Geologic Map of the Nogal Peak Quadrangle, Lincoln and Otero Counties, New Mexico.

By

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Open-file Digital Geologic Map OF-GM 134

Scale 1:24,000

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PRELIMINARY GEOLOGIC MAP
OF THE NOGAL PEAK QUADRANGLE,
LINCOLN AND OTERO COUNTIES, NEW MEXICO

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Cover Photo: Nogal Peak (9960 feet) looking northwest from the vicinity of Grizzly Peak. Nogal Peak is a stack of at least five thick trachytic lavas and interlayer breccias that overlie slightly older Sierra Blanca Volcanics (Thompson, 1972). The volcanic pile has been intruded by three monzonite to syenite stocks of economic interest since the 1880s. Although little was mined and even less was earned, the gold-silver-lead-zinc-copper-molybdenum prospects continue to attract attention from the serious and the hopeful (photo by F. Goff).

INTRODUCTION

Nogal Peak quadrangle, located in Lincoln and Otero counties, contains much of the White Mountain Wilderness, a scenic and remote portion of the beautiful Sierra Blanca (Figures 2, 3 and 4). The early Spanish named the peak "nogál," which means "walnut tree" or the wood and color of walnut (cover photo). Spanish influence in the area was mostly restricted to ranching. In the 1870s, Lincoln County became famous for ranch wars and the legend of Billy the Kid (Austin, 1991). Around the turn of the last century, the mountains of the quadrangle became a destination for prospectors and railroad men, the latter looking for water to supply steam locomotives. Bonito Reservoir, just east of the quad, was built for this purpose and a pipeline directed the water of Bonito Creek to the train depot in Carrizozo. These days, campers, hikers, horseback riders and other vacationers enjoy the area and the reservoir is a favorite fishing spot. The nearby city of Ruidoso has grown substantially in recent years creating a small housing boom and a need for more reliable water supplies. Thus, our 1:24,000 scale geologic map of Nogal Peak quadrangle supports ongoing geology and hydrology investigations to better determine water resources (Newton, 2011). We have also obtained chemical analyses of the various igneous rocks to evaluate possible sources of rare earth elements (REE), now so important in high-tech products (Kramer, 2010). Several adjacent geologic quadrangle maps have already been completed or will soon be completed in this rugged region of growing population and competing water demands (Rawling, 2004a, 2004b; Kelley et al., in press; Cikoski et al., in press).

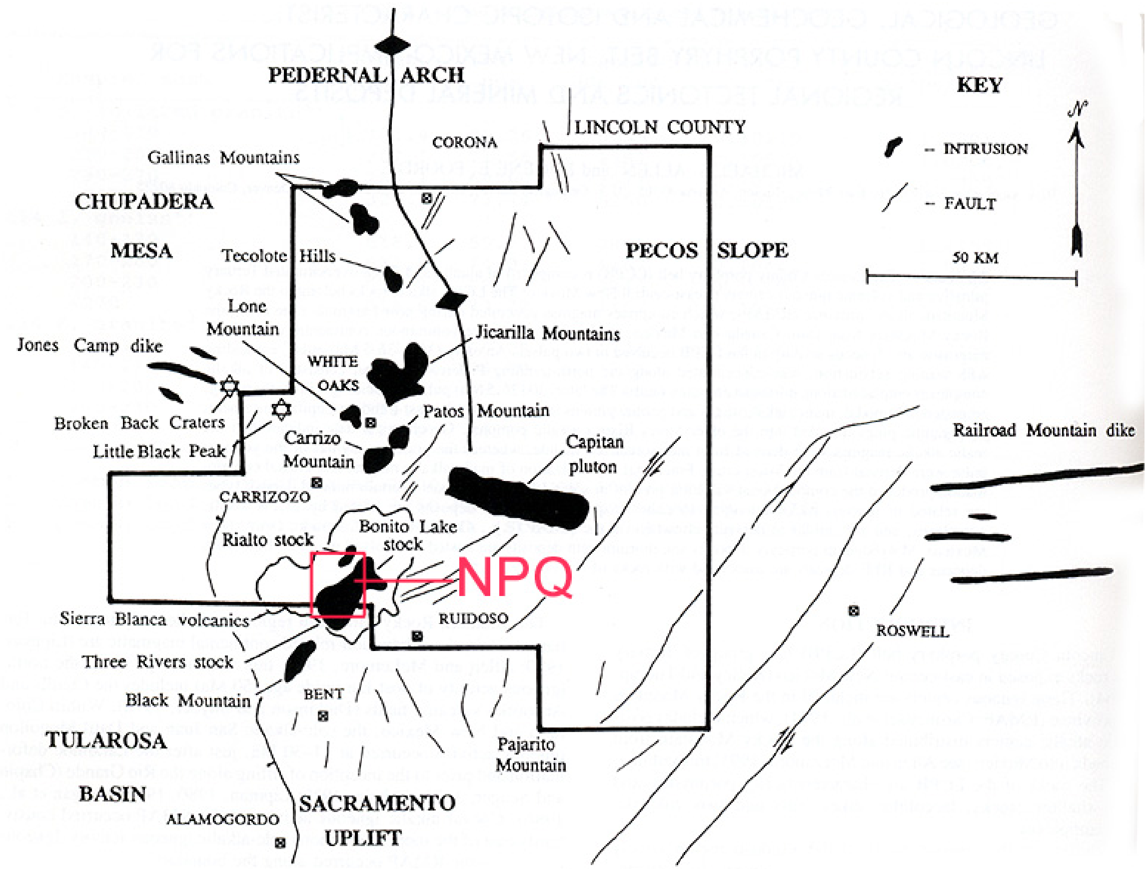

Figure 1: Location map of Lincoln County with respect to important igneous and tectonic features and Nogal Peak quadrangle (NPQ). The intrusions form what is called the Lincoln County Porphyry Belt (modified from Allen and Foord, 1991).

ACKNOWLEDGEMENTS

Thompson (1973) published the first modern geologic map of the Nogal Peak quadrangle and surrounding areas at 1:62,500-scale (15-minute). Without this previous contribution our endeavors would have been much more arduous and time consuming. Thompson's major units and stratigraphy are used herein (Thompson, 1966; 1972) except for modifications outlined in paragraphs below. Several other geologic maps exist for small areas within or near the mining areas (e.g., Black 1977). Moore et al. (1988) mapped the Mescalero Apache lands along the southern strip of the quadrangle (1:24,000 scale). After field checking their work along the reservation boundary, we have used most of their contacts. Fieldwork was conducted by standard methods (topographic maps, air photography, binoculars, rock hammers, hand lenses, GPS devices, brunton compasses, four-wheel drive trucks, and boot leather) on all non-reservation lands. Robert Runnels (Runnels Outfitter and Guide Service, Capitan, New Mexico) provided horses and packers for two horse pack trips into remote parts of the White Mountain Wilderness. We thank J. Michael Timmons (New Mexico Bureau of Geology and Mineral Resources) for logistical and tactical support. High Mesa Petrographics (Los Alamos, NM) prepared high-quality thin sections while ALS Laboratory Group (Reno, NV) performed the new chemical analyses appearing in the Appendix 1. $^{40/39}$Ar dates were obtained from L. Peters and W. McIntosh whereas X-ray diffraction analyses were provided by Virgil Lueth (all NMBG&MR). Stacy Timmons (NMBG&MR) loaned us equipment to collect a small suite of environmental water samples. The State Map Program jointly supported by the U.S. Geological Survey and the NMBG&MR funded much of this geologic map. Substantial funding was also received from Otero County, New Mexico.

PHYSIOGRAPHY AND LAND USE

Nogal Peak quadrangle occupies the core of the White Mountain Wilderness in the Sierra Blanca (White Mountains) and lies only a few scant miles west and northwest of Ruidoso, New Mexico (Figures 1 and 2). The landscape consists of a deeply dissected, north-trending horst of mostly mid-Tertiary volcanic rocks and associated sediments intruded by three somewhat younger dioritic to syenitic stocks. Just west of the quadrangle, the Sierra Blanca is offset from the Tularosa Basin by a number of prominent normal faults. Sierra Blanca Peak, barely south of the quadrangle, is just over 12,000 feet tall whereas the Tularosa Basin lies at roughly 4000 to 6000 feet, making this pair of features one of the largest and most spectacular horst-graben offsets in the United States (Figure 3). Within Nogal Peak quadrangle the maximum elevation is about 11,770 feet on the north shoulder of Sierra Blanca Peak (Figure 4) and the minimum elevation is just less than 6800 feet in the NW and SW corners. Nogal Peak (9957 feet, cover photo) dominates the landscape on the north edge of the quadrangle.

Rio Ruidoso in the southeast, Rio Bonito in the east, Rito Nogal in the northeast, and Three Rivers and tributaries to the west drain most of Nogal Peak quadrangle. Forest service roads 107, 108 and 400 access the northeastern part of the quad whereas NM Highway 532 accesses the southeastern part of the quad and Ski Apache resort. Forest service road 579 ends about a mile west of the southwest part of the quad at Three Rivers Campground. A few private lands and active mining claims occur in the northeast part of the quad and a couple of ranches border the west part of the quad. The Mescalero Apache Indian Reservation occupies a strip about 1.5 miles wide along the entire southern edge of the quad. Because the rugged White Mountain Wilderness occupies so much of the quad, portions of the west and north are most conveniently studied by back packing or horse packing.

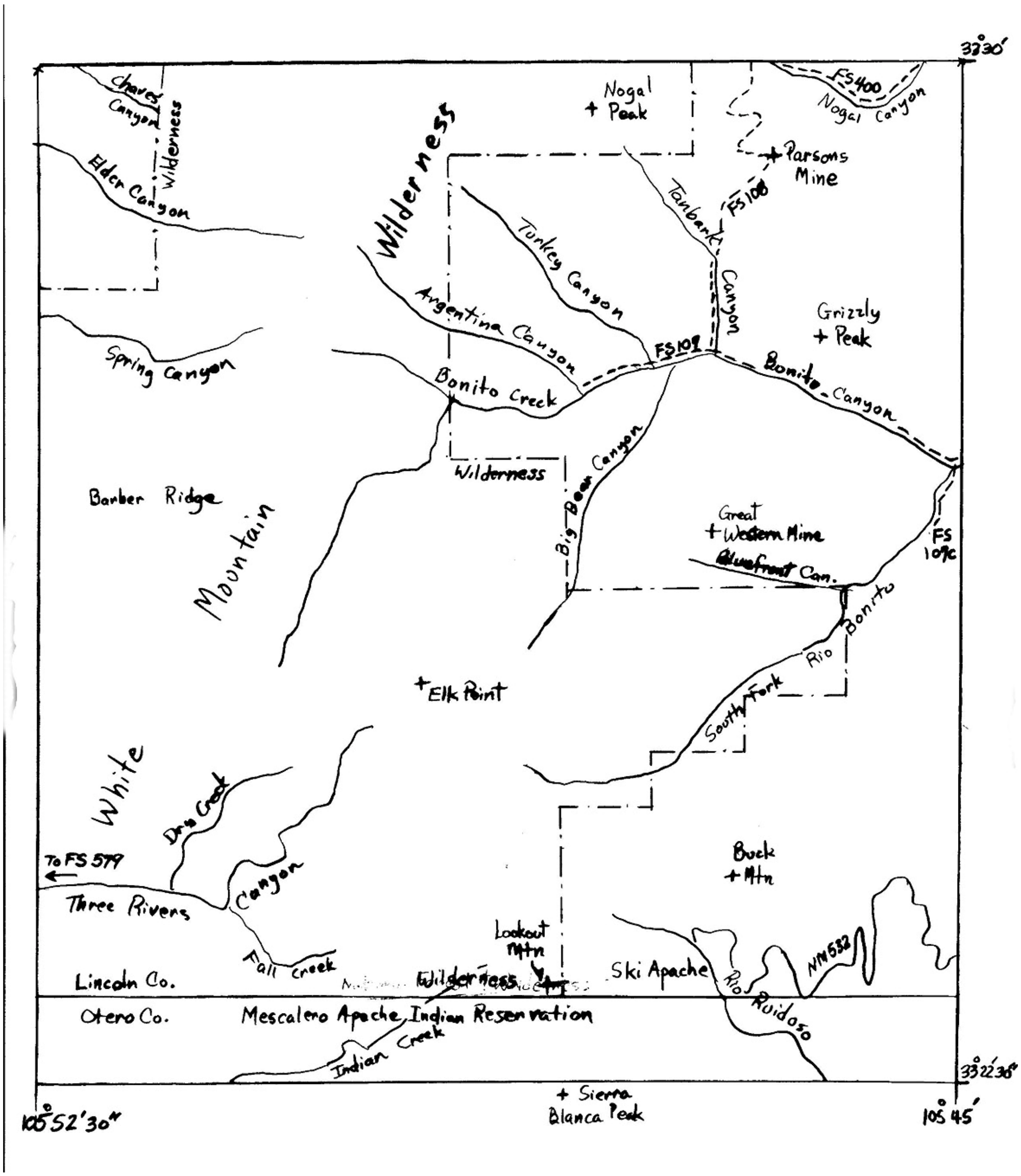

Figure 2: Map of Nogal Peak quadrangle showing major physiographic features, mines and roads.

The northeast part of the quadrangle and surrounding areas of Lincoln and Otero counties were heavily prospected for gold, silver and other metals in the later part of the 1800s (Thompson, 1973; Segerstrom et al., 1979; McLemore, 1991). The only significant discovery in the quadrangle was the Parsons Mine in a tributary of Tanbark Canyon (Figure 2), which produced gold ore from a breccia pipe within the Rialto stock (Thompson, 1973). About $300,000 of gold was mined from 1908 to the 1920s, perhaps $1,000,000 from the entire Nogal and Bonito mining districts (Lindgren et al., 1910; Thompson, 1973). Minor exploration and claim staking continues into the modern days (Eng, 1991). As a result ravines and mountains surrounding the tributaries

Figure 3: View looking east of Sierra Blanca Peak (12,003 ft) shot from the east side of the Godfrey Hills in the Tularosa Basin (about 5200 ft) in late September 2010.

of Rios Bonito and Nogal are littered with adits, shafts, glory holes, ruins, old equipment, drill holes, and abandoned roads, a treasure trove of early mining Americana. On the other hand, we found scant evidence that pre-Columbian inhabitants lived in the quadrangle.

GEOLOGY

The majority of exposed rocks in the Nogal Peak quadrangle consist of a thick sequence of late Eocene to Oligocene volcanic rocks and associated sediments intruded by three somewhat younger stocks: Rialto, Bonito Lake and Three Rivers (Figure 5 correlation chart). A diverse assemblage of dikes (basalt, gabbro, diorite, monzonite, syenite and rhyolite) cuts all igneous units. Collectively this igneous package is called the Sierra Blanca igneous complex (Thompson, 1966; 1972). The Sierra Blanca igneous complex (SBIC) is part of the greater Lincoln County Porphyry Belt (Figure 1) (LCPB, Allen and Foord, 1991) that apparently occupies the eastern end of a major NE-trending zone of igneous activity and associated ore deposits called the New Mexico Structure Zone (NMSZ, McLemore, 2008). Igneous activity along the NMSZ is oldest to the southwest (Laramide) and becomes somewhat younger to the northeast. If the LCPB is truly a NE extension of the NMSZ, it is the youngest part of the zone.

Eocene and Older Rocks

Folded and faulted Eocene, Cretaceous, Triassic and Permian sedimentary strata underlie the Sierra Blanca igneous complex forming the north-trending Sierra Blanca basin (Kelley and

Figure 4: View south toward Sierra Blanca Peak shot from Lookout Mountain (11,580 ft) in early October 2010. Apache Bowl, part of Ski Apache is visible left (east) of the ridgeline.

Thompson, 1964; Cather, 1991). These older strata are mostly exposed in areas surrounding Nogal Peak quadrangle, particularly to the east, west and south (Moore et al., 1988; Cather, 1991; Rawling, 2004b). Two unique sedimentary units were deposited within the upper part of the Sierra Blanca basin before volcanism ensued: the Cub Mountain Formation and Sanders Canyon Formation (Cather, 1991). The former unit was first defined by Bodine (1956) and was thought to be Late Cretaceous-early Tertiary in age. Lucas et al. (1989) discovered invertebrate fossils in the lower Cub Mountain that were Eocene. Weber (1964) divided the Cub Mountain into a non-volcanic sedimentary lower unit and volcaniclastic upper unit. His unit distinctions were used by Cather (1991) to separate the Sanders Canyon Formation from underlying Cub Mountain. The age of Sanders Creek is thought to be roughly 40 to 43 Ma (Cather, 1991) but it is gradational with overlying volcanic breccias of the Sierra Blanca Volcanics whose maximum age is roughly 38 Ma (Moore et al., 1991).

The southeastern portion of Cather's type section lies in the extreme NW part of Nogal Peak quadrangle in upper Chaves Canyon. At this location, the contact between Sanders Creek Formation sandstones and overlying coarse volcanic breccias of (mostly) pyroxene trachybasalt is found at about 6800 feet. Sandstone beds near the contact dip 8 to 12 ° to the ENE. In the type section, the thickness of Cub Mountain Formation is approximately 730 m (2400 ft) and the overlying Sanders Canyon Formation is about 150 m (490 ft).

Rocks of the Cub Mountain Formation are also exposed southeast of Nogal Peak quad where they are overlain by volcanic breccias and flows of trachybasalt and trachyphonolite (Moore et al.,

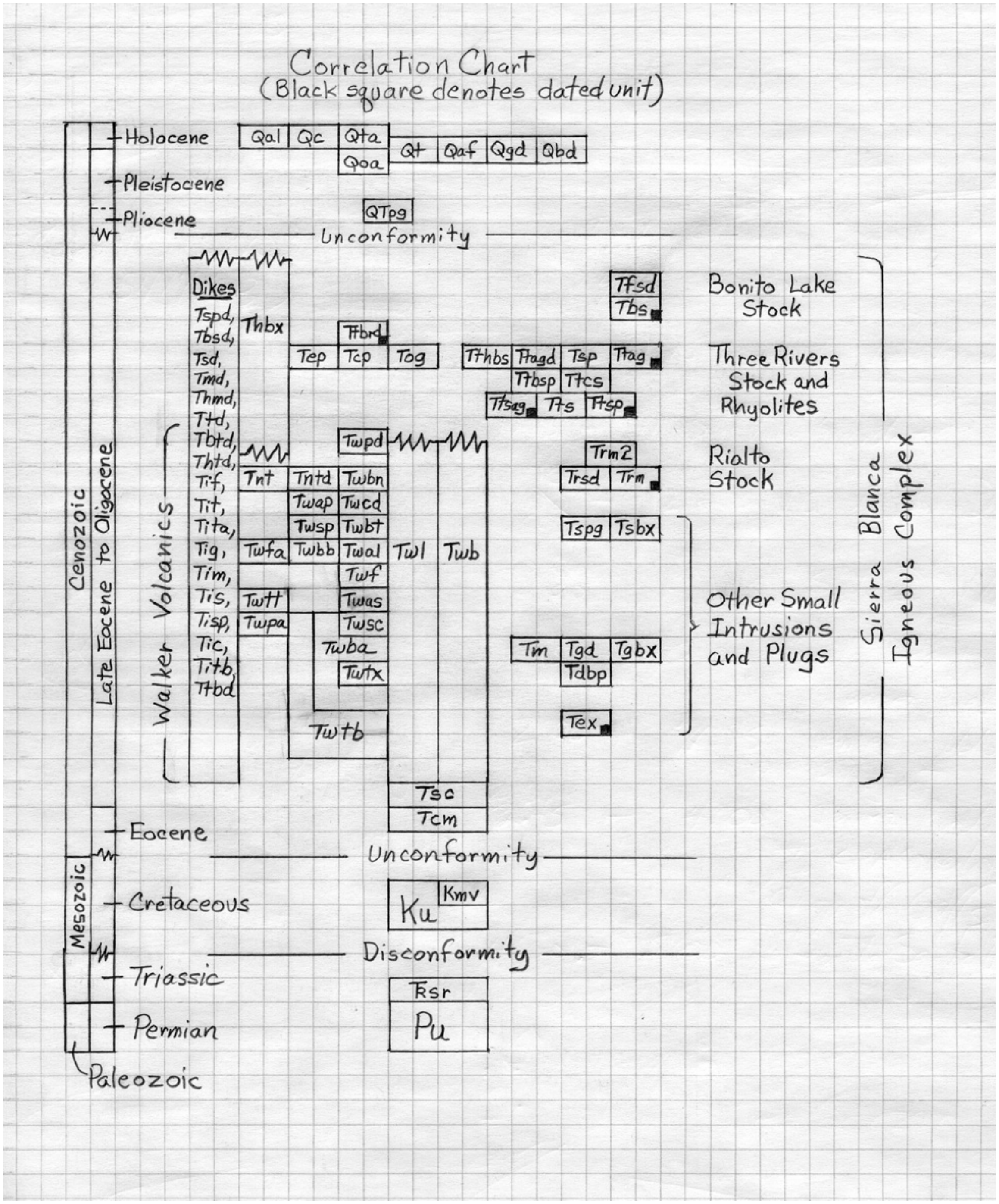

Figure 5: Correlation chart of rock units in the Nogal Peak quadrangle, Sierra Blanca, New Mexico.

1988). These authors did not separate the Sanders Canyon Formation. The thickness of the Cub Mountain unit is not given on the map of Moore et al. (1988) but it appears to be more than 450 m (1475 feet) with a general dip to NNW.

On the east side of the Sierra Blanca in the Angus quadrangle, Rawling (2004b) measured a total thickness of Cub Mountain and Sanders Canyon Formations at 450 m (1475 ft). Although Rawling (2004b) recognizes that Sanders Canyon rocks are present from their volcaniclastic nature, he did not map a contact between the two units. In the Angus quad, the Eocene package is highly deformed by faulting, folding and igneous intrusions, but the general dip seems to be 6 to 10 ° to the west. In the northwest part of the Angus quadrangle, the Eocene sediments are intruded by syenite of the Bonito Lake stock and by a NE-trending dike and sill complex of mafic to intermediate composition magmas. To the southwest, the Eocene strata are overlain by breccias of the Sierra Blanca Volcanics.

Sierra Blanca Volcanics

Thompson (1966, 1972) divided all the eruptive rocks of the Sierra Blanca Volcanics into four formations: Walker Andesite Breccia, Nogal Peak Trachyte, Church Mountain Latite and Godfrey Hills Trachyte. As mapped and defined by Thompson, the latter two units do not occur on Nogal Peak quadrangle, although the oldest volcanic rocks in the Godfrey Hills may be correlative with Thompson's Walker Andesite Breccia. Detailed mapping on this and adjacent quadrangles shows that the name "Andesite Breccia" is a misnomer because the unit contains substantial quantities of lava flows, particularly in the upper half of the sequence, and contains a significant volcaniclastic component in the lower part of the sequence. Additionally, rock chemistry published by Allen and Foord (1991), Moore et al. (1991), and this study (Appendix 1) shows that the lavas and breccias range compositionally from alkali basalt through trachyandesite and trachydacite. Thus, we have mapped the Walker "Andesite Breccia" as separate flows or flow packages where possible, particularly in the north and west portions of the quadrangle, and as undivided Walker Formation lavas (Twl) in the hydrothermally altered and structurally complex areas in the east, south and central portions of the quadrangle.

According to Thompson (1966, 1972, 1973), the greatest thickness of Sierra Blanca Volcanics (3340 feet or about 1020 m) is preserved west of Nogal Peak. A composite graphic section (Thompson, 1973, Fig. 6) runs from the summit of Nogal Peak to the NNW crossing 41 volcanic units. This section is representative, but not accurate in other parts of the quadrangle because we have found that many lava flows, flow breccias and other breccias in the Walker pinch and swell laterally. Some units pinch out entirely or are faulted out, while additional units appear in other parts of the quad that aren't identified in Fig. 6. The upper five units of Fig. 6 consist of 985 feet (300 m) of Nogal Peak Trachyte (actually trachyandesite to trachydacite based on analyses in Appendix 1 and the more recent classification scheme of La Bas et al., 1986) shown as flows and breccias. Our examinations show that many of the Nogal Peak breccias are not simple flow breccias but include combinations of flow breccia, volcanic debris flow and scoria-rich (possibly near vent) breccia from a variety of sources.

All Walker Formation volcanic rocks show some degree of alteration ranging from low-temperature argillic in the west and northwest of the quadrangle to propylitic in the core. Along margins of larger intrusions, the volcanics are metamorphosed to hornfels displaying calc-silicate, alumino-silicate, and minor high-temperature acidic alteration. Because of alteration and the general lack of dateable phases, there are few reliable dates published on the Sierra Blanca Volcanics (see Table 1 of Allen and Foord, 1991). West of the quadrangle, an essexite (feldspathoidal gabbro) dike cutting Eocene Cub Mountain Formation is dated by K-Ar at 36.5 Ma. A trachyphonolite flow south of the quad has fission track and K-Ar dates of 28.2 and 29.3 Ma, respectively but these ages are considered to be too young due to alteration. Lava from the Church Mountain Latite north of the quad, which may be roughly similar in age to Nogal Peak lavas, is dated by K-Ar at 31.8 Ma. Sanidine in trachyte lava from the Godfrey Hills, west of the quadrangle has a K-Ar date of 26.1 Ma. More recently, Kelley et al. (2010), also working in the Godfrey Hills, have obtained $^{40/39}$Ar dates of 28.59 ± 0.05 Ma and 28.67 ±0.07 Ma, on sanidine separated from a lava and underlying ignimbrite (Palisades Tuff), respectively. As of this writing, several additional samples of lavas and dikes in the Sierra Blanca Volcanics have been submitted

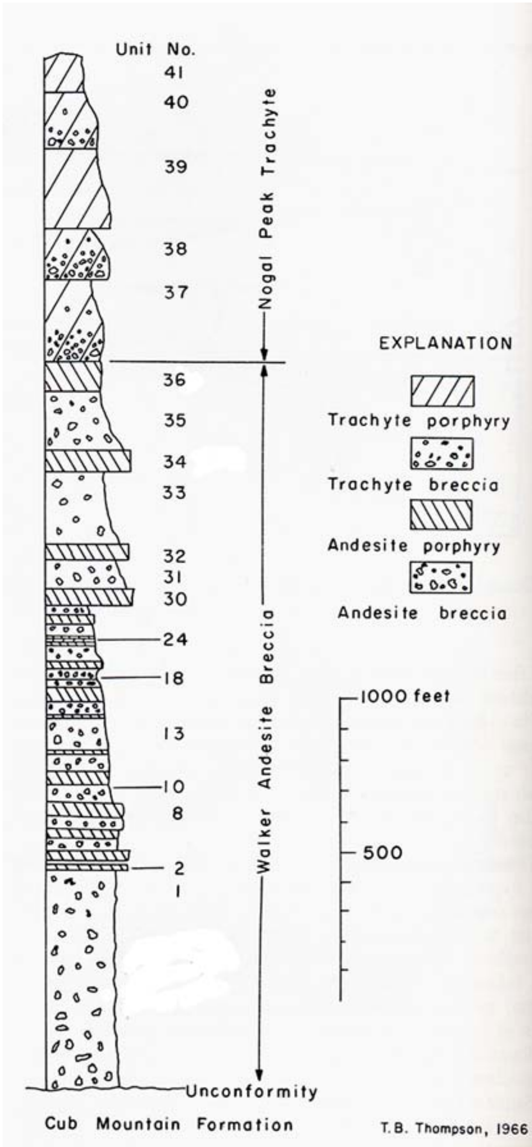

Figure 6: Graphic section of the Walker "Andesite Breccia" and Nogal Peak Trachyte. This section is actually a composite of two sections (See fig 2, Thompson, 1973 for locations), one NNW of Nogal Peak and a second further to the west. The west section line is redrawn on our geologic map and roughly corresponds to units 1 through 33. Since this section was published, Cub Mountain Formation sediments beneath the lowest breccia were renamed the Sanders Canyon Formation (Cather, 1991).

for $^{40/39}$Ar dating but we have not yet received results. For now, the Sierra Blanca Volcanics are bracketed between about 36.5 and 26 Ma.

Walker Formation breccias (Twb): These volcanic breccias are best exposed and least altered in the west and northwest portions of the quadrangle. They primarily consist of a wide variety of gray, purple gray and reddish gray volcanic debris flows, lava flow breccias, dome collapse breccias and vent breccias (agglutinate, scoria and spatter mixed with driblet flows) interlayered with minor quantities of fine- to coarse-bedded tuffs, fluvial deposits and relatively thin lavas. Thicker subunits of breccia near the bottom of the unit may exceed 40 m and be nearly monolithologic suggesting they are thick flow breccias (Figure 7). Some angular, clast supported

Figure 7: Photo of 40 m thick lava flow breccia (part of unit Twb) in bottom of lower McIver Canyon, near west edge of quadrangle. Chemistry shows this breccia is composed of basaltic trachyandesite.

Figure 8: Photo of hydrothermally altered debris flow breccia (Twb) on top of ridge between Argentina and Bonito canyons. This deposit (≤25 m thick) appears to be a channel fill in an ancient volcanic highland.

breccias are composed of lavas that contain 2-14% of 2-7mm pyroxene phenocrysts with subordinate plagioclase. Some debris flows contain a variety of pyroxene-phyric clasts that are generally angular to subrounded and are usually matrix supported. Breccia units thin up section and to the south and east, as lava flows become more voluminous. The thickness of the principal breccia sequence in the lower Walker exceeds 350 m (1150 ft) in lower Spring Canyon and western Daugherty Ridge. Bedding where measureable generally dips to the east. Thin section examinations and chemical analyses of a few breccia clasts indicate that the magma sources were mostly alkali basalt to basaltic trachyandesite. Many breccias higher up in the section appear to be heterolithologic debris flows filling shallow channels (Figure 8).

Walker Formation lavas: As originally mapped, Walker lava flows in the Nogal Peak quad show a wide range in composition and mineralogy. Based on the chemical criteria of La Bas et al. (1986), they consist of alkali basalt, trachybasalt, basaltic trachyandesite, trachyandesite, and trachydacite (Fig. 9). Sierra Blanca intrusive rocks have similar alkali-silica contents (Fig. 10). Previously, Thompson called the volcanic rocks "andesite and trachyte" while Moore et al. (1988; 1991) called some of the mafic lavas in the southern part of the quad "trachyphonolite" and "phonotephrite" due to their contents of minor interstial nepheline.

In our field area, thin section and geochemical examinations could not identify extremely alkalic lavas in the Nogal Peak quadrangle (i.e., no tephrite, trachyphonolite, etc.). Typical phenocrysts in the mafic lavas are olivine, plagioclase and clinopyroxene. Up section the lavas generally become more silicic containing, in addition to those minerals mentioned previously, biotite, hornblende, and sanidine. Generally speaking individual mafic flows are relatively thin (usually ≤10 m thick) although packages of related flows may exceed 40 m thick. More evolved flows are typically thicker; for example the Spring Canyon trachydacite (formerly Spring Canyon andesite, Thompson, 1972) is about 520 feet (160 m) thick near its vent area and is typically ≥30 m thick elsewhere.

Clear subdivision of the relatively unaltered mafic flows in the Walker "Andesite" Breccia is only possible west of and along the crest of the long north-trending ridge in the NW part of the quadrangle. The Crest Trail (Trail 29) conveniently follows this ridge. Detailed mapping and additional laboratory studies allow us to subdivide some of the lower to middle lavas of the Walker into several additional informal units starting from the bottom up. Erosion has probably removed much of what was once the upper Walker in Nogal Peak quadrangle. Extreme hydrothermal alteration and structural deformation prevents subdivision of most Walker lavas to the east and south, particularly near the margins of the three large stocks.

Bottom unit (Twl): These flows correspond with units 2 to 23 (Fig. 6, Thompson, 1973) north of Elder Canyon. In this area unit 2 is alkali basalt (Appendix 1). The lowermost flows are purple to reddish brown lavas that are generally crystal-rich. They have abundant plagioclase phenocrysts that grade from pyroxene-phyric to plagioclase-phyric. These reddish brown crystal-rich lavas are overlain by more mafic finer-grained lavas that are interbedded with red, matrix supported, heterolithologic debris flows containing rounded clasts. To the south in the area of Brush Canyon, the lowermost flow is also alkali basalt (Appendix 1). Up section, a variety of lava types can be found that include olivine basalt, pyroxene- and plagioclase-phyric mafic lavas, hornblende trachyandesite and trachydacite flows, and a variety of interbedded breccias. The bottom part of Twl pinches out against thick accumulations of Walker breccias (Twb) on the west edge of the quadrangle, north of Brush Canyon and south of Spring Canyon.

Plagioclase porphyritic basaltic trachyandesite (Twtx): We have mapped several flows and/or flow units having large jackstraw phenocrysts ("turkey tracks," Fig. 11) of plagioclase with

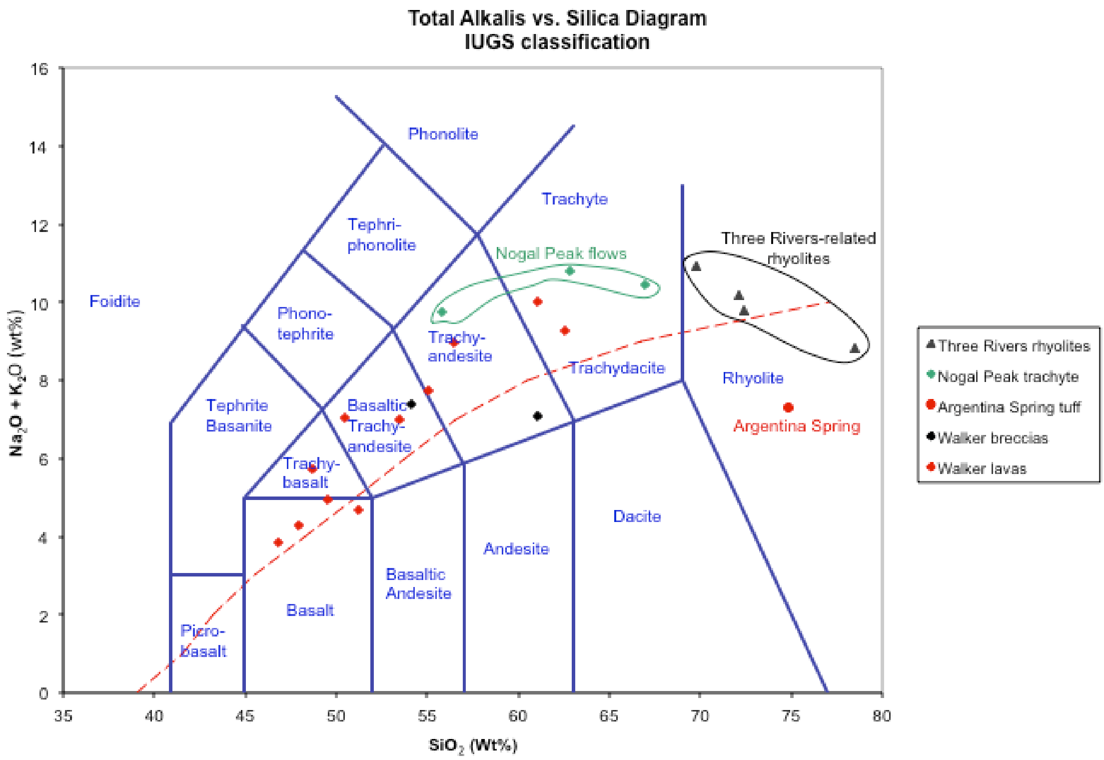

Figure 9: Alkali-silica plot of La Bas et al. (1986) for the Sierra Blanca volcanic rocks listed in Appendix 1. Red dashed line separates alkaline and sub-alkaline rock suites.

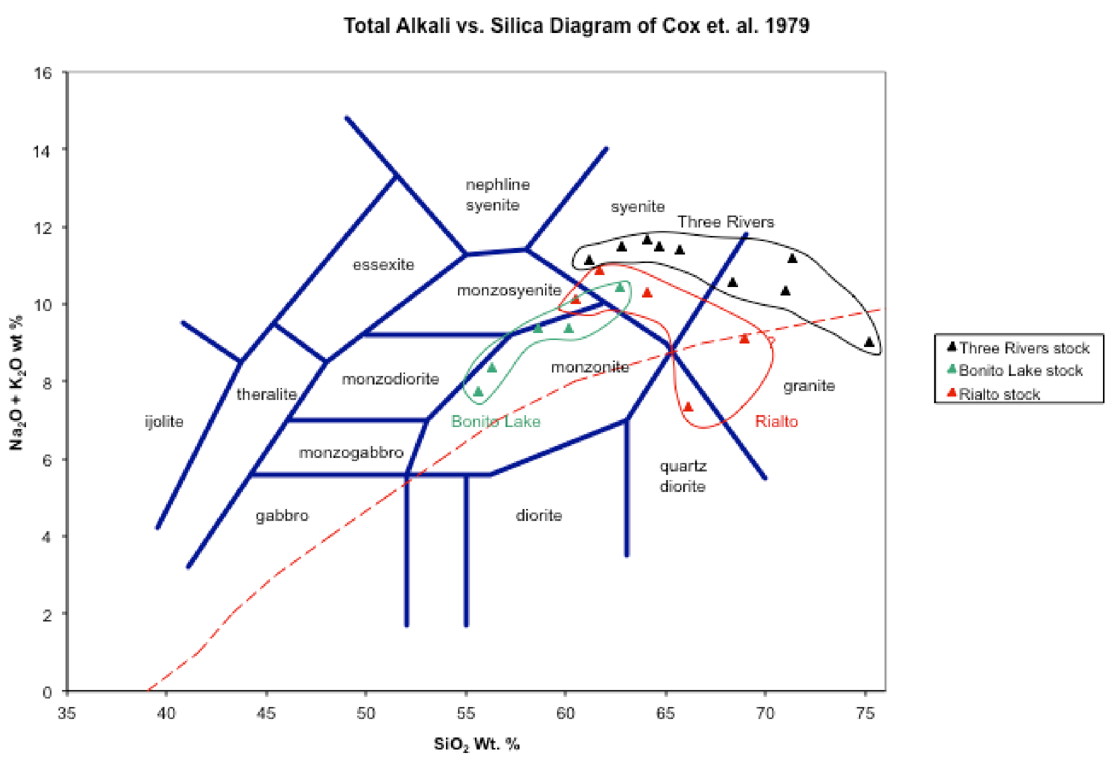

Figure 10: Alkali-silica plot of Cox et al., 1979 for Sierra Blanca intrusive rocks (Appendix 1); red dashed line same as in Fig. 9.

Figure 11: Example of "turkey track" basaltic trachyandesite (Twtx) exposed at confluence of Argentina and Little Argentina Creeks. Plagioclase phenocrysts may be two or three times larger in some flows.

Figure 12: Example of "spotted" trachybasalt from cliffs just south of upper Spring Canyon. The spots, which are most obvious on weathered surfaces, are small clusters of plagioclase crystals aligned parallel to the horizontal flow foliation.

Figure 13: Photo looking west toward Tularosa Basin shows ledge-forming Spring Canyon trachydacite (Twsc). Note distinctive flow foliation. Tiny biotite phenocrysts are difficult to find with hand lens.

Figure 14: Dark gray streaks of collapsed pumice (fiamme) in devitrified Argentina Spring rhyolite tuff (Twas). This unit forms a thick "flow" in upper ridges of the NW part of the quadrangle.

subordinate olivine and clinopyroxene. The unit appears to have multiple eruptive centers and textures vary from flow to flow, location to location. These lavas form a partial stratigraphic marker within the high ridges on the west and NW sides of the quadrangle but their stratigraphic position elsewhere, such as in Nogal Canyon, is unclear. Chemistry (Appendix 1) shows the flows on the west are basaltic trachyandesite and they roughly correspond with unit 24 of Fig. 6.

Spotted trachybasalt (in unit Twl): Multiple flows of fine- to medium-grained trachybasalt (Appendix 1) containing olivine, plagioclase, and clinopyroxene overlie turkey track flows north of Barber Ridge and extend north to at least Daugherty Ridge. Weathered horizontal surfaces are "spotted" with tiny clusters of aligned plagioclase (Fig. 12). Flows roughly correspond with unit 30 (Fig. 6) but are incorrectly shown as unit 34 by Thompson (1973) and probably correlate with uppermost flows of trachybasalt (unit Twtb) mapped elsewhere.

Spring Canyon trachydacite (Twsc): This unit consists of a thick, light colored, strongly foliated, ledge-forming, aphyric lava (Fig. 13) that contains tiny oxidized (rust red to bronze) biotite often too altered to see. Previously called "andesite," the analysis in Appendix 1 shows it is trachydacite. This flow extends for several kilometers south of Spring Canyon and is incorrectly shown above ignimbrite (Twas, unit 34) on the geologic map of Thompson (1973).

Argentina Spring tuff (Twas): This ash-flow tuff corresponds to unit 34 (Thompson, 1973, Figure 6) in the general area between Nogal Peak and the head of Spring Canyon. The tuff is not found south of this canyon. Although it superficially looks like a thick lava flow, it is actually a densely welded rheomorphic ignimbrite (see Branney et al., 2008, p. 297-300) containing collapsed fiamme and lithic fragments in a dark glassy to gray devitrified groundmass (Fig. 14). Phenocrysts are primarily sanidine and biotite. Chemical analysis shows it is rhyolite with lower alkali content than most Walker volcanics (Fig. 10). Thompson (1966, 1972, 1973) did not recognize this unit as ignimbrite and incorrectly shows it beneath Spring Canyon trachydacite (Twsc).

Above Spring Canyon trachydacite and Argentina Spring tuff, the ridge on the northwest side of the quadrangle contains several types of interfingering lava flows of basaltic trachyandesite to trachydacite composition (Appendix 1) that are subdivided on the map, correlation chart and rock descriptions. None of these units are very extensive but most have distinctive field characteristics and mineralogy.

Nogal Peak Trachyte (Tnt)

Thompson (1964) assigned a formation to the distinctive stack of five flows and interbedded breccias forming Nogal Peak (cover photo). These flows overlie Walker lavas and breccias (Fig. 6) but a thin flow of Nogal Peak trachydacite underlies Walker alkali basalt on Hill 9500 SSW of Nogal Peak. Three analyses (Appendix 1; Fig. 9) show that the unit varies from trachyandesite to trachydacite. The flows are porphyritic to slightly porphyritic. Mafic flows contain plagioclase, clinopyroxene, hornblende and biotite whereas the most evolved flow contains sanidine, plagioclase and biotite. All flows display some propylitic alteration and silicification making them impossible to date. Based on chemistry and spatial proximity, units in this formation are probably extrusive equivalents of some syenites in the Rialto stock.

Post-Walker Rhyolites (Tcp, Tep, Tog)

After Thompson published his work on the Sierra Blanca Volcanics, Black (1977) described a plug and dikes on the ridge west of Big Bear Canyon, which he named Cone Peak rhyolite. This unit, a rhyolitic dike swarm NE of the Three Rivers stock, and an additional rhyolite plug at Elk

Point were mentioned by Segerstrom et al. (1979, p. 14). We dated a NE-trending rhyolite dike that cuts the east margin of the Three Rivers stock at 25.4 ± 0.8 Ma. In addition, we identified an aphyric rhyolitic flow on the east margin of the quadrangle (Oak Grove rhyolite) that may be related to the same pulse of volcanism as the dikes. All of these rhyolitic manifestations occur on or near the margin of the Three Rivers stock and overlie or cut typical Walker breccias and lava flows; thus, these eruptions are unique from the Walker and probably related to the stock.

Cone Peak rhyolite (Tcp): This unit was first described by Black (1977) as a small plug and associated dikes of biotite rhyolite. We found many more small dikes and additional small, plug-like bodies flanking the northwest side of the Three Rivers stock. All samples show variable amounts of hydrothermal alteration and silicification. Chemical analyses presented by Black show extreme leaching of alkali components but our analysis of a dike from the east side of Big Bear Creek shows considerably less alteration (Appendix 1; Fig. 9). Because of proximity and rhyolitic chemistry, it is probably derived from late-stage alkali granite melts in the Three Rivers stock. Black did not elevate Cone Peak rhyolite to formal stratigraphic status, nor do we.

Elk Point rhyolite (Tep): This plug consists of highly porphyritic, flow-banded rhyolite with large Kspar phenocrysts. "Fresh" material is found only in the northwest part of the plug; most of it is highly silicified and brecciated (Segerstrom et al., 1979). Elk Point rhyolite lies in fault contact with the Three Rivers stock and is chemically similar to alkali granites in the stock (Figs. 9 and 10).

Oak Grove rhyolite (Tog): This rhyolite is extremely aphyric and flow-banded with rare quartz microphenocrysts. The lava unconformably overlies mafic Walker breccias on the east edge of the quadrangle and is chemically similar to alkali granites of the Three Rivers stock (Figs. 9 and 10). A nearby porphyritic flow of probable trachydacite composition occupies the same stratigraphic position but, lacking chemistry, we have placed it within the uppermost Walker lava package.

Intrusive Rocks

Essexite Plug (Tex): A small plug of essexite (feldspathoidal gabbro, Williams et al., 1954) intrudes lower to middle Sierra Blanca mafic lavas and breccias at the head of Eagle Creek in the southeast corner of the quadrangle (Moore et al., 1988). The rock is medium- to course-grained containing large phenocrysts of Kspar in a matrix of plagioclase, clinopyroxene, olivine, minor biotite and interstitial nepheline. Propylitic alteration is pervasive but the unit has a K-Ar date of 32.8 ± 1.2 Ma on altered plagioclase and biotite. We consider this to be a minimum age. A recently obtained whole rock $Ar^{40/39}$ date is 30.0 ± 0.5 Ma, which we consider to be a date on alteration resulting from intrusion of the adjacent Three Rivers stock.

Syenite, Monzonite and Diorite Plugs (Tspg, Tm, Tgd, Tdbp): A north-trending trio of small syenite and syenite breccia plugs lies along the ridge crest between Aspen and Little Bear canyons. The northern body is rather course-grained. A small plug of monzonite intrudes middle Sierra Blanca volcanics in the southwest corner of the quadrangle (Moore et al., 1988). Primary minerals consist of plagioclase, clinopyroxene and minor Kspar and the rock displays propylitic alteration. The plug is not dated but is overlain by a small roof pendant of trachybasalt and is cut by NW-trending syenite dikes. A smaller, hydrothermally altered plug with associated radiating dikes intrudes middle Walker lavas at Grizzly Peak, just north of Bonito Creek (Black, 1977). Petrographically, the plug has a mineral composition closer to diorite. Similar dikes of diorite (or monzonite) are apparently cut by intrusions of the Rialto Stock, suggesting that the latter body is younger. West of the plug, a small circular area of propylitically-altered, monzonite intrusion breccia is found in a small arm of Washington Creek (Black, 1977). One tiny plug of altered monzonite or diorite that contains small cavities filled with poor-quality amethyst, is located in a saddle just SW of Nogal Peak, Finally, we found a large plug of diorite porphyry in the upper reaches of Dark Betty Canyon.

Rialto Stock (Trm, Trm2): The Rialto stock (Thompson, 1972; Allen and Foord, 1991; Moore et al., 1991) is an irregular 3-km^2-body with a north-south elongation that straddles the many arms of Tanbark Canyon. Petrographically, the stock is composed of medium- to fine-grained “monzonitic” rocks containing plagioclase, clinopyroxene, hornblende, biotite, minor Kspar and quartz. We have mapped two phases of the stock: Phase 1 is the initial and slightly dominant phase comprising roughly 60% of the unit. Phase 2 intrudes Phase 1 and is composed of NNE-trending lenticular bodies to broad dikes that are usually finer-grained and contain substantially more biotite, Kspar and quartz. These dikes probably merge into a larger intrusive body at depth. We do not recognize the six late intrusive phases of Gander (1982) within Nogal Peak quadrangle. The Rialto stock intrudes middle (?) Sierra Blanca volcanics; contacts are usually high-angle, sometimes faulted. A single K-Ar date on hornblende and biotite from Phase 1 (?) “monzonite” is 31.4 ± 1.3 Ma (Moore et al., 1991). We have submitted additional samples of the stock for $^{40/39}$Ar and U-Pb dating.

According the analyses presented in Appendix 1 and the naming schemes of Cox et al. (1979) and De La Roche et al. (1980), the Rialto stock, Phase 1 is mostly syenite and the Phase 2 unit is quartz diorite (or “tonalite,” Williams et al., 1954). Most specimens display some combination of propylitic, phyllic and argillic alteration with secondary quartz and occasionally epidote in veins and fractures. Propylitic alteration is more pervasive around the margins of the stock whereas phyllic alteration later modified to argillic alteration is most common within the stock interior (see also Thompson, 1973). Numerous intermediate-composition dikes of varying texture cut the stock, many too altered to clearly identify.

A medium-grained syenite dike roughly 1 km long and ≥60 m wide is exposed in the ridge south of Bonito Creek and the Rialto stock. Much of this dike is quite fresh and has been submitted for $^{40/39}$Ar dating. Chemically, this dike is similar to Phase 1 of the Rialto stock.

Bonito Lake Stock (Tbs): This intrusive body covers an area of 19 km^2, much of it exposed in the Angus quadrangle east of Nogal Peak quad (Rawling, 2004b). Our examinations show it to be a single large body of medium- to coarse-grained monzonite, syenite and syenite porphyry containing plagioclase, hornblende, biotite, Kspar, minor clinopyroxene and minor interstial quartz (see also Thompson, 1972; Allen and Foord, 1991). Using representative analyses from Constantopoulos (2007; Appendix 1) and the schemes of Cox et al. (1979) and De La Roche et al. (1980), the rocks of the Bonito Lake stock are appropriately named syenite to syenodiorite (the latter is equivalent to most rocks called monzonite, Williams et al., 1954). Coarser grained, quartz-free syenodiorite is found near the west margin of the unit.

The stock is intruded by numerous dikes of diorite to aplite from many meters to a few centimeters wide, respectively. Diorite and syenodiorite dikes contain virtually no quartz and more clinopyroxene. Aplite dikes contain fine-grained quartz, Kspar, and minor biotite in a sugary matrix. Late-stage quartz has graphic texture. Black (1977, plate 2) measured the trends of roughly 100 joints in the Bonito Lake stock, which have pronounced NNE trends in the north part of the body but NE and NW trends in the south part. Most specimens display various amounts of propylitic alteration. This is overprinted by later argillic alteration. A single K-Ar date on biotite of 26.6 ± 1.4 Ma is reported by Thompson (1972) for a specimen from an unidentified location. We have submitted additional samples of the stock for $^{40/39}$Ar and U-Pb dating.

Contacts between the Bonito Lake stock and intruded Sierra Blanca volcanics vary from near vertical to horizontal. In the NE part of the quad, between Littleton and Kraut canyons, an eroded slab of altered, hornfelsed volcanics forms a roof pendant over the syenite.

Three Rivers Stock (several units): The Three Rivers stock is considerably larger and more complex than the previously described intrusive bodies, covering an area of roughly 75 km^2. It is also compositionally more evolved consisting of distinct masses of syenite (Ttcs, Ttsag, etc.) to alkali granite (Ttag), although Thompson (1973) calls it “principally lueco-syenite porphyry.” Giles and Thompson (1972) described three subunits, whereas Moore et al. (1988) described five. However, one of their five (sodalite-nepheline syenite) occurs as a small plug south of the quadrangle. We have mapped five major subunits including substantial amounts of alkali granite. Contacts between subunits can be relatively sharp to gradational; most contacts are relatively high-angle. In addition, separate bodies of syenite and alkali granite have varying textures and compositions such that some of the subunits and their boundaries are slightly subjective, both in terms of mapping and chemistry. Cross-cutting relations among units suggest that the alkali granites post-date most of the syenitic rocks. Many of the syenites contain xenoliths of fine-grained igneous rocks that we have not studied in any detail (Fig. 15).

Figure 15: Photo of coarse-grained, aegirine-arfvedsonite syenite (Ttcs) hosting xenolith of fine-grained igneous rock. Xenoliths ≤20 cm long are sporadically distributed in many Three Rivers intrusive bodies.

Giles and Thompson (1972) describe one of their Three Rivers units as “nordmarkite” (quartz syenite porphyry, Williams et al., 1954), which is unit Ttsp on our map. This unit typically has a gray very fine-grained groundmass of alkali feldspar, minor quartz, very minor plagioclase, aegirine, arfvedsonite and biotite engulfing large pink anorthoclase phenocrysts (≤3 cm long) rimmed with sanidine and minor plagioclase. The proportion of pink phenocrysts is highly variable, however, being more abundant along the top and interior of the stock than on the stock margins. Along NM highway 532 the contact between nordmarkite and contrasting white coarse-grained quartz syenite (our unit Tts) is quite sharp (Moore et al., 1988) providing a good basis for distinguishing this unit from other syenites. Elsewhere, the field distinction between nordmarkite and generic syenite porphyry as shown on the map by Giles and Thompson (1972) is difficult to apply; thus, our maps differ in detail.

Using chemical analyses in Appendix 1 and the diagrams of Cox et al. (1979) and De La Roche (1980), the Three Rivers stock varies from syenite to alkali granite. Chemically, the nordmarkite of Giles and Thompson (1972) resembles the other syenites. There is considerable variation among the alkali granites. Most samples have similar amounts of K_2O and Na_2O but one sample contains 10.3 wt-% K_2O and only 0.9 wt-% Na_2O. In this respect, the K_2O-rich granites resemble the K_2O-rich rhyolite at Oak Grove on the west margin of the quadrangle.

Giles and Thompson report a K-Ar date of 25.8 ± 1.1 Ma on anorthoclase phenocrysts from "early syenite porphyry" (our unit Tts) near the contact with nordmarkite. Allen and Foord (Table 1, 1991) list four K-Ar dates on syenite and quartz syenite ranging from 29.9 to 28.1 Ma and a single Rb-Sr date on alkali granite of 26.7 Ma. Because the syenitic rocks supposedly predate the alkali granites, the date of Giles and Thompson is probably too young. A quartz syenite that we sampled from the western contact of the body has an $Ar^{40/39}$ age of 28.24 ± 0.19 Ma. An alkali granite sample in Ski Apache has an $Ar^{40/39}$ age of 27.0 ± 2.0 Ma. At this point in our investigation, more samples are being dated; thus it is premature to completely evaluate all these ages.

Emplacement Mechanisms: Giles and Thompson (1972) identified several stoped blocks of Walker volcanic rocks within the Three Rivers stock. During our mapping, we found many more of these blocks ranging from only a few meters to one 700 x 250 m block exposed in Ski Apache (Fig. 16). Many, but certainly not all, blocks occur along contacts between different intrusive

Figure 16: Stoped block of hornfelsed and silicified Walker lava (Twl) exposed at Ski Apache. Traceable across several runs, this 700-m-long block is surrounded by syenite (Tts) and alkali granite (Ttag).

phases or near the stock boundary. In all cases, these blocks are hornfelsed and silicified but their original volcanic textures remain. Several roof pendants of Walker volcanics also occur on top of the stock. The most impressive is the continuous pendant capping the west margin of the stock in upper Three Rivers and Dry Creek canyons, but other large pendants occur south of Elk Point and the Great Western Mine. The latter two are deformed and faulted along the stock margin. Vertical contacts of the stock with Walker wall rock are difficult to find even though the contact is easy to map. One such location occurs in the bed of lower Dry Creek where quartz syenite cuts Walker basalt lava. Although hornfelsed, the lava still retains its texture of plagioclase, augite and olivine.

Paterson et al. (1991) discuss pluton emplacement mechanisms at some length. Many controversies remain on the subject. Giles and Thompson (1972) proposed a three-component, "concentric shell" model for emplacement of the stock, which we think is too simplistic. To us, the stock shows strong evidence for a) initial, non-concentric injections of several chemically similar syenite melts, b) concurrent stoping of country rocks during each injection, c) later intrusion of more centralized but chemically variable alkali granite melts, and d) final doming and faulting of the stock roof, which is easily observed along some stock margins (Paterson et al., 1991, fig. 1).

Dikes: Abundant dikes of various compositions, mineralogy, ages, widths, and orientations cut the Sierra Blanca volcanics and all intrusive bodies with the exception of the essexite plug. A full study of the dikes is far beyond the scope of this mapping project. We did not analyze many dikes; thus, our descriptions are based primarily on field, hand lens, and a few thin section examinations. Most of the dikes are mafic to intermediate in composition, although they cover a full range of trachybasalt to alkali rhyolite compositions. Some dikes are courser grained and fully crystallized, appearing to be gabbro, diorite, monzonite and syenite. Most dikes show some degree of argillic to propylitic alteration and are not suitable for dating.

The northeast-trending mafic dike swarms described by Elston (1991), Moore et al. (1988) and Rawling (2004b) are not found on Nogal Peak quadrangle. Those that occur to the east are termed a dike and sill complex of diorite to latite. This unit underlies the Bonito Lake stock and Sierra Blanca Volcanics (?) but cuts the Eocene Cub Mountain Formation (Rawling, 2004b). Further northeast, the dike swarm consists of a wide variety of alkali diabase with subordinate latite, phonolite and rhyolite that intrude Cretaceous rocks (Elston, 1991). South of Nogal Peak quadrangle, a spectacular zone of alkali gabbro to monzogabbro dikes comprise up to 70% of exposed rocks in the Black Mountain area (Moore et al., 1988). This swarm cuts Cretaceous rocks, underlies the Sierra Blanca Volcanics, trends beneath Sierra Blanca Peak, and is thought to be about 38.5 Ma (Moore et al., 1991).

IGNEOUS GEOCHEMISTRY AND PETROGRAPHY

We obtained 26 chemical analyses of volcanic and intrusive rocks in the Nogal Peak quadrangle and combined them with selected analyses from previous studies to determine up-to-date rock names and ranges in composition (Appendix 1; Figures 9 and 10). First we want to reiterate that most volcanic rocks in the quadrangle are best classified as slightly alkaline to alkaline in chemistry and are best identified by names such as alkali basalt, trachybasalt (hawaiite), basaltic trachyandesite, etc. Rocks mapped as Nogal Peak Trachyte are substantially enriched in Na_2O + K_2O, yet these rocks are still classified as trachyandesite to trachydacite in the scheme of La Bas et al. (1986) or as benmoreite to trachyte in the slightly older scheme of Cox et al. (1979). As such, the Sierra Blanca Volcanics erupted in the Nogal Peak quadrangle fall within typical chemical compositions expected for "continental rift zone magmatism" as defined by Wilson (1989) and resemble the chemistry and range of compositions displayed at the younger Mt. Taylor composite volcano (3.6 to 1.3 Myr) located west of Albuquerque and the Rio Grande rift (Perry et al., 1990; Goff et al., 2010; Fellah, 2011). Additionally, the primary mineralogy of most volcanic rocks occurring in the quadrangle resembles those in comparable rocks from other continental rift zone magmatic suites (Wilson, 1989, p. 340; Perry et al., 1990).

Rocks from the Nogal Peak area predominantly are metaluminous to slightly peraluminous (Shand, 1943), alkaline (Le Bas et al., 1986), and most have chemical compositions typical of A-type granites (Whalen et al., 1987) and "within plate granites" (Pearce et al., 1984), which is characteristic of igneous rocks found in the Rocky Mountain alkaline belt (Fig. 17). Our samples have light-REE enriched, chondrite-normalized patterns, typical of alkaline igneous rocks (Fig. 18). Nogal Peak area rocks are similar in chemical composition to other alkaline igneous rocks in the Lincoln County porphyry belt (Allen and Foord, 1991; Constantopoulos, 2007) and other alkaline igneous rocks in the Rocky Mountain alkaline belt (data compiled by V.T. McLemore).

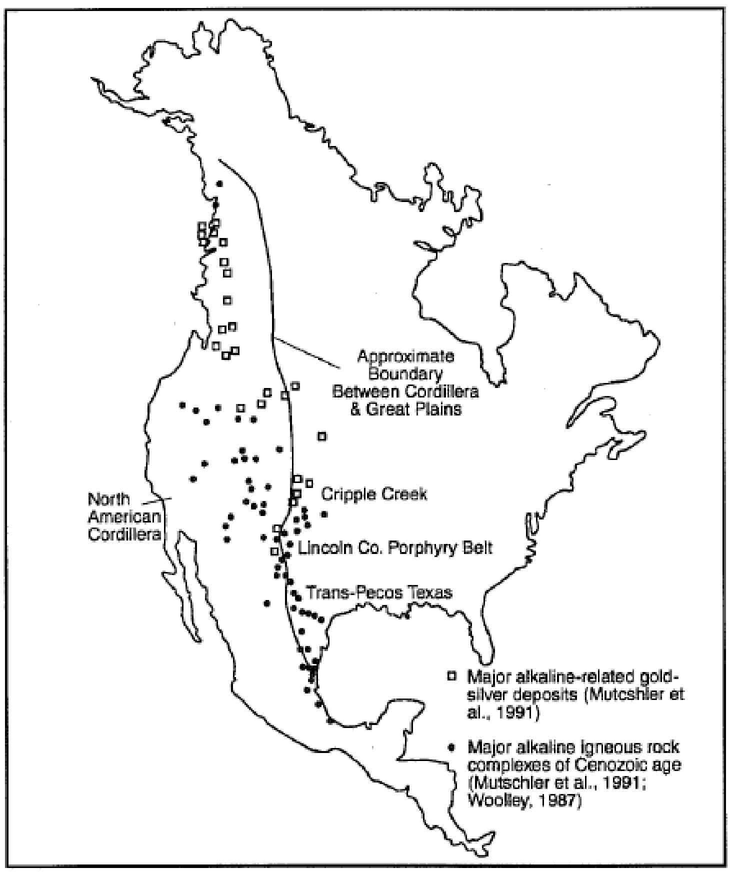

Fig. 17: Alkaline igneous rocks of the North American Cordillera-Great Plains belt (Woolley, 1987; Mutschler et al., 1991; McLemore, 1996). The LCPB is just east of the boundary between the two types.

Only a very few volcanic rocks in the southeast and southwest corners of the quadrangle (may) qualify as exceptionally alkaline: the essexite plug and a couple of trachyphonolite and related flows. Unfortunately, these rocks occur on the restricted lands of the Mescalero Apache Reservation; thus, we did not collect and study them during our investigations. Although discussed previously by Moore et al. (1988; 1991), the authors did not publish any chemical

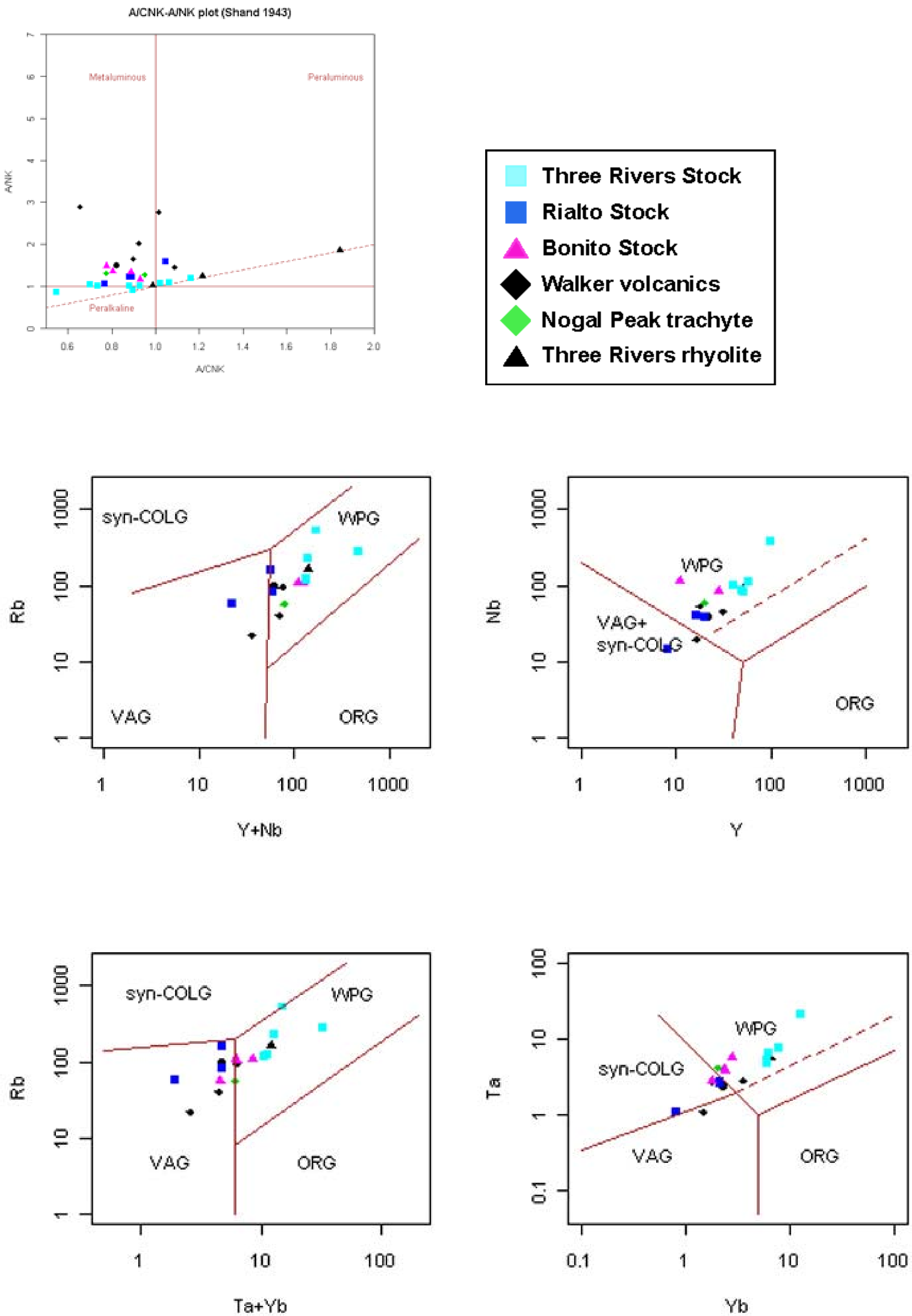

Fig. 18: Chemical plots of samples from Nogal Peak quadrangle (Shand, 1943; Pearce et al., 1984); syn-COLG = syn-collisional; WPG = within-plate; VAG = volcanic-arc; ORG = orogenic.

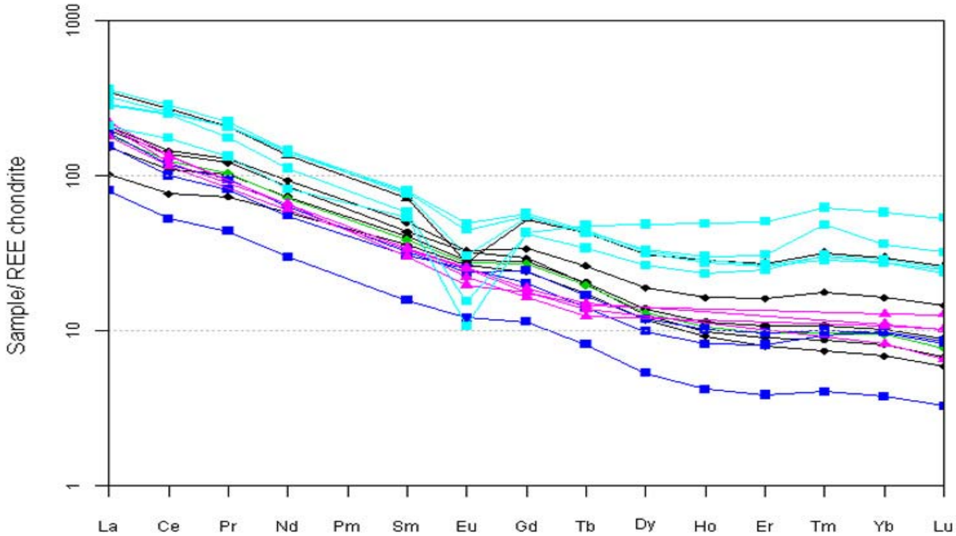

Fig. 19: Chondrite normalized REE plot for Nogal Peak rocks (Chondrite values from Nakamura (1974). Most rocks have "flat" REE patterns except the alkali granites from Three Rivers stock. These have negative Eu anomalies indicating plagioclase fractionation.

analyses of these fascinating rocks. Because of their spatial distribution, these rocks apparently erupted from a more alkali-rich volcanic center located south of the Nogal Peak quadrangle.

Chemically, it is probably no surprise that the intrusive rocks from the Rialto, Bonito Lake, and Three Rivers stocks have compositions resembling the more silicic members of the Sierra Blanca Volcanics (Fig. 9). The stocks mostly contain rocks that are >54 % SiO_2 and are alkaline to slightly alkaline. Gabbroic rocks that are equivalents to alkali basalts and trachybasalts may occur at depth or may be found in some of the many dikes and sills. Analyzed stock rocks fall into syenodiorite (monzonite), syenite, and alkali granite nomenclature fields. One analysis of quartz diorite from the Rialto stock is significantly different but it may be affected by silica addition due to hydrothermal alteration. Petrographically, the intrusives in the stocks contain the minerals expected from such rocks (see Williams et al., 1954, p. 106-115). Only the quartz-bearing syenites and alkali granites of the Three Rivers stock have slightly unusual mineralogy (aegirine and arfvedsonite), but these minerals are common in such rocks (Williams et al., 1954).

FAULT TRENDS AND UPLIFT

A summary of pre-Eocene development of the Nogal Peak region is given in Moore et al., 1991. The Sierra Blanca igneous complex is on the NE end of the northeast-trending New Mexico Structural Zone defined by McLemore (2008). Most of the igneous rocks were emplaced before 26 Ma; there are east and NE-trending structural elements preserved in the Nogal Peak quadrangle and surrounding areas. These include many of the dikes, especially the mafic dike swarms shown by Moore et al. (1988; 1991) and Rawling (2004) and the Phase 2 monzonitic dikes in the Rialto Stock. Many of the faults and mineralized veins, and the general elongation displayed by the Three Rivers stock also have a NE trend. Several prominent E-W trending faults such as those along Bonito Creek and the Bluefront Canyon developed during pluton emplacement. These are associated with several E-W trending mineralized veins and breccia zones.

Sometime around 25 Ma, the region around the quadrangle was subjected to development of the north-trending Rio Grande rift. This structural trend is reflected by later north-trending faults in the quadrangle and the pronounced north-trending boundary between the Sierra Blanca and Tularosa Basin. Uplift of the Sierra Blanca since 25 Ma has caused deep erosion that has removed most of the upper and middle Sierra Blanca volcanics, unroofed the tops of the various intrusive bodies, and exposed the veins and other mineralized zones in the quadrangle. Presently, the boundary between the Sierra Blanca and the Tularosa Basin coincides with a major structural and thermal transition in the Earth's crust, the boundary between the Rio Grande rift and the eastern Great Plains tectonic provinces (Reiter and Chamberlin, 2011).

NOGAL PEAK MINING DISTRICT

The Nogal mining district surrounds the town of Nogal (originally called Dry Gulch and then Parsons) in parts of T8, 9, 10, 11S, R11, 12, 13E in southern Lincoln County and includes several small mining camps or subdistricts (Figure 20; as defined by Griswold, 1959; File and Northrop, 1966): Vera Cruz, Parsons (Rialto), Bonito, Nogal, and Alto (Cedar Creek/Eagle Creek)). The district covers portions of the Nogal Peak, Angus, Church Mountain, and Nogal topographic quadrangles. Four types of mineral deposits found in the Nogal district include placer gold, Ag-Pb-Zn (±Au) and low Ag-Au fissure veins, gold breccia pipe deposits, and porphyry molybdenum-copper deposits. Hydrothermal alteration is extensive in the mining district.

The Nogal mining district is part of the Rocky Mountain alkaline belt, a north-south belt of alkaline-igneous rocks and crustal thickening roughly coinciding with the Great Plains physiographic margin along the Basin and Range (Rio Grande rift), and the Rocky Mountains physiographic province that is associated with relatively large quantities of gold, fluorite, rare-earth elements, uranium, and other elements. This belt continues northward into Canada and southward into Mexico (Figure 17; Mutschler et al., 1985, 1991; Bonham, 1988; Richards, 1995; McLemore, 1996). In Lincoln County, this belt is locally called the Lincoln County porphyry belt (Thompson, 1972, 1991c; Woodward, 1991; Fulp and Wooward, 1991a; Allen and Foord, 1991; McLemore and Zimmerer, 2009).

Mining and Exploration History

Placer gold was discovered in Dry Gulch about 1865. The oldest mining claim was in 1863 (Seagerstrom et al., 1979). By 1868, veins at the American mine were found. However, the area was part of the Mescalero Indian Reservation until 1882, after which exploration and mining began in earnest (Jones, 1904; Lindgren et al., 1910; Wells and Wootton, 1940). The Parsons mine was claimed in 1884 and by 1918, 75,000 short tons of low-grade ore were produced from that mine (Griswold, 1959, 1964; Griswold and Missaghi, 1964). In 1902-1910, the Parsons Mining Co. consolidated many of the claims near the mine.

The Rialto (Fulmer) claims were first located for gold in 1894; molybdenum became of interest in the 1950s. In 1957, Climax Molybdenum Co. drilled in the Rialto (Fulmer) area and found the grade averaged 0.2% Mo (Griswold, 1959; Griswold and Missaghi, 1964; Seagerstrom et al., 1979). Several companies explored and drilled in the area in the late 1970s and 1980s. Pioneer Metals Corp. explored the Great Western and Bonito mines in 1988-1989 and still controls some claims in the district. In 1989, the breccia deposits at Great Western were estimated to contain

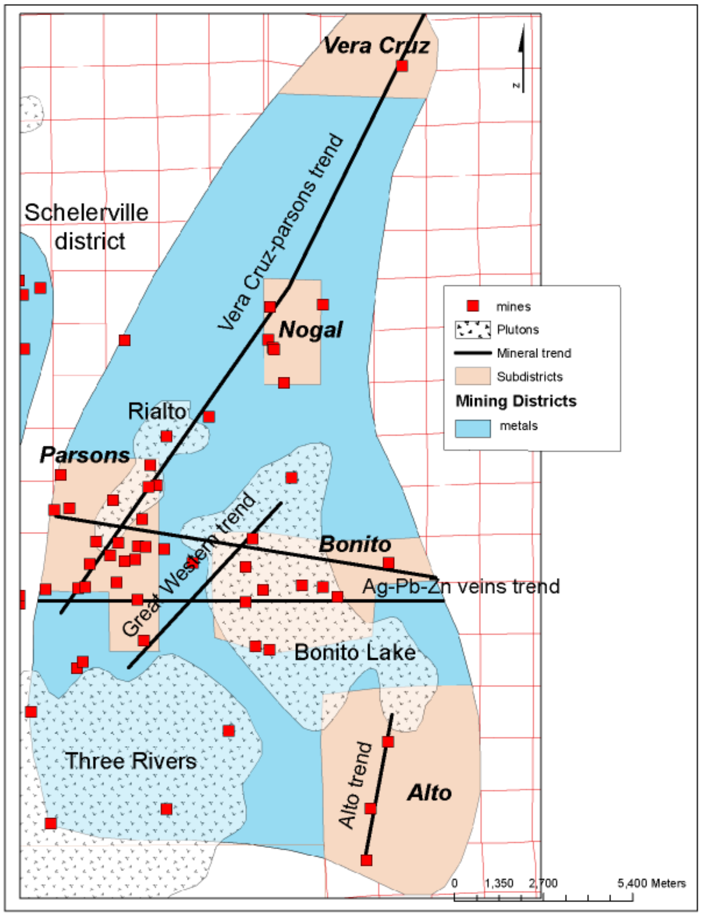

Fig. 20: Subdistricts, plutons, mines, prospects, and mineral deposits in the Nogal mining district.

190,000 oz of gold (Dayton, 1988). Minor exploration continued until the 1990s. Today many mining claims are active but no exploration permits have been applied for.

Seagerstrom et al. (1975, 1979, 1983) and Briggs (1983) conducted an extensive mapping and geochemical survey of the mines in the Nogal district as part of their examination of the mineral resource potential of the White Mountain wilderness area. Korzeb and Kness (1992) also conducted an extensive geochemical survey of the Nogal district as part of their study of the BLM Roswell Resource area. Berry et al. (1981) examined the uranium potential of the area and found no significant uranium resources in the district.

Metals production from the district is listed in Table 1. A summary of some of the more significant deposits is in Table 2 and additional information on mines, prospects, and deposits in the district is in Appendix 2. Thompson (1966, 1973) estimated that approximately $1 million worth of lead, zinc, silver, and gold were produced from this district, but the published and unpublished U.S. Geological Survey and U.S. Bureau of Mines records indicates that only an estimated $300,000 worth of lead, zinc, silver, and gold were actually produced (Table 1).

Description of deposits

Placer gold deposits: Placer gold deposits were first developed in stream gravels along Dry Gulch, northeast of Nogal Peak in 1865 (Johnson, 1972). The placers probably were eroded from the Helen Rae-American and American veins. The gold concentrates by gravity in incised stream valleys and alluvial fans in deeply weathered highlands. Native gold and electrum occur with

Table 1: Metals production from the Nogal mining district. Data compiled from U.S. Geological Survey (1902-1927), U.S. Bureau of Mines Mineral Yearbooks (1927-1990), Griswold, (1959), Johnson (1972) and (McLemore, 1991, 2001). W—withheld. *—includes placer production.

Year	Ore (short tons)	Copper (lbs)	Gold (lode oz)	Gold placer (oz)	Silver (oz)	Lead (lbs)	Total value $
1865-1932							250,000
1902-1933				50			
1933	196		240.04	14.27	90		5,289
1934	111		138.4	56.91	146	50	6,922
1935	132		157.06	24.6	81	600	6,440
1936	214		122.12	2.2	214	1,100	4,568
1937	288	100	15.8		340	200	840
1938	41		3.2		195	2,300	344
1939	1				52		35
1940	162		2		623	200	523
1941	51				720	200	523
1946	2				5	1,000	113
1949	9				18	2,000	332
1950	400		9		10		324
1955	3	100			7	100	21
1965	16						
Total 1932-1955	1626	100	1726	147.98	2501	7,750	26,274
Estimated total 1865-1955		W	15,000*	200	20,000	W	300,000

Table 2: Deposits in the Nogal mining district with reported historic (non 43-101 compliant) resources. Mine identification number is from the New Mexico Mines Database (McLemore et al., 2005a, b).

Mine identification number	Name of deposit	Tons of ore	Au grade (oz/ton)	Ag grade (oz/ton)	Mo Grade %	Year of estimate	Reference
NMLI0068	Vera Cruz	207,450 (assured) 435,000 (probable) 934,000 (possible)	0.14 0.12 0.12			1938	Ryberg (1991)
NMLI0207	Great Western	3,600,000	0.058			1992	NMBGMR file data
NMLI0271	Parsons	44,000	0.5			1991	Thompson (1991a, b)
NMLI0121	Rialto	30 million short tons			0.05-0.18%	1978	(Hollister, 1978)
NMLI0008	Bonito	1.7 million short tons	0.05	0.5		1989	NMBGMR file data

quartz, magnetite, ilmenite, amphiboles, pyroxenes, pyrite, zircon, garnet, rutile, and a variety of other heavy minerals. The best gold values occur where the gold is trapped by natural processes such as riffles in stream bottoms, fractures within the bedrock, along bedding or foliation planes, and/or structures that are transverse to the river flow. Most placer deposits in the Nogal district are thin, low-grade, disseminated deposits consisting of small flakes of gold.

Fissure vein deposits: Three types of fissure veins are found in the district: Ag-Pb-Zn (±Au), quartz with local low Ag-Au (±pyrite), and carbonate veins. During mapping, many of the fissure vein mines and prospects were examined, and additional calcite and quartz veins of various widths were mapped. These invariably contain accessory iron-manganese oxides and pyrite, with minor barite, galena, sphalerite and copper minerals. Segerstrom et al. (1979) present precious and base metal analyses from 1715 samples collected in and around the Wilderness area and a map showing five areas of anomalous molybdenum concentrations. Table 3 summarizes the main characteristics of the fissure veins found in the district.

Fissure veins are narrow (less than 2 m wide), north- to northeast-trending, quartz-carbonate veins with variable gold and copper, lead, and zinc sulfides. The sulfide minerals are in stringers of quartz and dolomite in the monzonite porphyry and quartz-calcite veins in andesite and monzonite porphyry. Some veins exhibit crustiform textures, followed by sulfide deposition and late carbonate (Douglass, 1992), suggesting epithermal origin. The ore minerals are gold, pyrite, sphalerite, galena, and chalcopyrite. Silver-gold veins are found predominantly around the Helen Rae-American and Rockford mines. A mass of bleached, kaolinized, and brecciated porphyry, located about 1 mile southeast of Nogal Peak, has also yielded gold and a little silver.

At the Helen Rae-American and American mines, carbonate-quartz veins contained gold, pyrite, galena, and sphalerite (Griswold, 1959; Thompson, 1973; Porter and Hasenohr, 1984). The highest-grade ore was found at the intersection of the main vein with smaller crosscutting veins. The 1-ft-wide Crow vein, exposed by the Renowned OK and Crow mines, consists of quartz with galena, sphalerite, pyrite, and chalcopyrite in altered (trachy) andesite and contained 11.3% Pb (Griswold, 1959). Samples from the Crow vein contained as much as 1800 ppb Au, 383 ppm Ag, 447 ppm As, 3650 ppm Cu, 30.09% Pb and 10.82% Zn (Korzeb and Kness, 1992). The Maud mine consists of a vein containing quartz, sphalerite, galena, pyrite, chalcopyrite, and barite. A composite sample assayed 7.1% Pb, 0.39% Mo, 0.32 oz/ton Au, and 1.28 oz/ton Ag (Thompson, 1973). The Great Western and Bonito mines consist of quartz-pyrite veins exposed by several adits. The Main Zone at the Great Western is estimated to contain 1.3 million tons of 0.045 oz/ton

Table 3: Mineral deposit characteristics, Nogal mining district (modified from Douglass, 1992).

Attributes	Breccia pipe deposits	Ag-Pb-Zn vein deposits	Porphyry Mo-Cu deposits
Metals	Au>Ag (±Cu, Mo)	Zn>Pb>Ag (±Au,Mo)	Mo, Cu (zoned)
Style of mineralization	Open spaces or breccia cements	Open space veins	Disseminated
Host rock	Volcanics, intrusions, Mesa Verde Group	Volcanics	Intrusions
Alteration	Vein envelope, phyllic, propylitic, weak argillic, carbonate	Pervasive, propylitic, weak phyllic	Propylitic, calc-silicate
S abundance	Low (S>2%)	High (S 50-75%)	Low
Temperature ore stage minerals	224-538ºC, average 260ºC	188-416ºC, average 240ºC	
Salinity of ore stage minerals	2-50 wt% NaCl	2-18 wt% NaCl	3-5 wt% NaCl
$\delta^{18}O$ fluid (per mil)	-5 to 9.5, average 1.9	-5.7 to -3.4, average -2.6	1.1
$\delta^{34}S$ (per mil)			-1.1 to -8.3

Au and the Blue Front Zone is estimated to contain 2.305 million tons of 0.057 oz/ton (Dayton, 1988; Bartsch-Winkler et al., 1995). Some veins contain high concentrations of molybdenum (Segerstrom et al., 1979).

Breccia pipes: Most breccia pipes are conical bodies, less than 200 m in diameter consisting of breccia clasts of host rock and highly altered and silicified country rock (Table 3). The breccias are cemented by silica and contain pyrite, chalcopyrite, bornite, gold, and local trace molybdenite. The upper portions of many breccia pipes are oxidized consisting of iron oxides, malachite, turquoise, and other supergene minerals. Best production of gold came from the Parsons mine, a breccia pipe within the Rialto stock (Figure 21). Some samples from the Parsons mine contain as much as 503 ppb Au, 4 ppm Ag, 10 ppm As, 1733 ppm Cu, 332 ppm Mo, 42 ppm Pb, and 248 ppm Zn (Korzeb and Kness, 1992). The Mudpuppy-Waterdog prospect is a breccia pipe and samples from the deposit assayed as high as 222 ppb Au, 0.60% Cu, 0.9% Mo, and 3.2 ppm Te

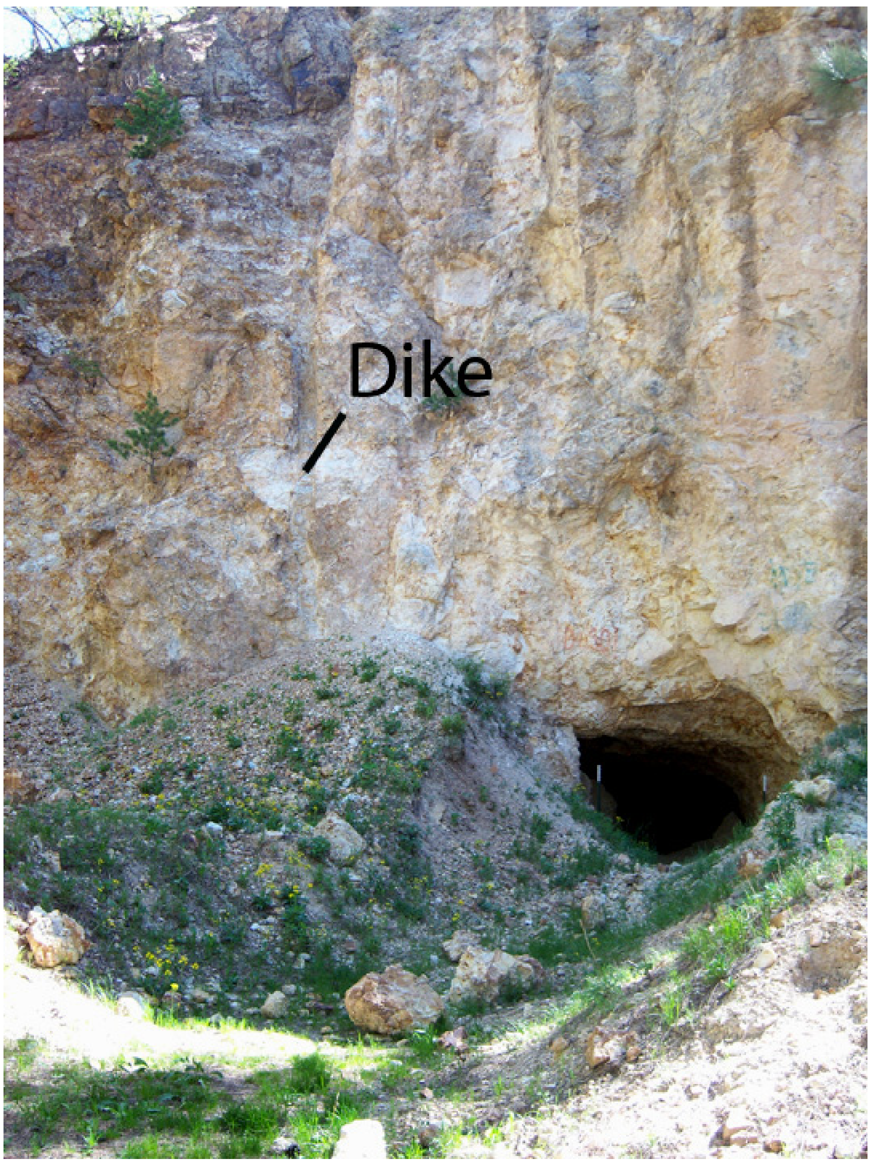

Figure 21: Photo of east wall of Parsons gold mine showing breccia pipe texture; phyllic alteration has retrograded to argillic alteration. Vertical dike of altered trachydacite (?) cuts large block left of “D.” The rocks surrounding the mine contain anomalous copper (partly as turquoise) and molybdenum.

(Fulp and Woodward, 1991b). The grade at the Great Western mine is 0.04 oz/ton (Eng, 1991). The Vera Cruz breccia pipe contains 934,000 tons of possible ore at a grade of 0.12 oz/ton (Table 2; Ryberg, 1991, historic resource, non 43-101 compliant).

Hydrothermal Breccia Characteristics

We have mapped five significant hydrothermal breccia zones (three shown previously by Thompson, 1973). The first two areas occur in the Rialto stock at the Parsons Mine (Figure 21; Thompson, 1973) and at the ridge crest east of Nogal Pass. In these deposits, the host rock is primarily ruptured, silicified syenite and quartz diorite. A later dike cuts the breccia pipe in the Parsons deposit. Alteration is distinctly phyllic replaced by later argillic alteration. Some of the altered rocks have large (≤1 cm) platy aggregates of sericite replaced by clays. Iron oxide staining is ubiquitous. Minor turquoise is visible in the float surrounding the Parsons deposit.

The third, at the Great Western Mine, consists of an E-W striking mass of broken, extremely silicified rock about 1 km long and 300 m wide occurring just north of the Three Rivers stock. Three "breccia pipes" occur within this mass and tower roughly 40 to 60 m above the main breccia body (Fig. 22). The original host rock is Walker volcanic lavas – a small trachyandesite vent or flow fragment is still recognizable within the west end of the breccia body. Accessory alteration consists of hematite, other iron oxides, pyrite, and manganese minerals but most of the body is fine-grained, massive, brecciated quartz. The Great Western body has been intensively explored for gold and molybdenum (Segerstrom et al., 1979; Eng, 1991; Fulp and Woodward, 1991b). Old adits, glory holes and scrapes are found all over and next to the breccia. We also found remains of seven abandoned exploration holes drilled into the main breccia body.

The fourth large mass of hydrothermal breccia occurs north and east of Elk Point on the north edge of the Three Rivers stock about 2 to 3 km southwest of the Great Western breccia body. This breccia is roughly 1.5 km long and 200 m wide. The Elk Point mass is developed within the Elk Point porphyritic rhyolite plug, and Walker lavas and breccias directly east of the plug. The breccia body looks very similar to the one at Great Western Mine. The silicified volcanic rocks contain many quartz veins that contain minor gold and molybdenum (Segerstrom et al., 1979).

The fifth hydrothermal breccia occurs on the north side of the mouth of Bluefront Canyon on the southwest edge of the Bonito Lake stock (Segerstrom et al., 1979). This mass is faulted off along both its south and east sides. What remains looks rather cylindrical in shape, about 400 m in diameter and extending over 200 m up the canyon wall. The mineralogy of this breccia body has been described by Goodell et al. (1998) and consists mostly of banded, fine-grained, blue corundum (sapphire) and lazulite, with egg shell-colored alunite and quartz (Fig. 23). Examination of brecciated rocks in the cliff above the canyon floor suggests that the alteration partly replaces relict flow banding or flow foliations in Walker lavas. Some of the banded material displays high angle dips indicating that large blocks of lava were disrupted before alteration. Presence of alunite and corundum suggests that the hydrothermal fluids causing the deposit were acidic (Myer and Hemley, 1967; White and Hedenquist, 1990; Barton et al., 1991).

The banded sapphire has no value; it was once sold for decorative facing stone in nearby villages but freezing conditions caused the stone to disintegrate along foliations. The US Geological Survey once evaluated the deposit for alumina (Segerstrom et al., 1979). A large pile of sapphire "ore" lies along the trail in the mouth of Bluefront Canyon. Pine trees nearly 80 feet tall have grown on the ore pile indicating that this rock was mined about 100 years ago. None-the-less, the Bluefront breccia pipe deserves considerably more research than our mapping project allows.

Figure 22: Hydrothermal breccia pipes developed in altered Walker lava at Great Western Mine consist of broken, massive quartz containing accessory iron-manganese minerals and minor gold and molybdenum.

Figure 23: Banded breccia of fine-grained sapphire, lazulite (Mg, Al phosphate), alunite and quartz occurs in a faulted pipe within Walker lava on the north side of the mouth of Bluefront Canyon.

Porphyry molybdenum-copper deposits
The porphyry molybdenum-copper deposits are found in the northern portion of the Rialto stock near Nogal Peak and along the northern and eastern portions of the Three Rivers stock. Both the Rialto and Three Rivers stocks are alkaline and high in F and Nb (Giles and Thompson, 1972; Segerstrom et al., 1979; Westra and Keith, 1981).

The deposit in the Rialto stock consists of disseminated sulfides and thin veinlets in a brecciated zone in monzonite and consists of quartz, pyrite, molybdenite, and copper sulfide minerals. Four zones are recognized: 1) inner molybdenite zone, 2) magnetite zone, 3) copper-rich zone that truncates the molybdenite and magnetite zones along the southern portion of the deposit, and 4) extensive lead-zinc zone on the eastern and southern portions of the stock (Thompson, 1968; Segerstrom et al., 1979). Molybdenum decreases outwards from the central molybdenite breccia zone (Thompson, 1973; Gander, 1982). The host rocks are extensively altered by silicification, sericitization, kaolinization, and pyritization (Griswold and Missaghi, 1959; Giles and Thompson, 1972; Thompson, 1973; Westra and Keith, 1981). The Rialto porphyry molybdenum deposit is estimated to contain 27 million metric tons (30 million short tons) of 0.05-0.18% Mo (Hollister, 1978, historic resource, non 43-101 compliant).

The deposits in the Three Rivers stock are in silicic altered zones. Three styles of mineralization are found: 1) thin fracture coatings of molybdenite and fine-grained disseminations in quartz veinlets, 2) molybdenite in breccia zones, and 3) fine-grained disseminations of molybdenite in high silica rocks (Giles and Thompson, 1972; Segerstrom et al., 1979). Purple euhedral fluorite is found in miarolitic cavities and open fractures throughout the Three Rivers stock, but is most noticeable in the syenites. Very low-grade molybdenum also is found in the Cone Peak rhyolite plug just northwest of the Three Rivers stock (Black, 1977a, b).

HYDROTHERMAL ALTERATION

Hydrothermal alteration has affected virtually all rocks within the quadrangle. White, brown and orange alteration zones are no doubt what excited prospectors in the late 1800s. Initially, prospectors found gold in small placer deposits along streams in Dry Gulch.

Our geologic map contains information on visible alteration that we could easily identify while mapping (Fig. 24). For example, a dot on the map with symbols “Ep, Chl” indicates that visible epidote and chlorite occur in the rocks at that location. We also examined most of the mine dumps in the quadrangle and found the minerals described in detail by Thompson (1973): quartz, pyrite, galena, sphalerite, hematite, and a few copper minerals. Appendix 3 contains X-ray diffraction results from a few altered rock samples that we had more trouble identifying. Except for the sapphire deposit from Bluefront Canyon (described above), the alteration minerals in these samples are quite predictable.

Names of alteration assemblages used herein follow the definitions and examples used in Myer and Hemley (1967). In general the rank and intensity of alteration (Browne, 1978, 1982) increase to the south and east, in particular near the margins of and within the stocks. As might be expected, alteration within a given area also increases downwards from ridge tops into canyon bottoms. In the northwest part of the quadrangle, alteration is best characterized as argillic consisting of smectite clay, mixed layer illite-smectite, some chlorite, opal or chalcedony, calcite and iron oxides. Veins are few and thin and most are carbonate veins. To the southeast alteration becomes progressively propylitic. Most rocks become “greenish” and contain substantial amounts

Figure 24: Photo of lime green epidote crystallized on fractured surface in hydrothermally altered Walker lava flow and debris flow breccia near Bonito Seep. Such alteration is commonly seen in the central portions of the Nogal Peak quadrangle.

of illite-smectite, illite, chlorite, chalcedony or quartz, calcite, pyrite, and epidote. Near stock margins or within some parts of the stocks, we have observed actinolite-tremolite, specular hematite, magnetite and adularia. Veins become more abundant and broader, and a few are small bonanza quartz veins.

Presence of epidote indicates that temperatures once exceeded 220 °C and presence of actinolite-tremolite suggests that temperatures exceeded 350 °C (Browne, 1978, 1982; Reyes, 1990; Simmons et al., 1992; Goff and Gardner, 1994, fig. 7). These temperatures match those determined independently by Douglass and Campbell (1994). Because epidote is a key indicator for higher-temperature epithermal conditions, we have drawn a dashed line on our map (Epidote Line) that indicates where epidote becomes visually obvious in many rock exposures. Southeast of this line, exploration for base and precious metals is possible; northwest of the line, exploitable deposits of precious and base metals probably do not exist unless they are very deeply buried.

We have also outlined a few areas that show intense phyllic (sericite) alteration (quartz-illite-pyrite), most of which is now undergoing secondary argillic alteration (pyrite altering to various Fe-oxides; rock matrix altering to opal and kaolinite). These phyllic zones occur within the Rialto stock, especially near and north of the Parsons Mine (Thompson, 1973), along the SE margin of the Rialto stock just west and south of Washington Canyon, and within an area surrounding the Great Western Mine. Black (1977b) has also outlined an area of phyllic alteration in the Bonito Lake stock just east of Kraut Canyon and the boundary of Nogal Peak quadrangle.

DISTRICT ZONATION AND ORIGIN OF THE DEPOSITS

The porphyry molybdenum-copper deposits were formed during or shortly after intrusion of the Rialto and Three River stocks. Mineralogy plus geochemical and isotopic data indicate that two additional, but separate mineralizing events occurred in the district: sulfide Ag-Pb-Zn (±Au) veins and gold-rich breccia pipes with little or no base metals (Campbell et al., 1991; Douglass and Campbell, 1994; 1995). Fluids of the gold breccia pipe deposits are chemically different from the Ag-Pb-Zn (±Au) veins and porphyry molybdenum-copper deposits (Table 3; Douglass, 1992). However, the age relationships are not well constrained.

The gold breccia deposits form two northeast trends (Figure 20; Douglass, 1992). The Parsons-Vera Cruz trend aligns the veins and breccia pipes of the Argentine, Parsons, Rockford, Helen Rae-American and Vera Cruz deposits. The Great Western trend aligns the Great Western and Waterdog breccia pipe deposits (Figure 20). The Ag-Pb-Zn (±Au) veins form an east-west trend cutting across the two northeastern trends. Another north-northeast trend of veins, the Alto trend, is found in the southeastern portion of the Nogal mining district and warrants further exploration. Subsequent erosion formed the placer gold deposits.

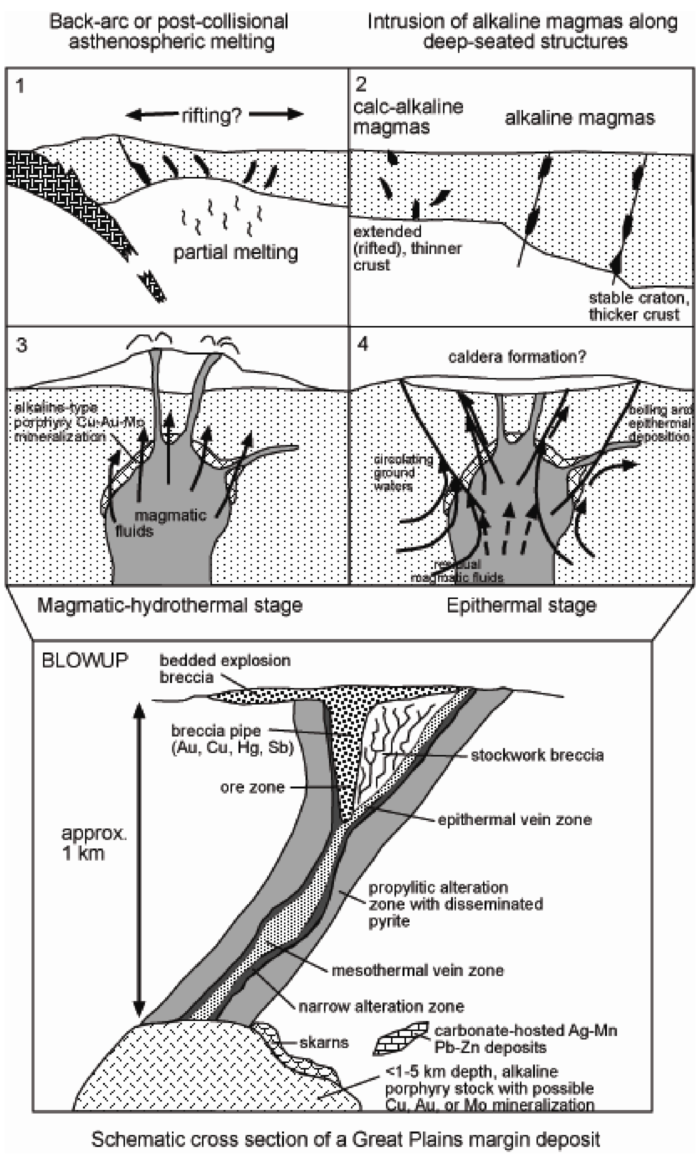

Figure 25: Schematic model for formation of Great Plains margin deposits (modified from Richards, 1995).

It has not been proven that the mineral deposits associated with the Lincoln County porphyry belt or even the Rocky Mountain alkaline belt are genetically related to the igneous rocks; however, it is likely that they are. Supporting evidence for a magmatic origin includes: 1) fluid inclusion and stable isotope data from the Nogal deposits (Douglass, 1992; Douglass and Campbell, 1994, 1995), 2) fluid inclusion, stable isotope, and age data from the Capitan quartz-REE-Th veins (Phillips et al., 1991; Campbell et al., 1995; Dunbar et al., 1996), 3) nature of stock work molybdenum deposits at Sierra Blanca, Three Rivers stock (Thompson, 1968, 1973), 4) close spatial association of mineral deposits with igneous rocks, 5) presence of skarn deposits along the contacts of igneous rocks in other areas of the Lincoln County porphyry belt, and 6) similarity to other deposits at Cripple Creek, Colorado and elsewhere where a magmatic origin is favored (Thompson et al., 1985; Porter and Ripley, 1985; Thompson, 1992; Maynard et al., 1989, 1990; Kelley and Luddington, 2002). Initial strontium isotope ratios from rocks of the Sierra Blanca igneous complex range from 0.7038 to 0.7045 and suggest a deep crustal or upper mantle source (Thompson, 1995). Sulfur isotopes from the Nogal deposits range from -3.1 to -0.3 per mil and suggest a meteoritic source (Thompson, 1995).

It is likely that the co-occurrence of Au, Cu, Fe, Mo, F, W, and other elements is the result of several complex magmatic fractionation and differentiation events and tectonic subenvironments, which overlap near the Great Plains margin. The association of lineaments and other major structures with igneous rocks and mineral deposits in New Mexico suggests that near vertical deep-seated fracture systems probably channeled the magmas and resulting hydrothermal fluids (McLemore and Zimmerer, 2009). Once the magmas and fluids reached shallow levels, local structures and wall rock compositions determined the final character and distribution of intrusions and mineralization. Figure 25 summarizes the general formation of GPM deposits in New Mexico.

Evidence suggests that complex, multiple intrusions are needed to generate the hydrothermal fluids necessary to produce GPM mineral deposits. The more productive districts, such as those at Nogal and White Oaks occur in areas of complex magmatism that lasted for more than 5 Ma and resulted in intrusions of different ages. In areas such as the Capitan Mountains, where intrusive activity occurred in less than 5 Ma, only localized minor Au, Ag, and REE occurrences are found (McLemore and Phillips, 1991).

OUTLOOK FOR MINERAL RESOURCE POTENTIAL IN THE FUTURE

Gold, silver, base metals

Many companies have explored the Nogal mining district looking for gold, silver and base metals. Although resources were identified in several deposits (Table 2), no significant production has occurred since 1965 (Table 1), other than very minor placer gold production. However, as the price of gold increases, companies will continue to re-examine the Nogal district because:

- Some gold and silver have been produced in the past
- Gold deposits have been found that are not yet mined and could be in the future (Table 2)
- The mineralized trends offer favorable exploration areas
- The alkaline igneous rocks and the mineralized veins and breccia pipes indicate potential for undiscovered deposits in the subsurface.

Some of the favorable areas for gold in the Nogal district are in or near the White Mountain Wilderness Area or in the National Forest and likely will require more strict reclamation standards. Detailed geochemical and geophysical surveys are recommended to delineate potential drilling sites for undiscovered deposits in favorable areas outside the wilderness boundary. It is unlikely that any exploration will occur for base metals in this district because these deposits are too small and low grade to be economic.

Rare earth elements

Rare earth elements (REE) are increasingly becoming more important in our technological society and are used in many of our electronic devices. REE include the 15 lanthanide elements (atomic number 57-71), yttrium (Y, atomic number 39), and scandium (Sc; McLemore, 2010) and are commonly divided into two chemical groups, the light REE (La through Eu) and the heavy REE (Gd through Lu, Sc, and Y). REE are lithophile elements (or elements enriched in the crust) that have similar physical and chemical properties, and, therefore, occur together in nature. However, REE are not always concentrated in easily mined economic deposits and only a few deposits in the world account for current production (Committee on Critical Mineral Impacts of the U.S. Economy, 2008; Hedrick, 2009). The U.S. once produced enough REE for U.S. consumption, but since 1999 more than 90% of the REE required by U.S. industry have been imported from China (Haxel et al., 2002; Kramer, 2010). However, the projected increase in demand for REE in China, India, U.S., and other countries has resulted in new exploration and production from known and undiscovered deposits in the U.S. and elsewhere (Gleason, 2011).

REE deposits (associated with Th and Zr) have been reported from New Mexico (McLemore et al., 1988a, b; McLemore, 2010), but were not considered important exploration targets in the past because other deposits in the world met the demand in past years. However, with the projected increase in demand and potential lack of available production from the Chinese deposits, these areas in New Mexico are being re-examined for their REE potential. The Lincoln County porphyry belt has known REE, Th and Zr deposits (i.e., Capitan Mountains, McLemore and Phillips, 1991; Gallinas Mountains, McLemore, 2010; Pajarito, McLemore, 1990, Sherer, 1990) and the alkaline rocks in the Nogal district are similar in composition to alkaline rocks found with known REE deposits in the world, suggesting a potential for REE in the Nogal district.

Available geochemical studies and known mineralogy throughout the Nogal district indicate elevated concentrations of REE (Segerstrom et al., 1979; Constantopoulos, 2007; NURE data; this study), but the REE concentrations are not high enough to warrant additional exploration in the district at this time. Fluorite is associated with most REE deposits and fluorite is found throughout the Three Rivers stock (Giles and Thompson, 1972; Segerstrom et al., 1979), suggesting a higher potential for REE in this intrusive complex.

Segerstrom et al. (1979) report a single sample from the head of Indian Creek in the SW part of the Wilderness area that contains elevated REE attributed to presence of the mineral xenotime in syentite. One of our samples (F09-35, Appendix 1) is an alkali granite at the head of the eastern Ski Apache chair lift containing 2850 ppm Zr. Zirconium at this level is 5 to 10 times the values in standard granite and rhyolite. This sample also contains slightly elevated Th (28.9 ppm). In thin section, this rock contains abundant zircon. The sample was taken just north of the Mescalero Apache Reservation boundary. Presumably, this phase of unit Ttag, which is coarser grained than most, continues to the south, but we did not attempt to map it out. Any future exploration for REE, Zr, and Th on Nogal Peak quadrangle should focus on the breccia pipes, alkali granite bodies, rhyolites, related dikes, and quartz veins of the Rialto and Three Rivers stock.

Tellurium

Tellurium (Te) is increasingly used in the manufacture of cadmium-tellurium (Cd-Te) solar cells. In solar cells, the thin films are typically 3-300 microns and approximately 8 grams of Te is used per solar panel, or approximately 696.8 kg of Te for 10 MW of photovoltaic (PV) production (http://greenecon.net/solar-energy-limits-possible-constraints-in-tellurium-production/solar-stocks.html, accessed on May 3, 2010). Tellurium is commonly associated with gold deposits in the Rocky Mountain alkaline belt, but only recently has tellurium become economic interesting. Tellurium can be found as a native metal, but it is more commonly found in more than 40 minerals, many of which are telluride minerals. Calaverite ($AuTe_2$) is the common Au-telluride mineral and sylvanite ($(Au,Ag)Te_2$) is the common Au-Ag telluride mineral. However, tellurium minerals have not been recognized in the Nogal district. Only one deposit has been examined for their tellurium content, the Mudpuppy-Waterdog deposit, where as much as 7.1 ppm Te has been reported from the veins (Fulp and Woodward, 1991b). Analyzed samples from this study indicate Te is very low (Appendix 1). Additional geochemical studies of the deposits including Te are recommended as other investigations are conducted.

HYDROGEOCHEMISTRY

A major impetus for geologic mapping of the Sierra Blanca is to gain better understanding of geology and climate controls on water resources (i.e., Newton, 2011). Thus, at the request of S. Timmons and T. Newton (NMBG&MR), we collected 10 water samples for isotope and chemical analyses that issue from a variety of rock types (Appendix 4). The sample locations span an elevation range of 3355 to 2390 m (11,000 down to 7840 ft) in hopes of showing an elevation gradient with respect to $\delta D/\delta^{18}O$ recharge models. *Ice Spring*, for example, has the highest discharge elevation of any spring in the quadrangle (Figure 26). Some samples were also collected for tritium to get data on water ages and circulation times. The laboratory data will not be discussed here but the interested reader is encouraged to link with the Tularosa Basin hydrogeology project at http://geoinfo.nmt.edu/resources/water/home.html for more information.

For the Nogal Peak quadrangle sampling campaign, we measured field parameters of five spring waters with a model YSI 556 Multiprobe using company procedures. We also collected a 250-ml sample of raw water for anion chemistry and a 125-ml sample of filtered (0.45 micron), acidified (10 drops spec. pure HNO_3) water for cation chemistry at these sites. Polypropylene bottles were used for the chemistry samples. We also collected a 1-liter bottle of raw water for tritium (^3H) analysis and a 30-ml bottle of raw water for $D/^{18}O$ analysis. For the remaining five sites, we measured temperature and pH with a calibrated digital thermometer with thermocouple and used pH-sensitive papers (see Trujillo et al., 1987 or Goff et al., 2002 for field procedures). A stable isotope sample was also collected at these remaining sites.

Flow rates of the 10 samples vary from 200 to ≤1 liters per minute. All collected waters discharge at ≤13.3 °C and all waters are near neutral in pH except for NPW10-5 (pH = 4.3). This latter water is downstream of a zone of intense phyllic (and secondary advanced argillic) alteration and probably contains dilute sulfuric acid from oxidation of pyrite. The waters of three other sites (NPW10-1, -3, and -4) contain visible Fe-oxide precipitates and/or are associated with hydrothermally altered rocks (Figure 27). Five of the 10 water samples were analyzed in situ for several other parameters and for complete chemistry (NPW10-1, -2, -4, -6 and -9). All samples have relatively high ORP (oxidation-reduction potential) and DO (dissolved oxygen) suggesting that they are near surface waters. All samples have low total dissolved solids (TDS) and specific conductivity except for those at the collapsed mine adit (NPW10-1) and *Washington Spring* (NPW10-4), which both discharge in and near the Rialto stock. The former issues from silicified syenite with quartz veins and the latter flows from a monzonite dike zone. The stock near the springs displays intense phyllic (quartz-pyrite-illite) and secondary advanced argillic (kaolinite-

Fig. 26: Photo of Ice Spring, which issues from Three Rivers quartz syenite at 3355 m elevation.

Fig. 27: Photo of Fe-rich cold spring south of Great Western Mine in upper Bluefront Canyon.

opal-iron oxide) alteration whereas rocks outside the stock contain propylitic alteration (epidote-chlorite-illite-calcite-quartz-pyrite).

There are many other interesting cold springs within the quadrangle that could be sampled in the future. These include:

1. *Skull Spring* and others within Tanbark and adjacent ravines of the Rialto stock
2. *Littleton Spring* and others within Littleton and Kraut canyons, Bonito Lake stock
3. Several unnamed springs in the major drainages and ridges of the Three Rivers stock
4. *Vanishing Spring* within the Ski Apache and *"Black Pipe" Spring* south of Elk Point (UTN NAD 27 423419/3698054, 10,420 ft).
5. The numerous springs issuing from Walker volcanic lavas and breccias in the west and northwest parts of the quadrangle.

Of those in the last group, several springs including *Canyon Spring* and *Spring Cabin Spring* discharge from the head to the bottom of Spring Canyon that could potentially show both isotopic variations due to elevation changes and chemical variations due to changing lithologies. These sites are accessible by Trail 27.

ROCK DESCRIPTIONS

Note: Due to restricted access on Mescalero Apache tribal lands, the geology of the southern strip of the quadrangle (the portion on Otero County) is adapted from the geologic map of Moore et al. (1988). We field checked their geology along the tribal land boundary and made a few changes appropriate to this map. Igneous rock names follow the general petrographic descriptions of Williams et al. (1954) or, if chemistry is available (Appendix 1), the classification schemes of Cox et al. (1979), De La Roche (1980) and La Bas et al. (1986). Thin section descriptions of about 30 samples appear in Appendix 5. For hand colored maps, a suitable color palette is a Prismacolor® 72 Color Set (indicated for units below) or an equivalent brand.

<u>Quaternary</u>

Qal **Alluvium—**Deposits of sand, gravel and silt in main valley bottoms; locally includes stream terraces, alluvial fans, and canyon wall colluvium; valley floor alluvium is typically finer-grained, silt- and sand-dominated deposits with interbedded gravel beds, whereas low terrace deposits are predominantly sand and gravel. Qal is mostly Holocene in age; maximum thickness of various alluvium deposits is uncertain but may exceed 15 m (Canary yellow – PC916).

Qc (Qco) **Colluvium—**Poorly sorted slope-wash and-mass wasting deposits from local sources; mapped only where extensive or where covering critical relations; thickness can locally exceed 15 m (Sand – PC940).

Qta **Talus deposits—**Angular rock-debris deposits at the heads of high cliffs in southern map area; composed mostly of syenitic blocks (Moore et al., 1988) (Sand – PC940).

Qt **Terrace deposits—**Deposits of pebble to boulder size gravel with a sandy matrix underlying terrace surfaces located approximately 5 to 15 m above local base level; mapped only in upper Salazar Canyon; deposits are only a few meters thick (French grey 20% - PC1069).

Qls **Landslides—**Poorly sorted debris that has moved chaotically down steep slopes; slumps or block slides partially, to completely intact, that have moved down slope; slumps and block slides usually display some rotation relative to their failure plane; ages vary from Holocene to mid- to late-Pleistocene; thicknesses vary considerably depending on the size and nature of the landslide (Beige – PC997).

Qaf **Alluvial fans—**Typically fan-shaped deposits of coarse to fine gravel and sand, silt, and clay within and at the mouths of valleys; associated with present drainages and usually not incised; grades into alluvial deposits along main channels; probably Holocene to middle Pleistocene in age; maximum exposed thickness about 15 m (Deco yellow – PC1011).

Qgd **Glacial deposits—**Bull Lake and Pinedale age glacial deposits at the head of the north fork Rio Ruidoso on high slopes in southern map area (Moore et al., 1988) (Warm grey 50% - PC1054).

Qbd **Glacial boulder deposits—**Glacial outwash debris in southeastern quadrangle composed of unsorted boulders, cobbles and pebbles of crystalline rocks eroded from the Three Rivers Stock (Moore et al., 1988) (French grey 70% - PC1074).

Qoa **Older alluvium—**Older deposits of alluvium now undergoing erosion in the mouths of some streams in northwest part of quadrangle; maximum thickness about 15 m (Light peach – PC927).

<u>Plio-Pleistocene</u>

QTpg **Palomas Gravel—**Fans of course syenite-rich gravel deposited in the southeastern map area (Moore et al., 1988) (Cool grey 20% - PC1060).

<u>Oligocene to Upper Eocene</u>

Thbx **Mineralized hydrothermal breccia—**White to pale gray to orange to blue breccia zones and pipes with secondary mineralization caused by severe hydrothermal alteration in and around the three major stocks; most are probably associated with hydrothermal explosions; most need substantially more investigation. The Blue Front Canyon deposit on SW margin of Bonito Lake stock consists of a 200-m-high faulted pipe of banded quartz-alunite-corundum rock within Walker lavas (Twl); Great Western Mine deposit on north edge of Three Rivers stock consists of three aligned silicified breccia pipes >1 km in length of quartz with minor Fe-oxides and pyrite; Elk Point deposit on NW edge of Three Rivers stock consists of similar silicified breccia zone about 1.5 km long; Parsons deposit in southern Rialto stock contains large blocks and fragments of intrusive rocks in a silicified pipe cut by a later dike; unnamed deposit in Rialto stock east of Nogal Pass consists of two pipes of brecciated, silicified intrusive rocks; age of breccia formation is assumed to post-date emplacement of stocks; thickness and dimensions of each deposit are highly variable (Vermillion – PC921).

Bonito Lake Stock and Associated Dikes

Tfsd **Fine-grained syenodiorite dikes—**Green to dark green, fine-grained dikes with sparse but conspicuous phenocrysts of white to pink alkali feldspar in groundmass of plagioclase, clinopyroxene and opaque oxides; occasionally has "bird's eye" appearance; alteration consists of quartz, sericite, chlorite, epidote, actinolite-tremolite, and smudgy magnetite; no obvious calcite; dikes cut Bonito Lake syenite (Tbs) but are not dated and are 1 to 3 m wide (too thin to color).

Tbs **Bonito Lake syenite to syenodiorite—**Gray to salt-and-pepper, medium- to coarse-grained, hypidiomorphic granular syenite in northeast map area; contains plagioclase, Kspar, minor quartz (≤2%), biotite, hornblende and clinopyroxene (Thompson, 1972; Black, 1978; Constantopoulos, 2007); accessories consist of apatite, sphene, zircon, ilmenite and magnetite; alteration minerals consist of epidote, chlorite, sericite and Fe-oxides; margins of intrusive body are generally dioritic containing more plagioclase and mafic minerals than core syenite; commonly contains aplite dikes about 0.1 to 0.5 m wide consisting of fine-grained quartz, potassium feldspar, minor biotite and rare magnetite; interstitial quartz often has graphic texture with Kspar. K-Ar date on biotite is 26.6 ± 1.4 Ma (Thompson, 1972); maximum exposed thickness about 425 m (Pink – PC929).

Three Rivers Stock and Associated Dikes, Plugs and Flows

Ttbrd **Biotite rhyolite dikes—**Two northeast- to east-trending dikes that cut “nordmarkite” (Ttsp) and Walker Group lavas (Twl) on the east margin of the quadrangle; part of the NE-trending rhyolite dike swarm further to the east mentioned by Segerstrom et al. (1979, p. 14); dikes are 1 to 3 m wide; consist of white, nearly aphyric, mildly altered rhyolite with sparse phenocrysts of Kspar and biotite in a silicified (or devitrified) groundmass with tiny quartz, Kspar, sericite and smudgy opaque oxides; Kspar phenocrysts are zoned. Preliminary $Ar^{40/39}$ age on biotite from northern dike is 25.4 ± 0.8 Ma (too thin to color).

Tog **Oak Grove rhyolite—**Flow of white to gray, aphyric rhyolite on east edge of the quadrangle just west of Oak Grove campground; contains microphenocrysts of quartz in flow-banded groundmass that is devitrified and spherulitic; lava displays flow-banding with extreme folding; may be contemporaneous with rhyolite dikes above although no biotite is visible; overlies Walker Group breccia (Twb); age unknown; maximum exposed thickness about 20 m (Mulberry – PC995).

Tcp/Tcpd **Cone Peak rhyolite—**Several small plugs and many thin dikes **(Tcpd)** of gray to white, slightly porphyritic rhyolite containing phenocrysts of small quartz, Kspar, biotite and sparse plagioclase; groundmass and phenocrysts usually altered and silicified (Black, 1977). Intrusions occur around NW margin of Three Rivers stock and do not cut the stock. Intrusions cut Walker Group lavas and breccias (Twl and Twb). Age unknown; thickness at Cone Peak is about 40 m (Mulberry – PC995).

Tep **Elk Point rhyolite—**Plug of gray, flow-banded, porphyritic rhyolite containing large phenocrysts of Kspar in devitrified to silicified groundmass having smaller crystals of Kspar, quartz, plagioclase, biotite, hornblende, opaque oxides, and rare tiny apatite; plug previously identified as rhyolite by Segerstrom et al. (1979). “Fresh” rhyolite found only at the NW corner of the plug where considerable intrusion breccia is visible; rhyolite is progressively silicified and brecciated further to the south and SE until the original rhyolite texture and mineralogy is lost; cuts Walker Group lavas and breccias (Twl and Twb); in fault contact with Three Rivers stock; age unknown; maximum exposed thickness roughly 200 m in Little Bear Canyon (Mulberry – PC995).

Ttagd **Alkali granite dikes—**Fine- to coarse-grained, pale pink to pale tan to salt-and-pepper dikes from 0.5 to 80 m wide; contain Kspar, quartz, minor plagioclase, minor biotite, arfvedsonite, trace sphene, apatite, zircon and opaque minerals. Thin dike on east edge of quadrangle cuts Walker Group lava and breccia (Twl and Twb); other dikes within interior of stock are much thicker and cut various syenite units; ages of various dikes unknown (Carmine red – PC926).

Tsp **Syenite Porphyry Plugs—**Two small plugs on ridge crest just north of Three Rivers stock in general vicinity of UTM 421000/3700000; consist of gray syenite with sparse phenocrysts of Kspar, biotite and clinopyroxene in fine-grained devitrified to altered groundmass of Kspar, minor plagioclase and biotite; alteration consists of chlorite, sericite, silica, minor Fe-oxides and epidote; cuts Walker Group lavas and breccias (Twl and Twb); cut by dikes of Tspd and Tbsd; ages unknown but appear to be associated with Three Rivers stock based on mineralogy and proximity; maximum exposed thickness ≤45 m (Blush pink – PC928).

Ttag **Alkali granite—**Fine- to medium-grained, equigranular to slightly porphyritic, pale gray to salt-and-pepper granite composed of Kspar, quartz, and minor plagioclase; commonly contains interstitial and graphic intergrowths of quartz-alkali feldspar. Mafic minerals consist of biotite ± arfvedsonite ± aegirine. Accessory minerals consist of apatite, magnetite, ilmenite, sphene and zircon. Some areas contain sparse larger crystals of alkali feldspar. Some zones contain essentially no mafic minerals. Alteration phases consist of epidote, sericite, chlorite and Fe-oxides. This unit forms several, relatively small to large intrusive bodies throughout the stock. According to Giles and Thompson (1972), Segerstrom et al. (1979 and Moore et al. (1988), anomalous molybdenum concentrations (as MoS_2) are associated with this unit but we found no veinlets, veins, pods, or streaks of molybdenite during our mapping. Rb-Sr age (whole rock) from unknown site is 26.7 ± 1.2 Ma (Moore et al., 1991); preliminary $Ar^{40/39}$ date on arfvedsonite from body at top of eastern chair lift, Ski Apache is 27 ± 2 Ma. Maximum exposed thickness is ≥700 m (Carmine red – PC926).

Tthbs **Hornblende-biotite syenite plug—**Tiny, ≤50-m-diameter plug of white to light gray, slightly porphyritic syenite; rock is very fresh, containing larger crystals of Kspar and smaller hornblende and biotite in a groundmass of tiny plagioclase, opaque oxides, some quartz, and clinopyroxene; also contains rare tiny zircon and apatite; intrudes syenite; SE edge of plug abuts very small stoped block of hydrothermally altered Walker Group trachyandesite or trachybasalt (Twl); age unknown; thickness unknown (Magenta – PC930).

Ttbsp/Ttbsd **Biotite syenite porphyry—**Small intrusion and nearby dike **(Ttbsd)** of pinkish-gray, sparsely porphyritic syenite; contains large Kspar phenocrysts with microcline twinning in fine-grained, granular groundmass having small Kspar, biotite, a bit of plagioclase and quartz, opaque oxides, and rare tiny apatite and zircon. Intrudes Walker Group lavas, Twl (as roof pendant) and Ttsp (“nordmarkite”); in fault contact with Twl and Twb; age unknown; maximum exposed thickness about 270 m (Magenta – PC930).

Ttcs/Ttqcs **Coarse-grained syenite—**Light gray, very coarse-grained, hypidiomorphic granular syenite consisting primarily of “hash” of large Kspar (anorthoclase) surrounded by small interstial Kspar and quartz (some with graphic texture), aegirine, arfvedsonite, opaque oxides, tiny apatite, rare rutile and zircon; no apparent plagioclase; a zone of more quartz-rich syenite **(Ttqcs)** is found on the east margin of the unit; sporadically contains ≤10 cm enclaves of fine-grained igneous (?) rock; intruded by thin porphyritic dikes of fine-grained, equigranular alkali granite (?) containing Kspar and clinopyroxene phenocrysts and unidentified blue and purple minerals; various units not dated; maximum exposed thickness about 650 m (Process red – PC994).

Ttsag **Quartz syenite to alkali granite—**Highly variable, but voluminous unit of medium-grained, light gray to bluish gray, equigranular to porphyritic, quartz syenite to granite; syenite is dominant; contains Kspar (often large and distinctly blue-gray) partly rimmed by other feldspar; blue-gray phenocrysts are most plentiful at higher elevations and western margin in the unit; plagioclase sparse to absent; quartz sparse to ≥10 modal percent; quartz is interstitial and may have graphic texture; contains minor arfvedsonite, aegirine, and/or biotite; some specimens contain augite; accessory minerals are opaque oxides, apatite, sphene, and zircon; may contain minor muscovite; alteration minerals consist of epidote, chlorite, sericite and Fe-oxides. K-Ar date on biotite is 28.1 ± 1.7 Ma (Moore et al., 1988); preliminary $Ar^{40/39}$ date on Kspar from west contact in Three Rivers canyon is 28.24 ± 0.19 Ma; maximum exposed thickness is ≥850 m (Pink – PC929).

Tts **Syenite and syenite porphyry—**Medium- to coarse-grained, light gray to very pale pink, hypidiomorphic granular syenite usually containing abundant large crystals of potassium feldspar and interstitial quartz; graphic texture common; plagioclase sparse to absent; contains minor biotite and arfvedsonite; accessories consist of apatite, sphene, zircon, magnetite and ilmenite; alteration minerals are quartz, chlorite, sericite, minor epidote and Fe-oxides; contains sporadic ≤8 cm enclaves of fine-grained igneous rock. K-Ar age on anorthoclase is 25.8 ± 1.1 Ma (Giles and Thompson, 1972), a date we consider much too young. Cuts unit Ttsp; maximum exposed thickness about 600 m (Deco pink – PC1014).

Ttsp **Quartz syenite porphyry—**Very distinctive unit of coarse-grained, brownish gray to rose, quartz syenite (nordmarkite, Williams et al., 1954; Giles and Thompson, 1972) with abundant, large crystals of pinkish Kspar in a granular matrix of Kspar, minor quartz and plagioclase, arfvedsonite, aegirine ± biotite. Kspar phenocrysts may be rimmed by sanidine and plagioclase. Accessory minerals are apatite, zircon, ilmenite and magnetite. Alteration minerals are sericite, chlorite, epidote, and Fe-oxides. Near contacts with country rocks or in the apparent roof zone, the phenocryst content of the syentite may exceed 70%. Contains sporadic ≤10 cm enclaves of fine-grained igneous rock; K-Ar date on arfvedsonite is 29.9 ± 1.8 Ma (Allen and Foord; 1991; Moore et al., 1991); preliminary $Ar^{40/39}$ age on large Kspar from east of Buck Mountain is 28.95 ± 0.18 Ma; maximum exposed thickness ≥730 m (Blush pink – PC928).

Rialto Stock and Associated Dikes

Trm2 **Monzonite to quartz diorite—**Secondary intrusive phase of Rialto stock consists of white to gray, weakly porphyritic, fine-grained quartz diorite having phenocrysts of plagioclase in groundmass of plagioclase, minor Kspar, euhedral biotite, hornblende, and small quartz (≤10%). Accessory phases are fine-grained magnetite, ilmenite and apatite. Occurs as extensive swarm of NE-trending dikes and possible sills that intrude stage 1 Rialto syenite and Walker Group metavolcanic rocks (Twl and Twb). Hydrothermal and supergene alteration processes have resulted in pervasive bleaching and limonite-staining with generally strong alteration ranging from phyllic (quartz ± sericite ± pyrite) to locally argillic. Mineralization occurs as ubiquitous fine-grained pyrite (oxidized) and small veins of lead, zinc and molybdenum sulfides (Thompson, 1973) that currently appear as narrow hematite-goethite gossans. Age of unit is yet to be determined; maximum exposed thickness about 280 m (Deco pink – PC1014).

Trsd **Quartz syenite dike—**Broad, NE-trending dike of salt-and-pepper, slightly pink, medium-grained, hypidiomorphic granular, quartz syenite containing plagioclase, Kspar, quartz, biotite, hornblende, a bit of clinopyroxene and opaque oxides with trace zircon, sphene, and apatite; alteration very minor; occurs on prominent ridge south of Bonito Creek and west of Big Bear Creek; dike is up to 20 m wide; cuts hydrothermally altered Walker Group lavas (Twl and Twb); age unknown (Parma violet – PC1008).

Trm **Syenite—**Initial (stage 1) intrusion of Rialto stock; greenish gray, medium- to coarse-grained, hypidiomorphic granular syenite containing plagioclase, Kspar, and sparse anhedral quartz (≤5%); mafic minerals consist of clinopyroxene, hornblende and biotite; accessories consist of sphene, rutile, apatite and magnetite. Propylitic alteration is generally mild to intense near margins of stock or in deep canyon exposures of unit, consisting of epidote, tremolite-actinolite, calcite, chlorite, illite, quartz, adularia, hematite and pyrite; alteration of syenite near core of stock is generally phyllic (quartz, pyrite, sericite) with later overprint of dispersed silica and Fe-oxide staining. K-Ar date on hornblende is 31.4 ± 1.3 Ma (Thompson, 1973); maximum exposed thickness is 300 m (Pink – PC929).

Other Small Intrusions and Plugs

Tspg/Tsbx **Syenite plugs—**Three small plugs on ridge between Aspen and Little Bear canyons. The northern plug consists of pale pinkish gray, medium-grained, hypidiomorphic granular syenite containing Kspar, plagioclase, biotite, hornblende and opaque oxides; alteration consists of epidote, actinolite (?) and Fe-oxides. The central plug consists of gray syenite porphyry with large Kspar in granular matrix of plagioclase, clinopyroxene, biotite and opaque oxides; alteration is epidote, chlorite and Fe-oxides. The southern plug **(Tsbx)** consists of gray, silicified, fine- to medium-grained syentite breccia containing clasts of mafic volcanic rocks up to 10 cm long in matrix of altered Kspar, plagioclase, clinopyroxene, biotite and smudgy opaque oxides; alteration is silica, chlorite and epidote (?). The plugs probably represent the top of a small syenite stock; intrude hydrothermally altered Walker Group lavas (Twl); maximum exposed thickness about 35 m; ages unknown (Burnt ochre – PC943).

Tm **Monzonite to diorite plugs—**Greenish gray, fine- to medium-grained monzonite to diorite plugs containing abundant plagioclase and sparse to very sparse Kspar; mafic minerals are clinopyroxene and lesser amounts of hornblende and biotite; most specimens show alteration to clay, chlorite, calcite, and quartz ± epidote. Tiny knob west of Nogal Peak cuts Walker Group breccias (Twb) and contains small vugs of amethystine quartz. Small plug in Nogal Canyon intrudes altered Walker lavas (Twl); exposed thickness about 100 m. Lenticular intrusion in SW map area identified by Moore et al. (1988) is overlain by trachybasalt lava and cut by two syenite porphyry dikes (Tspd); exposed thickness about 220 m. Ages of various features are unknown (Dark green – PC908).

Tgd/Tgbx **Grizzly Peak diorite—**Plug-like body and associated radiating dikes (Tmd) of greenish-gray, medium- to course-grained, hypidiomorphic granular diorite consisting almost entirely of plagioclase and clinopyroxene; has a small amount of tiny interstitial quartz and Kspar (?); unit is thoroughly altered to chlorite, epidote, sericite, secondary quartz, minor calcite, and smudgy magnetite; cut by small veinlets of epidote and quartz. A small, poorly exposed zone of diorite intrusion breccia **(Tgbx)** occurs on the slope west of the plug. Unit intrudes hydrothermally altered Walker lavas (Twl). Age unknown; maximum exposed thickness of Grizzly Peak is ≤100 m (Copenhagen blue – PC906).

Tdbp **Dark Betty diorite porphyry—**Small, circular intrusion on south side of upper Dark Betty Canyon containing conspicuous phenocrysts and phenocryst clots of white plagioclase ≤1.5 cm long in greenish gray, fine-grained groundmass of plagioclase, clinopyroxene, opaque oxides and rare olivine. Texture of plagioclase phenocrysts closely resembles texture in unit Twtx described below and may be source of some Twtx lavas. Alteration consists of chlorite, epidote, silica and calcite. Intrudes hydrothermally altered Walker lavas (Twl); a highly silicified zone occurs on the SE margin of the intrusion; exposed thickness is about 310 m; age unknown (Indigo blue – PC901).

Tex **Feldspathoidal gabbro porphyry—**Plug of very dark gray to splotchy black and white, feldspathoidal gabbro (essexite; Williams et al., 1954; Moore et al., 1988) in southeast corner of map; contains large (≤3 cm) phenocrysts of pinkish potassium feldspar and white plagioclase in a highly altered, medium-grained groundmass of nepheline, clinopyroxene, olivine, biotite and smudgy magnetite; alteration phases consist of epidote, chlorite, sericite, calcite, quartz and Fe-oxides. Intrudes Walker Group lavas and breccias (Twl and Twb); K-Ar date on "fresh" gabbro is 32.8 ± 1.2 Ma (Moore et al., 1988); preliminary $Ar^{40/39}$ date on hydrothermally altered gabbro is 30.5 ± 0.5 Ma, presumably affected by the adjacent Three Rivers stock. Maximum exposed thickness is 185 m (Lilac – PC956).

Dikes (all generic dikes: Crimson red – PC924)

Tspd/Tbsd/ Thsd **Syenite porphyry dikes—**Gray, fine- to medium-grained syenite containing sparse phenocrysts of potassium feldspar, plagioclase, biotite, clinopyroxene ± hornblende; a few dikes of this type have hornblende as dominant mafic phase; some dikes more than 10 m wide; intrudes Twl, Twb and Tsp; those in the south map area may be associated with the Three Rivers stock; ages of various dikes unknown.

Tsd **Syenite dikes—**Light gray, medium to course-grained dikes containing alkali feldspar, plagioclase, clinopyroxene, hornblende, biotite and sparse quartz; dikes are 1 to 50 m wide; ages unknown.

Tmd/Thmd **Monzonite to diorite dikes—**Gray to greenish gray, medium- to course-grained dikes containing plagioclase, clinopyroxene ± hornblende ± biotite; dikes are generally 1 to 6 m wide; rare dikes are more than 25 m wide; ages unknown.

Ttd **Porphyritic hornblende trachydacite dikes—**An unusual bluish gray, fine-grained porphyritic dike with NNE trend can be traced as fins or as float for a distance of several kilometers through units Twb and Twl on SW side of quadrangle; contains phenocrysts of plagioclase and hornblende in a groundmass of plagioclase, clinopyroxene, magnetite, apatite and hornblende; dike has variable width of 5 to 50 m. Another dike of porphyritic hornblende trachydacite trends ENE in the vicinity of Argentina Spring.

Tbtd/Thtd **Biotite and hornblende trachydacite to alkali rhyolite dikes—**Gray to tan, slightly porphyritic dikes containing sparse phenocrysts of Kspar, plagioclase ± biotite ± hornblende ± quartz; dikes typically 1 to 6 m wide; ages unknown.

Ttbd **Clinopyroxene-phyric trachybasalt dikes—**Greenish black, fine-grained, porphyritic basalt with conspicuous clinopyroxene ≤2 cm in diameter in intersertal groundmass of plagioclase, olivine, clinopyroxene and magnetite; olivine has iddingsite rims; plagioclase is slightly aligned; clinopyroxene is zoned and contains olivine inclusions; alteration consists of quartz, calcite, Fe-oxides, chlorite, and epidote; dikes generally ≤3 m wide; ages of dikes unknown.

Tif **Felsite—**White, fine-grained, aphyric, felsic dikes, 1 to 5 m wide; ages unknown.

Tit **Trachyte—**Light to dark gray porphyritic dikes with 15 to 25% plagioclase laths 10 to 20 mm long set in an equigranular to fine-grained matrix of dark green pyroxene and feldspar. The plagioclase laths are often distinctively aligned parallel to the margins of the dikes. Dikes are generally 1 to 4 m wide; ages of dikes unknown.

Tita **Porphyritic trachyandesite—**Dikes and small sills of light gray to purple gray porphyry with 5 to 15% of 1 to 10 mm diameter plagioclase phenocrysts, dark green pyroxene, black hornblende, opaque oxides ± potassium feldspar; some dikes may grade into more equigranular textures (Tig). Dikes often contain syenitic and sedimentary xenoliths; dikes in center and east of quadrangle are altered to silica, calcite, clay, chlorite and epidote; dikes generally 1 to 12 m wide; ages of dikes unknown.

Tig **Alkali gabbro to syenogabbro—**Salt-and-pepper, fine- to medium-grained, equigranular dikes and small sills containing plagioclase and pyroxene phenocrysts; may grade into more porphyritic dikes (Tita); generally 2 to 6 m wide; ages of dikes unknown.

Tim **Megacrystal trachyte porphyry—**Greenish gray porphyritic dikes and sills with megacrysts of embayed hornblende and/or green pyroxene that are up to 2 to 4 cm across; groundmass contains hornblende ± biotite; may contain xenoliths of pink coarse-grained syenite; dikes may be up to 20 m across; ages of dikes unknown.

Tis/Tisp **Syenite—**Pink, medium-grained, equigranular dikes and sill composed of potassium feldspar, green pyroxene, occasional biotite and sparse quartz; some contain large Kspar **(Tisp).** Dikes may be up to 20 m across; ages of dikes unknown.

Tic **Mafic clot syenite—**White sparsely porphyritic dikes with about ±7 % conspicuous clots of altered mafic minerals; dike rock contains phenocrysts of Kspar and plagioclase in matrix of plagioclase, clinopyroxene and biotite; cuts Tita dikes; ages unknown.

Titb **Trachybasalt—**Black to gray dikes containing phenocrysts of plagioclase in groundmass of plagioclase, olivine, clinopyroxene ± phlogopite; dikes may be up to 10 m in width; ages of dikes unknown.

Oligocene to Upper Eocene

Sierra Blanca Volcanics

Tnt/Tntd **Nogal Peak Trachyte—**White to pale pinkish gray, slightly porphyritic to aphyric lavas with intercalated flow and flow breccia; at Nogal Peak lavas consist of five flows having a total thickness of 300 m (Thompson, 1972, 1973; see Fig. 6); flows contain phenocrysts of plagioclase in a trachytic matrix of fine plagioclase, clinopyroxene, biotite, hornblende, sparse sanidine and devitrified glass with accessory apatite and magnetite. Alteration minerals include epidote, chlorite, sericite, quartz and Fe-oxides. Some flows include fragments of trachyandesite from underlying units. The contact with the underlying Walker Volcanic Breccia (our name, Twb) appears to be conformable. West and southwest of Nogal Peak, the unit consists of a single flow of gray, slightly porphyritic, medium- to fine-grained lava containing phenocrysts of plagioclase in a trachytic matrix of plagioclase, clinopyroxene, Kspar, biotite (?) and hornblende (?); mafic phases are completely altered to sericite, chlorite, clays, silica, calcite, smudgy opaque oxides and minor limonite. This flow is intruded by dikes **(Tntd)** of similar mineralogy but coarser texture; maximum exposed thickness of flow is ≤35 m. Rocks of this formation generally overlie Walker Volcanic Breccia (Twb) but flow at Hill 9500 underlies basalt (Twbn). Various flows and dike are not dated but a K-Ar age of 31.8 ± 1.3 Ma (Thompson, 1972) has been obtained on glass from the Church Mountain latite, which occupies a similar stratigraphic position as Nogal Peak Trachyte (Tnt = Peach – PC939; Tntd = Orange – PC918).

Walker Volcanic Breccia (formerly Walker Andesite Breccia of Thompson, 1972, 1973)

Twl **Lava-rich unit, undivided—**Aphyric to porphyritic lavas consisting of tephrite, alkali basalt, trachybasalt, basaltic trachyandesite, trachyandesite, phonolite and minor trachyte (Moore et al., 1988). The sequence generally becomes more trachytic higher in the section and the proportion of interbedded breccia is ≤40%. Individual flows of distinctive texture and/or mineralogy can be broken out in the winding cliffs of the escarpments along the west and north edges of the quadrangle. Elsewhere, pervasive hydrothermal alteration and poor exposure prevent effective separation of individual flows. Lava at base of unit in western Three Rivers Canyon is tephrite or trachybasalt containing phenocrysts of clinopyroxene in greenish black groundmass of plagioclase, altered olivine, magnetite and devitrified glass; alteration minerals are chlorite, calcite and Fe-oxides. Alteration minerals are epidote, chlorite and clay. Bluish gray lava and flow-breccia sequence in lower Blue Front canyon contains phenocrysts of plagioclase in a highly devitrified groundmass of plagioclase, clinopyroxene and altered phlogopite (?). Light gray slightly porphyritic trachyandesite or trachyte flows midway up the north slope of Brush Canyon contains phenocrysts of hornblende and plagioclase in groundmass of plagioclase, clinopyroxene, magnetite and devitrified glass. Unit also occurs as roof pendants and hornfelsed septa above and between the stocks described above. Near contacts, the volcanic rocks are altered to cordierite- and/or andalusite-bearing, pyroxene hornfels with scattered occurrences of dumortierite and topaz (Giles and Thompson, 1972). Thickness of individual flows is rarely greater than 20 m. Unit is ≥500 m thick on west side of quadrangle, 400 m thick in NE corner of quadrangle, and 475 m thick east of South Fork Rio Bonito. None of the flows of map unit **Twl** have been dated due to hydrothermal alteration (Jade green – PC1021).

The following subunits, youngest to oldest, have been mapped separately from the undivided Walker lava sequence:

Twpd **Porphyritic trachydacite east of Highway 532—**Gray, porphyritic, slightly trachytic lava containing phenocrysts of Kspar, plagioclase, biotite, opaque oxides and minor quartz in groundmass of tiny plagioclase, clinopyroxene and silicified glass; alteration consists of silica, sericite, chlorite, and smudgy opaque oxides; overlies Walker lavas and breccias (Twl and Twb); occupies same stratigraphic position as Oak Grove rhyolite (Tog) and could conceivably be associated with Three Rivers stock; age unknown; thickness about 20 m (Yellow ochre – PC942).

Twbn **Alkali basalt of Hill 9500—**Dark greenish gray to black lava and minor scoria deposits capping hill SSW of Nogal Peak; contains small but conspicuous phenocrysts of clinopyroxene and plagioclase in groundmass of plagioclase, clinopyroxene, iddingsitized olivine, opaque oxides and altered glass; alteration consists of clay, sericite, silica, calcite and chlorite; overlies flow of Nogal Peak Trachyte (Tnt); cut by biotite syenite dike (Tbsd); age unknown; thickness about 15 m (Copenhagen blue – PC906).

Twcd **Porphyritic trachydacite north of Argentina Spring—**Gray, coarse porphyritic lava containing large phenocrysts of plagioclase and Kspar (?) in trachytic matrix of plagioclase, clinopyroxene, opaque oxides and devitrified glass; alteration consists of silica, clay, sericite and chlorite; overlies Twfa; age unknown; thickness about 50 m (Yellow orange – PC1002).

Twfa **Fine-grained trachydacite north of Argentina Spring—**Dark gray to black, aphanitic, trachytic lavas containing a few very small phenocrysts of plagioclase and biotite in an altered groundmass of plagioclase, clinopyroxene, opaque oxides and tiny Kspar (?); alteration consists of silica, sericite, Fe-oxides and chlorite; underlies Twcd and overlies Twas; age unknown; maximum thickness about 60 m (Lime peel – PC1005).

Twap **Basaltic trachyandesite of Argentina Peak—**Dark gray to reddish black, medium-grained lavas containing a few small phenocrysts of plagioclase in an altered, felty groundmass of plagioclase, clinopyroxene, olivine, and magnetite; alteration consists of hematite, limonite, silica, sericite and chlorite; southern part of unit contains probable vent area; overlies Twf and Twas; age unknown; thickness about 60 m (Grass green – PC909).

Twsp/Twspd **Aphyric trachyandesite of Spring Point—**Eroded plug, associated flows and east-trending dike **(Twspd)** of dark gray to black trachyandesite; contains very rare phenocrysts of plagioclase in very fine-grained altered groundmass of plagioclase, magnetite, clinopyroxene, and rare biotite; alteration consists of silica, sericite, chlorite and a little hematite; overlies Twf; age unknown; maximum exposed thickness about 50 m (Parrot green – PC1006).

Twbt **Basaltic trachyandesite of Hill 9395—**Dark gray to black, sparsely porphyritic, fine-grained lavas containing phenocrysts of plagioclase in completely altered groundmass of tiny plagioclase, clinopyroxene, olivine and opaque oxides; contains sparse gabbroic xenoliths; alteration consists of silica, sericite, chlorite, Fe-oxides and epidote; Hill 9395 is probable vent area; hill to south capped by Twbt is eroded flow; overlies Twbb; age unknown; maximum thickness about 20 m (Aquamarine – PC905).

Twbb/Twal **Basaltic trachyandesite flows, agglutinate and breccia—**Lumped unit of gray thin driblet flows and dark red agglutinate, spatter, scoria, breccia and tuff representing multiple eruptive events; most specimens contain plagioclase, clinopyroxene and olivine; upper material is probably associated with lavas of Hill 9395; contains thin bed (±3 m) of white accretionary lapilli tuff layers **(Twal)** in ravine east of Trail 25; several layers contain balls ≤0.5 cm in diameter of opalized mud with a few tiny feldspar and magnetite crystals; unit **Twbb** underlies lavas of Twbt and is cut by various dikes and plugs; overlies units Twf, Twsc and Twtb; ages of various deposits unknown; maximum thickness about 100 m (Twbb = Burnt ochre – PC943; Twal = Poppy red – PC922).

Twf **Aphyric trachybasalt south of Argentina Spring—**Multiple flows of dark gray to greenish gray aphyric basalt with sparse phenocrysts of plagioclase and clinopyroxene in altered groundmass of plagioclase, clinopyroxene, opaque oxides and olivine; alteration consists of silica, Fe-oxides, sericite, chlorite and epidote (?); unit extends south to Spring Point area; underlies Twbb, Twsp and Twap; overlies Twas and Twsc; ages of various flows unknown; maximum exposed thickness about 130 m (Peacock – PC1027).

Twas **Argentina Spring tuff—**Black to gray to pale tan, slightly welded to densely welded, lithic-rich, biotite rhyolite ash flow tuff (ignimbrite); contains flattened welded pumice (fiamme) with maximum aspect ratio of ≥25:1; bottom of unit resembles reomorphic tuff (Branney et al., 2008); small abundant phenocrysts consist of sanidine, plagioclase, biotite, opaque oxides, ≤2 % quartz and tiny altered hornblende (?) in banded eutaxitic groundmass; some bands contain spherulites; pumice, spherulites and bands contain deuteric tridymite and fine alkali feldspar; alteration consists of silica, sericite and Fe-oxides; lithic fragments consist of white chert to fine-grained sandstone and a variety of light to dark-colored volcanic rocks; also contains flattened mafic clots; upper layers of unit conceivably represent another tuff (Bucky Pasture tuff) in Godfrey Hills to west; source of tuff is unclear; underlies Twf, Twap, Twfa, and Tnt; interbedded in Twb; overlies Twsc and Twl; age unknown; maximum thickness is roughly 100 m (Poppy red – PC922).

Twsc **Spring Canyon trachydacite** (formerly trachyandesite of Spring Canyon, Thompson, 1972, 1973)**—**Thick, cliff-forming lava of aphyric, flow-banded trachydacite; contains very sparse small phenocrysts of plagioclase in felty groundmass of tiny plagioclase, clinopyroxene, biotite and magnetite; some specimens are spotted with clots of tiny plagioclase; biotite is difficult to find at many locations; alteration consists of minor quartz, sericite and Fe-oxides; vent area for unit is just east of Hill 9350; overlies various Walker lavas and breccias (Twl and Twb); underlies Twas, Twf and Twbb; age unknown; maximum exposed thickness near vent is 110 m (Goldenrod – PC1034).

Twtt **Porphyritic trachydacite tuff east of Little Bear Canyon—**Possible eroded vent of brownish gray, porphyritic, fragmental tuff; caps small hill on ridge north of Cone Peak; contains phenocrysts of plagioclase, Kspar (?), magnetite, very altered biotite and hornblende, and rare quartz; lithics consist of mafic volcanic rocks. Tuff is quite altered containing silica, sericite, chlorite, smudgy opaque oxides, other Fe-oxides and sparse epidote; overlies Walker lavas and minor interbedded breccias (Twl); age unknown; thickness about 30 m (Sunburst yellow – PC917).

Twpa **Porphyritic trachyandesite—**Circular, vent-like body of dark gray, massive to scoriaceous trachyandesite with 0.5 cm long phenocrysts of plagioclase in groundmass of plagioclase, clinopyroxene and altered glass; surrounded by hydrothermal breccia at Great Western Mine; alteration consists of clay, silica, Fe-oxides, and chlorite; maximum exposed thickness about 40 m; age unknown (Apple green – PC912).

Twtx **Plagioclase porphyritic trachybasalt to basaltic trachyandesite—**Distinctive group of related lavas distributed throughout north and west quadrangle; consists of dark gray to gray porphyritic lavas that contain large jackstraw plagioclase and plagioclase clots; typical specimens contain 15-20% elongate plagioclase laths up to 2 cm long in a groundmass of plagioclase, clinopyroxene, altered olivine, opaque oxides and glass. Lava in lower Nogal Canyon (NE corner of quadrangle) contains additional groundmass phlogopite (?); alteration consists of silica, calcite, sericite, chlorite, epidote, and Fe-oxides. Between upper Barber Ridge and Brush Canyon areas, **Twtx** consists of two superimposed lava flows separated by layer of Twba; stratigraphic relations elsewhere are uncertain, although the unit probably occurs in the central part of the Walker lava package (Twl); ages of various flows unknown; maximum thickness is roughly 25 m (Violet – PC932).

Twba **Porphyritic trachyandesite—**Black to gray to blue-gray flows and flow breccias of porphyritic trachyandesite containing phenocrysts of plagioclase ± Kspar in groundmass of plagioclase, clinopyroxene ± hornblende ± biotite and devitrified glass; generally displays argillic to weak propylitic alteration; overlies Twb in northwest slopes of quadrangle; interbedded with both Twtx and Twtb; various flows not dated; maximum exposed thickness about 245 m (True blue – PC903).

Twtb **Trachybasalt and tephrite—**Dark gray, fine-grained trachybasalt to tephrite lavas that form conspicuous thin (≤20 m) shelves within unit Twb described below and forms a package of flows (often with spotted texture) and interbedded breccias in the northwest part of the quadrangle; flows interbedded in Twb are equivalent to unit Tvtf of Moore et al., (1988); usually contains small phenocrysts of clinopyroxene ± iddingsitized olivine; groundmass consists of plagioclase, augite, magnetite, apatite, olivine ± biotite ± nepheline; generally displays argillic to weak propylitic alteration; overlies Cub Mountain Formation (Tcm) in the SE corner of quadrangle; individual flows not dated; maximum exposed thickness about 260 m (Imperial violet – PC1007).

Twb/Twbc **Breccia-rich unit, undivided—**Purple gray to reddish brown volcanic breccia consisting of flow breccia, debris flows, mudflows, minor pyroclastic deposits, minor lava flows and subordinate vent breccia; clasts consist primarily of aphyric to porphyritic tephrite, trachybasalt and trachyandesite (unit Tsb of Thompson, 1972, 1973). Typical breccia fragments are 5 to 20 cm in diameter although some are more than 1 m across; breccia fragments generally constitute more than 50% of the rock; most fragments are rimmed with earthy red hematite. The breccia matrix is fine-grained containing alteration products of Fe-oxides, clay, zeolites, calcite and chlorite ± epidote. An analysis of a large clinopyroxene-porphyritic clast from a thick monolithologic breccia in lowermost Spring Canyon area (west end of cross section A-A') is basaltic trachyandesite. Base of unit is not exposed throughout most of Nogal Peak quadrangle. Maximum thickness is at least 550 m. Another breccia-rich horizon occurs beneath the Nogal Peak trachyte near the northern edge of the quadrangle. This horizon consists of roughly 150 m of purple gray to reddish gray volcanic breccia with 25% interlayered lava flows of alkali basalt to trachyte composition and is equivalent to a roof pendant of volcanic breccia overlying the NW portion of the Rialto Stock. Some areas of breccia particularly rich in agglutinate, scoria and spatter are mapped separately **(Twbc).** Age of the lower breccia is unknown but is estimated to be between 38 and 32 Ma (Thompson, 1972; Moore et al., 1991) (Twb = French grey 50% - PC1072; Twbc = Terra cotta – PC944).

Late Eocene

Tsc **Sanders Canyon Formation—**Gray to purple gray volcaniclastic sediments consisting of sandstone, mudstone and minor conglomerate (Cather, 1991); provenance of most volcanic detritus is thought to be derived from intermediate composition volcanic sources to the southwest; contains some interfingering lenses of Sierra Blanca derived pebbles and cobbles near the top of unit; contact with overlying Walker breccia (Twb) is gradational; contact with underlying Cub Mountain Formation (Tcm) is also somewhat gradational; type reference section for Sanders Canyon Formation (Tcm) occurs in vicinity of Chavez Canyon in northwest map area; age is thought to be Eocene; thickness in reference section is 150 m (Burnt ochre – PC943).

Eocene

Tcm **Cub Mountain Formation—**Sediments composed of interlayered, white to yellowish brown arkosic sandstone and red, maroon, and greenish gray mudstone, siltstone and fine-grained sandstone (Bodine, 1956; Moore et al., 1988). Unit contains thin lenses of chert, quartzite-pebble conglomerate and silicified wood. Unconformably overlain by units Tsc, Twb, and Twtb. Age is thought to be Eocene (Cather, 1991). Exposed thickness in map area is roughly 65 m (Goldenrod – PC1034).

Upper Cretaceous

Kmv **Mesa Verde Group—**Interbedded, light gray, yellowish gray, and reddish gray, massive to medium-bedded, fine- to medium-grained sandstone of continental margin or overbank river deposit origin (Moore et al, 1988); medium-dark gray carbonaceous siltstone; and a few coal beds in carbonaceous siltstone; exposed only in extreme SW corner of quadrangle where thickness is roughly 30 m (True green – PC910).

Ku **Cretaceous rocks, undivided (cross sections only)—**Undivided stack of sedimentary rocks consisting of Mesa Verde Group (Upper Cretaceous), Mancos Shale (middle to upper Cretaceous), and Dakota sandstone (lower to middle Cretaceous); see Rawling, 2004b for distinguishing characteristics of each unit. Most of this stack is not exposed on Nogal Peak quadrangle. Aggregate thickness is about 680 m (Rawling, 2004b) (True green – PC910).

Triassic

TRsr **Santa Rosa Formation (cross section B-B' only)—**Gray to bluish gray limestone and dolomite; unit is not exposed on Nogal Peak quadrangle; estimated thickness ≤45 m; see Rawling, 2004b for distinguishing characteristics (Cool gray 70% - PC1065).

Permian

Pu **Permian rocks, undivided (cross section B-B' only)—**Undivided stack of sedimentary rocks consisting of Grayburg Formation (upper Permian), San Andres Formation (middle to upper Permian), and Yeso Formation (middle Permian); this stack is not exposed on Nogal Peak quadrangle; estimated thickness ≤925 m; see Rawling, 2004b for distinguishing characteristics (Light aqua – PC992).

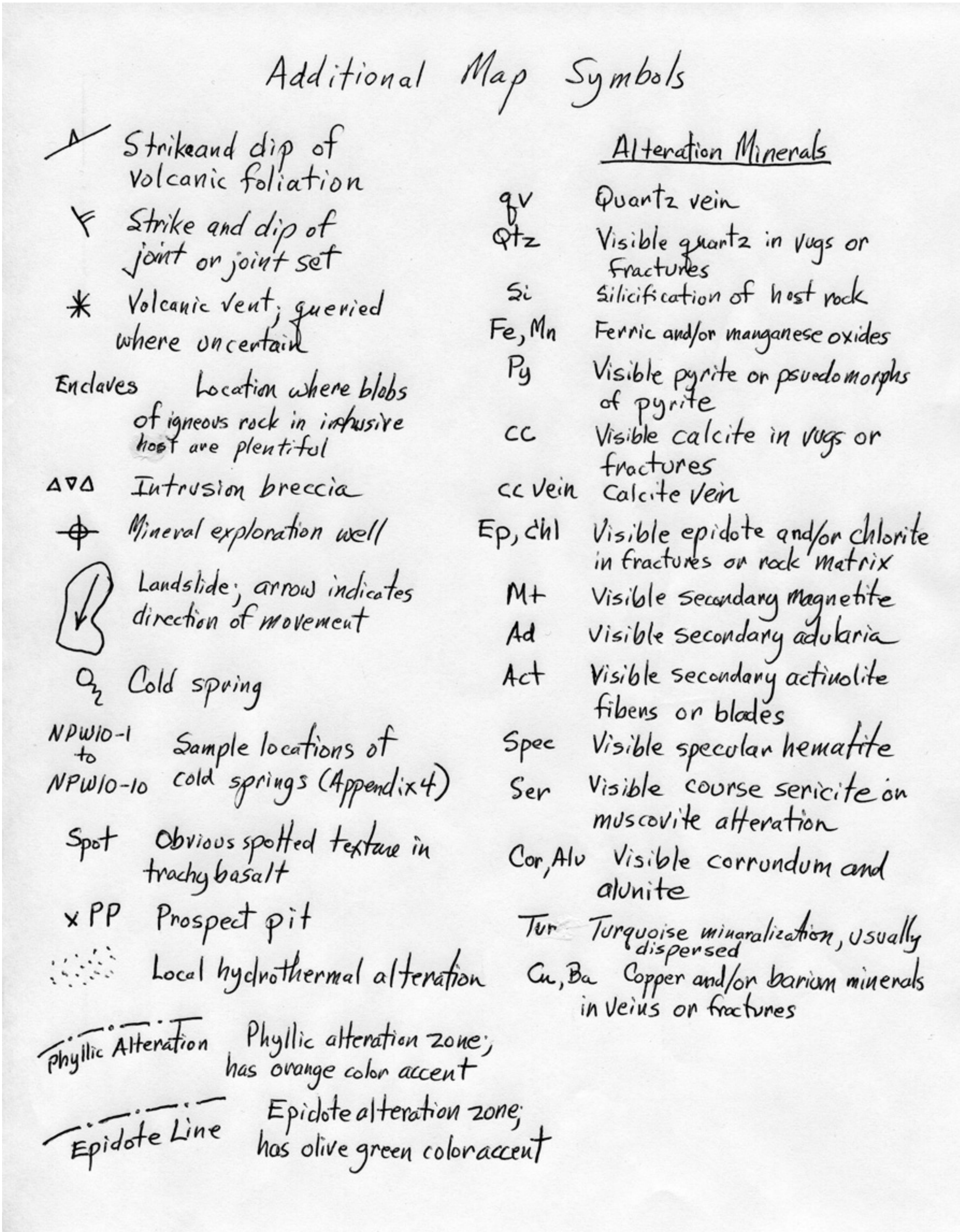

Figure 27: Additional map symbols used for the Nogal Peak quadrangle, Sierra Blanca, New Mexico.

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APPENDIX 1: CHEMICAL ANALYSES OF ROCKS

Table 1a: Representative chemical analyses of volcanic rocks and dikes in the Nogal Peak quadrangle and immediate vicinity; rock names use classification scheme of La Bas et al. (1986). Units in blue are analyses paid for by F. Goff and C.J. Goff in May 2011.

Formation	Walker	Walker	Walker	Walker	Walker	Walker	Walker	Walker	Walker
Rock Unit	Twl	Twb	Twl	Twl	Twtx	Twl	Twl	Twsc	Twas
Gen location	Unit 2, Fig. 6	McIvar Can	Brushy Can	Nogal Can	Goat Can	SE Spg Can	Tanbark Can	Upper Spg Can	Argentina Spg
Sample no.	17	F10-41	F09-156	FA2	F09-162a	F10-44	FA1	F10-43	F10-37
Type	Lava breccia	Lava clast, bx	Porph lava	Lava	Plag-phyr lava	Spotted lava	Lava	Aphyric lava	Welded tuff
Easting	nr	418845	418449	nr	420705	420969	nr	421692	422208
Northing	nr	3703815	3697321	nr	3699235	3702664	nr	3703328	3704970
Data source	T(72)	ALS	ALS	D&C(94)	ALS	ALS	D&C(94)	ALS	ALS
Rock Name	(Alkali) Basalt	Basaltic	(Alkali) Basalt	(Alkali) Basalt	Basaltic	Trachybasalt	(Altered)	Trachydacite	Rhyolite
		Trachyandesite			Trachyandesite		Trachyandesite		welded tuff
Major Elements (Wt-%, normalized to 100%)									
SiO2	46.8	54.1	47.9	49.5	50.5	48.7	55.1	62.6	74.8
TiO2	1.5	0.86	1.33	1.57	1.38	2.07	1.51	1.02	0.52
Al2O3	17.9	19.7	18.3	21.0	21.4	17.4	17.6	19.4	13.9
Fe2O3	12.0	7.37	10.9	10.8	8.83	11.3	8.11	4.29	2.24
MnO	0.14	0.10	0.15	0.16	0.16	0.15	0.17	0.07	0.05
MgO	8.0	2.20	4.70	3.94	2.54	4.59	4.17	0.51	0.29
CaO	9.6	7.65	11.9	7.20	6.92	8.63	4.92	2.50	0.79
Na2O	2.86	5.84	3.02	3.98	5.25	4.39	4.08	5.82	3.34
K2O	0.99	1.56	1.26	0.96	1.79	1.32	3.65	3.44	3.97
P2O5	na	0.57	0.58	0.86	1.23	1.41	0.64	0.41	0.14
Total	**99.79**	**99.97**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.1**	**100.0**
LOI	na	3.58	4.50	3.54	4.04	4.33	2.25	3.07	3.18
C	na	0.31	0.48	na	0.10	0.17	nr	0.09	0.06
S	na	0.03	0.02	na	0.01	<0.01	nr	<0.01	0.03
Na2O + K2O	3.85	7.40	4.28	4.94	7.05	5.71	7.73	9.26	7.31

Data Source: ALS Laboratory Group, Reno NV; B(77) = Black (1977); D&C(94) = Douglas and Campbell (1994); T(72) = Thompson (1972); De la Rochce (1980)

Table 1a. Continued

Formation	Walker	Walker	Walker	Walker	Walker	Nogal Peak	Nogal Peak	Nogal Peak	Rialto?
Rock Unit	Twfa	Twap	Twsp	Twb	Twbn	Tnt	Tnt	Tnt	Tbtd
Gen location	N. Argen. Spg	Argentina Peak	Spring Point	Unknown	Hill 9500	Hill 9500	Unit 37	Unit 38 matrix	SW Argentina Pk
Sample no.	NPQ-004	F10-39	F10-40	G-E	F27-11	F11-26	F10-51	63	F10-36
Type	Aphyric lava	Med-gd lava	Aphyric lava	Breccia matrix	Basalt lava	Trachytic lava	Porph lava	Lava	Porph dike
Easting	422385	422016	421566	nr	424622	424585	425877	nr	421665
Northing	3704903	3704110	3702246	nr	3705826	3705748	3706357	nr	3703472
Data source	ALS	ALS	ALS	T(72)	ALS	ALS	ALS	T(72)	ALS
Rock Name	Trachydacite	Basaltic	Trachyandesite	Trachyandesite	(Altered)	(Altered)	(Altered)	(Altered)	Trachydacite to
		Trachyandesite			(Alkali) Basalt	Trachydacite	Trachyandesite	Trachydacite	(Alkali) Rhyolite
Major Elements (Wt-%, normalized to 100%)									
SiO2	61.1	53.5	56.5	61.1	51.2	67.0	55.8	62.8	68.9
TiO2	0.97	1.37	0.83	1.2	1.73	0.66	1.30	0.8	0.71
Al2O3	18.0	18.9	19.2	17.7	17.9	17.8	19.1	18.6	16.7
Fe2O3	4.87	8.52	6.35	6.37	11.3	3.38	5.93	3.79	3.09
MnO	0.15	0.17	0.19	0.11	0.15	0.25	0.13	0.17	0.09
MgO	0.69	1.02	1.66	1.53	4.27	0.22	1.90	0.24	0.30
CaO	3.83	8.82	5.85	4.89	8.03	0.14	5.58	2.74	1.00
Na2O	5.91	4.28	5.45	4.83	2.78	5.95	7.04	5.10	2.83
K2O	4.11	2.73	3.48	2.26	1.91	4.48	2.70	5.71	6.29
P2O5	0.36	0.77	0.51	nr	0.70	0.09	0.56	nr	0.11
Total	**100.0**	**100.1**	**100.0**	**100.0**	**99.97**	**100.0**	**100.0**	**100.0**	**100.0**
LOI	3.00	5.22	1.86	nr	6.74	2.38	5.60	nr	3.40
C	0.53	0.97	0.22	nr	0.98	0.08	0.98	nr	0.21
S	<0.01	<0.01	<0.01	nr	≤0.01	<0.01	0.01	nr	0.02
Na2O + K2O	10.02	7.01	8.94	7.09	4.69	10.43	9.74	10.81	9.12

Table 1a. Continued

Formation	Three Rivers	Three Rivers	Three Rivers	Three Rivers	Three Rivers
Rock Unit	Tep	Tog	Tcp	Tcpd	Tbrd
Gen location	NW Elk Point	Oak Grove	Cone Peak	Big Bear Can	S of Eagle Crk
Sample no.	F10-71	F09-120	C8	F10-52	F09-118
Type	Por Rhyo Plug	Aphyric lava	Altered plug	Porph dike	Aphyric dike
Easting	422713	429896	424292	425828	429497
Northing	3699411	3695793	3700770	3701568	3695817
Data source	ALS	ALS	B(77)	ALS	ALS
Rock Name	(Alkali) Rhyolite	(Alkali) Rhyolite	(Altered) Rhyolite	(Alkali) Rhyolite	(Alkali) Rhyolite
Major Elements (Wt-%, normalized to 100%)					
SiO2	72.4	72.1	81.1	78.5	69.8
TiO2	0.63	0.37	0.18	0.19	0.68
Al2O3	13.8	15.2	10.6	10.0	16.4
Fe2O3	2.87	1.82	2.6	2.36	1.71
MnO	0.12	0.03	0.006	0.03	0.01
MgO	0.08	0.18	0.18	0.02	0.14
CaO	0.28	0.14	0.018	0.06	0.24
Na2O	5.10	2.18	0.25	0.22	5.71
K2O	4.68	8.01	4.9	8.62	5.24
P2O5	0.10	0.03	0.100	<0.01	0.09
Total	**100.0**	**100.1**	**99.9**	**100.0**	**100.0**
LOI	1.37	2.00	nr	1.00	1.27
C	0.03	0.02	nr	0.03	0.02
S	0.02	<0.01	nr	<0.01	<0.01
Na2O + K2O	9.78	10.19	5.15	8.84	10.95

Table 1b: Representative chemical analyses of plutonic rocks in the Nogal Peak quadrangle and immediate vicinity; rock names use classification scheme of Cox et al. (1979). Units in blue are analyses obtained in May 2011.

Formation	Rialto	Rialto	Rialto	Rialto	Three Rivers	Three Rivers	Three Rivers	Three Rivers	Three Rivers
Rock Unit	Trm	Trsd	Trm	Trm2	Ttsp	Ttsp	Ttsp	Ttsag	Ttcs
Gen location	Nogal Pass	Bonito Crk	S Nogal Crk	Bonito Crk	SW GW Mine	Ski Hill Road	East Buck Mtn	Near W contact	Up Thr Rivers
Sample no.	F10-33	F10-27	S.B. 100	F10-60	S.B. 113	S.B. 2000	F09-107	S.B.C	F09-139
Type	Monzonite	Syenite dike	Monzonite	Qtz Monzonite	Nordmarkite	Nordmarkite	Nordmarkite	Quartz Syenite	Coarse Syenite
Easting	427439	425287	nr	426802	nr	nr	427993	nr	421290
Northing	3706351	3702080	nr	3703218	nr	nr	3695541	nr	3696930
Data source	ALS	ALS	T(72)	ALS	T(72)	T(72)	ALS	T(72)	ALS
Rock Name	Syenite	Syenite	Syenite	Qtz Diorite	Syenite	Syenite	Syenite	Syenite	Syenite
Major Elements (Wt-%, normalized to 100%)									
SiO2	60.5	61.7	64.1	66.1	61.2	64.1	65.7	62.8	64.7
TiO2	0.95	0.50	1.6	0.64	1.2	1.3	0.95	1.2	0.98
Al2O3	17.6	18.4	15.6	16.4	16.1	12.7	16.0	16.4	16.1
Fe2O3	5.63	4.03	4.51	4.32	5.56	5.16	4.01	3.98	4.14
MnO	0.12	0.10	0.14	0.16	0.34	0.18	0.16	0.15	0.20
MgO	1.61	1.02	0.64	1.84	0.36	0.49	0.71	0.59	0.86
CaO	3.07	3.06	3.10	2.93	4.12	4.58	0.83	3.4	1.27
Na2O	6.17	5.79	6.31	4.19	6.07	4.00	6.04	6.62	6.28
K2O	3.96	5.08	4.00	3.18	5.08	7.66	5.37	4.88	5.22
P2O5	0.41	0.29	nr	0.23	nr	nr	0.25	nr	0.28
Total	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.2**	**100.0**	**100.4**	**100.0**
LOI	1.00	1.30	nr	4.37	nr	nr	0.70	nr	0.39
C	0.04	0.02	nr	0.56	nr	nr	0.02	nr	0.02
S	0.01	0.01	nr	0.02	nr	nr	<0.01	nr	0.03
Na2O + K2O	10.13	10.87	10.31	7.37	11.15	11.66	11.41	11.50	11.50
de la Roche, R1	748	745	945	2036	569	887	941	548	719
de la Roche, R2	674	700	641	726	797	762	438	716	494

Table 1b. Continued									
Formation	Three Rivers	Three Rivers	Three Rivers	Three Rivers	Bonito Lake	Bonito Lake	Bonito Lake	Bonito Lake	Bonito Lake
Rock Unit	Ttag	Ttag	Ttag	Ttag	Tbs	Tbs	Tbs	Tbs	Tbs
Gen location	Unknown	Up Thr Rivers	West Buck Mtn	Ski Apache	Unknown	Bonito Crk	Unknown	Unknown	Unknown
Sample no.	S.B. 20	F10-82	F09-105	F09-135	NB-100P	F10-30	NB-60	NB-87	NBD-100D
Type	Equig Alk Gran	Fine Alk Gran	Fine Alk Gran	Med Alk Gran	Syenodiorite	Syenodiorite	Syenite	Syenite	Syenite dike
Easting	nr	422327	426225	426305	nr	430214	nr	nr	nr
Northing	nr	3698259	3696160	3694614	nr	3701882	nr	nr	nr
Data source	T(72)	ALS	ALS	ALS	C(07)	ALS	C(07)	C(07)	C(07)
Rock Name	Alkali Granite	Alkali Granite	Alkali Granite	Alkali Granite	Syenodiorite	Syenodiorite	Syenodiorite	Syenite	Syenodiorite
Major Elements (Wt-%, normalized to 100%)									
SiO2	68.3	71.0	71.3	75.2	55.6	58.6	60.1	62.7	56.3
TiO2	0.89	0.54	0.75	0.48	1.11	1.25	0.89	0.71	1.01
Al2O3	15.5	15.0	15.1	11.0	16.4	17.8	17.5	16.8	16.1
Fe2O3	3.59	2.51	1.21	3.82	9.70	5.88	6.05	5.90	10.52
MnO	0.14	0.11	0.01	0.11	0.14	0.11	0.11	0.12	0.13
MgO	0.61	0.13	0.04	0.13	3.13	2.10	1.44	1.04	2.63
CaO	0.45	0.21	0.22	0.15	5.52	4.43	3.68	2.02	4.47
Na2O	5.23	4.54	0.86	4.02	4.81	5.37	5.14	5.51	5.00
K2O	5.33	5.81	10.34	5.00	2.93	4.02	4.24	4.95	3.36
P2O5	nr	0.11	0.13	0.02	0.51	0.46	0.32	0.24	0.46
Total	**100.0**	**100.0**	**100.0**	**100.0**	**99.9**	**100.0**	**99.9**	**100.0**	**100.0**
LOI	nr	0.90	0.60	0.70	0.15	0.79	0.05	tr	tr
C	nr	0.03	0.04	0.02	nr	0.01	nr	nr	nr
S	nr	<0.01	<0.01	<0.01	nr	<0.01	nr	nr	nr
Na2O + K2O	10.56	10.35	11.20	9.02	7.74	9.39	9.38	10.46	8.36
de la Roche, R1	1410	1670	1968	2292	1024	856.5	993	884	890
de la Roche, R2	390	323	321	238	902	916.8	803	593	922

Table 1c: Trace element analyses for some of the volcanic rocks in Table 1 compared with various rock standards and the Bandelier Tuff. Units in blue are analyses paid for by F. Goff and C.J. Goff in May 2011.
Data sources: ALS = ALS Laboratory Group, Reno, NV; G(04) = J. Gill website, 2004; G(11) = F. Goff, unpub. data, 2011; USGS = US Geological Survey rock standards website, 2011.

Formation	Walker	Waker	Walker	Walker	Walker	Walker	Walker	Walker	Walker	Nogal Peak	Nogal Peak	Rialto?	Three Rivers	Three Rivers
Rock Unit	Twb	Twl	Twtx	Twl	Twsc	Twas	Twap	Twsp	Twfa	Tnt	Tnt	Tbtd	Tbrd	Tog
Gen location	McIver Can	Brushy Can	Goat Can	SE Spg Can	Upper Spg Can	Argentina Spg	Argentina Peak	Spring Point	N. Argen. Spg	Unit 37	Hill 9500	SW Argentina Pk	S of Eagle Crk	Oak Grove
Sample no.	F10-41	F09-156	F09-162a	F10-44	F10-43	F10-37	F10-39	F10-40	NPQ-004	F10-51	F11-26	F10-36	F09-118	F09-120
Type	Lava clast, bx	Porph lava	Plag-phyr lava	Spotted lava	Aphyric lava	Welded tuff	Med-gd lava	Aphyric lava	Aphyric lava	Porph lava	Trachytic lava	Porph dike	Aphyric dike	Aphyric lava
Easting	418845	418449	420705	420969	421692	422208	422016	421566	422385	425877	424585	421665	429497	429896
Northing	3703815	3697321	3699235	3702664	3703328	3704970	3704110	3702246	3704903	3706357	3705748	3703472	3695817	3695793
Data source	ALS	ALS	ALS	ALS	ALS	ALS	ALS	ALS	ALS	ALS	ALS	ALS	ALS	ALS
Rock Name	Basaltic	(Alkali) Basalt	Basaltic	Trachybasalt	Trachydacite	Rhyolite	Basaltic	Trachyandesite	Trachyandesite	(Altered)	(Altered)	Trachydacite to	(Alkali) Rhyolite	(Alkali) Rhyolite
	Trachyandesite		Trachyandesite				Trachyandesite			Trachyandesite	Trachydacite	(Alkali) Rhyolite		
Trace Elements (ppm, not normalized, arranged by interest group)														
Petrologic Elements														
Ba	1120	773	1240	1315	1765	1775	1160	1125	1930	1200	418	1785	634	251
Co	13	31	22	24	1	2	21	6	1	10	2	2	2	<1
Cr	<10	90	20	<10	<10	<10	<10	<10	<10	<10	<10	<10	20	<10
Cs	0.43	0.30	1.26	6.71	1.14	0.68	1.22	1.21	1.99	0.68	1.1	1.33	0.97	2.78
Ga	16.9	20.5	20.1	20.8	21.6	14.3	22.3	20.7	22.7	21.2	26.1	21.9	27.0	26.5
Hf	3.5	3.4	4.1	4.6	8.2	8.4	5.9	6.4	8.0	6.8	13.1	13.6	20.1	15.3
Nb	17.7	19.5	53.1	40.9	45.1	43.7	34.9	38.5	51.5	59.1	153	90.4	97.3	105.5
Ni	4	27	15	<1	<1	<1	3	<1	<1	<1	<1	<1	2	1
Rb	25.9	22.1	40.2	17.1	93.5	80.3	69.2	99.8	106	56.4	110	161	157	292
Sr	1595	1130	1710	1475	900	355	938	914	1130	832	351	319	103	99.7
Ta	0.8	1.1	2.7	2.2	2.8	2.5	2.0	2.4	2.9	4.1	8.1	5.5	5.8	7.3
Th	8.05	5.59	11.6	8.03	13.8	15.2	8.28	9.59	14.6	14.4	28.8	37.0	29.4	38.9
U	1.07	1.11	2.26	1.65	2.64	2.97	2.41	2.40	3.25	3.86	6.94	8.32	8.47	12.8
V	179	72	<5	281	48	14	176	63	30	53	32	35	33	155
Zr	135	134	179	189	306	358	245	262	324	283	568	612	855	548
Rare Earth Elements (arranged by increasing atomic number)														
Y	18.7	16.7	18.1	28.7	31.3	41.5	26.2	21.5	41.5	20.0	34.8	23.2	38.8	43.1
Ce	80.1	65.9	119.5	116.5	124.5	129	101	95.3	152	106.5	197	141	70.9	128.5
La	44.6	33.7	64.8	58.8	68.4	71.8	52.9	50.1	80.1	60.8	118	79.1	60.5	77.8
Pr	9.14	8.18	13.5	13.7	14.4	15.3	12.2	11.4	16.7	11.6	20.4	14.2	11.5	15.8
Nd	34.8	36.4	53.4	55.3	58.2	52.4	45.4	45.9	63.2	45.2	64.1	45.3	40.1	58.1
Sm	6.06	7.29	8.79	10.2	10.1	9.35	8.21	8.19	10.9	7.78	9.69	7.04	7.57	10.0
Eu	1.81	2.05	2.46	3.08	2.54	1.97	2.46	2.19	2.94	2.10	1.62	1.62	1.42	1.05
Gd	4.63	6.60	8.08	8.07	9.31	6.59	6.18	7.68	8.06	7.46	5.00	4.05	6.36	9.64
Tb	0.64	0.81	0.93	1.10	1.23	1.09	0.90	0.95	1.29	0.92	0.98	0.69	1.10	1.40
Dy	3.55	3.98	4.29	5.76	6.43	6.72	4.98	4.72	7.22	4.49	5.94	4.06	6.72	7.64
Ho	0.64	0.64	0.68	1.09	1.14	1.41	0.96	0.79	1.45	0.74	1.16	0.79	1.41	1.43
Er	1.77	1.77	2.02	2.70	3.59	4.28	2.55	2.41	4.15	2.18	3.31	2.34	4.09	4.45
Tm	0.24	0.22	0.26	0.41	0.53	0.67	0.38	0.32	0.59	0.29	0.57	0.36	0.63	0.72
Yb	1.48	1.50	1.78	2.20	3.59	4.51	2.36	2.25	3.90	2.06	3.54	2.38	4.12	5.19
Lu	0.25	0.20	0.23	0.33	0.49	0.74	0.38	0.30	0.63	0.26	0.55	0.40	0.67	0.70
Pathfinder Elements, Mineral Exploration														
Ag	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
As	0.1	<0.1	<0.1	0.7	0.4	0.4	4.2	0.4	1.7	0.2	0.7	0.8	0.4	0.8
Bi	0.11	0.03	0.01	0.02	0.01	0.11	0.03	0.05	0.03	0.02	0.08	0.05	0.40	0.30
Cd	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Cu	11	31	79	23	2	3	14	1	1	<1	3	8	3	2
Hg	0.01	0.007	<0.005	0.007	<0.005	0.01	0.005	<0.005	0.008	<0.005	0.007	0.007	0.005	<0.005
Mo	<1	<1	<1	1	1	<1	2	2	2	<1	1	2	4	<1
Pb	11	6	10	9	13	10	21	11	11	10	14	23	19	27
Sb	0.05	<0.05	<0.05	0.06	<0.05	<0.5	0.09	<0.05	0.14	<0.05	0.18	0.13	0.11	0.46
Se	0.30	0.4	0.5	0.6	0.5	0.3	0.5	0.4	0.6	0.3	<0.2	0.3	0.2	0.3
Sn	1	1	2	1	2	3	1	2	2	1	3	2	4	4
Te	0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01
Tl	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	0.5	0.8	1.2
W	2.00	2	2	4	2	2	2	2	2	2	2	9	7	4
Zn	51	73	81	97	67	37	116	83	89	74	63	86	31	78

Table 1c: Continued								
Formation	Three Rivers	Three Rivers	Standard	Standard	Standard	Standard	Bandelier Tuff	
Rock Unit	Tep	Tcpd						
Gen location	NW Elk Point	Big Bear Can	Bridal Veil, OR	Lake Co. OR	Lake Co. OR	Glass Mtn, CA	Valles caldera, NM	
Sample no.	F10-71	F10-52	BCR-1	AGV-2	QLO-1	RGM-1	F09-14	
Type	Por Rhyo Plug	Porph dike	Basalt	Andesite lava	Qtz latite lava	Obsidian	Ignimbrite	
Easting	422713	425828						
Northing	3699411	3701568						
Data source	ALS	ALS	G(04) & USGS	G(04) & USGS	USGS	G(04) & USGS	G (2011)	
Rock Name	(Alkali) Rhyolite	(Alkali) Rhyolite	Basaltic andesite	Andesite	Trachydacite	Rhyolite	Rhyolite tuff	
Trace Elements (ppm, not normalized, arranged by interest group)								
Petrologic Elements								
Ba	190	53.2	687	1140	1370	831	733	Ba
Co	<1	1	39	16	7.2	2.1	2.9	Co
Cr	<10	40	9	17	3.2	4.9	10	Cr
Cs	6.24	1.85	0.99	1.16	1.8	10.5	1.72	Cs
Ga	24.9	24.8	23	20		15	23.1	Ga
Hf	20.0	28.1	4.86	5		5.81	10	Hf
Nb	90.6	156.5	13.1	15	10	9.57	35.5	Nb
Ni	<1	<1	12	19		3.7	5	Ni
Rb	163	498	48	68	74	155	73.7	Rb
Sr	80.7	26.3	326	655	340	102	204	Sr
Ta	5.8	9.7	0.795	0.88	0.82	0.97	2.1	Ta
Th	29.2	48.7	6.19	6.1	4.5	15.1	9.57	Th
U	5.14	14.1	1.68	1.89	1.9	5.56	2.5	U
V	57	<5	401	120	54	12	19	V
Zr	846	915	201	244	185	241	461	Zr
Rare Earth Elements (arranged by increasing atomic number)								
Y	50.6	64.7	39	21	24	25	30	Y
Ce	234	73.7	53.3	68	54	47	121	Ce
La	115	26.6	25.5	38	27	24	65.9	La
Pr	23.0	4.9	6.88	8.23		5.33	13.2	Pr
Nd	84.5	16.2	28.8	30.3	26	19	45.1	Nd
Sm	14.5	3.66	6.6	5.51	4.9	4.30	8.03	Sm
Eu	2.12	0.41	1.89	1.54	1.43	0.66	1.23	Eu
Gd	14.4	4.00	6.69	4.69		3.7	7.22	Gd
Tb	1.99	0.91	1.07	0.66	0.71	0.61	1.07	Tb
Dy	10.7	7.40	6.35	3.55	3.8	4.1	5.51	Dy
Ho	1.97	1.89	1.32	0.69		0.769	1.13	Ho
Er	6.03	6.64	3.67	1.86	2.3	2.33	3.14	Er
Tm	0.94	1.17	0.53	0.26	0.37	0.37	0.46	Tm
Yb	6.43	8.62	3.35	1.65	2.3	2.6	2.94	Yb
Lu	0.88	1.43	0.50	0.25	0.37	0.40	0.48	Lu
Pathfinder Elements, Mineral Exploration								
Ag	<0.5	<0.5		0.078	0.064	0.11	<1	Ag
As	0.6	1.3		0.88	3.50	3.0	0.7	As
Bi	0.14	0.25		0.057			0.06	Bi
Cd	<0.5	<0.5		0.069			nr	Cd
Cu	1	8	19	60	29	12	<5	Cu
Hg	0.006	0.009		0.02			0.011	Hg
Mo	<1	1	248	2.7	2.6	2.3	2	Mo
Pb	49	12	13.2	36	20	24	15	Pb
Sb	0.58	0.28		4.3		1.3	0.14	Sb
Se	0.3	<0.2		nr			0.2	Se
Sn	3	7		4.2	2.3		1	Sn
Te	<0.01	0.02		nr			0.01	Te
Tl	<0.5	2.6		0.34			<0.5	Tl
W	24	14		0.55	0.58	1.5	3	W
Zn	94	20	127	88	61	32	64	Zn

Table 1d: Trace element analyses for some of the intrusive rocks in Table 1 compared with various rock standards. Data Sources: Same as Table 1c except C(07) = Constanopoulis (2007). Units in blue are analyses paid for by F. Goff and C.J. Goff in May 2011.

Formation	Rialto	Rialto	Rialto	Bonito Lake	Bonito Lake	Bonito Lake	Bonito Lake	Bonito Lake
Rock Unit	Trm	Trm	Trm2	Tbs	Tbs	Tbs	Tbs	Tbs
Gen location	Nogal Pass	Bonito Crk	Bonito Crk	Unknown	Bonito Crk	Unknown	Unknown	Unknown
Sample no.	F10-33	F10-27	F10-60	NB-100P	F10-30	NB-60	NB-87	NBD-100D
Type	Monzonite	Monzon dike	Qtz Monzonite	Syenodiorite	Syenodiorite	Syenite	Syenite	Dike
Easting	427439	425287	426802	nr	430214	nr	nr	nr
Northing	3706351	3702080	3703218	nr	3701882	nr	nr	nr
Data source	ALS	ALS	ALS	C(07)	ALS	C(07)	C(07)	C(07)
Rock Name	Syenite	Syenite	Tonalite	Syenodiorite	Syenodiorite	Syenodiorite	Syenite	Syenodiorite
Trace Elements (ppm, not normalized, arranged by interest group)								
Petrologic Elements								
Ba	1375	1265	1390	1440	1535	1550	1240	1390
Co	12	6	<1	20.5	11	8.25	7.84	20.1
Cr	10	<10	40	96.9	10	37.7	45.5	134
Cs	0.74	4.49	2.28	0.612	1.56	2.12	1.18	0.776
Ga	22.1	22.6	20.0		21.6			
Hf	7.1	11.5	3.4	3.67	7.6	7.97	18.1	7.95
Nb	38.4	40.0	14.2	58	63.4	83	116	80
Ni	8	<1	20	53.3	9	32.0	<9	50.6
Rb	81.5	162	57.4	56	86.2	110	107	102
Sr	887	689	337	852	864	817	479	803
Ta	2.7	2.6	1.1	2.81	3.5	3.81	5.75	4.01
Th	11.6	31.0	7.23	10.8	15.0	17.3	30.8	22.9
U	4.19	7.86	2.05	2.7	4.5	4.9	5	10.0
V	73	58	54		118			
Zr	287	556	122	110	332	322	740	339
Rare Earth Elements (arranged by increasing atomic number)								
Y	20.1	16.7	8.1	tr	20.7	28	11	tr
Ce	101.5	86.4	45.3	100	124	115	106	117
La	62.7	51.3	26.4	58.9	69.6	68.1	69.6	72.8
Pr	10.6	9.12	4.88		13.5			
Nd	39.4	34.7	18.7	38.0	45.5	40.8	41.5	41.0
Sm	6.58	6.21	3.16	6.70	7.24	6.83	6.07	6.91
Eu	1.82	1.93	0.93	1.94	2.18	1.95	1.51	1.70
Gd	6.71	5.57	3.12	4.81	4.91	5.13	4.83	4.53
Tb	0.79	0.66	0.38	0.641	0.73	0.70	0.677	0.578
Dy	4.05	3.37	1.81		4.02			
Ho	0.71	0.57	0.29		0.77			
Er	2.16	1.81	0.86		2.01			
Tm	0.30	0.28	0.12		0.29			
Yb	2.13	2.15	0.82	1.80	1.83	2.41	2.80	2.34
Lu	0.28	0.29	0.11	0.22	0.30	0.35	0.43	0.35
Pathfinder Elements								
Ag	<0.5	<0.5	<0.5		0.5			
As	2.3	1.5	0.1	4.25	0.7	3.29	2.61	5.94
Bi	0.52	0.15	0.12		0.11			
Cd	<0.5	<0.5	<0.5		<0.5			
Cu	82	6	1		24			
Hg	<0.005	<0.005	<0.005		0.01			
Mo	2	1	<1		10			
Pb	23	25	14		17			
Sb	0.10	<0.05	<0.05	1.33	0.07	0.916	1.06	2.56
Se	0.4	0.2	0.2	5.29	0.3	6.78	9.75	7.00
Sn	2	1	1		1			
Te	0.11	<0.01	<0.01		<0.01			
Tl	<0.5	<0.5	<0.5		<0.5			
W	5	2	2	3.67	8	1.80	<4.5	2.78
Zn	77	56	123	54.9	71	59.1	62.9	50.8

Table 1d: Continued									
Formation	Three Rivers	Three Rivers	Three Rivers	Three Rivers	Three Rivers	Standard	Standard	Standard	Bandelier Tuff
Rock Unit	Ttcs	Ttsp	Ttag	Ttag	Ttag				
Gen location	Up Thr Rivers	East Buck Mtn	Up Thr Rivers	West Buck Mtn	Ski Apache	Bridal Veil, OR	Silver Plume, CO	Glass Mtn, CA	Valles caldera, NM
Sample no.	F09-139	F09-107	F10-82	F09-105	F09-135	BCR-1	GSP-2	RGM-1	F09-14
Type	Coarse Syenite	Nordmarkite	Med Alk Gran	Fine Alk Gran	Med Alk Gran	Basalt	Granodiorite	Obsidian	Ignimbrite
Easting	421290	427993	422327	426225	426305				
Northing	3696930	3695541	3698259	3696160	3694614				
Data source	ALS	ALS	ALS	ALS	ALS	G(04) & USGS	USGS	G(04) & USGS	G (2011)
Rock Name	Syenite	Syenite	Alkali Granite	Alkali Granite	Alkali Granite	Basaltic andesite	Granodiorite	Rhyolite	Rhyolite tuff
Trace Elements (ppm, not normalized, arranged by interest group)									
Petrologic Elements									
Ba	1580	1290	389	507	29.2	687	1340	831	733
Co	1	<1	1	<1	<1	39	7.3	2.1	2.9
Cr	<10	<10	<10	10	<10	9	20	4.9	10
Cs	1.49	0.83	1.47	2.24	0.61	0.99	1.2	10.5	1.72
Ga	29.6	29.2	26.7	29.1	36.0	23	22	15	23.1
Hf	16.5	18.1	18.4	24.6	68.3	4.86	14	5.81	10
Nb	82.2	85.9	98.9	113	376	13.1	27	9.57	35.5
Ni	<1	<1	<1	<1	<1	12	17	3.7	5
Rb	115	121	224	528	282	48	245	155	73.7
Sr	91	52.4	59.0	21.3	12.9	326	240	102	204
Ta	4.8	5.2	6.5	7.5	20.5	0.795		0.97	2.1
Th	20.5	21.8	47.2	42.5	41.7	6.19	105	15.1	9.57
U	4.6	5.3	9.21	9.77	28.9	1.68	2.40	5.56	2.5
V	66	136	50	7	60	401	52	12	19
Zr	725	738	715	991	2850	201	550	241	461
Rare Earth Elements (arranged by increasing atomic number)									
Y	52.0	48.8	41.1	57.8	97.1	39	28	25	30
Ce	218	223	215	248	151	53.3	410	47	121
La	96.1	106	93.8	119	68.7	25.5	180	24	65.9
Pr	23.2	23.1	19.7	25.0	14.9	6.88	51	5.33	13.2
Nd	91.3	88.3	70.0	90.8	51.7	28.8	200	19	45.1
Sm	16.1	15.8	11.7	15.4	10.9	6.6	27	4.30	8.03
Eu	3.78	3.42	1.18	2.34	0.82	1.89	2.3	0.66	1.23
Gd	15.7	15.1	11.6	14.90	11.8	6.69	12	3.7	7.22
Tb	2.09	2.00	1.59	2.04	2.25	1.07		0.61	1.07
Dy	11.3	10.8	9.00	11.35	16.6	6.35	6.1	4.1	5.51
Ho	1.97	1.92	1.63	2.11	3.42	1.32	1.0	0.769	1.13
Er	5.99	5.83	5.54	6.89	11.3	3.67	2.2	2.33	3.14
Tm	0.9	0.85	0.92	1.44	1.86	0.53	0.29	0.37	0.46
Yb	6.02	5.99	6.31	7.88	12.7	3.35	1.6	2.6	2.94
Lu	0.80	0.84	0.85	1.09	1.80	0.50	0.23	0.40	0.48
Pathfinder Elements, Mineral Exploration									
Ag	<0.5	<0.5	<0.5	<0.5	<0.5			0.11	<1
As	0.5	0.8	0.2	1.5	0.2			3.0	0.7
Bi	0.11	0.12	0.25	0.18	0.19				0.06
Cd	<0.5	<0.5	<0.5	<0.5	<0.5				nr
Cu	1	1	3	3	5	19	43	12	<5
Hg	<0.005	<0.005	<0.005	<0.005	<0.005				0.011
Mo	3	<1	1	5	1	248	2.1	2.3	2
Pb	23	22	29	27	17	13.2	42	24	15
Sb	<0.05	<0.05	<0.05	0.18	<0.05			1.3	0.14
Se	0.7	0.5	0.6	0.3	0.2				0.2
Sn	4	4	5	5	16				1
Te	0.01	<0.01	0.02	<0.01	<0.01				0.01
Tl	<0.5	<0.5	0.5	1.5	<0.5		1.1		<0.5
W	5	2	4	6	5			1.5	3
Zn	86	128	94	23	130	127	120	32	64

APPENDIX 2

APPENDIX 2. Mines, prospects, and deposits in the Nogal mining district, Lincoln County, New Mexico. Mine identification number is from the New Mexico Mines Database (McLemore et al., 2005a, b).

Mine identification number	Mine name	Township	Range	Section	Latitude (Decimal Degrees)	Longitude (Decimal Degrees)	UTM easting	UTM northing
NMLI0132	American	9S	12E	13	33.5277778	-105.7425	431052	3709853
NMLI0291	Area A	10S	13E	32	33.396129	-105.815587	424150	3695307
NMLI0336	Area B	10S	11E	20	33.4271079	-105.821887	423592	3698747
NMLI0338	Area C	10S	11E	24	33.4217912	-105.757363	429586	3698112

Mine identification number	Mine name	Township	Range	Section	Latitude (Decimal Degrees)	Longitude (Decimal Degrees)	UTM easting	UTM northing
NMLI0337	Area D	10S	11E	35	33.4001756	-105.777714	427676	3695730
NMLI0280	Argentine	10S	11E	4	33.46806	-105.802538	425425	3703273
NMLI0279	Bailey	10S	11E	3	33.470348	-105.79589	426045	3703522
NMLI0290	Blue Jay	10S	13E	29	33.418519	-105.705376	434417	3697715
NMLI0008	Bonito	10S	11E	4, 9	33.461219	-105.80645	425056	3702517
NMLI0335	Capitan Horn	10S	11E	16	33.4409194	-105.804911	425182	3700266
NMLI0134	Christmas	10S	11E	12	33.4574736	-105.751715	430140	3702064
NMLI0126	Cougar	9S	11E	23	33.5086111	-105.763611	429076	3707742
NMLI0274	Creek Lead	10S	13E	7	33.458655	-105.721771	432923	3702175
NMLI0285	Crow	10S	9E	3	33.47285	-105.784322	427122	3703791
NMLI0331	Dry Gulch	9S	13E	7	33.5396736	-105.726200	432575	3711161
NMLI0334	EPS-1	10S	11E	8	33.4592951	-105.825524	423282	3702318
NMLI0135	EPS	10S	11E	8	33.456958	-105.825557	423,277.1	3,702,059
NMLI0207	Great Western	10S	11E	15	33.446729	-105.784907	427046	3700896
NMLI0283	Greenville	10S	11E	10	33.45808	-105.786977	426863	3702155
NMLI0020	Helen Rae-American	9S	12E	12, 13	33.5299907	-105.744172	430899	3710099
NMLI0125	Hope	10S	13E	1	33.4619444	-105.733333	431852	3702548
NMLI0333	Hyperion	10S	11E	9	33.4616355	-105.804064	425279	3702562
NMLI0292	Jenny Linn	11E	10S	34	33.489351	-105.783432	427219	3705620
NMLI0030	Maud	10S	11E	3	33.462813	-105.793797	426233	3702685
NMLI0127	Mayberry	10S	13E	5	33.4680556	-105.705	434489	3703207
NMLI0275	McCrory	11S	13E	5, 6	33.3858541	-105.712485	433732	3694098
NMLI0140	Michigan	9S	12E	12	33.5389529	-105.743415	430976	3711092
NMLI0124	Mineral Farms	10S	13E	6	33.4615595	-105.726523	432484	3702500
NMLI0128	Monte Carlo Montezuma	9S	11E	33	33.483504	-105.809242	424816	3704990
NMLI0273	Old Abe	10S	11E	3	33.473801	-105.793297	426289	3703903
NMLI0277	Old Red Fox	9S	11E	34	33.485566	-105.794935	426147	3705208
NMLI0271	Parsons	9S	11E	34, 35	33.489689	-105.780701	427473	3705655

Mine identification number	Mine name	Township	Range	Section	Latitude (Decimal Degrees)	Longitude (Decimal Degrees)	UTM easting	UTM northing
NMLI0272	Renowned	3	10S	11E	33.472881	-105.786728	426899	3703796
NMLI0121	Rialto	9S	11E	27	33.4952778	-105.782777	427284	3706277
NMLI0289	Rock	10S	12E	13	33.444227	-105.744005	430846	3700590
NMLI0293	Rockford	9S	12E	13, 24	33.518063	-105.739038	431366	3708773
NMLI0136	Shikeys Shyster	10S	11E	9	33.439,211,4	-105.806863	424,999	3,700,078
NMLI0139	Silver King	9S	11E	34	33.480449	-105.78543	427026	3704634
NMLI0286	Silver Nugget	10S	9E	1	33.467141	-105.751744	430145	3703136
NMLI0044	Silver Plume	10S	13E	31	33.400111	-105.711083	433872	3695678
NMLI0287	Silver Spoon	10S	9E	8	33.460955	-105.817068	424069	3702496
NMLI0288	Soldier	10S	9E	12	33.46062	-105.745894	430683	3702409
NMLI0047	Spur	10S	11E	3	33.469209	-105.787788	426797	3703390
NMLI0137	Stonewall Jackson	9S	11E	33	33.483013	-105.814158	424359	3704939
NMLI0138	T-Claim	9S	11E	28	33.492736	-105.811958	424572	3706016
NMLI0282	unknown	10S	11E	2	33.472064	-105.778247	427686	3703700
NMLI0061	unknown	9S	11E	27	33.503389	-105.77744	427787	3707172
NMLI0133	unknown	9S	12E	13	33.5272222	-105.74222	431078	3709791
NMLI0332	unknown	9S	12E	25	33.4917873	-105.73653	431578	3705859
NMLI0068	Vera Cruz	13E	8S	17	33.605713	-105.69992	435064	3718465
NMLI0281	Washington	10S	11E	2	33.468227	-105.76897	428545	3703268
NMLI0276	Waterdog	10S	12E	1	33.47494	-105.74935	430373	3703999
NMLI0278	White Swan	10S	11E	3	33.468729	-105.79111	426487	3703339
NMLI0284	Willis	10S	9E	4	33.474167	-105.80051	425618	3703949
NMLI0141	Yours Truly	10S	11E	13	33.445,116,5	-105.74854	430,425	3,700,692

Mine identification number	Commodities produced	Commodities present not produced	Host formation	Type of deposit	USGS quadrangle
NMLI0132	Au, Ag, Cu, Pb, Zn		Walker Andesite	vein	Nogal
NMLI0291		Mo	Three Rivers stock	porphyry Mo-Cu	Nogal Peak
NMLI0336		Mo	Three Rivers stock	porphyry Mo-Cu	Nogal Peak

Mine identification number	Commodities produced	Commodities present not produced	Host formation	Type of deposit	USGS quadrangle
NMLI0338		Mo	Three Rivers stock	porphyry Mo-Cu	Nogal Peak
NMLI0337		Mo	Three Rivers stock	porphyry Mo-Cu	Nogal Peak
NMLI0280	Au, Ag, Pb, Zn	Cu		vein	Nogal Peak
NMLI0279		Au, Ag		vein	Nogal Peak
NMLI0290		Au, Ag	Bonita stock	vein	Angus
NMLI0008		Mo, Ag, Au, Cu, U	Sierra Blanca Volcanics	vein	Nogal Peak
NMLI0335		Au, Ag		vein	Nogal Peak
NMLI0134		Au, Ag		vein	Nogal Peak
NMLI0126		Au, Ag		vein	Church Mountain
NMLI0274		Au, Ag		vein	Angus
NMLI0285	Au, Ag			vein	Nogal Peak
NMLI0331	Au			placer gold	Nogal
NMLI0334		Au, Ag		vein	Nogal Peak
NMLI0135		Au, Ag		vein	Nogal Peak
NMLI0207		Au, Ag	Walker Andesite	breccia pipes	Nogal Peak
NMLI0283		Au, Ag		vein	Nogal Peak
NMLI0020	Au, Ag, Cu, Pb, Zn	U	Walker andesite	vein	Nogal
NMLI0125		Ag		vein	Angus
NMLI0333		Au, Ag		vein	Nogal Peak
NMLI0292	Au, Ag		Rialto stock	breccia pipes	Nogal Peak
NMLI0030		Au, Pb, Ag, U	Sierra Blanca Volcanics	vein	Nogal Peak
NMLI0127		Ag, Pb, Zn		vein	Angus
NMLI0275		Ag, Pb		vein	Angus
NMLI0140		Au, Ag		vein	Nogal
NMLI0124		Au, Pb, Zn		vein	Angus
NMLI0128		Au, Ag		vein	Nogal Peak
NMLI0273	Au, Ag			vein	Nogal Peak
NMLI0277	Pb, Zn	Ag, Mo		vein	Nogal Peak
NMLI0271	Au, Ag	Mo, Pb, turquoise		breccia pipes	Nogal Peak
NMLI0272	Au, Ag			vein	Nogal Peak

Mine identification number	Commodities produced	Commodities present not produced	Host formation	Type of deposit	USGS quadrangle
NMLI0121		Mo, Cu, Au	Rialto stock	porphyry Mo-Cu	Nogal Peak
NMLI0289		Ag, Pb, Cu		vein	Angus
NMLI0293		Au, Ag		vein	Nogal
NMLI0136		Au, Ag		vein	Nogal Peak
NMLI0139		Au, Ag		vein	Nogal Peak
NMLI0286		Au, Ag		vein	Nogal Peak
NMLI0044		Cu, Au, U, Ag	Walker andesite	vein	Angus
NMLI0287		Au, Ag		vein	Nogal Peak
NMLI0288		Ag		vein	Angus
NMLI0047		Au, U, Pb, Zn	andesite	vein	Nogal Peak
NMLI0137		Au, Ag		vein	Nogal Peak
NMLI0138		Au, Ag		vein	Nogal Peak
NMLI0282		Au, Ag		vein	Nogal Peak
NMLI0061		Au, Mo, U	Rialto stock	vein	Church Mountain
NMLI0133		Au, Ag		vein	Nogal
NMLI0332		Au, Ag		vein	Angus
NMLI0068	Au, Ag	Cu	Vera Cruz laccolith, Mesa Verde Group	breccia pipes	Nogal
NMLI0281		Ag, Pb, Zn		vein	Nogal Peak
NMLI0276		Au, Ag, Pb, Te	Bonito stock	breccia pipes	Angus
NMLI0278		Au, Ag		vein	Nogal Peak
NMLI0284		Au, Ag, Cu, Zn		vein	Nogal Peak
NMLI0141		Au, Ag		vein	Angus

APPENDIX 3: X-RAY DIFFRACTION ANALYSES OF ALTERED ROCKS

Appendix 3: Alteration minerals identified by X-ray diffraction (V. Lueth, NMBG&MR).					
Description and Map Unit	**Sample No**	**Location**	**Minerals**	**Notes**	**Reference**
		(UTM NAD 27)			
Blue banded breccia in altered	F09-96	428720	Corrundum, alunite, quartz,	Low-grade saphhire	Segerstrom et al., 1979;
Walker Formation (Thbx)		3700091	lazulite		Goodell et al., 1998
White faulted dike of phase 2	F10-31	427026	Quartz, illite, pyrite		Thompson, 1973
Rialto monzonite (Trm2)		3703861	(kaolinite, Fe,Mn-oxides)		
White breccia pipe in monzonite,	F10-32	429444	Quartz, illite, pyrite	Trace turquoise in	Thompson, 1973;
Parsons Mine (Thbx)		3705652	(kaolinite, Fe-oxides)	breccia	Segerstrom et al., 1979
Pale gray Rialto Monzonite (Trm)	F10-34	427283	Quartz, illite, pyrite		Thompson, 1973
		3706167	(kaolinite, Fe-oxides)		
Vugs in lava flow, Walker	F10-59a	423880	Quartz	No zeolites	
Formation (Twl)		3703599			
Gray groundmass in above flow	F10-59b	same as above	Epidote, chlorite, albite	No zeolites	
Black breccia in roof pendant	F10-61	426567	Cryptomelane	Trace pyrite in	
above TR syenite (Ttsp)		3699864		breccia	
Gray fine-grained fracture fill	F10-87	426567	Hematite, cryptomelane and	No moly; near	Segerstrom et al., 1979
in TR syenite (Ttsag)		3699864	other Fe,Mn-oxides	Lookout Mtn	
Dark brown acicular crystals in	NPC-18	423889	Actinolite		
vug, TR syenite (Ttsag)		3695238			

APPENDIX 4: HYDROGEOCHEMICAL FIELD DATA

Appendix 4: Field data of water samples collected in the Nogal Peak quadrangle for ongoing studies of regional geohydrology.
All samples collected by C.J. Goff and F. Goff; see text for procedures; locations in UTM NAD 27.

Sample	Name (if any)	Date	Location	Elev	Flow	Temp	pH	TDS	ORP	DO	Sp Cond	Comments	Samples
NMBG&MR		(time)		(ft)	(l/min)	(°C)		(mg/l)	(mV)	(mg/l)	(μS/cm2)		
NPW10-01	Unnamed spring at	Oct 11,	425922	7840	≤1	13.3	7	0.924	185	10.16	1.38	Fe, Mn stains;	CH, ^{3}H, D/^{18}O
TB-1058	collapsed mine adit	(4:00 P)	3703456									altered Twl	
NPW10-02	Bluefront Spring	Oct 12,	427083	8615	200	6.1	7.3	0.147	170	13.60	0.225	Contact Ttsp	CH, ^{3}H, D/^{18}O
TB-1059	(lots of watercress)	(12:45 P)	3700097									& Twl	
NPW10-03	Unnamed spring on Trail	Oct 12,	426829	8730	≤1	8	7.0p	nd	nd	nd	nd	Fe stains;	D/^{18}O only
TB-1060	33, Great Western Mine	(2:00 P)	3700441									Altered Twl	
NPW10-04	Washington Spring, from	Oct 13,	427962	7840	1.5	9.75	6.9	0.659	160	10.62	1.012	Altered Twl	CH, ^{3}H, D/^{18}O
TB-1061	dike in ravine	(10:00 A)	3703302									and dikes	
NPW10-05	Unnamed spring by road	Oct 13,	426575	8100	4	10.2	4.3p	nd	nd	nd	nd	Some Fe ppt;	D/^{18}O only
TB-1062	to Great Western Mine	(12:15 P)	3701821									Qal & Twl	
NPW10-06	Ice Spring, in ravine	Oct 14,	424253	11,000	≥60	5.05	6.3	0.052	151	8.67	0.08	From Ttsag	CH, ^{3}H, D/^{18}O
TB-1063	(lots of watercress)	(12:00 P)	3695649										
NPW10-07	Unnamed spring by Ski	Oct 14,	424788	10,650	8	8.03	6.4	nd	nd	nd	nd	From Ttsag	D/^{18}O only
TB-1064	Apache perimeter road	(2:00 P)	3695449										
NPW10-08	Unnamed spring, bottom	Oct 14,	425154	10,380	40	5.27	6.7	nd	nd	nd	nd	From Ttag	D/^{18}O only
TB-1065	of Terrible ski run	(2:30 P)	3695526										
NPW10-09	Unnamed spring near	Oct 14,	425549	10,260	20	4.24	6.4	0.030	157	9.42	0.082	From iron pipe	CH, ^{3}H, D/^{18}O
TB-1066	Sierra Blanca Trail	(3:25 P)	3695460									in hornfelsd Twl	
NPW10-10	Unnamed spring along	Oct 14,	426136	9910	2	5.91	6.2	nd	nd	nd	nd	From Ttag	D/^{18}O only
TB-1067	Sierra Blanca Trail	(4:15 P)	3695424										

Notes: Under sample, the upper number is the field number and the lower number is the NMBG&MR laboratory number.
Under comments, Qal = alluvium, Twl = Walker lava;Ttsp = syenite porphyry; Ttag = alkali granite; Ttsag = quartz syenite.
Under samples, CH = major and trace element chemistry.

APPENDIX 5: THIN SECTION DESCRIPTIONS, NOGAL PEAK QUADRANGLE (by Fraser Goff)

General Comments: Locations use US Geological Survey, Nogal Peak 7.5 minute topographic quadrangle, UTM NAD 27 (1982) and US Forest Service, White Mountain Wilderness map (1988), unless otherwise noted. Textures, petrology and rock names generally follow the examples in Williams et al. (1954). Rock names use classification schemes of Cox et al. (1979) for plutonic rocks and La Bas et al. (1986) for volcanic rocks.

The Sierra Blanca volcanic rocks adjacent to diorite to granite intrusive bodies are too altered to date. Most samples contain chlorite + sericite and/or chlorite + epidote. However, many of the intrusive rocks contain fresh biotite and Kspar and have sparse to abundant zircon. Rock samples that appear to be dateable are flagged in the descriptions.

Abbreviations: Kspar = generic potassium feldspar (variety noted if possible); plag = plagioclase, qtz = quartz, bio = biotite, hbd = hornblende (arfvedsonite noted if possible), opx = orthopyroxene, cpx = clinopyroxene, ol = olivine; mt = magnetite, ilm = ilmenite, ser = sericite, chl = chlorite, cc = calcite, ep = epidote, trem-act = tremolite-actinolite, Fe-oxide = generic low-temperature secondary iron oxide(s).

F09-79a: Bonito Lake syenite w/ aplite vein

Location: 0430310/3702074 Cliff north side of FS 107 near junction with FS 107c.
Relations: Syenite is cut by several types of dikes and veins; intrudes Walker volcanic package
Syenite (Unit Tbs)
Color & Texture: White, slightly salt-n-pepper, medium-grained, hypidiomorphic granular
Primary: Kspar, some with plag cores, many large plag, brown bio, dark green hbd (blue-green pleochroism), minor qtz (2%), rare zircon and sphene
Secondary: Kspar has pervasive qtz-ser alteration; chl pervasive in some mafic minerals
Comments: Similar sample submitted for $Ar^{40/39}$ date (F10-30); also submitted for U-Pb date
Petrographic Name: Altered biotite-hornblende syenite (Syenodiorite, F10-30, Appendix 1)
Aplite (not shown on map; only 15 cm wide)
Color & Texture: White, fine-grained granular
Primary; Kspar, qtz, minor bio, mt, has late stage graphic texture in Kspar-qtz
Secondary: Virtually none
Comments: Bio is dateable
Petrographic Name: Biotite aplite

F09-79b: Bonito Lake syenite dike (Unit Tfsd)

Location: Same as F09-79a
Relations: North-trending dike cuts main syentite body
Color & Texture: Gray-green, fine-grained, hypidiomorphic granular; a few larger, whitish feldspar phenocrysts give rock a "birds eye" texture in hand sample
Primary: Plag, Kspar, cpx, mt; larger feldspars appear rounded
Secondary: Qtz, ser, chl, ep, trem-act, smudgy mt, minor Fe-oxides, no obvious cc; larger cpx altered to chl and act
Petrographic Name: Altered fine-grained syenite

F09-80a: Rialto monzonite, phase 1 (Unit Trm)

Location: 0426386/3702879 Near mouth of Bear Creek
Relations: Intrudes Walker volcanic package
Color & Texture: Greenish gray, medium-grained, hypidiomorphic granular
Primary: Plag, cpx, some Kspar, minor bio and hbd, mt; did not find zircon
Secondary: Highly altered rock: Chl, ep, trem-act, secondary mt and qtz, Fe-oxides

Petrographic Name: Altered diorite (or monzonite?)

<u>F09-82: Nogal Peak trachyte lava</u> (Unit Tnt)
Location: 042541/370652 Summit of Nogal Peak
Relations: Youngest and highest flow in Nogal Peak Trachyte of Thompson (1972, 1973).
Color & Texture: Pale pinkish white, slightly splotchy, slightly porphyritic, trachytic texture
Primary: Plag, cpx, bio, hbd (?), apatite, mt, sparse Kspar (?); cpx looks unusual
Secondary: Contrary to Thompson (1973), this rock is highly altered to chl, qtz-ser, ep, Fe-oxides; silicified groundmass
Comment: See F10-51 below
Petrographic Name: Altered sparsely porphyritic trachydacite

<u>F09-88: Porphyritic trachybasalt lava</u> (Unit Twtx – similar to Goat Canyon lavas, see below)
Location: 042919/370650 Bottom of Nogal Canyon near NE edge of quadrangle
Relations: Part of Walker lava package; intruded by Rialto and Bonito Lake intrusive bodies
Color & Texture: Dark gray, very porphyritic, slightly trachytic
Primary: Large plag, rounded ol replaced by Ti-rich phlogopite, small nepheline (?), need microprobe to verify; groundmass contains small plag, mt, cpx (?)
Secondary: Glass is altered to qtz-ser, contains chl, ep and clay
Comment: Texture resembles F09-162a below
Petrographic Name: Coarse plagioclase-porphyritic trachybasalt

<u>F09-93: Rialto monzonite, phase 1</u> (Unit Trm)
Location: 042566/370364 Bottom of Turkey Canyon near Trail 40
Relations: Intrudes Walker volcanic package
Color & Texture: Greenish-gray, medium- to coarse-grained, hypidiomorphic granular
Primary: Plag, cpx, mt; no obvious apatite or zircon
Secondary: Original minerals are psuedomorphed; ep, cc, chl, qtz-ser; adularia-ep-qtz in veinlets
Major comment: In the field, this sample looks relatively fresh but in thin section it is really "hammered!"
Petrographic Name: Altered monzonite (or syenite?)

<u>F09-102: Three Rivers porphyritic syenite</u> (Unit Tts)
Location: 042741/369465 Hwy 532 about 1 km east of Ski Apache
Relations: Syenite body intrudes Walker volcanic package; locally has enclaves
Color & Texture: Whitish gray, coarse-grained, hypidiomorphic granular
Primary: Big milky Kspar (anorthoclase), interstial qtz and Kspar, some qtz has graphic texture, bio, minor blue-green hbd, mt, ilm; tiny apatite and zircon, no plag
Secondary: Ser on Kspar cleavage, chl, minor ep, qtz-ser, Fe-oxide
Comment: Zircon is dateable
Petrographic Name: Porphyritic biotite quartz syenite

<u>F09-105: Three Rivers alkali granite</u> (Unit Ttag)
Location: 042623/369617 On Trail 25 west of Buck Mountain
Relations: This and similar granite bodies apparently intrude syenite
Color and Texture: Pale light gray, fine-grained, equigranular; almost aplitic
Primary: Sparse small Kspar (anorthoclase) phenocrysts: groundmass of 80% Kspar, interstial qtz, bio, mt, ilm, apatite; zircon, if present, is not obvious; no plag
Secondary: Ser, minor chl, Fe-oxides
Comment: Submitted for $Ar^{40/39}$ date; chemical analysis listed in Appendix 1
Petrographic Name: Biotite (alkali) granite

<u>F09-107: Three Rivers syenite porphyry</u> (Unit Ttsp; equivalent to nordmarkite of Giles and Thompson, 1972; nordmarkite = quartz-bearing alkali syenite, Williams et al., 1954, p. 114)
Location: 0427993/3695541 East flank of Buck Mountain above Hwy 532
Relations: Intrudes Walker volcanic package
Color & Texture: Pinkish gray, porphyritic; granular minerals around large anorthoclase
Primary: Large Kspar (anorthoclase); groundmass of small Kspar, qtz, very minor plag, two types of cpx (one is aegirine), hbd (arfvedsonite), bio, mt, ilm, tiny zircon
Secondary: Sample is amazingly fresh! Very little ser, chl, Fe-oxide
Comment: $Ar^{40/39}$ age on Kspar is 28.95 ± 0.18 Ma; chemical analysis listed in Appendix 1
Petrographic Name: Biotite-arfvedsonite-aegirine syenite porphyry

<u>F09-118: Three Rivers biotite rhyolite dike</u> (Ttbrd)
Location: 0429849/36966650 On 180° bend, Hwy 532
Relations: NE-trending dike cuts main syenite body
Color & Texture: White to pale gray, very fine-grained to aphanitic groundmass, sparsely porphyritic, hyalopilitic texture
Primary: Kspar, sparse but seemingly fresh bio, groundmass qtz and Kspar; Kspar zoned
Secondary: Kspar altered to qtz-ser; groundmass altered to secondary silica, ser, smudgy mt
Comments: Similar dike (F09-116) has $Ar^{40/39}$ age on bio of 25.4 ± 0.8 Ma (integrated age; recoil)
Petrographic Name: Slightly altered biotite rhyolite (chemical analysis listed in Appendix 1)

<u>F09-120: Aphyric, flow-banded felsic lava</u> (Unit Tog)
Location: 0429896/3695793 Along Hwy 532 near east margin of quadrangle
Relations: Lava unconformably overlies typical Walker volcanic breccia
Color & Texture: Whitish, aphyric, tightly flow-banded, spherulitic
Primary: Tiny sparse crystals of what appears to be qtz and possibly Kspar
Secondary: Groundmass is devitrified; contains tiny alkali feldspar; slightly silicified
Comment: Chemical analysis listed in Appendix 1
Petrographic Name: Aphyric alkali rhyolite (from chemistry)

<u>F09-129: Essexite Porphyry Plug</u> (Unit Tex; Moore et al., 1988; essexite is a type of feldspathoidal gabbro, Williams et al., 1954, p. 66)
Location: 042883/369357 SE of Hwy 532
Relations: Small intrusion cutting Walker volcanic package at head of Eagle Creek
Color & Texture: Splotchy black and white, porphyritic, fine-grained granular; slightly sheared
Primary: Large Kspar (orthoclase); groundmass of Kspar, minor plag, phlogopite, (nepheline, cpx, ol?); the latter phases are so altered that their presence is deduced from shape and association
Secondary: Black smudgy mt, ep, cc, qtz, ser, chl, zeolite, rutile, Fe-oxide; really "hammered!"
Comments: Whole rock $Ar^{40/39}$ date is 30.5 ± 0.5 Ma (integrated age; affected by alteration)
Petrographic Name: Phlogopite alkali gabbro (or mica feldspathoidal gabbro)

<u>F09-132: Monzonite porphyry dike</u> (Unit Tmd)
Location: 043016/369493 Along Hwy 532 near east margin of quad
Relations: NW-trending dike cuts Walker volcanic breccia; overlain by aphyric lava (F09-120)
Color & Texture: Dark yellow-green, splotchy, porphyritic; fine-grained granular groundmass
Primary: Plag, cpx, bio, hbd (?), mt, possibly smaller Kspar, tiny apatite
Secondary: Plag altered to qtz-ser-chl; mafic phenocrysts altered to chl-ep; groundmass is highly silicified containing fine chl, ser, qtz, ep
Petrographic Name: Altered monzonite (or diorite?) porphyry

<u>F09-134 Three Rivers alkali granite w/ aplite vein</u>
Location: 042646/369471 Near top of eastern Ski Apache chairlift
Relations: Part of Three Rivers stock; aplite cuts granite
Granite (Unit Ttag)
Color and Texture: Light gray, medium-grained, hypidiomorphic granular
Primary: Kspar, lots of qtz, aegirine, arfvedsonite, mt, minor tiny bio, zircon; some qtz has graphic texture
Secondary: Contains minor qtz-ser-chl alteration of mafic phases
Comment: zircon is dateable
Petrographic Name: Arfvedsonite-aegirine alkali granite
Vein (much too small to map; only 10 cm wide)
Color and Texture: White to light gray, fine-grained, equigranular; has finer grained (chill) margin with granite
Primary: Qtz, Kspar, bio, mt
Secondary: A little Fe-oxide
Petrographic Name: Biotite aplite

<u>F09-135: Three Rivers alkali granite</u> (Unit Ttag)
Location: 042631/369464 Top of east chair lift, Ski Apache
Relations: Part of Three Rivers stock; appears to intrude surrounding syenites
Color & Texture: Salt-and-pepper, medium-grained, hypidiomorphic granular
Primary: Kspar, interstial qtz (some graphic texture), sparse small plag, aegirine, arfvedsonite, bio, mt, ilm, lots of zircon
Secondary: Bio is oxidized; arfvedsonite altered to chl; some qtz-ser
Comment: $Ar^{40/39}$ date on amphibole is 27 ± 2 Ma; also submitted for U-Pb date (so much zircon!); chemical analysis listed in Appendix 1; contains less alkalis than other granites in stock
Petrographic Name: Biotite-arfvedsonite-aegirine granite

<u>F09-136: Three Rivers porphyritic syenite</u> (Unit Ttsag)
Location: 042583/369448 Ski Apache summit ridge road
Relations: Part of Three Rivers stock; apparently predates the granites
Color & Texture: Bluish gray, coarse-grained, hypidiomorphic granular; with anorthoclase phenocrysts (see F09-140c)
Primary: Big rounded bluish Kspar (anorthoclase); groundmass of small Kspar, minor plag, interstitial qtz (some graphic texture), arfvedsonite, bio, zircon, lots of sphene
Secondary: Minor qtz-ser
Comment: Dateable zircon
Petrographic Name: Porphyritic biotite-arfvedsonite quartz syenite

<u>F09-137: Porphyritic trachybasalt dike</u> (Ttbd; designation may be different on adjacent quad)
Location: 0417952/3696005 On Trail 44 east of campground, E edge Godfrey Peak quad
Relations: NW-trending dike cuts Walker volcanic breccia
Color & Texture: Greenish black, porphyritic, slightly ophitic, highly altered
Primary: Big plag and a few altered ol phenocrysts, fine-grained groundmass of plag, cpx (titanaugite), mt
Secondary: Cc, clay, ser, chl, silica, ep, Fe-oxides
Petrographic Name: Altered porphyritic trachybasalt

<u>F09-138: Basalt lava as breccia clast</u> (Within Unit Twb)
Location: 041837/369618 Above and north of Trail 44; east of campground, west of TR stock
Relations: Large clast of cpx porphyritic mafic lava in Walker volcanic breccia; many lava types

Color & Texture: Greenish black, medium-grained, slightly porphyritic
Primary: Sparse large cpx phenocrysts in hand sample; smaller cpx and plag phenocrysts in thin section; groundmass of cpx, plag, ol, mt; altered glass
Secondary: Chl, cc, qtz-ser, ep, Fe-oxides; olivine completely altered
Comment: Similar lava chemically analyzed (F09-156; Appendix 1)
Petrographic Name: Altered cpx-porphyritic alkali olivine basalt

F09-139: Three Rivers coarse-grained syenite (Unit Ttcs; "ultra porphyritic" syenite)
Location: 0423222/3697580 Along Trail 25, east of Three Rivers canyon
Relations: Part of Three Rivers stock; apparently intrudes other syenites and granites
Color & Texture: Gray, very coarse-grained, hypidiomorphic granular; rock contains enclaves of finer-grained igneous rock
Primary: Hash of large rounded Kspar (anorthoclase) surrounded by smaller interstial Kspar and qtz (some graphic texture), aegirine, arfvedsonite, mt, ilm, tiny apatite; rare rutile (?); no apparent zircon; no plag
Secondary: Minor qtz-ser, Fe-oxides
Comment: Chemical analysis in Appendix 1
Petrographic Name: Coarse-grained aegirine-arfvedsonite syenite

F09-140c: Three Rivers syenite (Unit Ttsag)
Location: 042009/369584 Trail 44 in main Three Rivers canyon
Relations: Sample is 30 m east of intrusive contact with Walker volcanic lava package
Color & Texture: Light gray, medium- to coarse-grained, hypidiomorphic granular; has blue-gray anorthoclase phenocrysts
Primary: A few larger Kspar (anorthoclase) in groundmass of Kspar, interstial qtz (some graphic texture), minor cpx, arfvedsonite, mt, ilm, very minor plag and bio, sphene, zircon
Secondary: Minor qtz-ser, Fe-oxides
Comment: $Ar^{40/39}$ date on Kspar is 28.24 ± 0.19 Ma (good spectra); zircon dateable
Petrographic Name: Arfvedsonite quartz syenite

F09-143: Three Rivers syenite & metavolcanic wall rock
Location: 042018/369680 Contact exposed in bed of Dry Creek, Trail 46
Relations: Syenite intrudes Walker lava package; vertical contact
Syenite (Unit Ttsag)
Color & Texture: Light gray, Medium- to coarse-grained, hypidiomorphic granular
Primary: Kspar, minor interstial qtz, arfvedsonite, very sparse bio and cpx, mt, ilm, sphene, zircon, no plag
Secondary: Minor ser, Fe-oxides
Comment: Probably dateable
Petrographic Name: Arfvedsonite (quartz) syenite
Metavolcanic (Unit Twl)
Color & Texture: Pale gray, smudgy, slightly porphyritic, hornfelsed
Primary: Larger plag and a few cpx in groundmass of plag, cpx, ol, small mt
Secondary: Chl, ser, ep, qtz
Petrographic Name: Hornfelsed porphyritic olivine basalt

F09-144: Three Rivers alkali granite (Unit Ttsag)
Location: 042027/369793 On ridge NW of Dry Creek
Relations: Intrudes Walker volcanic package; just south of contact with Ttag
Color & Texture: Pale brownish-gray, medium-grained, hypidiomorphic to equigranular

Primary: Kspar, interstial qtz (some graphic), a bit of plag (?), mt, ilm; altered bio and hbd (?); apatite, sphene, tiny zircon
Secondary: Rock is sheared; mafic minerals altered to qtz-ser, Fe-oxides
Petrographic Name: Altered quartz syenite to alkali granite

F09-153: Cpx-porphyritic trachybasalt dike (Unit Ttbd)
Location: 041904/3695262 On ridge in SW part of quadrangle
Relations: West-trending dike and small plug cuts lower part of Walker volcanic breccia and lower part of lava package
Color & Texture: Greenish black, fine-grained, porphyritic; has large (≤2 cm) cpx phenocrysts; in thin section, texture is intersertal with slightly aligned plag
Primary: Plag, ol, cpx, mt; cpx phenocrysts are zoned, some contain ol inclusions; a few tiny cpx clots; ol has iddingsite rims
Secondary: Chl, ep, cc, Fe-oxides, qtz
Petrographic Name: Altered cpx-porphyritic trachybasalt

F09-157: Hbd-porphyritic trachyandesite flow (Within unit Twl)
Location: 0418927/3697965 North wall of Brushy Canyon
Relations: Flow in Walker volcanic lava package; about 50 ft thick
Color & Texture: Gray, slightly porphyritic, intersertal texture
Primary: Plag and hbd phenocrysts; groundmass contains small plag, cpx, opx, glass, mt
Secondary: Hbd altered to mt, qtz, ser-chl; plag altered to ser, qtz, cc; opx altered to mt, qtz, chl, Fe-oxides
Comment: Altered hbd is easily confused with cpx in field
Petrographic Name: Altered hbd-porphyritic trachyandesite

F09-162a: Porphyritic (turkey track) trachyandesite (Unit Twtx)
Location: 0420705/3699235 In upper part of Goat Canyon near Trail 47
Relations: Flow(s) in Walker volcanic lava package
Color and Texture: Spotted black-and-white, very porphyritic; phenocrysts make "turkey tracks"
Primary: Abundant large plag phenocrysts (≥2 cm), minor cpx phenocrysts; groundmass of small plag, altered ol, cpx, mt
Secondary: Qtz, ser, chl, cc, ep, Fe-oxide
Comment: Chemistry listed in Appendix 1
Petrographic Name: Altered plagioclase-porphyritic basaltic trachyandesite

F10-11: Grizzly Peak diorite dike **(**Tmd – actual plug is Tgd)
Location: 0428506/3703714 Just below summit of peak
Relations: Part of extensive dike and plug complex at Grizzly Peak; cuts altered Walker lavas, minor interlayered breccia
Color and Texture: Greenish-gray, medium-grained, hypidiomorphic granular
Primary: Plag, cpx, minor small Kspar (?), interstitial qtz, mt
Secondary: Chl, ep, ser, qtz, minor cc, smudgy mt; small veinlets of ep, qtz
Petrographic Name: Altered diorite to monzonite

F10-27: Biotite-hornblende syenite dike (Trsd)
Location: 0425287/3702080 On ridge south of Bonito Creek
Relations: NE-trending dike is up to 60 ft wide; cuts Walker lava package; resembles Rialto
Color and Texture: "Salt-and-pepper," slightly pink, medium-grained, hypidiomorphic granular
Primary: Plag, Kspar, qtz, bio, hbd, small cpx, mt, ilmenite, trace zircon, sphene, apatite
Secondary: Very fresh rock, minor ser, qtz

Comment: Submitted for $Ar^{40/39}$ date; chemical analysis listed in Appendix 1
Petrographic Name: Biotite-hornblende syenite

F10-36: Biotite trachydacite dike (Unit Tbtd)
Location: 0421665/3703472 On Trail 50 SW of Argentina Peak
Relations: West- to NW-trending dike cuts Walker lava package; traceable for 0.5 km
Color & Texture: Pale rusty-brown, fine-grained to aphyric, slightly porphyritic, slightly banded
Primary: Small bio, Kspar, plag phenocrysts; groundmass of tiny plag, Kspar, bio, qtz (?), mt
Secondary: Qtz, ser, cc, Fe-oxides
Comment: Fresh bio could be dated
Petrographic Name: Slightly altered biotite trachydacite (practically a rhyolite, Appendix 1)

F10-37: Welded biotite rhyolite tuff (Unit Twas)
Location: 0422208/3704970 About 80 ft down slope (west) of Trail 25
Relations: Tuff interlayered in Walker lava package; higher up by trail, the rock looks like lava
Color & Texture: *In outcrop,* dark gray to black lithic-rich tuff; lithics flattened parallel to layering. *In thin section,* dark brownish gray, banded, slightly porphyritic lithic tuff with odd eutaxitic texture and a lot of small crystals. Banded groundmass of glass is partially devitrified and replaced by small spherulites. Very odd rock; lithics are chert to fine-grained sandstone, trachybasalt, andesite, silicic volcanics
Primary: Sanidine (partly altered), plagioclase, some with sanidine rims, biotite, possible small hbd (now altered), sparse quartz ($\leq$2 %), mt, ilmenite, tiny sparse zircon, apatite and sphene; spherulites and bands contain small tridymite and alkali feldspar
Secondary: Fairly intense qtz, ser, Fe-oxides
Comment: Bio is dateable; lower part of reomorphic unit; aspect ratio, 5 fiammi: 14.2 ± 4.1 (1σ)
Petrographic Name: Welded biotite rhyolite tuff (analysis in Appendix 1).

F10-39: Medium-grained trachybasalt lava, Argentina Peak (Unit Twap)
Location: 0422016/3704110 On thin ridge north of peak
Relations: Youngest flow in local area; caps the summit and ridge of the peak; overlies a fine-grained flow which in turn overlies the “reomorphic tuff”
Color & Texture: Reddish-black medium-grained, intersertal
Primary: A few small phenocrysts of plag; groundmass of felty plag, tiny altered cpx and ol, mt
Secondary: Hematite, other Fe-oxide, qtz, ser, chl
Petrographic Name: Altered trachybasalt (Basaltic trachyandesite, Appendix 1)

F10-40: Aphyric mafic lava, Spring Point (Unit Twsp)
Location: 0421566/3702246 Small cliff on west side of plug forming the “point”
Relations: Youngest lava in local area; similar looking flows drape area to east
Color & Texture: Dark gray to black, very fine-grained, aphyric, slightly trachytic
Primary: A few plag microphenocrysts; groundmass of plag, mt, tiny cpx, a few tiny bio
Secondary: A little hematite, qtz, ser, chl
Comment: Submitted for $Ar^{40/39}$ date; chemical analysis listed in Appendix 1
Petrographic Name: Aphyric (biotite) trachyandesite

F10-41: Cpx-porphyritic lava as breccia clast (in Unit Twb)
Location: 0418845/3703815 Extreme west end of ridge north of Spring Canyon
Relations: Clast is >1 m in diameter; within thick, monolithologic breccia locally exposed in bottom of Walker breccia package; looks like collapse breccia or thick (>60 m) flow breccia
Color & Texture: Gray, medium-grained, porphyritic, intersertal
Primary: Plagioclase, cpx, altered ol, mt; very minor altered Kspar (?)

Secondary: Severely altered; qtz, ser, cc, chl, Fe-oxide; no ep
Petrographic Name: Altered cpx-porphyritic trachybasalt (Basaltic trachyandesite, Appendix 1)

F10-43: Biotite trachydacite lava, Spring Canyon (Unit Twsc)
Location: 0421692/3703328 Just north of junction Trails 50 and 25 in pass at 8780 ft
Relations: Thick flow extends more than 1 mile south of collection site; underlies "reomorphic tuff;" *equivalent to Spring Canyon andesite of Thompson* (1973, figure 2, geologic map)
Color & Texture: Dark gray, fine-grained, flow banded; foliated surfaces sometimes spotted
Primary: Very sparse, tiny plag phenocrysts; trachytic groundmass of tiny felted plag, mt, rare oxidized bio and tiny, tiny cpx; bio hard to find at all locations
Secondary: Minor qtz, ser, Fe-oxide
Comment: Submitted for $Ar^{40/39}$ date (groundmass dateable); chemical analysis in Appendix 1
Petrographic Name: Biotite trachydacite (or Aphyric trachydacite)

F10-44: Spotted trachybasalt lava (in unit Twl; directly underlies Twsc)
Location: 0420969/3702664 West-facing cliff roughly 200 ft below main ridge top
Relations: One of several similar flows beneath Spring Canyon lava (F10-43)
Color & Texture: Black, aphanitic, trachytic, spotted, no phenocrysts (boring!)
Primary: Tiny plag, cpx, ol, mt in black glass; rare slightly larger plag; spots are accumulations of plag with little glass
Secondary: Qtz, ser, hematite, Fe-oxide, chl; cc (and possibly fine opal and zeolite) in cracks and vesicles; fine ep?
Comment: Trachybasalt, Appendix 1
Petrographic Name: Altered aphyric trachybasalt

F10-51: Nogal Peak Trachyte (Unit Tnt)
Location: 0425877/3706357 Southeast flank of Nogal Peak
Relations: Lowest of five somewhat similar flows and interlayered breccias (Flow 37, Thompson, 1973; Figure 6).
Color & Texture: Greenish-gray, slightly porphyritic, slightly trachytic, obviously altered
Primary: Plag, hbd, bio, cpx, mt; possibly some tiny altered Kspar (?)
Secondary: Rock is thoroughly altered; plag gone to qtz, ser, cc; hbd gone to chl, mt, ep, qtz, ser (some coarse grained like muscovite)
Comment: Chemical analyses listed in Appendix 1
Petrographic Name: Altered porphyritic trachyandesite

F10-52: Cone Peak rhyolite dike (Unit Tcpd; plugs are Tcp)
Location: 0425828/3701568 On bluff 8405 east of Big Bear Creek
Relations: Dike cuts Walker lava package; mineralogy is similar to dikes and plug west of Big Bear Creek named Cone Peak rhyolite (Black, 1977).
Color & Texture: Light gray to white, slightly porphyritic, aphanitic groundmass
Primary: Small phenocrysts of qtz, Kspar, bio, sparse plag; a few graphic intergrowths of qtz and Kspar; much of qtz is embayed (out of equilibrium); qtz contains melt inclusions
Secondary: Groundmass is silicified; Kspar altered to ser; bio gone to mt and other Fe-oxides
Comment: Chemical analysis listed in Appendix 1
Petrographic Name: Altered porphyritic biotite rhyolite

F10-60: Rialto monzonite intrusive, Phase 2 (Unit Trm2)
Location: 0426802/3703218 North side of FS 107 west of Tanbark Canyon
Relations: Second main phase of Rialto stock; intrudes Walker volcanics and Trm
Color & Texture: Gray, fine-grained, hypidiomorphic granular

Primary: Plag, some small Kspar, hbd, fresh bio, interstial qtz, mt, small altered cpx (?)
Secondary: Qtz, ser, chl, Fe-oxide; no apparent ep
Comment: Submitted for $Ar^{40/39}$ date (bio is dateable); chemical analysis listed in Appendix 1
Petrographic Name: Altered hornblende-biotite quartz diorite

F10-65: Opalized accretionary lapilli tuff (Thin layer of Twal in Twbb)
Location: 0421116/3700136 In ravine just east of Trail 25
Relations: Thin bed of rhyolitic tuff (±3 m) interlayered in scoria and agglutinate-rich Walker volcanic breccia (unit Twbb); laterally traceable for ±80 m
Color & Texture: White to gray thin beds of clay-rich mud; some beds with balls ≤0.5 cm diam
Primary: Balls are accretionary lapilli formed of concentric layers of fine mud and tiny crystals (Fisher and Schminke, 1984); a few small crystals of altered feldspar and mt in beds
Secondary: Mud altered to opal, clay (and ser?); feldspar altered to qtz, ser, cc; beds cut by tiny veinlets of opal and cc; rare, tiny stains of bright blue turquoise (?)
Petrographic Name: Opalized accretionary lapilli tuff

F10-66: Basaltic trachyandesite lava (Unit Twbt)
Location: 0421170/3700996 Summit of hill 9395 east of Trail 25
Relations: Probable vent area; overlies scoria-rich Walker breccia (Twbb) and flow Twsc (above)
Color & Texture: Dark gray to black, fine-grained, sparsely porphyritic, trachytic
Primary: Small plag phenocrysts; groundmass contains tiny plag, cpx, iddingsitized ol, mt, rare apatite; groundmass glass completely altered; lava contains sparse gabrroic xenoliths
Secondary: Qtz, ser, chl, ep, Fe-oxide
Petrographic Name: Altered basaltic trachyandesite

F10-71: Porphyritic rhyolite plug of Elk Point (Unit Tep)
Location: 0422713/3699411 On low hill just east of Trail 35 NW of Elk Point
Relations: Rhyolite intrudes mixture of Walker breccias and lavas; rhyolite is only "fresh" at this location; otherwise highly silicified and brecciated
Color and Texture: Light to dark gray, coarsely porphyritic, some flow banding
Primary: Large Kspar (sanidine?) and smaller phenocrysts of Kspar, qtz, plag, hbd, bio, mt; tiny apatite
Secondary: Qtz, ser, smudgy mt, chl (?); large Kspar partially altered; groundmass silicified
Comment: Chemical analysis listed in Appendix 1
Petrographic Name: Altered porphyritic hornblende-biotite rhyolite

F10-73: Biotite syentite porphyry (Unit Ttbsp)
Location: 0423693/3698091 Just south of hill 10518 and Trail 33
Relations: Small intrusion within Three Rivers stock; mapped as nordmarkite (Thompson, 1973)
Color & Texture: Pinkish-gray, sparsely porphyritic, fine-grained granular groundmass
Primary: Large Kspar (anorthoclase?) phenocrysts with microcline (herringbone) twinning; fairly fresh groundmass contains small crystals of Kspar, a bit of plag and qtz, mt, bio, tiny apatite and zircon
Secondary: Minor qtz, ser, Fe-oxides
Comment: Zircon is dateable
Petrographic Name: Biotite syenite porphyry

F10-76: Medium-grained alkali granite dike (Unit Ttag)
Location: 0423406/3696889 On Trail 25 SE of hill 10826
Relations: Broad NE-trending dike (±50 m wide) cuts very coarse-grained syentite, TR stock
Color & Texture: "Salt and pepper," medium-grained, hypidiomorphic granular

Primary: Large Kspar (orthoclase?) surrounded by smaller Kspar, interstial qtz, arfvedsonite (blue pleochroism), bio, mt, tiny zircon; some Kspar and qtz have graphic texture; arfvedsonite projects into qtz; very fresh rock
Secondary: A bit of ser
Comment: Zircon and bio are dateable
Petrographic Name: Biotite-arfvedsonite alkali granite

F10-77b: Fine-grained hornblende-biotite syentite plug (Unit Tthbs)
Location: 0423713/3696588 On Trail 25 in saddle between low hills
Relations: Small (±50 m diameter) plug-like body intruding coarse-grained syenite, TR stock
Color & Texture: Light gray, porphyritic, fine-grained granular
Primary: Very fresh; contains larger Kspar (anorthoclase?), and smaller bio and hbd in groundmass of tiny plag, mt, some qtz, and rare cpx; rare tiny zircon and apatite
Secondary: Minor qtz, ser, chl
Comment: Bio and zircon dateable
Petrographic Name: Hornblende-biotite quartz syenite

F10-82: Medium-grained alkali granite (Unit Ttag)
Location: 0422327/3698259 Just NW of Trail 44 in Three Rivers canyon
Relations: Large intrusion within the Three Rivers stock
Color & Texture: Light gray, medium- to fine-grained, hypidiomorphic to equigranular
Primary: Kspar (orthoclase?), qtz, biotite, mt; a bit of arfvedsonite; some graphic texture
Secondary: Qtz, sericite, Fe-oxide, chlorite (?)
Comment: Chemical analysis in Appendix 1
Petrographic Name: Biotite alkali granite

NPQ-004: Aphyric trachydacite lava (Unit Twfa)
Location: 0422385/3704903 On low ridge west of Trail 25, north of Argentina Spring
Relations: overlies Twas (F10-37) described above
Color & Texture: Dark gray to black, aphanitic, trachytic, a few very small phenocrysts
Primary: Sparse small plag and bio in groundmass of plag, cpx, tiny Kspar (?) and glass
Secondary: Qtz, ser, Fe-oxides, chl (?)
Comment: Texture is quite different than F10-37; analysis in Appendix 1
Petrographic Name: ***Aphyric trachydacite***

F10-90: Syenite porphyry (Unit Ttsp)
Location: 0428861/3695282 On Hwy 532 west of Windy Point
Relations: Large intrusive body in TR stock; equivalent to nordmarkite (Thompson, 1972; 1973)
Color & Texture: Dark pinkish brown, porphyritic, fine-grained granular; slightly fractured
Primary: Large Kspar (anorthoclase) phenocrysts; smaller crystals of Kspar; minor qtz and plag, mt, bio, cpx, a bit of altered hbd; sparse tiny apatite
Secondary: Qtz, ser, chl (?); a few tiny qtz veinlets
Petrographic Name: (Altered) Biotite Syenite Porphyry

F10-91: Porphyritic trachydacite lava (Unit Twpd)
Location: 0429958/3695162 Just east of Hwy 532, near east edge of quadrangle
Relations: Unconformably overlies Walker breccias and lavas; may be related to TR stock
Color & Texture: Gray, porphyritic, slightly trachytic
Primary: Kspar (sanidine), plag, bio, mt, qtz; groundmass has plag and cpx
Secondary: Qtz, ser, chl, smudgy mt, other Fe-oxide; groundmass is silicified
Petrographic Name: Altered porphyritic biotite trachydacite (possibly rhyolite?)

<u>F10-97: Porphyritic trachydacite tuff</u> (Unit Twtt)
Location: 0424275/3701109 On hill just north of Cone Peak
Relations: Possible vent of tuff cutting horizontal Walker volcanics and minor breccias
Color & Texture: Brownish-gray, porphyritic, fragmental, minor mafic volcanic lithics
Primary: Plag, Kspar, mt, very altered bio and hbd, rare qtz
Secondary: Quite altered; qtz, ser, chl, smudgy mt, other Fe-oxide; tiny ep (?)
Petrographic Name: Altered porphyritic trachydacite tuff

<u>NPC-18: Porphyritic quartz syenite</u> (Unit Ttsag)
Location: 0423889/3695238 SW of Trail 25 in head of unnamed canyon
Relations: Large intrusive body in Three Rivers stock
Color & Texture: Light gray w/bluish gray spots, slightly porphyritic, medium-grained, hypidiomorphic granular
Primary: Large, bluish gray Kspar (anorthoclase), quite a bit of interstial qtz, bio, smaller Kspar, a bit of tiny sphene, zircon; very fresh rock
Secondary: Very little secondary qtz, ser
Comment: Resembles F09-136 & F09-140c but no obvious arfvedsonite and less sphene
Petrographic Name: Porphyritic biotite quartz syenite

<u>F11-26: Porphyritic trachydacite lava</u> (unit Tnt)
Location: 0424585/3705748 west side of Hill 9500 SW of Nogal Peak
Relations: Underlies basalt lava (Twbn); overlies thin layer of breccia (Twb)
Color & Texture: Light gray, porphyritic, trachytic
Primary: Altered aligned plagioclase and smaller blocky sanidine; altered bio and hbd (?)
Secondary: Silica, ser, chl, clay, smudgy opaque oxides
Comment: Trachyte texture very obvious but so is alteration; analysis in Appendix 1
Petrographic Name: (Altered) Porphyritic biotite trachydacite