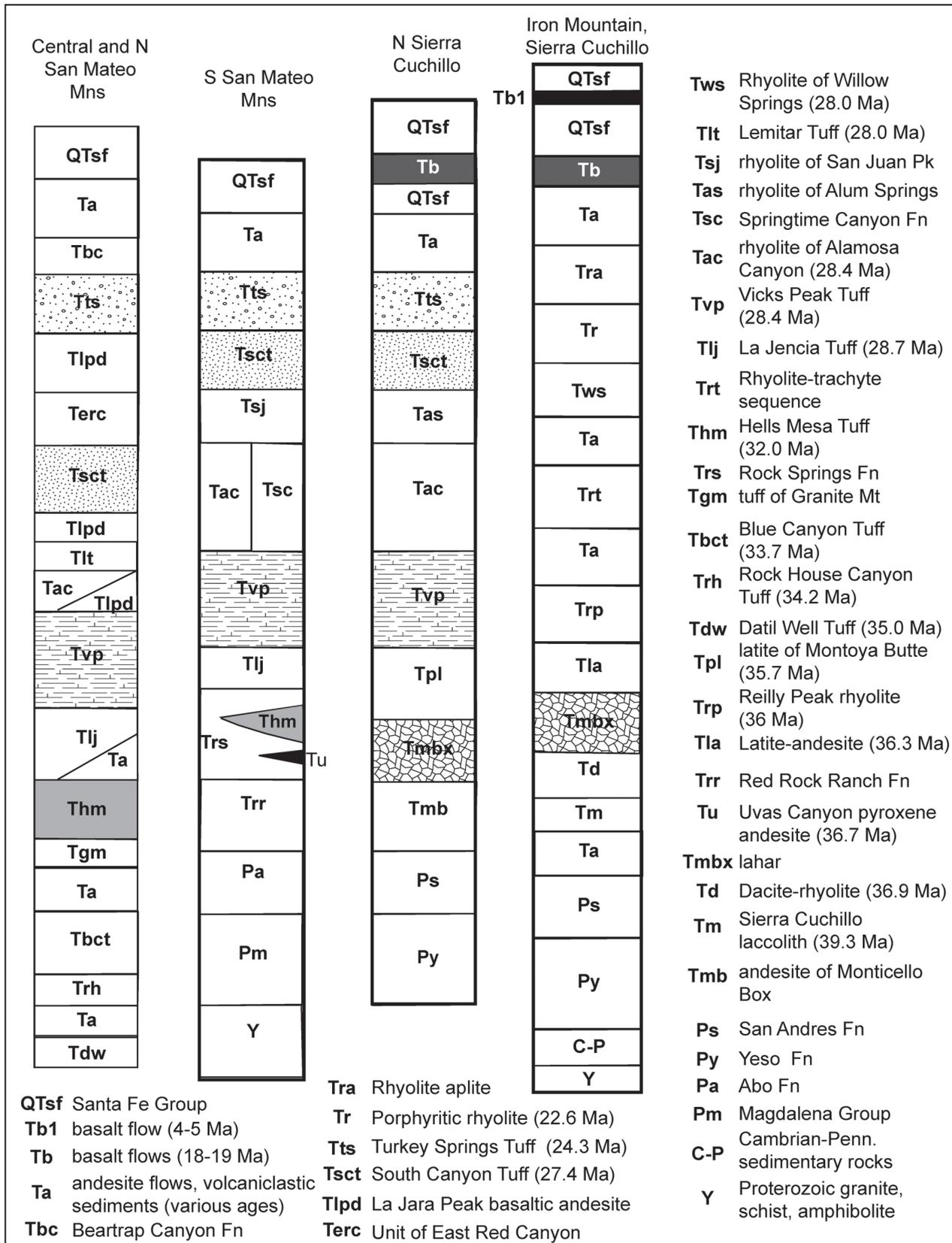


FIGURE 8. Preliminary stratigraphic correlations of units in the San Mateo Mountains and Sierra Cuchillo Range. Stratigraphic sections and ages of units modified from Hillard (1967, 1969); Farkas (1969), Maldonado (1974, 1980, 2012), Jahns et al. (1978, 2006), Davis (1986a, b), Robertson (1986), Hermann (1986), Smith (1992), Michelfelder (2009), McLemore (2010, 2012a, b), Michelfelder and McMillan (2012) and McLemore et al. (2012). Ages of ash flow tuffs from McIntosh et al. (1992a, b), Lynch (2003), Chapin et al. (2004), and McLemore (2010).

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