Text and references to accompany Nevada Bureau of Mines and Geology Map 148

GEOLOGY OF THE DOGSKIN MOUNTAIN QUADRANGLE

NORTHERN WALKER LANE, NEVADA

by

Christopher D. Henry, James E. Faulds, Craig M. dePolo, and David A. Davis

INTRODUCTION

The Dogskin Mountain Quadrangle (DMQ) lies about 40 km (25 miles) north of the Reno-Sparks metropolitan area (fig. 1). The DMQ encompasses most of Dogskin Mountain and the western part of the Virginia Mountains, two northwest-trending ranges that are separated by Winnemucca Valley. Dogskin Mountain reaches a maximum elevation of 2282 m (7487 feet), whereas the maximum elevation of the Virginia Mountains is 2480 m (8140 feet) within the DMQ and 2659 m (8724 feet) at Tule Peak immediately to the east. Elevations in Winnemucca Valley and Bedell Flat, the valley southwest of Dogskin Mountain, range from 1400 to 1500 m (4590 to 4920 feet).

Geologic mapping of the DMQ was undertaken for several applied and scientific reasons and is part of a broader investigation of the northern Walker Lane, a northwest-trending belt of active, right-lateral strike-slip faults (fig. 2). Two major strands of the northern Walker Lane, the Warm Springs Valley and Honey Lake faults, pass through the DMQ. Western Nevada has experienced 13 earthquakes of magnitude 6 or greater since 1851 and two of magnitude 7 or more (dePolo and others, 1996). Geodetic data indicate the northern Walker Lane is undergoing about 10 mm/year of right-lateral motion, which represents 20–25% of Pacific-North American plate motion (Bennett and others, 1999, 2003; Thatcher and others, 1999). However, the earthquake hazard potential, as well as the Quaternary and late Tertiary structural-tectonic origin and evolution of the northern Walker Lane, remain poorly understood. Important questions related to young faulting include (1) which faults are taking up this motion, (2) have all important faults been identified, (3) what is the Pleistocene to Holocene displacement history, and (4) what is the earthquake potential for these faults? Furthermore, the DMQ contains one of the region's most complete records of Oligocene to lower Miocene ash-flow tuffs. Our new mapping and other recent research show that these tuffs flowed down and are mostly preserved in generally west-striking paleovalleys cut into Mesozoic rocks (Davis and others, 2000; Henry and others, 2002). Because they trend nearly perpendicular to the strike-slip faults, the paleovalleys are the best known piercing points to measure strike-slip displacement (Faulds and others, 2005). Previous mapping of the DMQ consisted of a thesis map, which covered part of the northern Dogskin Mountain (Hutton, 1978), and 1:250,000-scale maps of Washoe County (Bonham and Papke, 1969) and the Reno 1°x2° Quadrangle (Greene and others, 1991).

Major rock types in the DMQ (fig. 2) are Mesozoic metamorphic and plutonic rocks, a complex sequence of Oligocene to lower Miocene ash-flow tuffs, a similarly complex sequence of middle Miocene mafic lavas and clastic sedimentary rocks (Pyramid sequence), and a wide array of Quaternary, mostly alluvial fan, deposits (see plate). Major structural elements of the DMQ are northwest- and north-striking normal faults in Dogskin Mountain and the Virginia Mountains and northwest-striking, right-lateral strike-slip faults of the Warm Springs Valley and Honey Lake fault systems. General characteristics of the rocks are described in the map legend. This discussion focuses on regional geologic setting, especially on how the rocks and structures of the DMQ fit into that setting.

MESOZOIC ROCKS

Mesozoic rocks consist of probably Jurassic metavolcanic (Jmv) and metasedimentary (Jms) rocks, and three distinct plutonic rocks. The metavolcanic rocks are metamorphosed, porphyritic andesite lavas, possible hypabyssal intrusions, and possible rhyolite ash-flow tuff. The metasedimentary rocks are metamorphosed, coarse volcanic conglomerate composed of andesite clasts and sandstone and shale (schist). The metamorphic rocks crop out adjacent to major plutons in the central part of Dogskin Mountain and in Black Canyon, as well as in deeper canyons in the western part of the DMQ. This distribution suggests that Tertiary rocks in the northern part of the DMQ are mostly underlain by the metamorphic rocks. Similar metavolcanic rocks are widely distributed in western Nevada (fig. 2; Garside, 1998).

Parts of three Mesozoic plutons crop out in the DMQ (table 1). Quartz monzodiorite (Kqmd) makes up most of Dogskin Mountain and continues about 8 km south and southeast into the adjacent Bedell Flat (Garside, 1993) and Fraser Flat Quadrangles (Garside and others, 2003).

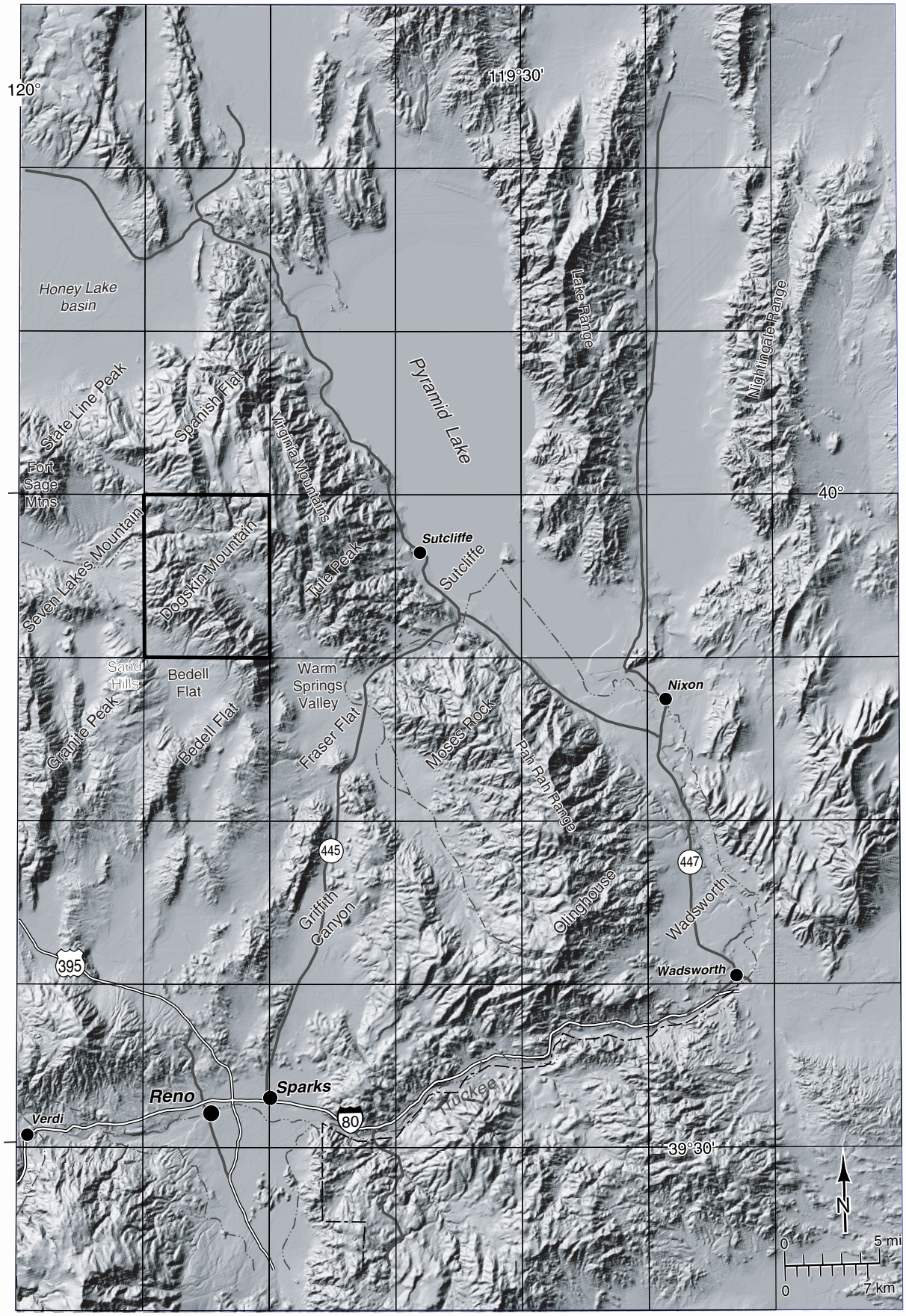

Figure 1. Location map of the Dogskin Mountain Quadrangle (bold outline), showing place names. Names sloping down to left are of quadrangles discussed in text.

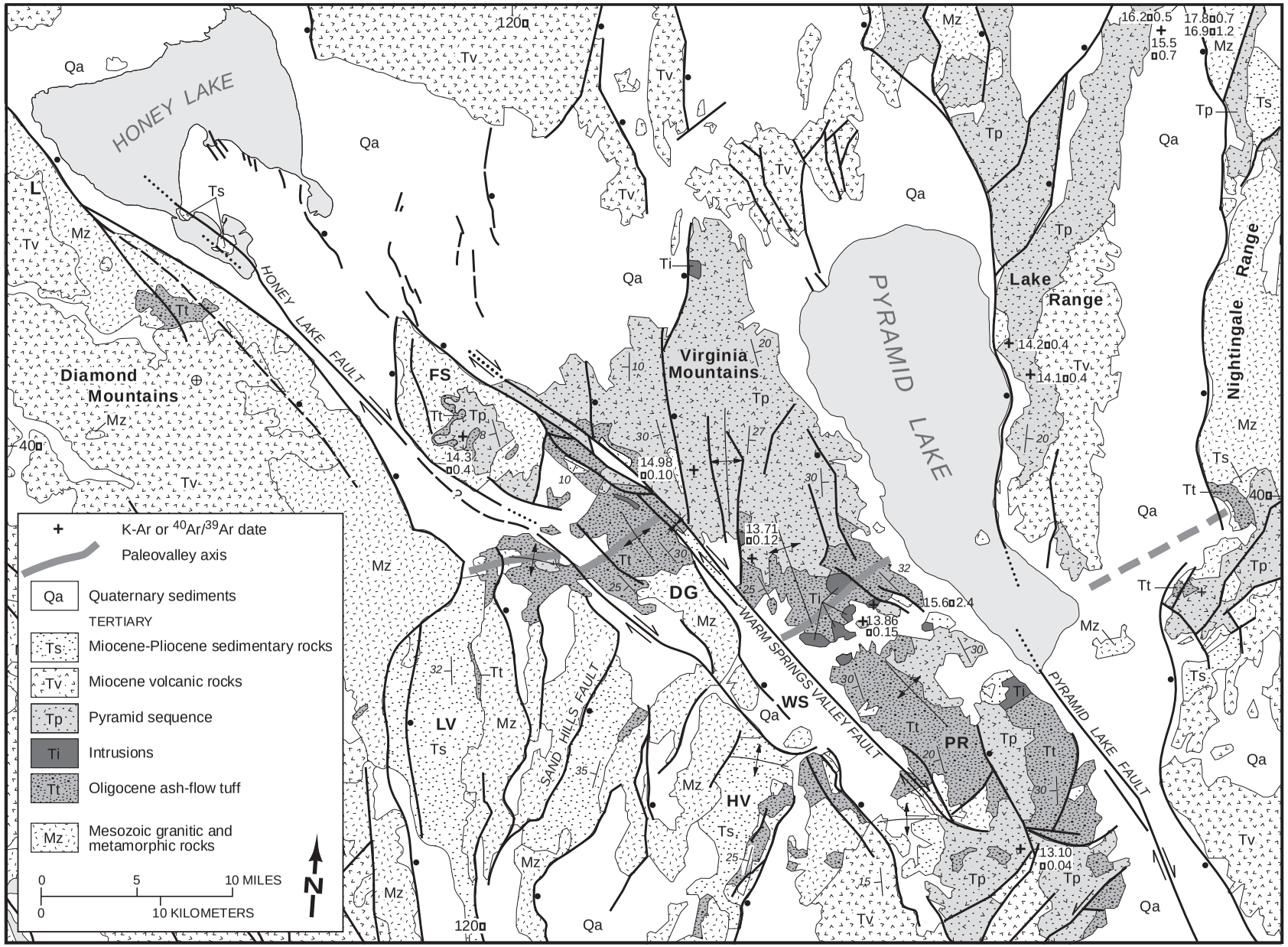

Figure 2. Simplified geologic map of the northern Walker Lane region in Nevada and California surrounding the Dogskin Mountain Quadrangle. FS = Fort Sage Mountains, LV = Long Valley, DG = Dogskin Mountain, WS = Warm Springs Valley, HV = Hungry Valley, and PR = Pah Rah Range.

Table 1. Chemical analyses of granitic rocks.

Sample		H01-118	H02-44	H02-110	H01-172
Map symbol		Kqmd	Kqmd	Kgg	Kgb
Rock name		quartz monzodiorite		granite	granodiorite
Quadrangle		D	D	S	D
Longitude 119°		48.03	48.5	53.084	48.56
Latitude 39°		55.57	55.2	52.787	59.60
SiO_2		64.50	63.31	68.11	70.28
TiO_2		0.60	0.58	0.46	0.31
$Al2O_3$		15.65	16.29	15.87	15.26
FeO		4.45	4.65	3.07	2.06
MnO		0.08	0.08	0.07	0.05
MgO		2.04	2.12	1.25	0.80
CaO		4.17	4.57	4.00	2.31
Na_2O		3.38	3.56	4.71	4.46
K_2O		3.59	3.32	1.30	4.03
P_2O_5		0.12	0.13	0.15	0.11
Total*		99.25	99.50	99.55	100.31
XRF	V	109	111	62	38
	Zn	61	61	71	34
	Ga	16	17	20	16
	Rb	161	142	68	94
	Sr	361	399	480	564
	Y	16	17	9	8
	Zr	168	205	125	125
	Nb	5	6	5	6
	Ba	697	786	330	1193
	Pb	16	15	13	8
ICP-MS	Sc	10.2	11.8	6.7	3.1
	Ti	3153	3058	2616	1504
	V	112	119	62	36
	Cr	29	30	24	28
	Co	13.1	13.8	8.7	4.2
	Ni	10.7	11.1	6.3	7.1
	Cu	49.4	35.8	>140	4.4
	Zn	49.4	51.4	61.7	27.1
	Ga	17.0	17.9	20.9	16.2
	Rb	>150	149	72	99
	Sr	369	407	497	569
	Y	17.2	19.3	9.9	7.8
	Nb	6	5.6	6.4	6.7
	Mo	1.3	1.0	0.7	0.5
	Cd	0.04	0.033	0.064	N.D.
	Sn	1.4	1.3	1.3	0.7
	Sb	>2	1.31	1.6	0.1
	Cs	9.1	7.4	5.7	0.9
	Ba	754	831	400	1222
	La	19.32	18.31	16.73	22.13
	Ce	42.57	40.72	37.81	42.42
	Pr	5.184	5.268	4.612	4.583
	Nd	20.5	21.01	17.4	16.16
	Sm	4.24	4.49	3.18	2.53
	Eu	0.834	0.852	0.813	0.684
	Gd	3.562	4.026	2.403	1.771
	Tb	0.543	0.603	0.329	0.243
	Dy	3.091	3.408	1.78	1.381
	Ho	0.608	0.667	0.336	0.277
	Er	1.766	1.922	0.954	0.809
	Tm	0.26	0.286	0.149	0.123
	Yb	1.72	1.8	1.02	0.85
	Lu	0.253	0.269	0.157	0.135
	Hf	2.8	2.8	2.5	1.6
	Ta	0.53	0.51	0.58	0.5
	W	1.05	0.33	0.23	0.09
	Tl	0.68	0.59	0.53	0.45
	Pb	13.9	12.5	18.5	8.5
	Th	17.0	19.3	8.3	5.2
	U	5.8	5.5	3.8	1.7

Analyses by XRF and ICP-MS at Carleton University, Ottawa, Canada
Quadrangles: D = Dogskin Mountain, S = Seven Lakes Mountain. All analyses normalized to 100% anhydrous.
FeO* = all Fe expressed as FeO; Total* = total before normalization to 100% anhydrous

Comparison of samples from the different quadrangles suggests a single pluton at least 15 km across. The quartz monzodiorite is cut by numerous small bodies of aplite and pegmatite (Kf) and contains abundant bodies of fine-grained diorite (Kd), including both dikes and inclusions. A distinct paleoweathered zone (Kqw) is commonly developed along the contact with the overlying Oligocene tuffs. Granodiorite (Kgb) crops out in a small area (about 0.5 km^2) in the footwall of a major normal fault in Black Canyon at the north end of the DMQ. The body is exposed for about another 2 km northward into the Spanish Flat Quadrangle. Cenozoic rocks cover it otherwise, and its overall distribution is unknown. A small area in the southwestern corner of the DMQ is underlain by granite of Granite Peak (Kgg; equivalent to quartz monzonite of Granite Peak of Garside, 1987). Granite continues at least another 7 km to the southwest and makes up the Sand Hills, which lie mostly within the Granite Peak Quadrangle (Garside, 1987). None of the intrusions in the DMQ are dated or contact each other, so absolute and relative ages are unknown. However, John and others (1993) assigned a Cretaceous age (about 90–100 Ma) to them as well as to intrusions throughout the area based upon their similarity to dated intrusions in the region. A Jurassic age is possible for the quartz monzodiorite, which has chemical similarities (e.g., high Zr; table 1) to known Jurassic intrusions (John and others, 1993). The nearest definitely Jurassic intrusions are near Yerington, approximately 110 km to the southeast (Dilles and Wright, 1988).

CENOZOIC ROCKS

Lower Miocene and Oligocene Ash-flow Tuffs

A thick sequence of at least 15 distinct, Oligocene ash-flow tuffs crops out in the Dogskin and Virginia Mountains and is representative of tuffs that are extensive in western Nevada. Most of the outcrop in the western part of the DMQ consists of ash-flow tuff or interbedded sedimentary rocks. With the exception of the youngest tuff, all tuffs erupted from sources well to the east in central Nevada. In western Nevada, they mostly flowed down and were deposited in paleovalleys cut into Mesozoic rocks. The tuffs in the DMQ fall into three distinct age groups (tables 2 and 3 on plate): an oldest group deposited between 31.3 and 28.6 Ma; a second group erupted between 25.3 and 24.9 Ma; and a single, young tuff that is probably 23.8 Ma.

The oldest group of tuffs includes at least 10 mappable units that were formerly combined into the tuffs of Whisky Spring or Coyote Spring in regional studies (Garside and Bonham, 1992) or tuffs of McKissick Spring in mapping within the DMQ (Hutton, 1978). Many of these tuffs are petrographically similar, with varying proportions of plagioclase, sanidine, and biotite phenocrysts and little quartz (table 2 on plate and fig. 3 on plate). Their narrow age range and petrographic similarities suggest that they erupted from the same or similar sources. A caldera complex

in the Clan Alpine Mountains (Riehle and others, 1972) about 170 km to the east is probably one source. A caldera in the Desatoya Mountains (McKee and Conrad, 1987) about 200 km to the east was definitely the source of the 28.9-Ma tuff of Campbell Creek (Tcc). Our unpublished petrographic, stratigraphic, and age data indicate the tuff of Axehandle Canyon can be correlated 225 km eastward to Reese River Narrows in the Toiyabe Range. M.G. Best (personal commun., 2001) correlates the tuff in Reese River Narrows with part of the Windous Butte Formation. Further work is needed to evaluate possible correlation between the tuff of Axehandle Canyon and the Windous Butte Formation.

The middle group consists of four tuffs ranging from 25.3 to 24.9 Ma. The distinctive petrographic characters of the Nine Hill Tuff (Tnh) and tuff of Chimney Spring (Tcs) (fig. 3 on plate) have made correlation relatively easy, and they are recognized widely in western Nevada and the eastern Sierra Nevada (e.g., Deino, 1985, 1989; Best and others, 1989; John, 1995; Brooks and others, 2003). The tuff of Chimney Spring and upper tuff of Painted Hills (Tpu) correlate with the tuff of Poco Canyon and tuff of Elevenmile Canyon, which erupted from calderas in the Stillwater Range (John, 1995; Hudson and others, 2000), about 120 km to the east. The source of the extremely widespread Nine Hill Tuff (Deino, 1985, 1989) remains unknown.

The rhyolite-dacite ash-flow tuff (Trt) is part of the informal "rhyolite group," which, in the Dogskin Mountain- Virginia Mountains-Pah Rah Mountains region, consists of rhyolitic to dacitic intrusions and lava domes; related, commonly andesitic dikes; rhyolitic to dacitic tuff and lava; related megabreccia; and rhyolite-clast conglomerate. Only the rhyolite-dacite tuff, megabreccia, and rhyolite-clast conglomerate are present in the DMQ. The tuff is petrographically similar and probably related to a series of rhyolite to dacite intrusive domes that are concentrated in the southern parts of the Tule Peak and Sutcliffe Quadrangles and northern parts of the Fraser Flat and Moses Rock Quadrangles (figs. 1 and 2; Faulds and others, 2003a, b; Garside and others, 2003). Slumping from the flanks of steep intrusive domes generated the megabreccia, and clasts of rhyolite are a prominent constituent of megabreccia. Two domes are precisely dated at 23.66±0.04 and 23.82±0.06 Ma in the Tule Peak and Sutcliffe Quadrangles, respectively (Faulds and others, 2003a, b). The domes are adjacent to and could be genetically related to the possible Perry Canyon caldera (Garside and others, 2000, 2003).

Still older ash-flow tuffs may be present in deeper, unexposed parts of the paleovalley. However, no tuffs older than the tuff of Axehandle Canyon, the oldest currently recognized tuff in the DMQ, are known in western Nevada.

All ash-flow tuffs are laterally discontinuous, because they were deposited almost exclusively in the deep paleovalley and commonly variably eroded before deposition of the next tuff. The oldest tuffs were deposited in and are largely restricted to the deeper parts of the paleovalley and crop out only in deep canyons, mostly in the western part of the DMQ (see plate). The southern edge of the paleovalley is readily apparent on the geologic map where the tuffs thin and pinch out southward against quartz monzodiorite (Kqmd). Younger tuffs, such as Nine Hill Tuff, rest directly on quartz monzodiorite outside the paleovalley, both in the range and along its southwest flank. A northern paleovalley margin is exposed in Black Canyon in the north central part of the DMQ. In that area, the tuff of Cove Spring (Twc) rests on Mesozoic rocks and pinches out northward, where Pyramid sequence rocks rest directly on granodiorite (Kgb). Because this location is on the other side of the Warm Springs Valley fault and amount of displacement on that fault zone is uncertain, the original position of this northern margin and whether it is the northern margin to the paleovalley exposed in Dogskin Mountain are uncertain.

Conglomerate, breccia, and some finer grained sedimentary rocks underlie and are interbedded with the tuffs. Clasts in the stratigraphically lowest conglomerate (Tck), exposed only in Dry Valley Creek near the western edge of the DMQ, are exclusively meta-andesite and a few granitic rocks. The lack of tuff clasts indicates deposition of the conglomerate preceded deposition of any of the tuffs. Coarse clasts of tuff are abundant in stratigraphically higher conglomerates. Although sedimentary deposits are found locally between all tuffs, the coarsest, thickest, and most distinctive deposit developed during the approximately 3.3- Ma hiatus between the older and middle group of tuffs. This conglomerate and breccia (Tcn) contains angular to moderately rounded clasts of tuff of Dogskin Mountain (Tdm) up to 12 m in diameter and of andesite up to 8 m in diameter. Andesite clasts include both Mesozoic metaandesite (Jmv), distinguished by metamorphism of plagioclase and mafic phenocrysts, and probable Cenozoic andesite, characterized by unaltered mafic minerals. A thin surface layer of clasts is commonly brecciated, but the clasts are not disaggregated. The deposit generally underlies Nine Hill Tuff (Tnh) or tuff of Chimney Spring (Tcs) and overlies tuff of Campbell Creek (Tcc), but it may locally underlie the tuff of Campbell Creek.

The complex interbedding of tuffs and sedimentary deposits is particularly well illustrated by a down-dip view of northeast-dipping rocks about 1 km southwest of Winnemucca Ranch (see plate). In that area, the tuff of Dogskin Mountain (Tdm) was deeply eroded before deposition of the tuff of Campbell Creek (Tcc). The tuff of Campbell Creek was itself deeply incised and the resulting valley filled with the coarse conglomerate/breccia (Tcn). Unit Tcn was then eroded, and Nine Hill Tuff (Tnh) partly filled the valley. Finally, Nine Hill Tuff was eroded, and the tuff of Chimney Spring (Tcs) filled that valley. Each of these deposits varies considerably in thickness and pinches out to the southeast or northwest against older rocks.

Pre-Cenozoic outcrops within and along the southern edge of the paleovalley are mostly Mesozoic metamorphic rocks. This suggests that the paleovalley is largely eroded into the metamorphic rocks and that the contact between metamorphic rocks and quartz monzodiorite controlled the edge of the paleovalley. The northern margin in Black Canyon shows a similar pattern, but whether that was the northern margin of the Dogskin Mountain paleovalley is not certain. Present-day relief on the paleovalley is at least

500 m, from Dogskin Mountain at 2275 m to the top of metamorphic rocks at about 1775 m north of McKissick Canyon.

Cenozoic Intrusions

Distinctive dikes of hornblende andesite (Tih), having only sparse plagioclase phenocrysts, crop out in four locations in the west-central part of the DMQ. The age and association of these dikes are unknown except that they cut ash-flow tuff as young as the tuff of Dogskin Mountain (Tdm, about 29 Ma). The dikes are unlike most other andesites in adjacent quadrangles, which have abundant, large plagioclase phenocrysts.

The presence of apparently Cenozoic andesite clasts up to 1 m in diameter in the sedimentary breccia (Tcn) requires a nearby source at least 25.3 Ma, the age of the overlying Nine Hill Tuff. Although we have found 28 Ma andesites near Carson City, the oldest dated andesites nearby are 22.7-Ma dikes in the Moses Rock Quadrangle (Garside and others, 2003).

Pyramid Sequence

The informally named Pyramid sequence (Bonham and Papke, 1969), which constitutes the oldest, locally derived Cenozoic volcanic rocks in the DMQ, crops out extensively in the northern part of the DMQ and in one area along the west side of Dogskin Mountain. The Pyramid sequence consists of complexly interbedded basalt to basaltic andesite and sparse andesitic lavas, one rhyolitic lava(?), coarse to fine clastic rocks, and a dacitic ash-flow tuff. The lavas range, apparently gradationally, from aphyric to abundantly and coarsely porphyritic; they are subdivided on the basis of phenocryst content (fig. 4 on plate and table 4 on plate) and known or inferred chemical composition (table 5 on plate). Two end members are aphyric to very finely porphyritic basalt to basaltic andesite (Tpb) and coarsely porphyritic basaltic andesite (Tpp). The coarsely porphyritic rocks are characterized by prominent, tabular plagioclase phenocrysts up to 20 mm long and 2 to 4 mm wide. Other mappable units are sparsely porphyritic basaltic andesite (Tpb′), finely porphyritic basaltic andesite (Tpp′), bimodal porphyritic basaltic andesite (Tpp″), and rhyolite lava or breccia (Tpr). The rhyolite (Tpr) at the northern edge of the DMQ occurs as boulders. Whether these boulders represent in-situ lava or were reworked is uncertain. The different lava types are distributed throughout the stratigraphic sequence. A well-exposed section through the Pyramid sequence in the Virginia Mountains (fig. 5) demonstrates the complex interbedding of different lavas and sedimentary rocks.

The dacitic tuff of Mullen Pass (Tpm) crops out at one location in the lower part of the Pyramid sequence. It correlates with the upper of two dacitic tuffs mapped to the east and southeast in the Tule Peak and Moses Rock Quadrangles (Faulds and others, 2003b; Garside and others, 2003).

Conglomerate, breccia, and sandstone (Tpc) dominated by clasts of lava occur throughout the Pyramid sequence. Clastic rocks dominate distal exposures of the Pyramid sequence, e.g., along the Warm Springs Valley fault system in the east-central part of the DMQ. Locally, the clastic rocks fill deep channels cut into lavas. Diatomite forms mostly thin, discontinuous lenses, too small to be mapped separately, within the sedimentary rocks. Where weathered to boulders of Pyramid lavas, the coarse deposits can be difficult to distinguish from late Pliocene-Quaternary alluvial deposits (QTa).

Both isotopic ages of lavas and leaf fossils in diatomite (Axelrod, 1956) demonstrate that the Pyramid sequence is middle Miocene. However, $^{40}Ar/^{39}Ar$ dates on different parts of the sequence are contradictory, with ages around 13.9 Ma in the lower part and about 15 Ma in the upper part. Hornblende from the tuff of Mullen Pass in the lower part of the Pyramid sequence in the Sutcliffe Quadrangle (Faulds and others, 2003a) yielded a date of 13.86±0.15 Ma. Swisher (1992) reported an indistinguishable $^{40}Ar/^{39}Ar$ date of 13.84±0.15 Ma on plagioclase from the same tuff. A basaltic lava (Tpb) at the base of the sequence in the western part of the Tule Peak Quadrangle (Faulds and others, 2003b) yielded an age of 13.71±0.12 Ma. However, lavas in the upper part of the sequence in the northern Tule Peak Quadrangle gave ages around 15 Ma (unpub. $^{40}Ar/^{39}Ar$ dates, J.E. Faulds and C.D. Henry), and plagioclase from the rhyolite (Tpr) is 14.98±0.10 Ma. Dates on the Pyramid sequence and regionally similar rocks are mostly about 14 Ma but range from 13 to 18 Ma (fig. 2).

The Pyramid sequence is widespread in western Nevada with a center of distribution approximately in the Virginia Mountains (figs. 1 and 2). It extends to the northern end of the Virginia Mountains (Faulds and Henry, 2002), to the Pah Rah Range (Sutcliffe, Moses Rock, and Olinghouse Quadrangles) to the southeast (Faulds and others, 2003a; Garside and Bonham, 2003; Garside and others, 2003) to the Lake and Nightingale Ranges to the east (Benham, 1982; Ressel, 1996), and to the Fort Sage Mountains, including slightly into California to the northwest (Grose, 1984; Grose and others, 1989, 1990). Correlation throughout this area is based on similar stratigraphic position and petrographic character, as well as on composition and age where available. For example, rocks in the Lake Range east of Pyramid Lake have similar compositions and K/Ar dates of 14.2±0.4 at the base and 14.1±0.4 Ma near the top (fig. 2; Ressel, 1996). However, Ressel included silicic lavas at the base and top of what he mapped as Pyramid sequence, and the K-Ar dates are on these rocks. Our rhyolite lava or breccia (Tpr) could correlate with or be reworked from silicic lavas similar to these. An $^{40}Ar/^{39}Ar$ age of 13.10±0.04 Ma (fig. 2) on a lava at the base of the Pyramid sequence in the Olinghouse Quadrangle (Garside and Bonham, 2003) demonstrates that some mapped Pyramid sequence rocks in the area shown on figure 2 are younger than those in the Virginia Mountains. Without detailed mapping and precise $^{40}Ar/^{39}Ar$ dates, correlation can be uncertain.

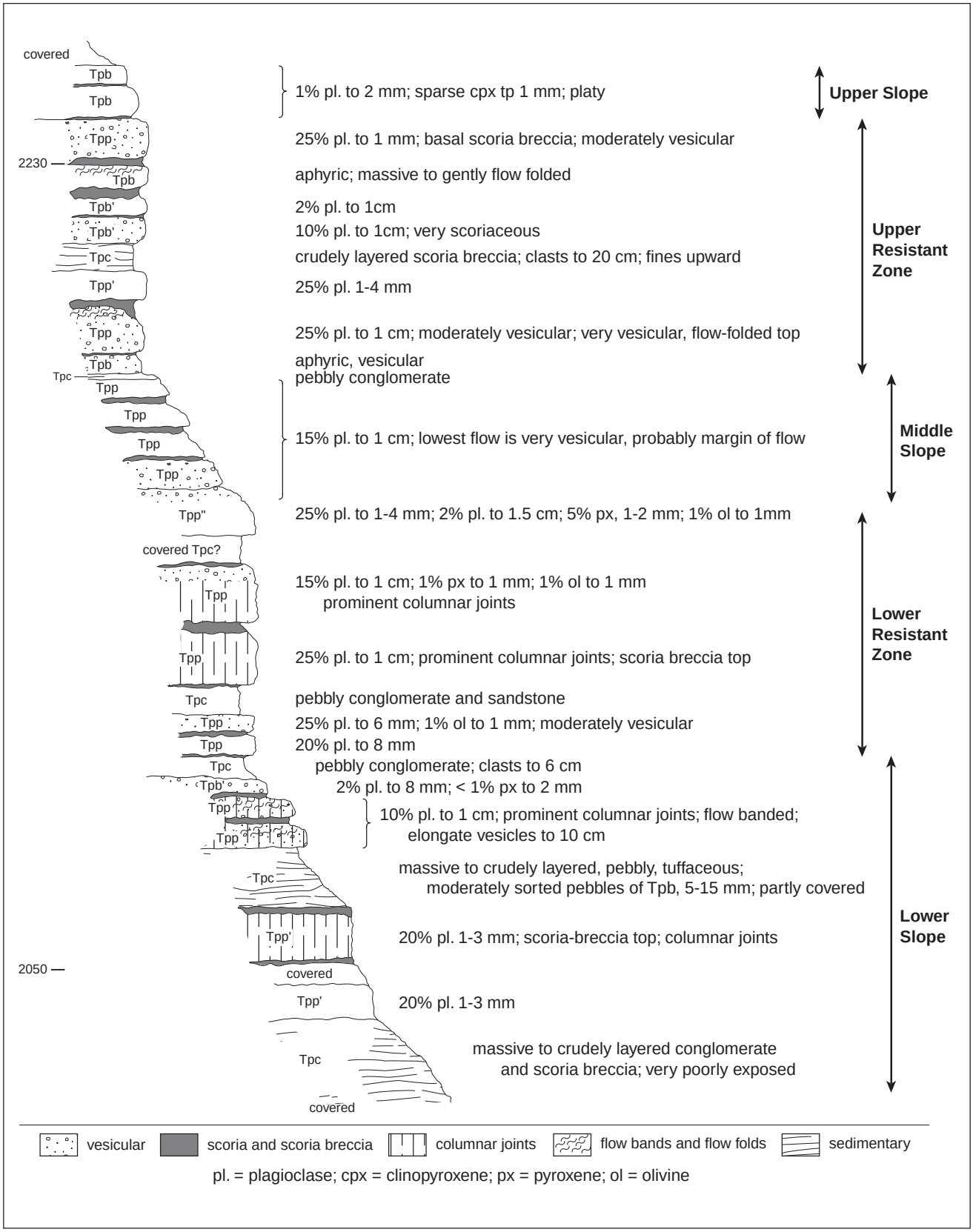

Figure 5. Stratigraphic section through a well-exposed part of the Pyramid sequence, west of Tule Peak in the northeastern part of the Dogskin Mountain Quadrangle. Based on exposures in the Tule Peak Quadrangle across the normal fault just to the east of this section, the sedimentary rocks at the base of this exposure are probably underlain by aphyric basalt lavas (Tpb), which rest upon Oligocene ash-flow tuff.

The tuff of Mullen Pass is recognized in the Tule Peak Quadrangle (Faulds and others, 2003b) and the southern Nightingale Range (Benham, 1982). The appearance of this distinctive and precisely dated tuff in the Nightingale Range indicates that lavas there are the same age, at least in part, to lavas in Dogskin Mountain and Tule Peak Quadrangles. Evans and others (1981) mapped a petrographically similar tuff in what they called the Pyramid sequence in the northern Lake Range, just north of the area depicted in figure 2. However, they report K/Ar dates between 16.2±0.5 Ma and 17.8±0.7 Ma on the tuff, which is distinctly older than our $^{40}Ar/^{39}Ar$ date.

Major source areas of the Pyramid sequence include a large volcanic complex that was centered on the north-central Virginia Mountains in the adjacent Tule Peak Quadrangle to the east (Faulds and others, 2003b), several intrusions in the Pah Rah Range (Garside and others, 2003), several stocks and numerous dikes in the Lake Range (Ressel, 1996), and numerous subvolcanic intrusions in the Fort Sage Mountains (Grose, 1984; Grose and others, 1989, 1990). Most of the lavas in the northern part of the DMQ may have come from the volcanic center in the Tule Peak Quadrangle. The source of the tuff of Mullen Pass is unknown.

Pleistocene(?) and Late Pliocene Alluvial Deposits

Variably deformed, coarse to fine clastic deposits crop out extensively in linear ridges along the Warm Springs Valley fault system. Two distinct types are clearly tilted and possibly folded. The stratigraphically older deposit (QTk) consists of pebble conglomerate and sandstone composed almost entirely of clasts of quartz monzodiorite (Kqmd). A tephra layer in this unit in the southern part of the Tule Peak Quadrangle yielded a plagioclase $^{40}Ar/^{39}Ar$ date of 3.58±0.45 Ma (table 3; Faulds and others, 2003b; Henry and others, in review). At the dated sample location, beds dip 38° to the southwest. This relatively fine-grained deposit contrasts with Pleistocene to Holocene alluvial fans derived from Dogskin Mountain, which contain clasts of quartz monzodiorite up to 2 m in diameter all the way to the Warm Springs Valley fault. An initial interpretation is that unit QTk records erosion of a lower elevation, "ancestral" Dogskin Mountain. If so, most of the uplift of Dogskin Mountain may have occurred after about 3.6 Ma.

A second clastic unit (QTa) consists almost entirely of coarse clasts of Pyramid sequence lavas, presumably derived from erosion of the Virginia Mountains. Uplift of unit QTa in the linear ridges distinguishes it as a map unit from the undeformed Pleistocene to Holocene alluvial fans, which have the same clast types and sizes. However, because faulting is ongoing, part of unit QTa may be toes of alluvial fans deformed along the Warm Springs Valley fault. Other parts may be only slightly younger than unit QTk, which unit QTa overlies wherever they occur together. Also, we may have mistakenly identified some of the coarse clastic rocks of the Pyramid sequence (Tpc) as these younger rocks.

Quaternary Fans and Alluvium

Quaternary piedmonts cover the lower flanks of Dogskin Mountain and the Virginia Mountains, and Quaternary alluvium forms terraces along drainages within Winnemucca and Dry Valleys. The western piedmont of the Virginia Mountains and the eastern piedmont of Dogskin Mountain are separated by Winnemucca Valley Creek. The western piedmont of Dogskin Mountain is broad and is faulted by the distributed Honey Lake fault zone (HLF). The piedmonts are made up of coalescing fans of four principal ages: older Quaternary (with "o" endings, early to middle Quaternary), intermediate age Quaternary ("i", middle to late Quaternary), late Pleistocene ("y_2") and Holocene ("y_1"). Older Quaternary fans have highly eroded and rounded surfaces that are generally higher than surrounding younger surfaces. Late Pleistocene and Holocene fans make up most of the piedmont, with "y_1" being the active parts of the fans. Fan deposits are composed of channelized alluvial and overland flow deposits, debris flow deposits, and minor rock avalanche deposits. The piedmont of the Virginia Mountains contains volcanic clasts from the Pyramid sequence and older rhyolitic rocks, whereas the piedmonts of Dogskin Mountain contains granitic clasts. Most alluvial terraces mapped along drainages within the quadrangle are Holocene flood plain deposits (Qt_1) with local channels.

STRUCTURE

Rocks in the DMQ are highly faulted and locally folded. Understanding of the overall structure is aided by dividing faults into normal and strike-slip faults and the DMQ into four structural domains (see plate). These domains are (1) normal faults of Dogskin Mountain, (2) normal faults of the Virginia Mountains, (3) the Warm Springs Valley strike-slip fault system, and (4) the Honey Lake strike-slip fault system. The Sand Hills constitute a fifth domain that lies mostly in the Bedell Flat Quadrangle to the south (fig. 1).

Normal Faults

Dogskin Mountain

The southeastern part of Dogskin Mountain is a southwest-tilted fault block, bounded on the northeast by the major Dogskin Mountain normal fault. Displacement on this fault may be as much as 2.5 km, based on known and estimated elevations of quartz monzodiorite (Kqmd) on each side of the fault (section C–C′). However, additional deformation along the Warm Springs Valley fault system complicates this estimate. The Dogskin Mountain fault continues to the southeast, into the Tule Peak and Fraser Flat Quadrangles, where the fault forms the western boundary of Warm Springs Valley (figs. 1 and 2; Faulds and others, 2003b; Garside and others, 2003). Although the southeastern flank of Dogskin Mountain is a steep topographic scarp, there is no evidence of Pleistocene(?) displacement on it. A northwest-striking normal fault also bounds part of the southwestern

side of Dogskin Mountain. However, southwest dips of ash-flow tuffs along the southwestern side and the asymmetric shape of the range, steeper on the northeast, indicate it is mostly southwest tilted.

The tuffs along the southwest side dip toward another major, northwest-striking normal fault in the southwestern corner of the DMQ. This fault forms the range front of the Sand Hills, which is a west-tilted block that lies mostly in the Seven Lakes Mountain, Granite Peak (Garside, 1987), and Bedell Flat Quadrangles (Garside, 1993). Displacement on the Sand Hills fault is probably about 2 km, but estimation is again hampered by proximity to the Honey Lake strike-slip fault. The Sand Hills fault curves to a north-northeasterly strike to the south (fig. 2; Garside, 1993).

The Dogskin Mountain frontal fault dies out northwestward, and the northern part of the range is a gently north-plunging, faulted anticline (section B–B′). Ash-flow tuffs dip southwest along the southwest flank and northeast along the northeast flank. The structural change is reflected in the shape of the range, from a steep face along the part bounded by the Dogskin Mountain fault to a much more gentle face along the anticlinal part (contrast sections B–B′ and C–C′). The anticline is cut by numerous, mostly moderate displacement normal faults that dip into the core of the anticline from both flanks. Displacements range up to about 1 km, but most faults have only a few hundred meters of offset.

Fault surfaces are rarely exposed, but we were able to measure fault and striae orientations on 23 faults in the northern part of Dogskin Mountain (fig. 6). The striae scatter widely but are consistent with approximately east to northeast extension. A few northwest-oriented striae may indicate reactivation during strike-slip faulting related to the Warm Springs Valley and Honey Lake fault systems.

Virginia Mountains

The Virginia Mountains in the DMQ are part of a broad, north-trending, faulted anticline whose main hinge line lies in the Tule Peak Quadrangle (Faulds and Henry, 2002; Faulds and others, 2003b). Outcrops are mostly rocks of the Pyramid sequence, which dip generally westward in the DMQ and eastward in the Tule Peak Quadrangle. However, dips reverse across several minor folds, including one in the DMQ.

The Black Canyon fault is the westernmost and has the largest displacement of a series of east-dipping normal faults (section A–A′). Granodiorite (Kgb) is exposed in the footwall of the fault in Black Canyon. Displacement on the Black Canyon fault in the DMQ is about 1.5 km, and appears to increase northward into the Spanish Flat Quadrangle. Pyramid sequence lavas dip generally about 30° westward in both the footwall and hanging wall. To the east, west-dipping Pyramid sequence lavas are repeated by another major normal fault in the canyon of Dry Valley Creek and by several small-displacement faults still farther east.

Along the eastern edge of the DMQ, two faults with about 300 to 500 m displacement dip to the west, and Pyramid sequence rocks dip gently (≤ 10°) to the east. Pyramid sequence rocks in the keystone block between east-

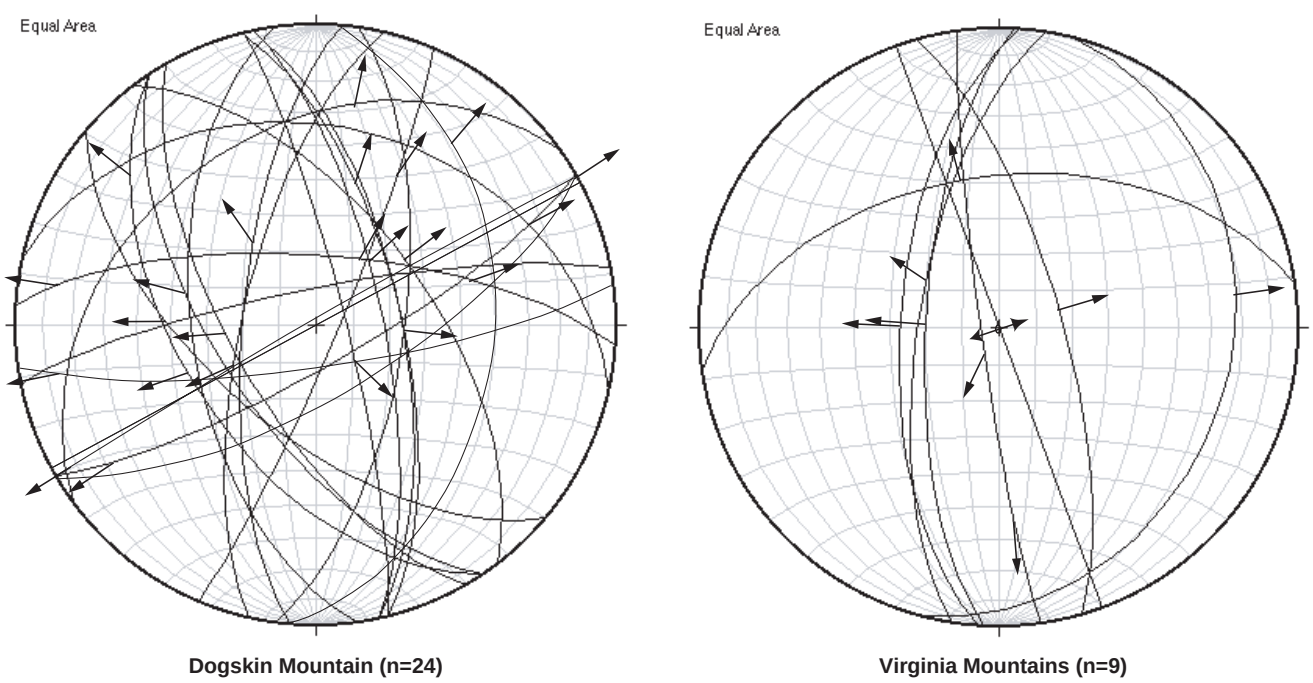

Figure 6. Stereonet plots of fault and striae orientations on 19 faults of the northern part of Dogskin Mountain (a) and seven faults in the Virginia Mountains (b) in the Dogskin Mountain Quadrangle. All faults are in Oligocene ash-flow tuffs or Pyramid sequence. These data indicate that faulting resulted from generally east to east-northeast extension.

and west-dipping faults dip gently westward and are cut by several small-displacement faults. Rocks in the hanging wall of these minor faults dip less than rocks in the footwall, which suggests the faults steepen downward.

Fault surfaces are poorly exposed in the Virginia Mountains, and we were able to measure fault and striae orientations at only eight locations (fig. 6). Nevertheless, these data as well as the predominant northerly strike of faults may also indicate approximately east to east-northeast extension as in the Dogskin Mountain domain. Reactivation during younger, strike-slip faulting is again possible.

The northeast tilt of tuffs in the northern part of Dogskin Mountain and the west tilt of rocks in the Virginia Mountains create a syncline between the two areas. The Warm Springs Valley fault system passes through the core of this syncline. Before the about 10 km of right-lateral displacement on the fault system (Faulds and others, 2004), southwest-dipping tuffs along the southwestern flank of the Virginia Mountains lay opposite the northeast-dipping tuffs of Dogskin Mountain (fig. 2).

Strike-slip Faults

Warm Springs Valley Fault System

The Warm Springs Valley fault system (WSF) is a northwest-striking, right-lateral fault system that extends southward about 80 km from the Honey Lake basin in California to near the east-northeast-striking, left-lateral Olinghouse fault (fig. 2). About 14 km of the fault system lie in the DMQ. Alignment of the tuff-filled paleovalleys indicate about 10 km right-lateral displacement on the WSF (fig. 2; Faulds and others, 2005).

The WSF consists of as many as four strands over a width of about 1.5 km in the DMQ. The fault system over most of its length cuts bedrock consisting of Pyramid sequence or Oligocene ash-flow tuffs. In a zone about 4 km long in the southeastern part of the DMQ, the fault system cuts Quaternary fans and late Pliocene-Pleistocene (?) deposits. Linear hills are well developed along much of the WSF in the DMQ and for about another 5 km southeast into the Tule Peak Quadrangle (Henry and others, 2002, in review; Faulds and others, 2003b).

Movement along faults of the WSF has significantly deformed both bedrock and surficial units. In bedrock, this deformation has greatly accentuated the syncline developed between the northeast dips of Dogskin Mountain and west dips of the Virginia Mountains. The northeastern limb of the syncline is overturned, whereas dips developed only from extension are generally about 30° and nowhere more than about 50°.

The WSF is marked by a series of linear ridges cored by Quaternary fan deposits and late Pliocene-Pleistocene deposits in both the DMQ and Tule Peak Quadrangle. Unit QTk is tilted 38° where it contains the 3.58±0.45 Ma tephra in the Tule Peak Quadrangle about 2.5 km east of the DMQ; correlative deposits just 0.5 km east of the DMQ are vertical. These units are probably similarly deformed in the DMQ, but poor exposure of the unconsolidated deposits makes measuring attitudes difficult. By analogy to the bedrock deformation, these units may also be folded.

The most obvious fault scarps show vertical rather than horizontal displacement. Although this may mostly reflect poor preservation and the difficulty in recognizing lateral scarps, the faults certainly have a vertical component. Vertical scarps are preserved along the borders of older, deformed fan deposits (Qado) approximately 2 and 4 km southeast of Winnemucca Ranch. Possible fault scarps are preserved in probable mid to late Holocene alluvial fan deposits (Qfy_1) and ponded deposits (Qp) along the same fault strand about 3 and 5 km southeast of Winnemucca Ranch.

Comparison of the type and sizes of clasts in deformed fan deposits (Qado) along the WSF and in their, undeformed proximal equivalents indicate little mid- to late-Pleistocene lateral displacement on some fault strands. For example, unit Qado approximately 2 km southeast of Winnemucca Ranch is bordered on the southwest by a down-to-the-southwest fault scarp. Clasts in Qado are of ash-flow tuff at its northwestern end. Southeastward along Qado outcrop, clasts of metavolcanic rocks (Jmv) and then of quartz monzodiorite (Kqmd) appear. This distribution matches clast-type distribution in the adjacent, more proximal alluvial fans ($Qfdy_2$ and Qfdi), which reflects bedrock distribution in the source areas of the fans. This relationship implies that Qado is the uplifted toe of the proximal fan deposits and has undergone negligible lateral displacement relative to them. This limits mid- to late-Pleistocene displacement along this strand to much less than 1 km. Unit Qado, adjacent Quaternary fans, their clast types, and bedrock distribution about 4 km southeast of Winnemucca Ranch show a similar pattern.

Displacement along one major strand of the WSF apparently blocked southwest-flowing drainage across the large alluvial fan complex at the eastern edge of the DMQ. This displacement, which could have been either lateral or vertical, created a closed basin in which ponded deposits (Qp) accumulated up fan from the linear ridges. Fan drainage subsequently cut through the ridges in two locations and dissected the ponded deposits. Dating of the ponded deposits could indicate at least one time of major displacement along the WSF.

The WSF changes strike from about N40°W to about N55°W northward across a poorly exposed, east-striking fault or fold zone along Dry Valley Creek. This zone is along a particularly linear, east-trending part of the creek that is distinctly aberrant to regional drainage patterns and extends another 4 km beyond the western end of the cross zone. Along most of the western half of the zone, volcanic rocks strike easterly on both the north and south sides, in contrast to their regional north to northwest strikes. A west-northwest-trending syncline is slightly oblique to the cross structure on its south side. Along the eastern part of the cross structure, volcanic rocks on the north side maintain their north-northwest strike but are clearly truncated against gently south-dipping rocks on the south side.

Honey Lake Fault System

The Honey Lake fault system is another northwest-striking right-lateral fault system that extends about 80 km from Honey Lake (Grose and others, 1990; Wills and Borchardt, 1993) at least to Warm Springs Valley (figs. 1 and 2; Garside and others, 2003). About 2.5 km of the fault system, entirely in alluvial fan deposits, crosses the southwestern corner of the DMQ. The HLF in this area displays several similarities to the WSF, including parallelism to an adjacent, major normal fault, wide zone of faulting, linear ridges, and obvious vertical displacements along some fault strands. The HLF parallels part of the Sand Hills fault to the southwest (fig. 2; section C–C′). Young fault scarps are developed over a width of nearly 2 km across the HLF. Correlation of the tuff-filled paleovalley across the HLF suggests about 4 km of displacement at this latitude (Faulds and others, 2005; C.D. Henry, mapping in progress).

Uplift along the HLF is indicated by a series of discontinuous low hills along the fault zone that become higher toward the northwest. The southeasternmost line of hills is about 100 m wide and 500 m long, rises about 2 m above adjacent alluvial fans on the downstream side, and blends imperceptibly into fans on the upstream side. The hills are underlain by calcite-cemented fine to coarse sand, unlike the surrounding alluvial fan deposits and of uncertain age. Boulders of quartz monzodiorite (Kqmd) to 50 cm and tuff to 30 cm lie along the flanks of the hills. We interpret a faint photolinear along the southwest flank of these hills as a fault scarp.

The next line of hills (Qfdo) to the northwest are almost 1 km long, continue into the Seven Lakes Mountain Quadrangle, and up to 250 m across. These hills rise as much as 10 m above adjacent alluvial fans, higher to the northwest. Abundant boulders, mostly of felsite (Kf) up to 80 cm in diameter, with lesser tuff (Tcs, Tnh, and Tmd) and quartz monzodiorite (Kqmd) up to 50 cm and 1 m in diameter, respectively, coat the hills, mostly along their steeper southwest flanks. These boulders contrast with clasts on the surface of adjacent, undeformed alluvial fans, where the coarsest grains are pebbles up to about 5 mm in diameter. A faint linear break along the southwest side of the hills may be another fault scarp. We interpret these hills to be uplifted, lower and coarser parts of the alluvial fans. Hills farther northwest into the Seven Lakes Mountain Quadrangle are still higher and expose ash-flow tuff bedrock.

Numerous faults cut the alluvial fans. The most obvious displacements are vertical, both down-to-the-northeast and down-to-the-southwest. The largest scarp, about 20 m, separates deeply incised older fans (Qfdo) on the northeast from less dissected younger fans ($Qfdy_2$) on the southwest. Three drainages show apparent right-lateral deflections of about 20 to 40 m, which constitutes the strongest evidence for relatively young strike-slip displacement along the HLF.

Lack of Strike-Slip Displacement in the Ranges

Several features indicate that little if any strike-slip displacement has occurred within Dogskin Mountain or the Virginia Mountains within the DMQ. The southern edge of the paleovalley in Dogskin Mountain forms a continuous wall striking west-southwest across the central part of the range. Coarse conglomerate/breccia (Tcn) forms a discontinuous series of outcrops parallel to and within about 1 km of Mesozoic outcrop and the southern edge of the paleovalley. In the Virginia Mountains, the northern pinch-out of the distinctive bimodal porphyritic basaltic andesite lava (Tpp″), probably the margin of the flow, makes an east-west line across several of the fault zones.

The relative timing of, and genetic relation between, normal and strike-slip faults is uncertain. The northwest-striking normal faults, including the Dogskin Mountain range-front fault, the northern part of the Sand Hills fault, and normal faults within the ranges, may have formed and were active mainly during one or two episodes of approximately east to east-northeast extension that preceded strike-slip faulting. Strike-slip faulting may have begun only in the last 3 Ma. Northwest-striking parts of range-front faults are now mostly inactive. In contrast, north- and north-northeast-striking normal faults could be kinematically related to the northwest-striking strike-slip faults, and both active contemporaneously (Faulds and others, 2003c; Faulds and others, 2005). Normal displacement on these normal faults would allow relative northwest-southeast displacement, as would the strike-slip faults.

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