GEOLOGY OF THE MOUNT WASHINGTON
7.5-MINUTE QUADRANGLE,
BERNALILLO AND VALENCIA COUNTIES, NEW MEXICO

by

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Geologic mapping by strata and Phanerozoic structures
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INTRODUCTION

The Mount Washington 7.5-minute quadrangle comprises an area of about 158 km^2 (61 mi^2) along the western flank of the Manzanita Mountains, in Bernalillo and Valencia Counties, New Mexico (Fig. 1). The quadrangle is approximately 15 km (10 mi) east of the Pueblo of Isleta and about 19 km (12 mi) southeast of the Albuquerque Civic Center. The quadrangle lies within the Pueblo of Isleta, Kirtland Airforce Base (KAFB) and Sandia National Laboratories (SNL). Earlier studies of the Manzanita Mountains were done by Reiche (1949) and Myers and McKay (1970 and 1976). Several unpublished studies have refined the stratigraphy, structure and geomorphology of portions of the quadrangle area (Thomas et al., 1995; Cavin, 1985; Parchman, 1981). The geologic map (Plate I) is the result of additional detailed field mapping and integration of previous work that has refined the structure and stratigraphy of the western flank of the Manzanita Mountains and the eastern margin of the Albuquerque basin.

Geologic mapping was completed in cooperation with the University of New Mexico (UNM) and the New Mexico Bureau of Mines and Mineral Resources (NMBMMR). The topographic base for the geologic map is the Mount Washington quadrangle, 7.5-minute topographic series, published by the United States Geological Survey at a scale of 1:24,000 (one inch equals 2000 feet). Proterozoic rocks and structures were mapped at a scale of 1:12,000 and compiled onto the geologic map at 1:24,000 (Plate I). Paleozoic rocks and associated structures were mapped in reconnaissance, with some modifications after Myers and McKay (1970; scale 1:24,000). Numerous observations of slip relationships were made on faults cutting the Paleozoic rocks. Piedmont deposits were delineated and compiled at a scale of 1:24,000. Compilation of data from various sources (Fig. 2) and scales of mapping onto the geologic map resulted in significant variations in the apparent precision of mapping across the study area; therefore, differences in map detail are inevitable.

Principal contributions and revisions to previous work (Reiche, 1949; Myers and McKay, 1971; Kelley, 1977; Cavin, 1985; Parchman, 1981; and Thomas et al., 1995) include: refinement of the stratigraphy structure and metamorphic and plutonic history of the Manzanita Mountains; differentiation of the piedmont stratigraphy on the Isleta Reservation; recognition of range-bounding structures (see Myers and McKay, 1970); and incorporation of subsurface data (Table 1).

The quadrangle map has been placed on open file in order to make it available to the public as soon as possible. The map has not been reviewed according to New Mexico Bureau of Mines and Mineral Resources standards. Revision of the map is likely because of the on-going nature of work in the region. ***The contents of the report and map should not be considered final and complete until it is published by the New Mexico Bureau of Mines and Mineral Resources.***

Comments to Map Users

A geologic map graphically displays information on the distribution, nature, orientation and age relationships of rock and surficial units and the occurrence of structural features (Bates and Jackson, 1987). Geologic and fault contacts are irregular surfaces that form boundaries between different types or ages of units. Data depicted on the Mount Washington quadrangle geologic map are based on reconnaissance field geologic mapping, compilation of published and unpublished work, and photogeologic interpretation. Locations of contacts are not surveyed, but are plotted by interpretation of the position of a given contact onto a topographic base map; therefore, the accuracy of contact locations depends on the scale of mapping and the interpretation of the geologist. Significant portions of the study area were mapped at scales smaller than depicted on the geologic map; therefore, the user should be aware of significant variations in map detail. Site-specific conditions should be verified by detailed surface mapping or subsurface exploration. Topographic and cultural changes associated with recent development may not be shown everywhere.

Any enlargement of this map could cause misunderstanding in the detail of mapping and may result in erroneous interpretations. The information provided on this map cannot be substituted for site-specific geologic, hydrogeologic or geotechnical investigations. The use of this map to precisely locate buildings relative to the geological substrate is **not** recommended without site-specific studies conducted by qualified earth-science professionals.

Accessibility

The Mount Washington quadrangle lies within the northeastern part of the Isleta Indian Reservation and southeastern sector of the Sandia Military Reservation (KAFB & SNL); travel within KAFB, SNL and Isleta Reservation is prohibited or locally restricted. The area is not accessible by public roads; however, several graded dirt and paved roads allow access to portions of the study area. The eastern half lies within the Manzanita Mountains and has very limited road access.

Geologic and Physiographic Setting

The quadrangle traverses the western flank of the Manzanita Mountains and the eastern margin of the Albuquerque basin (Kelley, 1977). The quadrangle lies south and east of the Tijeras and Hubbell Springs fault zones. The mountain-front, north of Hell's Canyon, is deeply embayed. The western half of the quadrangle forms a deeply to moderately dissected west-sloping piedmont. Several inselbergs of Proterozoic and inliers of Pennsylvanian rocks mark the northeastern part of the piedmont. Topography is generally steep and rugged in upland areas, which are held up by resistant Pennsylvanian sedimentary and Proterozoic crystalline rocks. Tertiary and Quaternary deposits are exposed along valley floors and in the piedmont. The study area exhibits 833 m (2734 ft) of maximum topographic relief, with a maximum elevation of 2434 m (7988 ft) at the Manzano Lookout Tower near the northeast corner, and a minimum elevation of approximately 1719 m (5640 ft) near Cañon de Sanchez along the southwestern corner of quadrangle. Maximum piedmont relief is about 135 to 170 m (440 to 560 ft). Relief along the mountain-front escarpment ranges between about 91 to 582 m (300 to 1910 ft).

STRATIGRAPHY

All map units are described in Table 3 (p. 26). The age and stratigraphic relationships of these map units are summarized in the Correlation of Map Units (p. 45).

Quaternary and Pliocene Deposits

Alluvial Deposits

Quaternary and Pliocene alluvial deposits of the Mount Washington 7.5-minute quadrangle contain variable proportions of gravel, sand and silt, deposited by intermittent and ephemeral streams; mass-movement deposits typically occur on hill slopes. Map-unit differentiation is based on stratigraphic position (inset or depositional relations), surface morphology, degree of soil-profile development (see Gile et al., 1966; 1981) and sedimentary character. Deposits are a mixture of poorly sorted, poorly to moderately stratified, clast- and matrix-supported alluvium, having predominantly gravelly to sandy textures; silt-clay textures are locally common. Clast constituents typically reflect bedrock composition of local upland drainage systems associated with the western flank of the Manzanita Mountains. Alluvial deposits are 12- to 21-m thick and unconformably overlie Mesozoic and older rocks. Detailed soil-profile descriptions were not made during this study, therefore, unit subdivisions (i.e., Qvm1 or Qvm2) may not be correlative across individual drainage basins. Alluvial deposits are divided into three major classes: 1) valley-fill alluvium, 2) piedmont-slope alluvium, and 3) colluvium and spring deposits. General characteristics of these classes are:

1) *Valley-fill alluvium (Qv subunits)* — Stream (floodplain, fill-terrace) deposits are restricted to major entrenched valleys and tributaries, such as Hell's Canyon Wash, Cañada Colorada and Cañon de Sanchez. Units typically have an elongated planform shape and are differentiated on the basis of inset relationships and surface morphology;

2) *Piedmont-slope alluvium (Qp subunits)* — Stream and alluvial-fan deposits on constructional and erosional parts of piedmont slopes. Units include fan and

debris-flow deposits and shallow-valley fills that are not graded to major entrenched arroyo systems;

3) *Colluvium and spring deposits (Qca and QTr subunits)* — Mass-movement deposits and calcareous spring recognized in upland regions and valleys.

The Pliocene and Quaternary alluvial sequence, as discussed in this report, is a sequence of stepped piedmont and valley-fill and valley-border landforms, deposits and geomorphic surfaces that unconformably overlie lower(?) Tertiary and older rocks. Members of this sequence range from historical to Pliocene in age and are informally defined, mapped and correlated on the basis of stratigraphic superposition, surface morphology, landscape-topographic position, and to a limited extent, soil-profile characteristics.

Deposits are a mixture of poorly sorted, poorly to moderately stratified, clast- and matrix-supported alluvium having predominantly gravelly and sandy textures. Details of deposit character are discussed in the Description of Map Units (Table 3) section accompanying the geologic map. Tentative correlations to previous studies are listed on Table 2. These deposits record episodes of deep valley entrenchment and partial backfilling that are graded to the Llano de Manzano and to former base levels on the footwall of the Hubbell Springs fault zone. Alluvial deposits range from 12 to 21 m in thickness and overlie Madera, Yeso and Abo Formations (Table 1). Clast lithology reflects composition of older units exposed within local upland drainage-basins. Upland regions are dominated by erosion with only local, short-term sediment storage on hillslopes and valley floors. Mass-movement deposits are common on hillslopes; hyperconcentrated-flow, debris-flow and local stream-flow deposits occur in higher order drainages. Piedmont-slope deposits extend westward from the mountain front and form constructional landforms on coalescent piedmont alluvial-fan complexes. Colluvium is common along unit margins and on terrace risers associated with major drainages. Valley-floor deposits occupy former floodplain positions of major drainages.

Unit QTspc is topographically the highest unit on the piedmont and unconformably overlies Paleozoic and Mesozoic rocks (Tables 1 and 2). This unit is poorly exposed and contains well-indurated, limestone-rich conglomerate with minor sandstone interbeds preserved on the footwall of the Hubbell Springs and Sanchez fault zones. The top of unit QTspc forms a fairly broad constructional summit surface that exhibits a partially stripped petrocalcic soil with stage IV to V pedogenic calcium-carbonate morphology. This unit locally forms two inset deposits or straths that sit between 11- to 30-m above present valley floors in the study area (Fig. 3). The top of QTspc1 sits about 52 m above the floor of the Llano de Manzano in the adjacent Hubbell Spring quadrangle, where the escarpment of the Hubbell Bench is deeply embayed, exhibits a sinuosity of about 3.7, and has retreated about 640 m to the east. The magnitude of hillslope retreat and strong soil development suggests that QTspc is probably at least Pliocene in age and is therefore correlated to the Santa Fe Group.

Unit QTpo is inset against QTspc and mapped as rounded inliers north of Cañada Colorada. This unit is poorly exposed and occurs along the western edge of the quadrangle where it is physically correlated with unit Tf2 in the Hubbell Springs quadrangle (Love et al., 1996).

Unit Qpo is inset against QTspc and QTpo and forms rounded hills, whose summits are between 5- to 10-m above local base level. This unit is poorly exposed, but exhibits stage III calcium-carbonate morphology and locally, multiple buried soils, indicating episodic aggradation. This unit is locally divided into three subunits of the basis of inset relations. Unit Qvo is correlative to Qpo and is associated with the early incision of the Hells Canyon Wash and Cañada Colorada stream systems.

Unit Qvm forms broad valley-fill deposits that are inset against Qpo. This unit forms prominent terraces along the margins of Hell's Creek Wash, Cañon de Sanchez and Cañada Colorada and associated tributary systems. This unit sits between 3.5 and 8.5 m above local base level in the study area. This unit is locally buried by deposits of unit Qvy. Deposits contain conglomerate and minor sandstone and exhibit stage III calcium-carbonate morphology with multiple calcic (Bk) horizons within Hell's Creek Wash. Unit Qvm is locally divided into two subunits on the basis of inset relations.

Unit Qvy is inset against Qvm and forms sandy to conglomeratic valley-fill deposits that are at least 4 m in thickness. Light-gray clayey carbonate and distinct (high-chroma) orange-brown mottles are common along reaches within Colorada Canyon and may be related to fluctuating water levels perched above well cemented Santa Fe Group deposits. Deposits were drained as the streams continued to incise into their modern valleys. Because of its position on valley floors, the soils are rather complicated, ranging from weakly developed (weak stage I carbonate morphology) and locally possessing multiple buried Bk horizons with stage II and III morphology. This unit forms a late Pleistocene to Holocene valley fill that is locally buried or incised by historic and late Holocene streams.

Pediment gravels were not observed in the study area; however two inliers of Madera

Formation flanking the mouth of Hell's Canyon slope to the west at angles less than bedding dips. In particular, a prominent inlier north of the creek projects beneath QTspc2 and may be the exhumed surface of erosion (ie. pediment) that underlies piedmont deposits of the Santa Fe Group.

Paleozoic Rocks

Upper Paleozoic strata within the quadrangle, both exposed and concealed (Table 1), include the Sandia Formation, Madera Group (lower and upper), Abo Formation and Yeso Formation. They represent marine and non-marine sedimentary deposits of Pennsylvanian and Permian age. For a description of these units see Table 3.

Upper Paleozoic strata of Mississippian to Permian age in the New Mexico region were deposited in and adjacent to widespread shallow seaways. These widespread syntectonic basins may have formed during collision of the South and North American continents in the region that now includes Texas and Oklahoma (Kluth and Coney, 1981). Alternatively they may have formed during collision of island arcs along the SW margin of the continent in the region of northern Mexico (Royden et al., 1996).

Proterozoic Rocks

Early Proterozoic rocks in the Mount Washington quadrangle consist of ductiley deformed and metamorphosed volcanic, sedimentary and plutonic rocks. These rocks generally formed in volcanic arcs and related arc basins along the growing southern periphery of cratonic North America in the Early Proterozoic (ca. 1.6–1.7 Ga). The complex metamorphic sequence is described in Table 3. The metavolcanic and metasedimentary succession is probably equivalent to rocks dated at 1680 Ma in the southern Manzano Mountains (Bauer et al., 1993). They are intruded by various units, most notably the Manzanita Granite dated at 1632 ± 45 Ma by the U-Pb zircon method (Unrue, unpublished data). A non-metamorphosed granitic to rhyolitic dike (Ygd, Table 3) is here confirmed to be of middle Proterozoic age (1428 ± 3.6 Ma) on the basis of a new $^{40}Ar/^{39}Ar$ plateau age from muscovite (New Mexico Geochronology Research Laboratory; M. Heizler, written commun. 1997). This east-trending dike cuts metasedimentary rocks about 2 km northwest of the mouth of Hells Canyon.

Mapping in this quadrangle has led to a new proposed stratigraphy for the Sandia-Manzano uplift. This proposed stratigraphy is based on correlation of similar lithologies across major folds and thrusts, so the stratigraphic interpretation is strongly based on the accompanying structural interpretation. In particular, we have correlated mafic to intermediate metavolcanic packages (Xmv and Xiv) that have been variously named (from north to south) the Tijeras (Connolly 1982), Coyote (Cavin, 1985), and Isleta (Parchman, 1981) greenstones. These units all contain a heterogeneous assemblage of metavolcanic and volcaniclastic units and all appear to grade upwards into phyllites (Xp) and dirty lithic arenites (Xla). The more mature quartzites (Xq) and schist (Xs) of the northern part of the quadrangle probably overlies the lithic arenite as part of a trend towards more mature sediments, but contacts are not exposed in this quadrangle.

A diverse assemblage of intrusive units are present in the Mount Washington quadrangle. Units within the greenstone include mafic intrusives (Xmi), diorite (Xd), and biotite-bearing granite (Xbg) that all may be part of an intrusive suite related to the nearby Ojito pluton to the south and the Cibola granite to the north. The latter has been dated as 1653 ± 21 Ma by Unrue (unpublished data). The Manzanita Granite (Xmg) forms a major plutonic complex in the northern part of the quadrangle; it has yielded a U-Pb zircon date of 1632 ± 45 Ma (Unrue, unpublished data). It is intruded by leucocratic granite, aplite, and pegmatites that may be evolved units of the same intrusive event. A series of quartz veins (Xqv) intrudes along the main foliation throughout the central part of the quadrangle. A single dike of fine grained granite (Ygd) intrudes along foliation in the northern part of the quadrangle; this dike yields a $^{40}Ar/^{39}Ar$ date on muscovite of 1428 ± 3.6 Ga.

STRUCTURAL GEOLOGY

Folds, faults and shear zones in the Mount Washington quadrangle exhibit several styles of deformation related to different periods of tectonic activity since the Proterozoic. This section discusses some of the recent refinements to the structure of the study area.

The range-front and intra-basinal faults are buried by Pliocene basin-fill and younger deposits in the study area. The Coyote fault, named by Myers and McKay (1971), is a north-striking high-angle fault (most recent movement probably normal) that juxtaposes Sandia and Madera Formations down-to-the-west against Proterozoic crystalline rocks between Coyote Canyon and the northern boundary of the Isleta Reservation. This frontal fault is associated with a deeply dissected west-facing escarpment, north of the projected trace of the Colorada fault. The Colorada fault is a structure named by Kelley (1977) for a northwest-striking fault along the Cañada Colorada drainage. The Colorada fault is poorlly known with respect to sense of shear; it displaces Madera Formation against Proterozoic crystalline rocks along a northwest trending mountain-front reentrant at the mouth of Hells Canyon. The northwestward projection of this structure is also recognized in the subsurface by an abrupt southward thickening of basin fill, just west of the study area (Thomas et al., 1995). The Manzanita fault, which lies between Hells Canyon and Seis Canyon, is a continuation of the north-trending Manzano fault. The Manzanita fault probably represents a Laramide transpressional fault reactivated by late Cenozoic rifting. The Hells Canyon fault, of late Paleozoic character (ie. sinistral) also may have been reactivated by Laramide deformation.

The Sanchez fault is here named for a northwest trending escarpment along the southeastern corner of the Hubbell Springs quadrangle (see Love et al., 1996). This fault is subparallel to the Colorada fault and displaces QTpsc down to the southwest. This structure is buried by Qvm in the study area; however, the fault trace projects towards a major mountain-front reentrant at Seis Canyon, just south of the study area, where it probably connects to the Manzano Mountains frontal fault system. Newly named northerly trending faults displacing Pennsylvanian rocks include the Torre, Malacate, Tiro, Sol Mete, Cueva and Puerta faults. Many of these faults appear to have complex slip histories, as described below.

Paleozoic and Younger Structures

Paleozoic and younger structures consist primarily of faults and gentle- to steep-limbed drape or drag folds adjacent to these faults. Most faults trend NNE; less common and shorter fault segments locally trend NW, NNW and ENE. Reiche (1949) recognized strike slip, reverse and normal faults in the Manzanita Mountains area. New mapping for this report suggests a complex slip history for many faults in the Mount Washington Quadrangle. Several faults, namely the Malacate, Torre and Hells Canyon, show an early history of sinistral strike slip probably associated with Ancestral Rocky Mountains deformation in late Paleozoic time. Sinistral slip on these NNE trending faults is generally indicated by NNW striking releasing bends and ENE striking constraining bends (reverse faults), in addition to *local* preservation of subhorizontal striations on high-angle fault surfaces.

Constraining bends, one observation of subhorizontal striations, and en echelon folds along the Hells Canyon fault (near Gotera Canyon) clearly represent an early period of sinistral transpression. Reidel like splays from the Hells Canyon fault may also represent a period of Laramide right lateral transpression. The northern portion of the Hells Canyon fault (and other local segments) exhibits dip-slip normal displacement, which may represent later reactivation by late Cenozoic rifting. It could also represent second-order transtensional forces of Laramide origin.

Local thickness variations and facies relationships in the Sandia Formation strongly suggest that segments of the Torre and Cueva faults, which locally display normal slip, were active in Middle Pennsylvanian time. The Sandia is anomalously thick (approx. 180 m), dominantly conglomeratic, and distinctly tilted in the hanging wall block of the Torre fault north of the HERTF site. Dips of the Pennsylvanian beds locally decrease upsection here, which implies contemporaneous westward tilting of the block. At the Cueva fault, the Sandia Formation appears to thicken abruptly from approximately 80 feet (24 m), to greater than 120 feet (36 m) on the southwestern downthrown-block. On the upthrown northern block the

Sandia is mostly conglomeratic, whereas on the southern depressed side, shales and shell-rich limestones are prevalent. The latter presumably reflect greater water depths and lower energy depositional environments on the downthrown block. Sparry, calcite-filled cavernous blocks of tilted limestone locally occupy a narrow graben developed in the overlying Madera limestone adjacent to the Cueva footwall block. Another limestone bed at the ridge crest appears to be unfaulted where it overlies the projected trace of the Cueva fault. The Cueva fault could represent a releasing-bend-type splay from the projected trend of the sinistral Malacate fault.

Echelon folds and one minor dextral slip fault adjacent to the Manzanita fault suggest an earlier period of right-lateral transpression, presumably Laramide, along this range bounding fault. The Tiro fault locally shows a minor zone of right-slip within a complex hanging wall zone; however this fault appears to be dominated by later down-to-the-west, dip-slip normal displacement, of probable late Cenozoic age.

Major, down-to-the-west, range-bounding structures most likely represent dip-slip normal faults associated with spreading along the Rio Grande rift in middle to late Cenozoic time. Examples are the Coyote, Colorada and Manzanita faults. Extension (gravitational collapse) along the rift may have removed earlier components of crustal shortening (reverse faulting) from many of these preexisting fault zones of Laramide and late Paleozoic ancestry. For instance, the down-to-the-east EOD reverse(?) fault may represent an unextended section of the down-to-the-west Hubbell Springs fault trend, which lies directly southwest of the EOD fault. The Hubbell Springs fault zone shows evidence of Pliocene to Pleistocene normal displacement associated with extension along the Rio Grande rift; the EOD fault does not show indications of Cenozoic displacement.

No clear evidence of Quaternary faulting was found in the Mount Washington quadrangle. However, warping and displacement along the range bounding faults has probably influenced the distribution and thickness of Pliocene alluvial deposits (eg. QTspc) in the western portion of the quadrangle (Table 1).

Minor thrust faults are widely observed in Paleozoic quartzites and limestones within the quadrangle. These minor contractional faults suggest incipient thin-skinned shortening in an easterly (ENE to ESE) direction. They may have been associated with a Laramide transpressional highland now engulfed by the Rio Grande rift. An ENE striking segment of the Torre fault, which defines a sinistral thrust fault, most likely represents NNW directed shortening in late Paleozoic time. Small fluorite and quartz veins in Paleozoic and Precambrian rocks may represent local tensional zones adjacent to strike-slip faults of late Paleozoic and/or Laramide ancestry.

Proterozoic Structures

The character of Proterozoic structures is illustrated in the accompanying cross section (Plate II). Metamorphic and plutonic rocks are ductilely deformed and show evidence for multiple generations of deformation. The main tectonic fabric is a penetrative foliation (Sl) that strikes northeast and dips moderately, 30°–70° towards the southeast. The major structures of this generation in a north to south cross section are as follows.

1) The Vincent Moore shear zone (named the Vincent Moore thrust by Cavin, 1985) is a low angle shear zone that is mainly exposed in the Tijeras Quadrangle to the

north. In the north, it places clean quartzites (Xq) over mafic volcanic rocks of the Tijeras greenstone; in the south it places quartzite over granites that resemble the Cibola granite of the Tijeras Quadrangle, dated by U-Pb zircon as 1653 ± 21 Ma (Unrue, unpublished data). This thrust dips south, under the Mount Washington quadrangle, and shows top-to-the north shear sense in mylonitic rock. Phyllonite from the zone yielded a whole-rock $^{40}Ar/^{39}Ar$ date of 1423 ± 2 Ma (Karlstrom et al., 1997), which is interpreted to be time of reactivation of an earlier shear zone during 1.4 Ga tectonism in the aureole of the Sandia pluton (Kirby et al., 1995). This structure is considered here to be the frontal thrust of the Manzanita thrust system, described below.

2) The Coyote Creek synclinorium is an asymmetrical, north-verging synclinorium involving rock units Xq and Xs. These folds are apparently truncated by thrust-sense shear zones on the Manzanita shear zone.

3) The Manzanita shear zone is a new name proposed for the 2–4 km wide shear zone in the northern part of the Mount Washington quadrangle. This zone includes the Coyote "thrust" of Cavin (1985), but is a wide zone of distributed deformation rather than a discrete thrust. This zone forms the tectonized intrusive contact between greenstones (named the Coyote greenstone by Cavin, 1985) and the Manzanita Granite. Intrusive relationships are suggested by the complex interfingering of granite and greenstone, but the zone contains an impressive array of mylonitic and ultamylonitic rock. Units mapped by Cavin (1985) as metarhyolite are interpreted here to be ultamylonitic Manzanita Granite based on preserved feldspar porphyroclasts of

similar size to the megacrysts in the Manzanita Granite. The southern edge of the Manzanita shear zone is not well defined, as shearing decreases southward into the pluton. Shearing is top-to-the-north based on abundant kinematic indicators such as shear bands, S-C fabric, and porphyroclast systems. Early shearing took place at temperatures in excess of 500°C based on ductiley deformed feldspar porphyroclasts, and continued at lower temperatures based on low- to moderate- temperature quartz microstructures such as core and mantle structure and ribboned quartz. We interpret these features to indicate that top-to-the-north shearing took place as the pluton was being emplaced and subsequently cooled to ambient (green schist-grade) conditions. This dates development of the Manzanita thrust system as Early Proterozoic, about 1630 Ma.

4) The Isleta shear zone (Isleta thrust of Parchman, 1981) is a wide zone of shearing near the south margin of the Manzanita Granite. Like the Manzanita shear zone, this zone also grades into less deformed plutonic rock, shows kinematic evidence for top-to-the-north shear, and represents a syn-plutonic shear zone that modified the original intrusive contact. Evidence that the zone represents the margin of the pluton comes from the contact aureole preserved in the adjacent country rock defined by sillimanite, and andalusite isograds that are generally parallel to the shear zone and the pluton margin.

5) A major synclinorium–anticlinorium pair occurs in the southern part of the quadrangle. The synclinorium is defined on the basis of opposing graded bedding indicators in the lithic sandstone unit (Xla) and by repetition of a distinctive chert

marker layer. The anticlinorium, here named the Hells Canyon anticlinorium, was mapped by Parchman (1981) based on repetition of a distinctive dacitic tuff unit (Xdt) both north and south of Hells Canyon. Units in these folds are strongly transposed parallel to the northeast-striking axial plane (Sl) of the folds. Based on frequently-seen thrust belt geometries, the cross section suggests that the synclinorium overlies a flat, and the anticlinorium overlies a ramp in the Manzanita thrust system.

A second generation of ductile structures occurs as variably-developed, but often weakly expressed crenulations of the main foliation. The axial plane crenulation cleavage strikes northwest and is subvertical; crenulation fold axes plunge southeast. Timing of formation of these structures could be either Early or Middle Proterozoic.

HYDROGEOLOGIC FRAMEWORK

Water well data within the Mount Washington sector of the Isleta Reservation indicate very thin basin fill, much of which is above the water table. These wells are completed within Permian strata (Table 1) and are adequate for limited pumping for livestock. The Hells Canyon drainage is the largest drainage basin in the Manzanita Mountains, about 103 km^2 (39 mi^2) in area. It represents a significant local source of mountain-front recharge into the basin aquifer system, especially where the stream crosses the Sanchez fault.

Coyote Spring occurs where the generally westward groundwater flow is blocked by relatively impermeable shales of the Sandia Formation, which is juxtaposed against fractured crystalline basement rocks. Other springs in the quadrangle also appear to be fault controlled.

Dense pine forest above 7000 feet elevation (ca. 2100 m) and some lower north-facing slopes generally represent areas of more significant precipitation and potential groundwater recharge. All surface drainages lead into the eastern flank of the Albuquerque Basin, and presumably most of the groundwater moves in that direction. However, some ground may move along the regional NNE dip toward the Tijeras fault and the Estancia Basin. Permeability in well indurated Paleozoic and Precambrian rocks is most likely associated with fractures. Uncemented (ie. younger) fault breccias may be the most significant pathways of groundwater flow in these older rocks. Pliocene and Pleistocene paleovalley fills, locally entrenched into down faulted blocks along the western margin of the quadrangle, could represent significant, but difficult to locate, local aquifers. Temperature regimes and flow paths of shallow groundwater in the Kirtland sector of the Mount Washington quadrangle are currently being studied by Marshall Reiter (Prin. Sr. Geophysicist) at the New Mexico Bureau of Mines and Mineral Resources.

GEOLOGIC HAZARDS

Potential geologic hazards in the Mount Washington quadrangle include earthquakes, flooding along entrenched drainages, and landsliding or slumping on steep mountain slopes underlain by shales (eg. upper Sandia Formation). Quaternary normal faults along the Rio Grande Rift represent a potential regional earthquake risk. All high-angle faults and range boundary faults mapped in the Mount Washington quadrangle should be considered capable of normal slip in the regional extensional stress domain of the rift. However, there is no indication of Holocene or Pleistocene displacement of any fault within the quadrangle. Mapped faults in adjacent quadrangles do show signs of Quaternary movement, so the threat facing slopes generally represent areas of more significant precipitation and potential groundwater recharge. All surface drainages lead into the eastern flank of the Albuquerque Basin, and presumably most of the groundwater moves in that direction. However, some groundwater may move along the regional NNE dip toward the Tijeras fault and the Estancia Basin. Permeability in well indurated Paleozoic and Precambrian rocks is most likely associated with fractures. Uncemented (ie. younger) fault breccias may be the most significant pathways of groundwater flow in these older rocks. Pliocene and Pleistocene paleovalley fills, locally entrenched into down faulted blocks along the western margin of the quadrangle, could represent significant, but difficult to locate, local aquifers. Temperature regimes and flow paths of shallow groundwater in the Kirtland sector of the Mount Washington quadrangle are currently being studied by Marshall Reiter (Prin. Sr. Geophysicist) at the New Mexico Bureau of Mines and Mineral Resources.

GEOLOGIC HAZARDS

Potential geologic hazards in the Mount Washington quadrangle include earthquakes, flooding along entrenched drainages, and landsliding or slumping on steep mountain slopes underlain by shales (eg. upper Sandia Formation). Quaternary normal faults along the Rio Grande Rift represent a potential regional earthquake risk. All high-angle faults and range boundary faults mapped in the Mount Washington quadrangle should be considered capable of normal slip in the regional extensional stress domain of the rift. However, there is no indication of Holocene or Pleistocene displacement of any fault within the quadrangle. Mapped faults in adjacent quadrangles do show signs of Quaternary movement, so the threat of regional shaking due to earthquakes cannot be ignored.

An inactive landslide deposit (mapped as Qca) lies upslope from the HERTF site, on the east wall of the canyon. Madera limestone blocks have locally slid down this slope where riding on northeast dipping shales of the Sandia Formation. The landslide deposit appears to be buttressed by crystalline bedrock at its western terminus. It is unlikely to be a future hazard to the HERTF site, but its existence should be noted. Extended periods of high precipitation could reactivate portions of this landslide, or form a debris flow from the loose blocks.

All areas underlain by recent alluvial deposits (QHva and Qvy3) represent localities of potential flash flooding.

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Table 1. Summary and interpretation of driller's logs for water-supply wells on Isleta Reservation and lithologic and geophysical logs on Sandia National Laboratories site and Kirtland Airforce Base (Plate I).

Well No.: **RWP-14**
Date drilled: 1958
Drilling method: unknown
Location: SE1/4, SW1/4, SW1/4, Section 12, T08N, R04E, NMPM
Elevation: 5810±20 feet (estimate from topographic map)

Depth (feet)	**Driller's Log**	**Interpretation**	**Notes**
0-3	top soil	piedmont alluvium (calcic soil?)	
3-40	caliche and boulders		
40-85	gray limestone, broken	Yeso Formation (?)	
85-100	gray limestone, broken		
100-140	red clay, sandy		
140-155	yellow clay		
155-235	red clay	Abo Formation	
235-370	red clay		
370-395	red sand		water
395-405	red sand		
405-415	red clay		

Well No.: **RWP-24**
Date drilled: 1967 and 1968
Drilling method: unknown
Location: SE1/4, SE1/4, NW1/4, Section 26, T08N, R04E, NMPM
Elevation: 5730±20 feet (estimate from topographic map)

Depth (feet)	**Driller's Log**	**Interpretation**	**Notes**
0-3	top soil	piedmont alluvium (calcic soil)	
3-6	white shale		
6-65	gravel and boulders	Santa Fe Group	
65-105	red shale	Abo Fm.	one-day drilling
105-125	red shale and boulders		one-day drilling
125-145	red rock, hard		one-day drilling
145-155	boulders		one-day drilling; water
155-160	red shale		water at 160 ft (1967): water at 130 ft (1968)
160-170	red shale		
170-205	red shale		
205-270	red shale		
270-290	brown sand		
290-297	shale		stop date: 07-09-68 depth to water: 162 ft

Table 1 (continued).

Well No.: **RWP-29**
Date drilled: 1970 and 1976
Drilling method: unknown
Location: SE1/4, SE1/4, SE1/4, Section 18, T08N, R05E, NMPM
Elevation: 6010±20 feet (estimate from topographic map)

Depth (feet)	Driller's Log	Interpretation	Notes
0-4	top soil and gravel	piedmont alluvium and Santa Fe Group	starting date: 10-7-70
4-10	gravel		
10-40	gravel		one-day drilling
40-65	gravel and boulders		one-day drilling
65-70	gravel and boulders		
70-78	limestone	Madera Formation	
78-91	limestone		
91-105	shale and boulders		date: 10-19-70
105-125	limestone		
125-155	brown shale		
155-163	gray shale		
163-170	limestone		date: 10-23-70
170-175	limestone		
175-178	broken limestone		water
178-188	limestone		stop date: 10-30-70 depth to water: 160 ft flow rate: 20 gpm
189-216	broken limestone		extended hole: 1976
216-222	gray shale		depth to water: 188 ft flow rate: 12 gpm

Well No.: **MW-13**
Date drilled: unknown
Drilling method: unknown
Location: NE1/4, Section 3, T09N, R04E, NMPM
Elevation: 5660±20 feet (estimate from topographic map)

Depth (feet)	Lithologic Summary	Interpretation
0-130	gravel and sand	undivided piedmont alluvium and Santa Fe Group

Table 1 (continued).

Well No.: **KAFB-1901**
Date drilled: unknown
Drilling method: unknown
Location: SE1/4, SW1/4, NE1/4, Section 35, T09N, R04E, NMPM
Elevation: 5750±20 feet (estimate from topographic map)

Depth (feet)	**Lithologic Summary**	**Interpretation**
0-150	gravel and clay	undivided piedmont alluvium and Santa Fe Group
150-240	red-brown to light-brown and gray clay, sandstone and limestone	Yeso Formation(?)

Well No.: **TRN-1**
Date drilled: unknown
Drilling method: unknown
Location: SE1/4, NE1/4, SW1/4, Section 35, T09N, R04E, NMPM
Elevation: 5730±20 feet (estimate from topographic map)

Depth (feet)	**Lithologic Summary**	**Interpretation**
0-160	gravel, sand, minor silt	undivided piedmont alluvium and Santa Fe Group
160-515	red-brown grayish-red, micaceous claystone, siltstone and sandstone	Abo Formation or undivided Triassic

Well No.: **TRS-1**
Date drilled: unknown
Drilling method: unknown
Location: NW1/4, SE1/4, SE1/4, Section 35, T09N, R04E, NMPM
Elevation: 5780±20 feet (estimate from topographic map)

Depth (feet)	**Lithologic Summary**	**Interpretation**
0-135	sand and gravel	undivided piedmont alluvium and Santa Fe Group
135-480	olive-gray to dark-brown limestone, siltstone and shale	Madera Formation

Table 1 (continued).

Well No.: **95-BH2**
Date drilled: August 1995
Drilling method: Hollow-stem auger
Location: NW1/4, NW1/4, NE1/4, Section 24, T09N, R04E, NMPM
Elevation: 5852 feet

Depth (feet)	Lithologic Summary	Interpretation
0-18	silty sand and clayey sand	cienega deposits, water at 15 ft.
18-60	gravel, clayey gravel and silty clay	valley-fill alluvium

Well No.: **95-BH4**
Date drilled: August 1995
Drilling method: Hollow-stem auger
Location: NW1/4, SW1/4, NW1/4, Section 24, T09N, R04E, NMPM
Elevation: 5790 feet

Depth (feet)	Lithologic Summary	Interpretation
0-36	sandy gravel, silty sand and gravelly sand	valley-fill and piedmont alluvium

Well No.: **95-BH7**
Date drilled: August 1995
Drilling method: Hollow-stem auger
Location: SE1/4, NW1/4, SE1/4, Section 24, T09N, R04E, NMPM
Elevation: 5730 feet

Depth (feet)	Lithologic Summary	Interpretation
0-31	sandy and clayey gravel and sand	valley-fill alluvium water at 28 ft.
31-43	sand	valley-fill alluvium
43-61	sandstone	Sandia Formation

Table 2. Table showing tentative correlations of alluvial units in the study area, based on stratigraphic relations, landscape-topographic position, degree of soil development and physical correlation of units.

This Study	Hubbell Springs Quadrangle *Love and others (1996)*	Sandia National Laboratories *Thomas & others (1995)*
QHva, QHvaf	QHsc, QHfp, QHae	H9, H8
Qvy3	QHt20, QHt19	H7
Qvy2, Qpy2	Qt17-Qt19	P6
Qvy1, Qpy1		P5
Qvm3, Qpm3	Qt7-Qt18	---
Qvm2, Qpm2		
Qvm1, Qpm1		
Qvo2, Qpo2	QT3-Qt6	
Qvo1, Qpo1		P4, P3
QTpo, QTspc3	Tf2	P3, P2, P1, Santa Fe Group
QTspc1, QTspc2	Tf1	Santa Fe Group