Preliminary Geologic Map of the Winston Quadrangle, Sierra County, New Mexico (Year 1 of 1-Year)

By

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Open-file Digital Geologic Map OF-GM 230

Scale 1:24,000

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PRELIMINARY GEOLOGY OF THE WINSTON QUADRANGLE, SIERRA COUNTY, NEW MEXICO

Cover photo: The small town of the Winston, the namesake of the quadrangle. Photo faces west-northwest. Tree-covered topography in background is the Black Range, underlain by Eocene to Oligocene volcancs. Lighter colored, grass-covered hills directly behind the town are underlain by the upper Santa Fe Group, derived from the Black Range. Dark brownish gray areas in front of town are underlain by the andesite of the Winston graben.

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INTRODUCTION

The Winston quadrangle lay along the east flank of the Black Range along Cuchillo Negro-Poverty Creek (Figure 1). It includes the towns of Winston and Chloride, geographic features such as Way-Up Mountain and Hagins Peak, and portions of Chloride, South Fork, and Monument Creeks, which drain into Cuchillo Negro Creek. Cuchillo Negro Creek turns eastward at the southeastern corner of the quadrangle, from where it traverses the Sierra Cuchillo to eventually merge with the Rio Grande. The area is mainly used as grazing and hunting land by several small to moderate-sized ranches, with one active zeolite mine (Figure 2) and processing facility along South Fork Creek. The west side of the quadrangle lay on National Forest Service land, and while many abandoned mines exist in this area no active mining is occurring today.

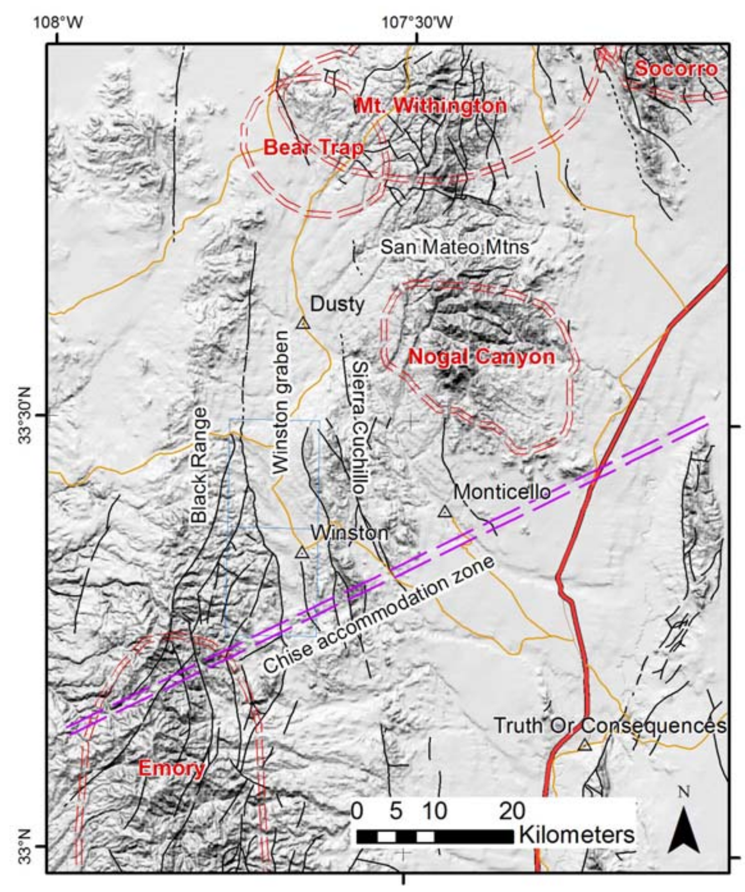

Figure 1 - Generalized geology of the Winston graben area. Black lines are major faults, red double lines are outlines of calderas (or calderons), and purple double line is the Chise accommodation zone (or "Chise lineament") of Harrison (1990, 1994). Triangles locate area towns, orange lines are state roads, and the thick red line is Interstate 25. Blue rectangles locate the Iron Mountain (northern) and Winston (southern) quadrangles.

Geologically, the Winston quadrangle lay along the west flank of the Rio Grande rift, where the rift is superimposed upon the older Mogollon-Datil volcanic field. Tertiary volcanics associated with this field dominate the stratigraphy of the Black Range, and also occur along the southern and southeastern margins of the quadrangle. The eastern half of the quadrangle lay within the Winston graben (Figure 1), an extensional basin in which sediments and local volcanics have accumulated since the late Oligocene (Cikoski and Harrison, 2012). The rift basin fill, up to and including the maximum level of aggradation and excluding intercalated volcanics, correlates to the Santa Fe Group of Baldwin (1963; redefined by Hawley et al., 1969). Post-Santa Fe Group alluvium is also present as terrace deposits along present-day streams.

Much of the geologic history of the area is discussed in detail by Harrison (1990, 1994) and Cikoski and Harrison (2012), and the interested reader is referred to these publications for more information.

Figure 2 - Active St. Cloud zeolite mine. White rocks are lower Santa Fe Group sediments (Tsfl), gray overlying sediment are Qao1 Pleistocene gravels. Skyline is the Sierra Cuchillo, off quad to the east. Cliffs in between are outcrop of the andesite of the Winston graben.

ACKNOWLEDGEMENTS

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GEOCHRONOLOGY

Numerous age controls are available in the literature particularly for the Eocene and Oligocene volcanic rocks, but are not always directly comparable due to changing ages for standards used in geochronology. Table 1 summarizes the known age controls on the Winston quadrangle and relevant surrounding quadrangles. Note that the $^{40}Ar/^{39}Ar$ ages have been adjusted here so as to be normalized to the Fish Canyon Tuff sanidine monitor age of Kuiper et al. (2008) of 28.201 Ma. This normalization means scaling ages from McIntosh et al. (1991) upwards by 1.3%, to account for their use of an accepted age of 27.84 Ma, and scaling new ages and those from McLemore et al. (2012) upwards by 0.6%, as these ages were originally calculated relative to the 28.02 Ma accepted age of Renne et al. (1998). Details for new age data are contained in the appendix. K-Ar ages are unchanged from their original publication.

PALEOZOIC ROCKS

The Pennsylvanian Madera Limestone and Permian Bursum and Abo Formations (in order of decreasing age) are locally exposed along the east flank of the Black Range on the Winston quadrangle. The Abo is a particularly distinctive unit, composed of commonly cross-stratified red siltstones and sandstones with local white reduction spots. Underneath the Abo lay interbedded gray fossiliferous limestones and calcareous shales of the Bursum Formation, and the light to medium gray fossiliferous limestones of the Madera Limestone. Only at the south end of the quadrangle are the older Bursum and Madera Formations exposed.

EOCENE TO OLIGOCENE IGNEOUS ACTIVITY

The northern Black Range is dominated by Eocene to Oligocene volcanic rocks (Harrison, 1990). The oldest such strata belong to the Rubio Peak Formation, which is divisible into a local basal conglomerate with significant nonvolcanic clasts (Trpc), a lower debris flow-dominated unit (Trp), and upper lavas of various textures (Trpa, Trph, Trpba). Also associated with this unit are map-scale exotic blocks of Pennsylvanian limestone (ℙme) that are surrounded by debris flows of the lower Rubio Peak, and the tuff of Miranda Homestead (Trpm), which intercalates with the basal conglomerate.

The limited outcrop extent of the basal conglomerate is interpreted to reflect localized deposition in deep paleocanyons carved into the underlying Permian Abo Formation (Harrison, 1990). It exhibits both gradational and sharp upper contacts with the overlying debris flow-dominated unit, and Harrison (1990) interpreted from contact relationships that the base of the debris flow-dominated unit is a significant erosion surface over much of the area. Paleocurrent indicators measured by Cather (1986) and Harrison (1990) suggest east to west transport for the basal conglomerate. The intercalated tuff of Miranda Homestead is a local moderately crystal-rich ash-flow tuff.

The debris flow-dominated lower Rubio Peak Formation is volumetrically the dominant Rubio Peak subunit. It encompasses the exotic limestone blocks, which Harrison (1989) interpreted to be gravity slide blocks, possibly derived from the southwest. Drill core and some mines expose the bases of these blocks, confirming that they are not in-place limestone. Up-section, the debris flows intercalate with andesitic lavas of various textures. Although this sequence of lava-over-debris flows is continuous into quadrangles to the north and west (Harrison, 1990), individual lava units are not regionally continuous.

Table 1 – Summary of age data

No.[1]	Unit	Age[2] (Ma)	±2σ	Age type[3]	Ref.[4]	Notes
1	Tbtm	4.8	0.1	K-Ar	Seager	basalt of Tabletop Mtn; exposed to east on Chise quadrangle
		4.26	0.72	SHPA/A	McLemore	
		4.94	0.06	SHPA/A	McLemore	
2	Twa	18.4	0.4	K-Ar	Seager	
3	Tsfl	27.73	0.14	SCSA/A	McIntosh	Age of South Canyon Tuff, erupted from Mt Withington caldera
4	Tvp	28.93	0.12	SCSA/A	McIntosh	Erupted from Nogal Canyon caldera; correlative to Bell Top tuff 7[5]
		28.78	0.18	SHSA/A	New	Sample WnC-30, from 253125mE, 3684156mN (NAD27 UTM)
5	Ttlm	29.06	0.06	SCSA/A	McIntosh	Highly variable local unit (Harrison, 1990)
		29.08	0.02	SHSA/A	New	Sample WnC-32, from 252300mE, 3682314mN (NAD27 UTM)
6	Tlmc	29.39	0.20	SCSA/A	McIntosh	Local unit (Harrison, 1990)
7	Tpc	28.3	0.6	K-Ar	Woodard	Part of the regional SCORBA suite of Cameron et al. (1989)
		28.8	0.6	K-Ar	Chapin	Age of overlying Tlmc indicates Tpc is locally older than these ages
8	Tkw	34.87	0.24	SCSA/A	McIntosh	Age of Rock House Canyon Tuff, to which the upper tuff of Koko Well is correlated (Harrison, 1990; McIntosh et al., 1991)
9	Tcnl	34.7	0.8	K-Ar	Chapin	
10	Tkn	35.34	0.10	SCSA/A	McIntosh	Erupted from Emory caldera; correlative to Bell Top tuff 5[5]
11	Trrc	35.41	0.08	SCSA/A	McIntosh	Correlative to Bell Top tuff 4[5]
12	Tcc	~36		Fossils	Lucas	early Chadronian mammalian fauna

[1]: Number refers to numbers on the correlation diagram on map.
[2]: $^{40}Ar/^{39}Ar$ ages have been scaled to fit the Fish Canyon Tuff sanidine monitor age of 28.201 Ma of Kuiper et al. (2008).
[3]: SHPA/A – step-heated $^{40}Ar/^{39}Ar$ plateau age; SCSA/A – single-crystal sanidine $^{40}Ar/^{39}Ar$ age; SHSA/A – step-heated single-crystal sanidine $^{40}Ar/^{39}Ar$ age.
[4]: References: Chapin – C.E. Chapin, pers. comm., cited in Harrison (1990, 1994); Lucas – Lucas (1986); McIntosh – McIntosh et al. (1991); McLemore – McLemore et al. (2012); New – new age, see appendix for details; Seager – Seager et al. (1984); Woodard – Woodard (1982).
[5]: Regional ignimbrite correlations according to McIntosh et al. (1991) based on single-crystal $^{40}Ar/^{39}Ar$ ages and paleomagnetic data. Bell Top Formation tuffs after Clemons (1976).

On the Winston quadrangle, the Rubio Peak Formation is overlain by the Cliff Canyon Sandstone (Tcc), followed by the tuff of Rocque Ramos Canyon (Trrc). The former is a local arkosic to quartzose sandstone unit interpreted by Lucas (1986) to be early Chadronian (~36 Ma) in age based on mammalian fauna. The later is a regional moderately crystal-rich ash-flow tuff, correlated to the Bell Top 4 tuff by $^{40}Ar/^{39}Ar$ and paleomagnetic data (McIntosh et al., 1991). This tuff has an average single crystal $^{40}Ar/^{39}Ar$ age of 35.41±0.08 Ma (McIntosh et al., 1991). To the north on the Iron Mountain quadrangle, these two units intercalate, but here the tuff exclusively overlies the sandstone. The two units vary in thickness considerably about the Winston quadrangle, and locally pinchout.

Overlying these units is the Kneeling Nun Tuff (Tkn), a regionally extensive crystal-rich ignimbrite that erupted from the Emory caldera at 35.34±0.10 Ma, based on single crystal $^{40}Ar/^{39}Ar$ ages (McIntosh et al., 1991). This tuff acts as a regional stratigraphic marker for much of the Mogollon-Datil volcanic field.

At around the same time, the Cuchillo Negro complex (Tcnl, Tcns) accumulated in the southeastern corner of the quadrangle (Harrison, 1990). A K-Ar age of 34.7±0.8 Ma was obtained from this quad (C.E. Chapin, pers. comm., cited in Harrison, 1990), which could make the unit either older or younger than the Kneeling Nun Tuff; Harrison (1990, 1994) suggests the complex is just younger than the tuff. The complex consists of both intrusive and extrusive units. The three intrusive units are (from oldest to youngest) flow-banded, phenocryst-poor rhyolite; basaltic andesite with common plagioclase and apple-green pyroxene phenocrysts; and amygdule-rich trachyte. The two earlier intrusive units appear to have extrusive equivalents, with the rhyolite being the dominant phase (Harrison, 1990). Three local generally lithic-rich ash-flow tuffs and intercalated volcaniclastic sediment are mapped as the Tcns unit.

Locally, the Kneeling Nun Tuff is overlain by the sandstone of Monument Park (Tms) and/or the tuffs of Koko Well (Tkw). The former consists mainly of sandstone with grains of quartz, sanidine, plagioclase, and minor biotite, with associated minor siltstone and pebble to cobble conglomerate. This unit thins and pinches out to the north and south. The tuffs of Koko Well are a pair of thin tuffs that are welded together. The lower is moderately to densely welded, and moderately crystal-rich. The upper tuff is poorly welded and generally crystal-poor, and pumice-rich. Based on lithologic and stratigraphic similarity, as well as paleomagnetic and $^{40}Ar/^{39}Ar$ data, the upper tuff is tentatively correlated to the 34.87±0.24 Ma Rock House Canyon Tuff (Harrison, 1990; McIntosh et al., 1991).

The tuffs of Koko Well are followed by a regional hiatus in volcanism, which Cather et al. (1994) used to divide the older Datil Group from the younger Mogollon Group. Harrison (1990) suggests that during this time the area existed as a stable volcanic plateau, subsequently buried by the basaltic andesite of Poverty Creek (Tpc). These dark, aphanitic basaltic andesites belong to the SCORBA suite of Cameron et al. (1989), a regionally extensive package of thick basaltic andesites that buried much of western New Mexico and adjacent areas in the late Oligocene. It is interpreted by some workers to reflect the initiation of extensional tectonism (Cameron et al., 1989; Harrison, 1990). Two K-Ar ages exist for the basaltic andesite of Poverty Creek from the northern Black Range, one at 28.3 ±0.6 Ma (Woodard, 1982) and another at 28.8±0.6 Ma from C.E. Chapin (pers. comm., cited in Harrison, 1990). However, on the Winston quadrangle, the andesite is overlain by the 29.39±0.20 Ma tuff of Little Mineral Creek ($^{40}Ar/^{39}Ar$ age from McIntosh et al., 1991), suggesting the andesite is at least some places as old as about 29.5 Ma.

The basaltic andesite of Poverty Creek is very locally overlain by an unnamed sanidine-rich rhyolitic unit (Tsrr) in Section 2, T12S R8W. This rock bears elongate dark gray bands that are possibly strongly flattened pumices, but the abundance of crystals suggests it is not an ash-flow. The rock occurs as two very narrow northeast-southwest elongate outcrops slightly inset upon the surrounding basaltic andesites. It has not as of yet been correlated to any other unit, and its exact location in the stratigraphy is uncertain.

In most places on the Winston quadrangle, the basaltic andesite of Poverty Creek is overlain by the tuff of Little Mineral Creek (Tlmc) and/or the Moccasin John Rhyolite (Tmj). The former is a very distinctively lithic-rich, crystal-poor ash flow tuff, with abundant (10-50%) lithic fragments of aphanitic rhyolite that are interpreted to be Moccasin John Rhyolite. McIntosh et al. (1991) obtained a single crystal $^{40}Ar/^{39}Ar$ age of 29.39±0.20 Ma for the tuff. The Moccasin John Rhyolite is a strongly flow-banded crystal-poor rhyolite, which bears only 1-3% crystals of quartz, sanidine, plagioclase, and biotite. It occurs in the southwest of the quadrangle. Harrison (1990) suggests these two units are genetically related and probably derived from the same vent area.

The tuff of Stiver Canyon (Ttsc) overlies the tuff of Little Mineral Creek and Moccasin John Rhyolite on the Lookout Mountain quadrangle (Harrison, 1990). Although it is relatively common in the Black Range, it is only very locally preserved on the Winston quadrangle, in the southeastern and south-central areas. It is a poorly to moderately welded, moderately crystal-rich ash-flow tuff with 10-20% phenocrysts of sanidine, quartz, and minor biotite. It has not been directly radiometrically dated, but its age is tightly constrained between the underlying 29.4 Ma tuff of Little Mineral Creek and locally overlying 29.2 Ma La Jencia Tuff (Harrison, 1990; McIntosh et al., 1991) to about 29.3 Ma.

Very locally, along the southern margin of the quadrangle, the tuff of Stiver Canyon is overlain by the tuff of Lookout Mountain. Within the Black Range, the tuff of Lookout Mountain, also referred to as the tuff of Diamond Creek by Woodard (1982) and Harrison (1990), is a complex sequence of multiple flows of varying textures, from crystal-rich to crystal-poor, lithic-rich to lithic-poor, and poorly welded to densely welded. On the Winston quadrangle, the tuff of Lookout Mountain is represented by a single outflow sheet that is moderately welded, moderately crystal-rich, moderately pumice-rich, and lithic-poor. Phenocrysts are dominantly of sanidine, with rare biotite and sparse quartz. This isolated outcrop is correlated to the tuff of Lookout Mountain within the Black Range by single-crystal sanidine $^{40}Ar/^{39}Ar$ data (see Table 1 and sample WnC-32 in the appendix). Harrison (1990) interpreted the flows of the tuff of Lookout Mountain to be vent-clearing eruptions associated with local rhyolitic volcanism.

Within the Winston graben, where the tuffs of Stiver Canyon and Lookout Mountain are not present, the tuff of Little Mineral Creek is often overlain by the 28.93±0.12 Ma Vicks Peak Tuff (Tvp; age from McIntosh et al., 1991) with slight angular unconformity. We have previously interpreted this angular unconformity to reflect the earliest Rio Grande rift-related fault block rotation and development of the Winston graben, placing initial development of the graben between the tuff of Little

Mineral Creek and the Vicks Peak Tuff at ~29 Ma (Harrison, 1994; Cikoski and Harrison, 2012). Harrison (1990, 1994) also suggested that the almost complete lack of Vicks Peak Tuff in the Black Range was related to late Oligocene uplift of the Range associated with early graben development. The tuff is generally very thin, and along the structurally high southern margin of the quadrangle the tuff locally pinches out. The only exception to this is a thick mass of Vicks Peak found in the northeastern corner, where it is surrounded by outcrop of the andesite of the Winston graben and upper Santa Fe Group sediments. This mass of Vicks Peak Tuff has anomalous sub-vertical foliations and is commonly highly brecciated around its margins, and Harrison (1990, 1994) interpreted it to be a gravity slide block emplaced just prior to eruption of the andesite of the Winston graben.

SANTA FE GROUP AND INTERCALATED VOLCANICS

The Santa Fe Group (SFG) is defined as all rift-related sedimentary basin fill up to and including the maximum level of aggradation, but excluding inset alluvial units and intercalated volcanics (Baldwin, 1963; Hawley et al., 1969). Here, the Group and its intercalated volcanics are discussed together for simplicity. The SFG is divided into lower, middle, and upper units, based on intercalated volcanics and an angular unconformity (Harrison, 1994; Cikoski and Harrison, 2012). Note that this lower-middle-upper division is not necessarily correlative to lower-middle-upper divisions used elsewhere in the Rio Grande rift.

The lower SFG (Tsfl) here includes a set of distinct lithic-rich ash-flow tuffs and associated volcaniclastic sandy pebble conglomerates and pebbly sandstones (Figure 3). Most of the tuffs are thin (1 to 1.5 m thick) and discontinuous, but one tuff that is up to 8 m thick is continuous across the exposure of the lower SFG. This tuff was tentatively correlated to the South Canyon Tuff by Harrison (1990), based on its similar lithologic appearance and similar stratigraphic setting to a tuff intercalated with the sandstone of Inman Ranch of Eggleston (1987), which is known to be the South Canyon Tuff based on a very distinctive remnant magnetism direction and an $^{40}Ar/^{39}Ar$ age of 27.6 Ma (McIntosh et al., 1991). The South Canyon Tuff has an average single crystal $^{40}Ar/^{39}Ar$ age of 27.73±0.14 Ma (McIntosh et al., 1991). The associated clastic rocks are matix-rich pebble to cobble conglomerates occurring commonly as discontinuous and channel-shaped beds with common cross-bedding and normal grading. These are intercalated with lesser ash-rich pebbly sandstones. Gravels are dominantly rhyolites with sparse andesites. Twelve channel axes were measured and are dominantly oriented northwest-southeast, and the averages of 15-17 imbrication direction measurements at three outcrops point east-southeastward. Taken together, southeastward paleoflow is inferred. This unit is similar to the Thurman Formation in the Caballo Mountains (cf., Seager and Mack, 2003), in that it consists of clastic sedimentary rocks associated with the South Canyon Tuff. Mack et al. (1998) suggests the Thurman Formation is the distal product of a volcaniclastic apron that emanated from the Mt Withington caldera in the northern San Mateo Mountains, approximately 45 km north-northeast of the Winston quadrangle, and the lower SFG here may also be a part of this apron.

Figure 3 - Old St. Cloud zeolite mine, looking north-northeast. Lower, dipping, white strata is the lower Santa Fe Group, massive white blocks are tuffaceous sandstones, gray layers are conglomerates. Overlying brown sediments are Qao2 Pleistocene gravels.

The lower SFG lay upon either the Vicks Peak Tuff with apparent conformity or, where the Vicks Peak Tuff is missing, the underlying tuff of Little Mineral Creek with slight angular unconformity. Where the Vicks Peak Tuff is not present, the lower SFG thickens. We interpreted this previously to indicate that the lower SFG was deposited by laterally-restricted streams that locally incised deeply into the underlying Vicks Peak Tuff before backfilling (Cikoski and Harrison, 2012). Furthermore, we interpreted this to indicate there was only a small amount of initial graben subsidence, as a large amount of subsidence would result in complete burial and preservation of the tuff, and not in erosion and local stripping.

The lower SFG is overlain with conformity by the middle SFG unit, which is divided into coarse (Tsfm) and fine (Tsfms) facies. The former is dominated by coarse pebbles and conglomerates in matrix-rich, generally moderately well-cemented beds (Figure 4). Gravels are dominantly rhyolitic in composition, but with up to 20% andesitic clasts; the increase in abundance of andesite may reflect unroofing of the ancestral Black Range. The fine facies is dominated by sandy siltstones and silty sandstones. The contact is placed where the ratio of conglomerate beds to finer beds is 1:1, i.e. where greater than 1:1 it is Tsfm, less than 1:1 it is Tsfms. The contact coincides with a fault, but appears to be interfingering based on strata exposed on either side of the fault. Pebble imbrications suggest dominantly eastward paleoflow for the coarse facies, but along the eastern side of the quadrangle there are local southward and westward pebble imbrication directions. Combined with our reinterpretation of the mapping of Jahns et al. (2006) on the Chise quadrangle to the east, we have previous suggested that the middle SFG unit is derived from both western and eastern highlands (Cikoski and Harrison, 2012). Locally, at the south end of the extent of the fine facies, just north of the zeolite mines, there are mudstones with significant clay content interbedded with the siltstones and sandstones

(Figure 5). These may reflect the presence of a lake or playa during this time period, consistent with the suggestion of Bowie and Barker (1986) that a sodic lake in this area could be the cause of the zeolite alteration of the lower SFG and tuff of Little Mineral Creek seen along South Fork Creek.

Along the eastern side of the quadrangle, the middle SFG unit is overlain by the andesite of the Winston graben (Twa), a dark aphanitic to sparsely porphyritic sequence of lavas (Figure 6) that are very similar to the basaltic andesite of Poverty Creek. This sequence is up to 152 m thick at the surface (Jahns et al., 2006), but thins rapidly westward. It also thins rapidly northward where overlying the thick mass of Vicks Peak Tuff interpreted as a gravity slide block; this could be the result of the andesite on-lapping a paleo hill formed by the gravity slide block. We also interpret the rapid westward thinning of the andesite to reflect on-lapping of the lava against an intrabasinal horst (Cikoski and Harrison, 2012). Seager et al. (1984) obtained a K-Ar age of 18.4±0.4 Ma for this unit, similar to the ages of basalts from further north and east on the Monticello Butte quadrangle (McLemore et al., 2012).

Figure 4 - Middle Santa Fe Group conglomerates. Note degree of cementation, abundance of coarse pebbles and cobbles, and moderate dip angle.

Figure 5 - Middle Santa Fe Group sandstones, siltstones, and mudstones. Slightly reddish sediment at bottom are clay-rich mudstones. Light colored sediment above are siltstones and sandstones.

The upper SFG unit overlies the andesite and middle SFG units with angular unconformity. This unit consists dominantly of sandy fine to medium pebble conglomerates with minor interbedded very poorly cemented pebbly sandstones. The deposits are generally noticeably finer-grained and less well cemented than the underlying middle SFG units (Figure 7). Along the west side of the graben, clast suite compositions range from rhyolite-dominated with subordinate but common andesite to subequal rhyolite and andesite, with limestone gravels found locally toward the top of the unit. We suggest that the limestone gravels are more likely derived from the exotic blocks in the Rubio Peak Formation than Paleozoic strata exposed at the south end of the quadrangle, as red siltstones are found nowhere in the clast suite of the SFG along the west side of the graben, and the Abo Formation overlies the limestones of the Bursum and Madera Formations. The increase in abundance of andesite up-section through the SFG likely reflects unroofing of the ancestral Black Range. In the northeast corner of the quadrangle, the upper SFG clast suite consists of common andesites with subordinate to subequal rhyolites with up to 20% limestone and minor red siltstone gravels; we interpret these gravels to be derived from an ancestral Sierra Cuchillo highland on the east side of the graben.

Locally, toward the top of the section, buried paleosols are found that are distinguished by particularly red horizons (hues of 5YR and 2.5YR). Koning (2012) observed a similar relationship in the upper SFG in the northern Winston graben, and suggested this may reflect slowing subsidence rates toward the end of SFG deposition.

In the southwestern corner of the graben, a boulder-rich unit (Tsfb) is found that is likely age-correlative to both the upper and middle SFG units. This unit is very poorly exposed, but appears to consist of very poorly sorted, angular to rounded pebbles to 2-m-diameter boulders of mainly rhyolite. The boulders in particular are mainly of Moccasin John Rhyolite. Locally consistent pebble imbrications indicate eastward paleoflow. The unit grades laterally into the upper and middle SFG strata away from the southeastern corner of the graben as the abundance of boulders declines.

Figure 6 - Outcrops of the andesite of the Winston graben, along Cuchillo Negro Creek. All rocky outcrop in this photo is of the andesite, which forms steep walls on either side of the Creek.

Figure 7 - Upper Santa Fe Group gravels. Note the abundance of fine pebbles, particularly at the top, the shallow dip angle, and the lack of cementation.

POST-SANTA FE GROUP ALLUVIUM

The SFG is locally capped by a Pliocene pediment deposit (Ta) that is up to 4 m thick of subhorizontal pebbles. It is in angular unconformity with the underlying SFG strata. This pediment is only locally preserved on the Winston quadrangle at the southern end, but is more extensive to the south and north. On the Chise quadrangle to the east, it is capped by the basalt of Tabletop Mountain, for which Seager et al. (1984) obtained a K-Ar age of 4.8±0.1 Ma and McLemore et al (2012) obtained ^{40}Ar/^{39}Ar ages of 4.26±0.72 and 4.94±0.06 Ma. These ages place a minimum age on the underlying SFG.

Three ages of pre-historic alluvium are recognized on the Winston quadrangle (Qao3, Qao2, Qao1, in order of increasing age). These units are distinguished from the underlying SFG by their subhorizontal bedding, planar capping treads, the presence of red siltstones among the gravels, and, in places, by very red surface colors visible on aerial imagery. Qao2 is by far the most prevalent of these units, and this observation helps to correlate units from Poverty Creek and Cuchillo Negro Creek to Chloride Creek and South Fork Creek and to Monument Creek, as terrace units are not continuous throughout the quadrangle. These units are generally thin, particularly along Monument Creek and Poverty Creek, but locally form very thick fill deposits, particularly along Chloride and South Fork Creeks, where Qao2 can reach 40 m thick, and Qao1 is up to 25 m thick.

Qao2 is locally divided into Qao2a and Qao2b, based on a continuous scarp that is mainly along South Fork Creek. Local exposures along small streams reveal a gravel rich deposit below the scarp and a finer grained deposit above the scarp. Three alternative explanations are: 1) Qao2b is a younger unit inset upon a slightly higher and older Qao2a; 2) the scarp is an erosional feature, and both Qao2b and Qao2a are the same deposit; or 3) below the scarp are sediments associated with the axial South Fork Creek, while above the scarp are sediments derived from the hills to the south of the Creek.

The basal contact of Qao2 is particularly complicated in places as the unit both overlies underlying strata and is buttressed against the same strata. Thus the same contact will behave both subvertically and subhorizontally along the margins of South Fork and Chloride Creeks.

STRUCTURE

Faults and folds associated with Laramide compression and Rio Grande rift extension are present on the quadrangle. Harrison attributed north-northeast-striking dextral strike-slip faults in the Black Range to Laramide compressional tectonics. Compressional deformation affects rocks as young as the Eocene Rubio Peak Formation. Harrison (1989) used some of the larger exotic blocks of limestone in the Black Range to determine that at least 3140 m of dextral offset has occurred along the strike-slip faults.

Normal faults associated with Rio Grande rift extension offset all units but the inset post-Santa Fe Group alluvial deposits. The earliest expression of extension appears to be a set of northwest-striking veins and mineralized small offset normal faults occurring just southwest of the town of Chloride (Harrison, 1990). M. Bauman (unpublished report, cited in Harrison, 1986) obtained K-Ar ages from vein adularia of some of these mineralized fault zones, which ranged from 26.2 to 28.9 Ma. This late Oligocene age is consistent with the previous interpretation that initial graben subsidence began between the eruptions of the tuff of Little Mineral Creek and the Vicks Peak Tuff, at ~29 Ma. The small offsets of these faults, generally less than a few hundred meters (Harrison, 1990), is also consistent with the interpretation that initial subsidence was minor.

Younger, larger normal faults striking dominantly northwest to north-south offset these veins and almost all strata on the quadrangle. Small offset faults can be found in outcrop even in upper SFG strata (Figure 8), while map patterns suggest the upper-middle SFG contact is offset by numerous faults, particularly at the south-central portion of the quadrangle. The largest normal fault is that lying at the base of the Black Range, which in places juxtaposes Pennsylvanian strata against late Miocene upper SFG strata. This fault mainly strikes north to north-northwest, and locally trends northwest, where it is possibly reactivating an older late Oligocene structure. The next largest faults lie in the southeastern corner of the quadrangle, and locally juxtapose Eocene ignimbrites (Tkn, Trrc) against Miocene middle SFG strata. These two faults strike north-northwest and have opposing dip directions, and bound an intrabasinal horst (“Cuchillo Negro uplift” in Cikoski and Harrison, 2012). The highest density of normal faults occurs in the southeastern corner of the quadrangle, where numerous relatively small offset faults uplift Eocene-Oligocene volcanics along the Chise lineament of Harrison (1990, 1994) to form the southern end of the graben. Normal faulting in the Winston graben appears to have continued into the Pliocene (Cikoski and Harrison, 2012; Koning, 2012).

There appear to be two distinct dip domains in the Winston graben, a westward domain that dominates the Winston quadrangle-portion of the graben and an eastward domain that appears on the northeastern corner of the quadrangle. We have previously suggested elsewhere (Cikoski and Harrison, 2012) that this observation reflects a

Winston graben which is divided into adjacent west-tilted and east-tilted half-graben, that merge northward to form a single ‘symmetric’ full graben.

Dip magnitudes in the upper SFG appear to progressively decrease up-section, suggesting a ‘fanning’ of strata against the graben-bounding fault that lay at the base of the Black Range. This ‘fanning’ of strata would indicate syndepositional slip along this fault.

Figure 8 - Small faults are locally found in outcrop in the upper Santa Fe Group. Fault is just right of hammer, dipping to the right.

UNIT DESCRIPTIONS

Quaternary

Artificial and colluvial units

af **Artificial fill** - Compacted sand, silt, and gravel. Along South Fork Creek, includes areas affected by the St. Cloud mining operation, including waste and ore piles, fill from reclamation efforts, and disturbed ground around the mines and processing plant. Mostly 0-2 m thick, up to 40 m thick around the mines.

Qca **Colluvium and alluvium, undivided** - Gravel, sand, and silt burying geologic features in the interior of the Black Range. Includes gravity-, slopewash-, and minor channel-transported material. 0-2 m thick.

Alluvial units

Qar **Recent alluvium** (0-50 years BP) - Gravel, sand, and silt associated with recent flows of active channels. Includes low terraces with treads up to 1 m above the channel floor. Poorly sorted silt to cobbles with local boulders, with no soil development and little vegetative cover. 0-1 m thick.

Qah **Historic alluvium** (50-500 years BP) - Gravel, sand, and silt associated with historic river flows. Includes old channels blocked by artificial fill and thin deposits atop Qay deposits associated with very large flood events. 0-1 m thick.

Qafy **Small alluvial fans** - Silty fine sand with rare pebbles associated with small alluvial fans locally burying older alluvial units. 0-1 m thick.

Qay **Younger alluvium** - Gravels, sand, and silt with weakly developed soils underlying terraces with treads 2-3 m above the local channel floors. Gravels occur as broad paleochannels, typically surrounded by silty sand that accumulated outside of channels. Poorly to moderately sorted, with subangular to rounded clasts, commonly bioturbated. Soil development includes several weak buried soils, distinguished by darkened A horizons, and carbonate horizons locally up to Stage II but generally Stage I in development. 0-3 m thick.

Qahr **Historic and recent alluvium, undivided -** Units Qah and Qar, undivided. See individual unit descriptions for details.

Qayr **Younger and recent alluvium, undivided -** Units Qay and Qar, undivided. See individual unit descriptions for details.

Qayh **Younger and historic alluvium, undivided -** Units Qay and Qah, undivided. See individual unit descriptions for details.

Qayhr **Younger through recent alluvium, undivided -** Units Qay, Qah, and Qar, undivided. See individual unit descriptions for details.

Qao3 **Older alluvium, youngest subunit -** Gravels and pebbly sands underlying terraces with treads 5-10 m above local channels. Poorly exposed, but surface sediments and rare exposure suggest gravels are mainly fine to medium pebbles, with rare coarse pebbles and cobbles, that are poorly sorted and angular to rounded, with a matrix of silty fine to medium sand. 1 to at least 6 m thick.

Qao2 **Older alluvium, intermediate subunit -** Gravels and pebbly sands with well-developed soils underlying terraces with treads 15-20 m above local channels along Poverty, Cuchillo Negro, and Monument Creeks; increasing to 40 m upstream along Chloride and South Fork Creeks; and to 27 m upstream along Dry Creek. Gravels are poorly to moderately sorted subangular to rounded pebbles to cobbles, and sands are poorly sorted silty fine to medium grains. Generally finer grained along minor tributary streams, coarser along major creeks, with a particularly coarse cap present along Chloride and South Fork Creeks. Up to Stage III carbonate horizon development, with colors of 5YR 5/3 to 7/3 measured. 4 to 40 m thick along Chloride and South Fork Creeks, 2 to at least 15 m thick along other Creeks.

Qao2b **Older alluvium, younger intermediate subunit** – Locally, a continuous scarp divides Qao2 into upper (Qao2a) and lower (Qao2b) units, with local exposures suggesting there is a coarse fill deposit associated with Qao2b. Exposure is poor, however, and the scarp may simply be an erosional feature. Unit only divided where scarp is present.

Qao2a **Older alluvium, older intermediate subunit -** Locally a continuous scarp divides Qao2 into upper (Qao2a) and lower (Qao2b) units. Exposure is poor, however, and the scarp may simply be an erosional feature. Unit only divided where scarp is present.

Qao1 **Older alluvium, oldest subunit -** Gravels and pebbly sands underlying terraces with treads lying above that of Qao2. Poorly exposed, but surface clasts and rare exposures indicate the deposit is similar to coarse-grained Qao2 in composition. Widespread along South Fork Creek, where tread heights increase upstream from 35 to 60 m above the channel, and along Dry Creek, where heights are 22 to 28 m above the local channel, but otherwise rare. Up to 25 m thick.

Qao **Older alluvium, undivided -** Older alluvium, undivided. Used where specific unit correlation is not clear. 0-3 m thick.

Tertiary

Ta **Pediment alluvium -** Poorly sorted pebbles locally truncating coarser, tilted Santa Fe Group sediments on top of high mesas. Gravels occur at the same elevation as the basalt of Tabletop Mountain on the Chise quadrangle, and likely correlate to the same pediment surface as that underlying the basalt. This basalt has Ar/Ar ages of 4.68±0.10 and 4.91±0.03 Ma (McLemore et al., 2012). Up to 4 m thick.

<u>Santa Fe Group</u>

Tsf **Santa Fe Group, undivided -** Conglomerates and sandstones filling the Winston graben, up to the maximum level of aggradation. Hence does not include inset alluvium. Typically divisible here into lower, middle, and upper units based on intercalated volcanics, an angular unconformity, and lithologic characteristics.

Tsfu **Upper Santa Fe Group -** Brown to light reddish brown to pale, poorly to moderately cemented pebble conglomerates to sandstones. Overlies Tsfm and Twa with angular unconformity. Dominated by fine to medium pebbles with uncommon coarse pebbles and rare cobbles; conglomerate beds are noticeably less coarse than Tsfm. Clast suites and pebble imbrications indicate derivation from both the west and east. Poorly sorted silty fine to medium sand matrices with colors of 5YR 5/3 to 7/3 and 7.5YR 5/6 to 7/3 measured.

Tsfm **Middle Santa Fe Group** - Very pale brown to light pink pebble to cobble conglomerates and interbedded pebbly sandstones. Conglomerate beds typically consist of common coarse pebbles and cobbles, with lesser fine to medium pebbles and rare boulders up to 60 cm across. Clayey, silty, fine to medium sand matrices have colors of 10YR 7/1 to 8/3. Appears to have an interfingering contact with adjacent Tsfms; contact placed where ratio of sandstones and mudstones to conglomerates drops below 1:1.

Tsfms **Middle Santa Fe Group, sandstone-dominated subunit** - Very pale brown to light pink silty sandstones, sandy siltstones, and mudstones with interbedded conglomerates. Sandstones and siltstones are poorly sorted with silts to medium sand grains in varying proportions with very locally abundant fine to medium pebbles. Colors of 7.5 YR 8/2 to 9/3. Clay-rich mudstones with rare visible silt and sand grains are common to the southern end of this unit. Appears to have an interfingering contact with Tsfm; contact placed where the ratio of sandstones and mudstones to conglomerates rises above 1:1.

Tsfb **Boulder-rich Santa Fe Group** - Poorly sorted, relatively boulder-rich Santa Fe Group sediments. Consists of angular to rounded clasts from fine pebble up to 2 m across boulders, mainly of Moccasin John Rhyolite. Contacts with adjacent middle and upper Santa Fe Group are gradual, basal contact is conformable with lower Santa Fe Group.

Tsfl **Lower Santa Fe Group** - Light gray to pale yellow tuffaceous pebble to cobble conglomerates, lithic-rich tuffs, and tuffaceous sandstones. Conglomerates dominate and consist of poorly sorted pebbles and rare cobbles, with matrices of poorly sorted clayey fine to coarse sand. Conglomerate beds are commonly channel-shaped and discontinuous, with common cross-bedding and normal grading. Tuffs are poorly to non-welded, with 5-25% lithic fragments of aphyric rhyolite. One continuous tuff that is up to 8 m thick has been tentatively correlated to the 27.73±0.14 Ma South Canyon Tuff based on stratigraphic position and lithologic similarity to known South Canyon Tuff outcrops (Harrison, 1990, 1994).

Volcanics intercalated with the Santa Fe Group

Twa **Andesite of the Winston graben** - Gray to dark gray and dark reddish gray aphanitic to sparsely porphyritic andesitic flow dome complex and outflow lavas. Rare phenocrysts of mainly plagioclase, but also pyroxene, olivine, and biotite, up to 3 mm across. Typically discontinuous flows, with common autobrecciated tops and bottoms.

Mogollon Group

Tvp **Vicks Peak Tuff** - Light gray to light brown, massive, moderately to densely welded, crystal-poor ash-flow tuff. Phenocrysts of sanidine (1-3%) and sparse quartz. Bears conspicuous large, elongate pumices, most of which bear a granular texture from vapor-phase mineralization and recrystallization. Correlation to the Vicks Peak Tuff is based on stratigraphic position, distinctive textures, and a single-crystal sanidine $^{40}Ar/^{39}Ar$ age of 28.78 ± 0.18 Ma, comparable to the average age of 28.93 ± 0.12 Ma published by McIntosh et al. (1991).

Ttlm **Tuff of Lookout Mountain** - Light gray, weathering brown, moderately welded, moderately crystal-rich, moderately pumice-rich, lithic-poor ash-flow tuff. Contains 10-15% phenocrysts of dominantly sanidine, with rare biotite and sparse quartz. Also contains up to 10% medium gray elongate pumices. Correlation to tuff of Lookout Mountain based on a single-crystal sanidine $^{40}Ar/^{39}Ar$ age of 29.08 ± 0.02 Ma, comparable to the 29.06 ± 0.06 Ma average age published by McIntosh et al. (1991).

Ttsc **Tuff of Stiver Canyon** - Poorly to moderately welded, moderately crystal-rich, pumice-poor, lithic-poor, ash-flow tuff. Contains 10-20% sanidine, quartz, and minor biotite, with sanidine 2-3 times more abundant than quartz. Rare lithics are of flow-banded rhyolite and andesite. Up to 170 m thick.

Tlmc **Tuff of Little Mineral Creek** - White to yellow poorly welded, pumice-rich, very lithic-rich, crystal-poor ash-flow tuff. Lithic fragments of red and gray, angular, aphanitic, commonly flow-banded lavas consititute 10-50% of the tuff. 1-4% phenocrysts of quartz and sanidine, as well as trace biotite. Includes local, thin, fluvially reworked zones. Average single-crystal sanidine $^{40}Ar/^{39}Ar$ age of 29.39 ± 0.20 Ma (McIntosh et al., 1991).

Tmj **Moccasin John Rhyolite** - Phenocryst-poor, strongly flow-banded rhyolite flow domes and lava flows. Contains 1-3% quartz, sanidine, plagioclase and biotite. Commonly contains volcanic glass and spheulitic textures, as well as basal vitrophyres. Rare carapace breccias and interbedded perlitic tuffs and tuffaceous sediment. Thought to be genetically related to the tuff of Little Mineral Creek (Harrison, 1990).

Tsrr **Unnamed sanidine-rich rhyolite** - Light gray to pink crystal-rich rhyolitic volcanic rock. Occurs as two isolated, elongate outcrops toward the top of unit Tpc. Contains 20-40% phenocrysts of dominantly sanidine with minor biotite. Also contains sparse lithic fragments and a few elongate dark gray bands that may be strongly flattened pumices.

Tpc **Basaltic andesite of Poverty Creek** - Gray to dark gray, aphanitic to sparsely porphyritic basaltic andesites. As much as 10% phenocrysts of plagioclase, pyroxene, and rare biotite, generally <1 mm across. Belongs to the widespread SCORBA suite of Cameron et al. (1989). Includes rare interbedded volcaniclastic rocks.

<u>Datil Group</u>

Tkw **Tuff of Koko Well** - Two local ash-flow tuffs, locally welded together. Lower is moderately to densely welded and moderately crystal-rich, with 6% sanidine, 2-3% plagioclase, 1% biotite, and trace honeblende and pyroxene. Upper is massive, poorly welded, pumice-rich, and crystal-poor, with 5% sanidine, up to 1% plagioclase, and trace quartz and biotite. Upper tuff tentatively correlated to Rock House Canyon Tuff (Harrison, 1990; 34.87±0.24 Ma: McIntosh et al., 1991). Two tuffs together up to 75 m thick.

Tms **Sandstone of Monument Park** - Local sandstone interval with minor purple siltstones and pebble to cobble conglomerates. Sandstones are well-sorted and consist of subrounded to rounded grains of quartz, sanidine, plagioclase, and minor biotite. Conglomerates dominated by clasts of Tkn with minor andesitic lavas.

Tcns **Cuchillo Negro complex, tuff subunit** - Local ash-flow tuffs and intercalated sediments. Tuffs are dacitic, tan to white, generally lithic-rich, with phenocrysts of biotite (2-4%) and plagioclase (2-10%). Sediments vary from thin planar bedded sandstones to heterolithic, chaotic pebble to boulder conglomerates interpreted to be co-ignimbrite lag breccias (Harrison, 1990).

Tcnl **Cuchillo Negro complex. lava subunit** - Local instrusive-extrusive andesitic and rhyolitic vent complex. Consists of a rhyolitic intrusive/extrusive member that is flow-banded with 5-10% plagioclase and sanidine phenocrysts, a basaltic andesite intrusive/extrusive member with 20-25% phenocrysts of plagioclase and pyroxene up to 5 mm across, and an amygdule-rich intrusive trachytic member than cuts the other two members. K-Ar age of 34.7±0.8 Ma (C.E. Chapin, pers. comm., cited in Harrison, 1990).

Tkn **Kneeling Nun Tuff** - Light gray to gray to tan to pink, poorly to moderately welded, crystal-rich ash-flow tuff. 20-45% phenocrysts, of quartz, sanidine, plagioclase, and biotite. Normally zoned, with more abudant quartz and sanidine at the base, and more abundant biotite toward the top. Ar/Ar age of 35.34±0.10 Ma (McIntosh et al., 1991).

Trrc **Tuff of Rocque Ramos Canyon** - Moderately to poorly welded, moderately crystal-rich ash-flow tuff. 10-20% phenocrysts of subequal sanidine and plagioclase, and 1-2% biotite. Common small (1.5-2 cm across) devitrified pumice. Rare andesitic lithic fragments. Correlated to the Bell Top 4 tuff by Ar/Ar age and paleomagnetic data; Ar/Ar age of 35.41±0.08 Ma (McIntosh et al., 1991).

Tcc **Cliff Canyon Sandstone** - Purplish to white, fine-grained and well-sorted arkosic to quartzose volcaniclastic sandstone. Grains are typically subrounded to rounded and of quartz, sanidine, plagioclase, and minor biotite. Includes purple to blue-gray siltstones, and a basal conglomerate. Poorly consolidated and exposed.

Trpa **Upper Rubio Peak Formation, andesitic lavas** - Plagioclase ± hornblende ± pyroxene andesitic porphyry lavas. Multiple flows overlying the debris flows of the lower Rubio Peak Fm.

Trph **Upper Rubio Peak Formation, hornblende phyric lavas** - Plagioclase + hornblende ± pyroxene andesitic porphyry lavas. Multiple flows overlying debris flows of the lower Rubio Peak Fm.

Trpba **Upper Rubio Peak Formation, basaltic andesite lavas** - Dark, aphanitic, intermediate lavas. Multiple flows overlying the debris flows of the lower Rubio Peak Fm.

Trp **Rubio Peak Formation, debris flow-dominated unit** - Volcaniclastic-dominated Rubio Peak Fm. Dominantly massive, heterolithic, matrix-supported debris flow deposits, with pebbles to boulders of aphanitic and porphyritic intermediate volcanic rocks. Interbeds with sandstones to the south. Surrounds landslide blocks of limestone (&me).

&me **Exotic blocks of Madera limestone** - Exotic blocks of Pennsylvanian limestone surrounded by debris-flows of the lower Rubio Peak Fm.

Trpc **Rubio Peak Formation, basal conglomerate** - Local very poorly sorted pebble to boulder conglomerate bearing significant nonvolcanic detritus. Clasts are of monzonite, red siltstone, andesitic lava, and limestone, in order of decreasing abundance. Fills paleovalleys carved into underlying non-volcanic strata. Includes minor sandstones.

Trpm **Tuff of Miranda Homestead** - Strongly altered, moderately welded, lithic-rich, moderately crystal-rich ash-flow tuff. 10-15% phenocrysts of white to beige feldspars, quartz, and biotite. Maximum thickness of 20 m.

Paleozoic

Pre-volcanic units

Pa **Abo Formation** - Reddish brown siltstones, fine to coarse sandstones, and mudstones. Thin to medium bedded with abundant cross-stratification. Thickness up to 120 m.

Pb **Bursum Formation** - Gray, fossiliferous limestone and calcareous shale, interbedded with gray, green, and red shale and siltstone. Up to 40 m thick.

&m **Madera Limestone** - Light to medium gray fossiliferous limestone. Thin to thick bedded, commonly cherty and locally nodular. Includes rare interbedded shale and siltstone. Thickness up to 100 m.

Intrusive units

Tir **Rhyolitic dikes** - Porphyritic dikes with phenocrysts of quartz, sanidine, and biotite.

Tira **Aphanitic rhyolitic dikes** – Aphanitic, locally flow-foliated, rhyolitic dikes and intrusions.

Tia **Andesitic dikes** - Dark and aphanitic and plagioclase±pyroxene porphyry dikes.

Tiah **Hornblende porphyry dikes** - Porphyritic dikes with phenocrysts of plagioclase, horneblende, and locally pyroxene.

Table A1: Summary of new $^{40}Ar/^{39}Ar$ results and analytical methods

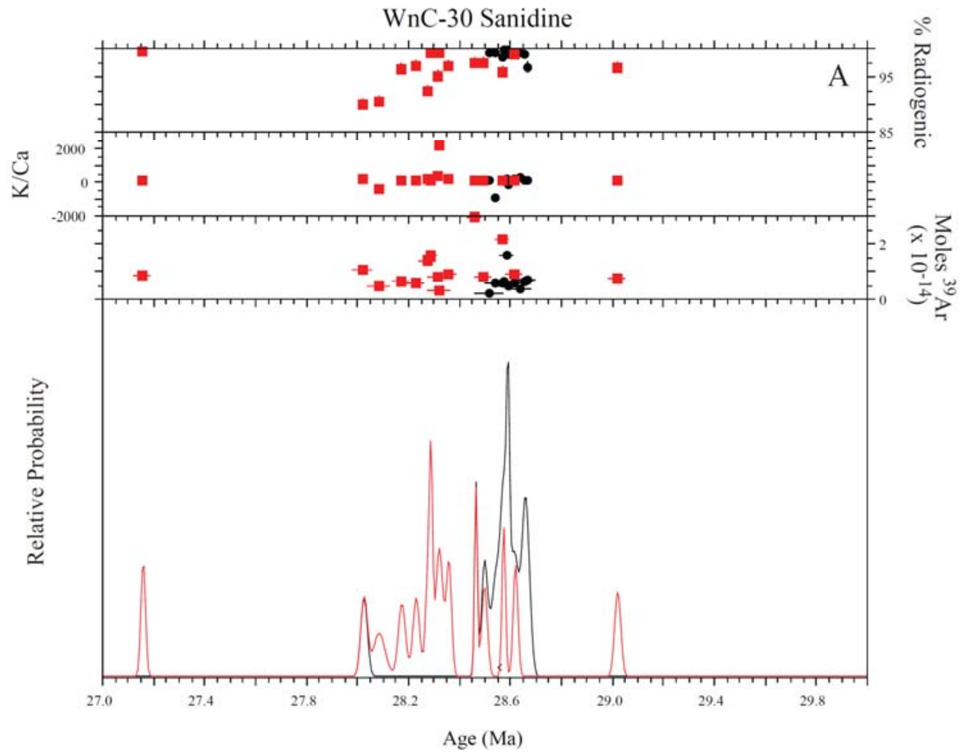
Sample[1]	Easting[2]	Northing[2]	Lab#[3]	Irr.[4]	Mineral	Analysis[5]	Total # analyses[6]	Used # analyses[6]	Age[7]	±2σ[7]
WnC-30	253125	3684155	61232	NM-250	sanidine	LSH	15	14	28.60	0.18
WnC-32	252300	3682313	61233	NM-250	sanidine	LSH	23	21	28.89	0.02

1: Sample name as used on the geologic map
2: Easting and Northing are UTM coordinates according to the NAD27 projection and datum.
3: NMBGMR argon laboratory sample number
4: Irradiation run number
5: LSH – laser step-heat
6: Samples were run at multiple wattages, two for WnC-30 crystals and three for WnC-32; "Total #" refers to the number of distinct data points excluding the lowest wattage analyses of each sample, while "Used #" refers to the number of data points used to calculate the age and standard deviation.
7: Age reported here is the original calculated age, relative to the 28.02 Ma Fish Canyon Tuff sanidine monitor age proposed by Renne et al. (1998); ages are scaled upwards in Table 1 to fit the 28.201 Ma Fish Canyon Tuff sanidine monitor age of Kuiper et al. (2008).

Technical details:

Sample preparation and irradiation:
Minerals separated with standard heavy liquid, Franz Magnetic and hand-picking techniques.
Samples in NM-250 irradiated in a machined Aluminum tray for 10 hours in C.T. position, USGS TRIGA, Denver, Colorado.
Neutron flux monitor Fish Canyon Tuff sanidine (FC-2). Assigned age = 28.02 Ma (Renne et al., 1998).
Instrumentation:
Biotite step-heating and associated monitors fused on a Argus VI mass spectrometer on line with automated all-metal extraction system.
Step-heating of groundmass and total fusion of monitors performed on a Mass Analyzer Products 215-50 mass spectrometer on line with automated all-metal extraction system.
Flux monitors and samples fused by a 50 watt Synrad or Photon Machines Inc. CO2 laser.
Analytical parameters:
Sensitivty for samples analyzed on Argus VI is 5 e-17 moles/fA.
Total system blank and background averaged 149, 0.20, 2.5, 0.10, 0.05 x 10-18 moles at masses 40, 39, 38, 37 and 36, respectively for the Argus laser analyses.
J-factors determined by CO2 laser-fusion of 6 single crystals from each of 6 radial positions around the irradiation tray.
Decay constants and isotopic abundances after Steiger and Jäger (1977).

Ideograms



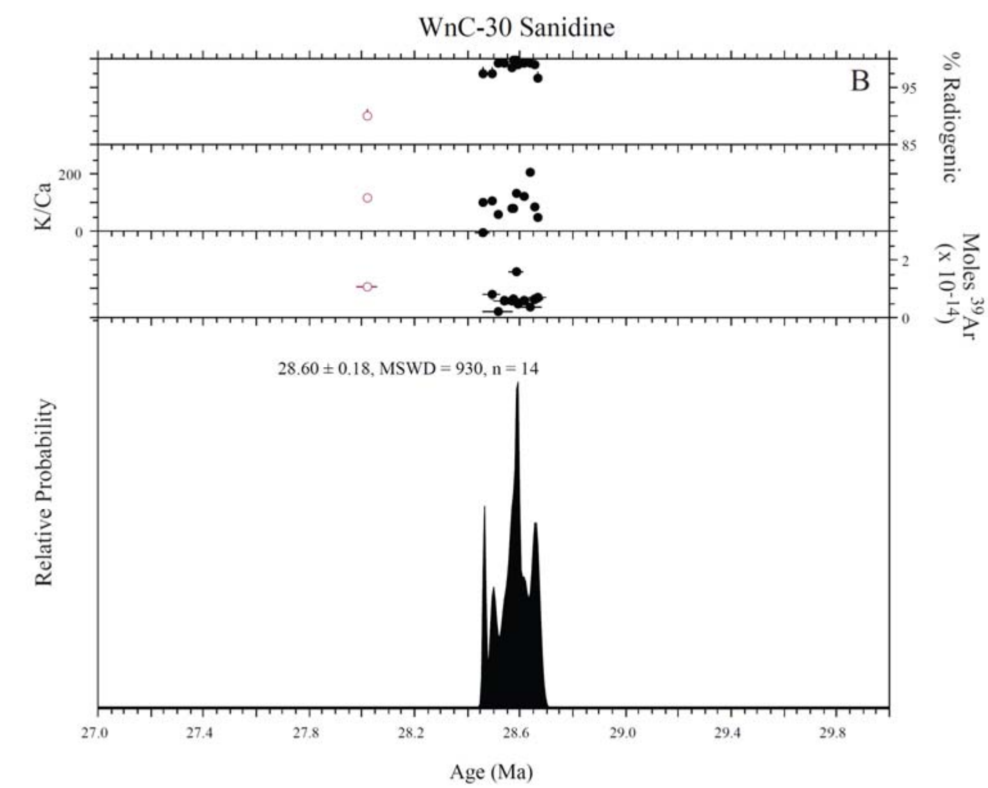


Figure A9 - Age probability distribution diagram of WnC-30. Figure A shows A (lower wattage) steps in red and B (higher wattage) steps in black. Figure B only includes data from the B steps.

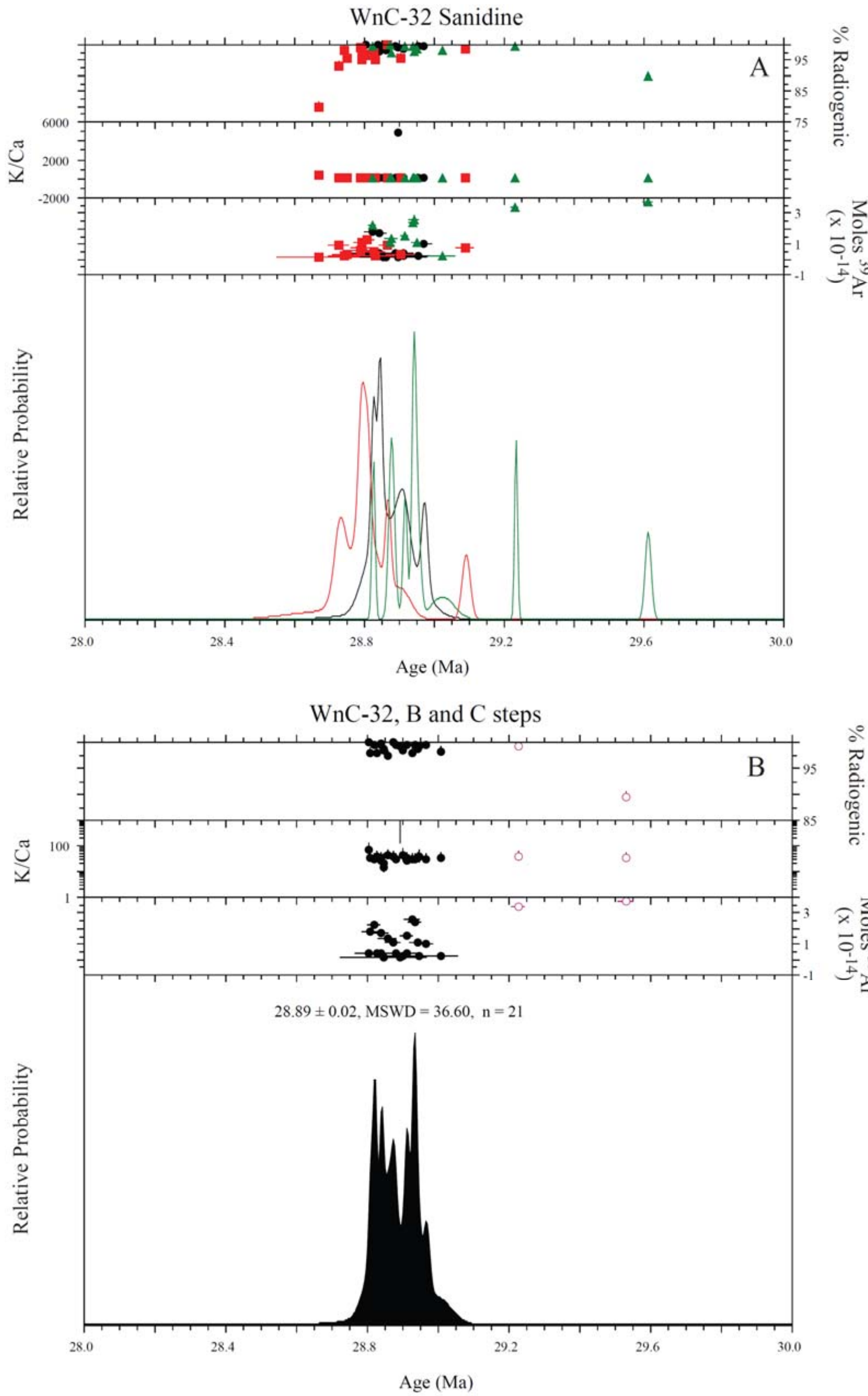


Figure A2 - Age probability distribution diagram of WnC-32. Figure A shows A (lower wattage) steps in red, B (medium wattage) steps in green, and C (higher wattage) steps in black. Figure B includes data from both B and C steps.

Data tables

ID	$^{40}Ar/^{39}Ar$	$^{37}Ar/^{39}Ar$	$^{36}Ar/^{39}Ar$ (x 10^{-3})	$^{39}Ar_K$ (x 10^{-15} mol)	K/Ca	$^{40}Ar^*$ (%)	Age (Ma)	±1σ (Ma)
WnC-30, San, J=0.0023679±0.01%, D=1±0, NM-250G, Lab#=61232								
X *03*	*7.371*	*0.0045*	*2.496*	*10.191*	*114.0*	*90.0*	*28.083*	*0.013*
02	6.912	0.0053	0.6247	28.952	96.9	97.3	28.479	0.005
01	6.926	0.0049	0.6451	7.879	103.2	97.3	28.513	0.011
05B	6.805	0.0088	0.2240	2.020	57.9	99.0	28.528	0.030
09B	6.810	-0.0005	0.2199	5.445	-	99.0	28.549	0.014
06B	6.780	0.0066	0.0971	5.818	77.8	99.6	28.578	0.013
14B	6.861	0.0068	0.3731	5.769	74.6	98.4	28.580	0.013
12B	6.779	0.0039	0.0825	15.297	130.5	99.6	28.592	0.006
08B	6.838	-0.0023	0.2728	4.240	-	98.8	28.601	0.016
04B	6.817	0.0044	0.1887	5.394	115.8	99.2	28.622	0.014
15B	6.831	0.0025	0.2136	3.297	201.0	99.1	28.647	0.021
13B	6.847	0.0063	0.2573	6.132	81.2	98.9	28.662	0.012
07B	7.029	0.0115	0.8528	6.673	44.2	96.4	28.688	0.013
10B	7.209	0.0026	0.1733	2.927	199.0	99.3	30.289	0.022
11B	7.896	0.0062	0.2193	1.110	81.9	99.2	33.114	0.060
Mean age ± 2σ	**n=14**	**MSWD=930.02**			**105.3 ±92.7**		**28.60**	**0.18**
WnC-32, , J=0.0023723±0.01%, D=1±0, NM-250G, Lab#=61233								
15B	6.795	0.0076	0.0090	3.236	66.9	100.0	28.804	0.023
02B	6.947	0.0152	0.4999	18.065	33.6	97.9	28.837	0.006
13B	6.822	0.0160	0.0739	3.841	31.8	99.7	28.843	0.016
05B	6.845	0.0198	0.1494	17.118	25.7	99.4	28.848	0.006
10B	6.963	0.0138	0.5383	3.609	37.0	97.7	28.855	0.020
11B	6.907	0.0253	0.3461	0.555	20.1	98.5	28.86	0.11
12B	6.928	0.0375	0.4150	1.380	13.6	98.3	28.871	0.041
07B	6.864	0.0183	0.1775	3.328	27.9	99.3	28.893	0.020
09B	6.877	0.0001	0.2054	1.335	4750.5	99.1	28.905	0.045
08B	6.817	0.0194	0.0001	3.788	26.3	100.0	28.914	0.016
14B	6.935	0.0129	0.3910	1.903	39.5	98.3	28.921	0.040
06B	6.888	0.0151	0.2027	1.453	33.8	99.1	28.958	0.041
01B	6.882	0.0176	0.1683	9.444	29.0	99.3	28.976	0.009
Mean age ± 2σ	n=13	MSWD=18.00			395.1 ±2617.4		28.870	0.029

WnC-32, , J=0.0023723±0.01%, D=1±0, NM-250G, Lab#=61233									
	15B	6.795	0.0076	0.0090	3.236	66.9	100.0	28.804	0.023
	14C	6.837	0.0175	0.1343	21.958	29.2	99.4	28.829	0.005
	02B	6.947	0.0152	0.4999	18.065	33.6	97.9	28.837	0.006
	13B	6.822	0.0160	0.0739	3.841	31.8	99.7	28.843	0.016
	05B	6.845	0.0198	0.1494	17.118	25.7	99.4	28.848	0.006
	10B	6.963	0.0138	0.5383	3.609	37.0	97.7	28.855	0.020
	11B	6.907	0.0253	0.3461	0.555	20.1	98.5	28.86	0.11
	12B	6.928	0.0375	0.4150	1.380	13.6	98.3	28.871	0.041
	08C	6.820	0.0149	0.0398	10.444	34.3	99.8	28.878	0.007
	07B	6.864	0.0183	0.1775	3.328	27.9	99.3	28.893	0.020
	15C	7.004	0.0123	0.6461	13.151	41.4	97.3	28.894	0.009
	09B	6.877	0.0001	0.2054	1.335	4750.5	99.1	28.905	0.045
	08B	6.817	0.0194	0.0001	3.788	26.3	100.0	28.914	0.016
	13C	6.859	0.0171	0.1375	15.031	29.8	99.4	28.920	0.006
	14B	6.935	0.0129	0.3910	1.903	39.5	98.3	28.921	0.040
	11C	6.860	0.0173	0.1223	23.652	29.5	99.5	28.942	0.005
	09C	6.979	0.0172	0.5128	25.626	29.7	97.8	28.956	0.006
	06B	6.888	0.0151	0.2027	1.453	33.8	99.1	28.958	0.041
	10C	6.928	0.0154	0.3360	10.493	33.1	98.6	28.961	0.008
	01B	6.882	0.0176	0.1683	9.444	29.0	99.3	28.976	0.009
	07C	6.971	0.0161	0.4259	1.991	31.7	98.2	29.033	0.033
X	*06C*	*6.950*	*0.0151*	*0.1885*	*33.190*	*33.8*	*99.2*	*29.238*	*0.004*
X	*12C*	*7.797*	*0.0164*	*2.704*	*36.525*	*31.0*	*89.8*	*29.674*	*0.009*
	Mean age ± 2σ	**n=21**	**MSWD=38.18**			**256.9 ±2059.3**		**28.89**	**0.02**

Notes:

Isotopic ratios corrected for blank, radioactive decay, and mass discrimination, not corrected for interfering reactions.
Errors quoted for individual analyses include analytical error only, without interfering reaction or J uncertainties.
Mean age is weighted mean age of Taylor (1982). Mean age error is weighted error of the mean (Taylor, 1982), multiplied by the root of the MSWD where MSWD>1, and also incorporates uncertainty in J factors and irradiation correction uncertainties.
Decay constants and isotopic abundances after Steiger and Jäger (1977).
X symbol preceding sample ID denotes analyses excluded from mean age calculations.
Ages calculated relative to FC-2 Fish Canyon Tuff sanidine interlaboratory standard at 28.02 Ma
Decay Constant (LambdaK (total)) = 5.543e-10/a
Correction factors:

$(^{39}Ar/^{37}Ar)_{Ca}$ = 0.000698 ± 8e-06
$(^{36}Ar/^{37}Ar)_{Ca}$ = 0.000273 ± 0
$(^{38}Ar/^{39}Ar)_{K}$ = 0.013
$(^{40}Ar/^{39}Ar)_{K}$ = 0.008236 ± 0.00013

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