Geologic Map of the Becker 7.5-Minute Quadrangle, Valencia and Socorro Counties, New Mexico

By

Amy L. Luther, Karl E. Karlstrom, Lea Anne Scott, Maya Elrick, and Sean D. Connell

May 2005

New Mexico Bureau of Geology and Mineral Resources Open-file Digital Geologic Map OF-GM 100

Scale 1:24,000

This work was supported by the U.S. Geological Survey, National Cooperative Geologic Mapping Program (STATEMAP) under USGS Cooperative Agreement 06HQPA0003 and the New Mexico Bureau of Geology and Mineral Resources.



New Mexico Bureau of Geology and Mineral Resources 801 Leroy Place, Socorro, New Mexico, 87801-4796

The views and conclusions contained in this document are those of the author and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government or the State of New Mexico.



Becker 7.5' Quadrangle OF-DM XX

GEOLOGY OF THE BECKER 7.5-MINUTE QUADRANGLE, VALENCIA AND SOCORRO COUNTIES, NEW MEXICO

by

Amy L. Luther, Karl E. Karlstrom, Lea Anne Scott, Maya Elrick and, Sean D. Connell

Geologic mapping by

Amy L. Luther (Bedrock Geology), Karl E. Karlstrom (Bedrock Geology), Lea Anne Scott (Paleozoic rocks), Maya Elrick (Paleozoic rocks), Sean D. Connell (Cenozoic Deposits), and previous mapping by Myers, McKay, and Sharps (1981)

New Mexico Bureau of Mines and Mineral Resources Open-File Report OFDM-XX May, 2005

Printed --

New Mexico Bureau of Geology and Mineral Resources A division of New Mexico Institute of Mining and Technology 801 Leroy Place Socorro, NM 87801-4796

INTRODUCTION

The Becker 7.5-minute quadrangle comprises an area of about 160 km² (60 mi²) in Valencia Counties and Socorro Counties, New Mexico. Most of this quadrangle is a part of the Sevilleta National Wildlife Refuge. The quadrangle lies on the boundary between the Rio Grande rift on the west and the mountainous rift-flank on the east. The rift-flank consists of the Los Pinos Mountains. Mapping of this quadrangle was done in conjunction with mapping of the adjacent Scholle quadrangle, located in the southern end of the Manzano Mountains. Past work in the Manzano and Los Pinos Mountains were done by Baer (2003), Shastri (1993), Bauer (1983), Stark (1956), Stark and Dapples (1946), Reiche (1949), Myers, McKay, and Sharps (1981), and Myers and McKay (1972). The geologic map (Plate I) is the result of additional detailed field mapping and integration of these previous works.

Geologic mapping was completed in cooperation with the University of New Mexico (UNM) and the New Mexico Bureau of Geology and Mineral Resources (NMBGMR). The topographic base for the geologic map is the Becker 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). For this map, Cenozoic deposits, mapped by Sean Connell, were mapped at a scale of 1:24,000. This mapping was aided by the used of 1996-vintage aerial photographs. These maps were enlarged to a scale of 1:12,000 for transfer on the final map (Plate I). Pennsylvanian units mapped by Lea Anne Scott and Maya Elrick, as well as Precambrian units mapped by Karl Karlstrom and Amy Luther were mapped at a scale of 1:24,000. Contacts for Paleozoic maps were checked against aerial photographs at a scale of 1:24,000, enlarged, and transferred to the final 1:12,000-scale map for compilation.

Principal contributions and revisions that have refined the structure and stratigraphy of this quadrangle include: 1) a revision of Pennsylvanian stratigraphy to correspond with lithology, rather than fusulinid biostratigraphy as defined by Myers et al. (1981) and Myers (1977); 2) differentiation of an additional lower unit in the Permian Abo Formation; 3) refinement of contacts in Paleozoic units; 4) refinement of structures within Paleozoic units; 5) differentiation and correlation of Proterozoic metasedimentary and metavolcanic units with other parts of the Manzano-Sandia Mountains; 6) delineation of previously unmapped Precambrian structures and refinement of the timing of these structures; 7) refinement of Paleozoic and younger structures and their relative movement sense; 8) refined mapping of range-bounding structures; and 9) differentiation of the Cenozoic (mostly Pleistocene and Holocene) stratigraphy along the western front of the Los Pinos Mountains and in the Abo Arroyo drainage system.

Two major revisions to the Paleozoic stratigraphy established by Myers (1977) were undertaken in the current mapping effort. 1) The Pennsylvanian units within the Wild Cow Formation of the Madera Group were subdivided and mapped as 5 different informal units (IPm-1 through IPm-5). These informal units were measured and described in a total of 5 locations, 3 of which are located on the adjoining Scholle quadrangle and 2 of which are located on the Becker quadrangle. Informal units are based on outcrop patterns of laterally persistent, mappable cliff-forming (dominated by limestone) and slope-forming intervals (dominated by fine marine and nonmarine(?) siliciclastic rocks). Myers' members were used only when readily identified in the field; those members defined using fusulinid foraminifera biostratigraphy were not utilized. This refinement of Pennsylvanian units allowed for better mapping of structures affecting Paleozoic units. Recently, Kues (2001) suggested that the Wild Cow Formation is essentially the same unit as the Atrasado Formation recognized to the west across the Rio Grande

Rift (~80 km) in the Lucero Mesa region, and recommended changing the name to reflect this similarity. Similarly, the Los Moyos Limestone is equivalent to the Gray Mesa Formation. For our mapping purposes, we did not assign any formal nomenclature to the Pennsylvanian units, but rather mapped large-scale patterns in lithology through inferences made about cliff- versus slope-forming intervals. 2) An informal unit in the basal Abo Formation was mapped separately based on a difference in grain size, sedimentary structures, color, and outcrop pattern. This basal unit is not regionally extensive, as it much thinner on the Becker quadrangle than in the Scholle quadrangle to the east, and does not extend across the Rio Grande Rift to the Lucero Mesa Area (~80 km; Lucas and Ziegler, 2004).

Faults splaying off the main Montosa fault were mapped by Steve Haden several years ago and are incorporated into the map along the Montosa fault; these faults were field checked for location accuracy. Pennsylvanian contacts were completely remapped in the current mapping effort. The location of the Montosa fault was checked in the field and modified slightly where necessary from previous mapping by Myers et al. (1981). In addition, contacts between the uppermost Pennsylvanian unit (IPm5) and the Bursum Formation (Pb) were mapped both in the field and from aerial photography, resulting in only slight modification to Myers et al. (1981) contacts between these units.

Cenozoic deposits were mapped along the range fronts of the southern Manzano and northern Los Pinos Mountains. This mapping substantially improved earlier mapping by Myers, Sharps, and McKay (1981). In particular, piedmont-slope deposits associated with the western fronts of the Manzano and Los Pinos Mountains were differentiated from deposits associated with the modern and ancestral Abo Arroyo drainage system, which enters the Albuquerque basin between these two ranges. No obvious signs of Pleistocene or Holocene range-front and

intrabasinal faulting (i.e., topographic scarps and offset strata) were recognized during mapping of the Becker quadrangle.

Precambrian units and structures were remapped with resulting new insights into the tectonic evolution of central New Mexico. The Paleoproterozoic rocks of the Becker quadrangle and adjacent Scholle quadrangle had been mapped by Myers et al. (1981) and Myers (1977), respectively, as a west-dipping homoclinal succession with Sais Quartzite at the base and Sevilleta Metarhyolite at the top. New mapping, and identification of cross bedding, graded bedding, and other younging indicators shows that the stratigraphic order is reversed, with Sevilleta Metarhyolite near the base of the section and Sais and Blue Ridge Formation near the top. The rocks were folded into a tight to isoclinal regional-scale synclinorium cored by schist and rhyolite of the Blue Springs Formation. The axial plane of this syncline strikes NE in the Becker quadrangle, gets folded into an F3 anticline, and is truncated by the Priest pluton in the adjacent Scholle quadrangle. The resulting complex interference patterns are delineated by interlayered quartzite and schist units and the complexity of fold overprinting and cross cutting schistosities are portrayed by structural symbols in the new mapping.

Another contribution involves a better understanding of the nature of tectonism associated with emplacement of the Priest pluton. In the Scholle quadrangle, at least portions of the southern contact dips about 30 degrees southward, as shown by mapping of the contact across rugged topography. Thus, Paleoproterozoic units of the Scholle quadrangle are in the roof of the pluton. Strong development of fabric and metamorphic isograds reflect thermal influences from the pluton. Increase in intensity of S3 as the contact is approached, as well as porhyroblastmatrix relationships, suggest that the pluton was synchronous with S3 and post- S2.

COMMENTS TO MAP USERS

Mapping of this quadrangle was funded by a matching-funds grant from the 2003-2005 STATEMAP program of the U.S. Geological Survey, National Cooperative Geologic Mapping Program, under USGS award number 00HQAG0078, to the New Mexico Bureau of Geology and Mineral Resources (Dr. Peter Scholle, Director; Dr. Paul W. Bauer, P.I. and Geologic Mapping Program Manager).

This quadrangle map has been open-filed in order to make it available as soon as possible. The map has not been reviewed according to New Mexico Bureau of Geology and Mineral Resources standards, and due to the ongoing nature of work in the area, revision of this map is likely. As such, dates of revision are listed in the upper right corner of the map and on the accompanying report. *The contents of the report and map should not be considered final and complete until it is published by the New Mexico Bureau of Geology and Mineral Resources.*

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 such as faults and folds. Geologic contacts are irregular surfaces that form boundaries between different types or ages of units. Data depicted on this geologic map are based on 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 may have been mapped at scales smaller than the final map; therefore, the user should be aware of potentially 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.

The cross-sections in this report are constructed based on surficial geology, and where available, subsurface and geophysical data. The cross sections are interpretive and should be used as an aid to understand the geologic framework and not used as the sole source of data in locating or designing wells, buildings, roads, or other structures.

The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government.

Accessibility

The southern portion of the Becker quadrangle is within the Sevilleta National Wildlife Refuge and is only accessible with a permit. Once attained, the area can be accessed off of N.M. Highway 60 through Bernardo, and onto the dirt road that belongs to the Refuge. The far eastern portion is BLM land and is also accessible from US Highway 60. The northern half of the map is located within the Belen Grant and the Casa Colorada Grant. The Atchison, Topeka, and Santa Fe railroad track also runs through the northern half of the Becker quadrangle.

Geologic and Physiographic Setting

The majority of the Becker quadrangle is covered with Quaternary deposits covering the Santa Fe Group (basin fill associated with the Albuquerque basin and Rio Grande rift). The southeastern potion of the quadrangle consists of structurally complex Paleoproterozoic rocks overlain by Upper Pennsylvanian and Lower Permian strata. Proterozoic units mainly consist of

quartzite, schist, and rhyolite rock types that were ductiley deformed and folded into a regional scale northeast trending overturned syncline. The Paleozoic strata that overlies the Precambrian units have been folded into a monocline, mainly on the Laramide Montosa Fault. East of the Montosa Fault the Paleozoic beds gently ($\leq 10^\circ$) dip to the east into the Great Plains region of the Scholle Quadrangle.

Abo Arroyo is a large drainage the flows through the Becker quadrangle and divides drainages (and associated deposits) associated with the small mountain-front drainages of the southern Manzano and Los Pinos Mountains. Piñon Canyon lies just east of Whiteface Mountain, the tallest peak in the quadrangle at 7530 feet (2295 m) above seal level.

STRATIGRAPHY

All map units are described in Table 1. The age and stratigraphic relationships of these map units are summarized in the Correlation of Map Units.

Quaternary and Pliocene Deposits

Quaternary and Pliocene alluvial deposits of the Becker 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., 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 Los Pinos Mountains. Alluvial deposits are 12- to 21-m thick and unconformably overlie older rocks. Alluvial deposits are divided into three major classes: 1) valley-fill alluvium, 2) piedmont-slope alluvium, and 3) colluvium and spring deposits.

Forward gravity modeling and seismic reflection profiling suggest that the Neogene basin fill and overlying Quaternary deposits are about 1 km in thickness (Cape et al., 1983). It is not clear how thick the Neogene succession is on the hangingwall of the Los Pinos range-front faults on the Becker quadrangle, but previous mapping on the nearby Becker SW and Cerro Montosa quadrangles (Myers et al., 1986) show Madera Group limestone exposed on the range-front hangingwall block and are overlain by more than 6 m of Plio-Pleistocene conglomeratic deposits that bury a pediment cut onto upper Paleozoic sedimentary rocks. The presence of a topographically high inlier of late Oligocene volcanic rocks (Turututu, or Black Butte, K-AR date of 24.3 Ma, Bachman and Mehnert, 1978) on the adjoining Black Butte quadrangle, suggests that the entire Neogene succession is likely thin. Oligocene volcaniclastic rocks are exposed on the La Joya and Becker SW quadrangle, as well as on the hangingwall of the Manzano Mountains frontal fault at Trigo Canyon, on the Capilla Peak quadrangle (Karlstrom et al., 2001; Connell et al., 2002). The distribution of these Oligocene rocks suggest that the Neogene deposits of the Santa Fe Group and younger Quaternary deposits is present beneath much of the western parts of the Becker quadrangle.

Paleozoic Rocks

The Pennsylvanian strata exposed within the quadrangle include the siliciclastic Sandia Formation, mixed carbonates and siliciclastics of the Pennsylvanian Madera Group and the Permian Bursum Formation, and siliciclastics of the Permian Abo Formation. The Pennsylvanian Madera Group was deposited within shallow seaways that formed in the basins of the Ancestral Rocky Mountains and for this mapping effort, was mapped as a series of cliff- and slopeformers. The overlying Permian Bursum Formation is interpreted to represent deposition in both marine and fluvial environments, while the overlying Permian Abo Formation represents deposition in an entirely continental setting, including fluvial and rare lacustrine environments. The lower portion of the Abo unit mapped may represent a fluvial environment that was not laterally extensive, given that the unit thins to the west and north.

Regional patterns in Los Moyos Limestone of the Madera Group

According to Myers (1977), unit IPm-1 (the Los Moyos Limestone of the Madera Group) is Desmoinesian in age. Kues (2001) recommends revising this name to the Gray Mesa Formation due to similarities in lithology and age. Approximately 80 km directly west across the Rio Grande Rift, the Gray Mesa Formation (Mesa Sarca; Scott and Elrick, 2004) is well-exposed in the Lucero uplift area. In the Lucero uplift area, the Gray Mesa Formation is significantly thicker (~290 m at Mesa Sarca versus ~170 m in Scholle quadrangle) and is characterized by five mappable slope- to limestone cliff-forming units (or sequences; 20-80 m) representing deposition during distinct transgressive-regressive intervals. Transgressive-regressive sequences were not recognized within the Scholle quadrangle. However, several key similarities were observed in both units: 1) chert is abundant, as isolated pods, as a pervasive, interlocking network overprinting the host rock, and as silicified fossils, 2) fossil abundance and diversity are similar, 3) coarse-grained siliciclastic sandstone deposits are generally lacking, and 4) laterally persistent diagenetic features including diagenetic mottling and laminar black calcretes are present on many bed tops.

Proterozoic Rocks

Proterozoic rocks in the Scholle and Becker quadrangles consist of ductiley deformed and metamorphosed volcanic, sedimentary and plutonic rocks. Our interpretation is that these rocks formed in volcanic arcs and related arc basins along the growing southern periphery of cratonic North America ca. 1.67-1.65 Ga (Karlstrom et al., 2004). The metamorphic rock sequence is described in Table 1. Due to the polyphase deformational history, construction of a coherent stratigraphy has been controversial and handled differently by different authors. Based on new mapping in the Manzano Peak, Scholle, and Becker quadrangles, there is an emerging regionally coherent stratigraphy that involves a lower metavolcanic suite (mafic and felsic rocks) overlain by a sedimentary succession that gets cleaner and more mature upward, towards massive white, relatively clean quartzite, overlying schist, and an upper rhyolite.

The stratigraphy is most completely exposed in the nearby Manzano Peak and Becker quadrangles. The basal unit is the Sevilleta metarhyolite (Xsr) that has been dated as 1662 +- 1 Ma (Shastri, 1993). The Sevilleta metarhyolite is interpreted to be the oldest unit of the area based on its stratigraphic relationship with other units. The Sevilleta metarhyolite of the Manzano Peak, Becker, and Scholle quadrangles forms a semi-continuous outcrop band along the west slope of the mountain front. This unit was divided by Myer et al (1981) into several mappable rhyolite units based on phenocryst content and other characteristics, and these subdivisions are generally retained here. In many areas, metarhyolite is interfingered with mafic units of the metavolcanic package including amphibolites (metabasalt and metagabbro) and mafic schists; these are interpreted as part of the "greenstone" packages mapped elsewhere in the Manzano and Los Pinos Mountains (Bauer, 1993). The overlying metasedimentary

succession is a complex sequence of phyllite and metamorphosed metalithic arenite. Near the base of the sedimentary succession are lenticular outcrops of dacitic breccia that resemble the Lacorocah metadacite of Parchman (1980). The lithic arenite succession is compositionally variable and contains more pelitic layers that contain garnet and staurolite schist. All of these rocks are intensely interlayered with amphibolites. The amphibolites have variable texture: some are coarse grained and resemble gabbroic sills and dikes; some are fine grained and contain vesicles and other evidence that they were eruptive units. The striped map pattern of the amphibolite within lithic arenite was referred to by Myer et al. as the "mixed flow" unit.

The arenites grade upward into cleaner metasediments of the White Ridge Quartzite and related Sais Quartzite units, which are separated by a pelitic schist unit named the Estadio Schist, for excellent outcrops in Estadio Canyon in the Manzano Peak quadrangle. The Sais Quartzite is overlain by the Blue Springs Quartzite, Blue Spring Schist, Blue Spring Rhyolite, and an upper Blue Spring Schist. The Blue Springs metarhyolite is banded metarhyolite defined by mm-10's cm scale compositional bands.

Metasedimentary rocks is intruded by two different plutons in this region. The Los Pinos granite of the Becker quadrangle appears to truncate S2 foliation in the Becker quadrangle and yields a U-Pb zircon age of 1655 +-3. This is similar in age to the strongly deformed Monte Largo quartz monzonite that intrudes the Blue Springs package in the NW corner of the Manzano Peak quadrangle that yields a U-Pb zircon date of 1656+/-10 Ma (Bauer et al., 1993). In the Scholle quadrangle, the Priest Pluton intrudes the Blue Springs Formation in the northwest part of the quadrangle. This pluton yields a U-Pb zircon date of 1443 +/- 10 Ma (Thompson et al. 1996). An extensive metamorphic contact aureole is mapped at the margin of the Priest Pluton with concentric isograds extending away from the pluton (Thompson et al. 1996).

STRUCTURAL GEOLOGY

Folds, faults and shear zones in the Becker and Scholle quadrangles 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.

There is evidence for multiple generations of deformation including: D1, D2, and D3 (Baer, 2004). D1 involved west- directed thrusting. Field observations include an early foliation, S1, which is generally subparallel to bedding and is seen in thin section, or associated with minor nappe folds (Karlstrom et al. 2001). These F1 folds are subsequently refolded by F2 folds. F2 folds in the Becker quadrangle trend to the northeast, and have shallow plunge. D2 involved upright folding and establishment of the main NE-trending cleavage in the rocks. The large F2 synclinorium in the eastern part of the Becker Quadrangle, and continuing into the Scholle quadrangle is named the Manzano Peak synclinorium (Baer, 2004). Preserved cross bedding in the quartzite units and bedding-cleavage relationships both help define it as an upright syncline. It is refolded in the Scholle quadrangle and truncated at the southern margin of the Priest pluton indicating the fold developed before the pluton was emplaced. Its axial plane dips steeply to the west, throughout the Becker quadrangle.

F3 folds fold, kink, or deflect the main S2 schistosity. D3 can be shown to be pluton related shortening because of porphyroblast-matrix studies using contact minerals and intensification of S3 as the pluton is approached.

The Montosa reverse fault and associated monocline is well exposed in the eastern Becker and northwestern Scholle quadrangles. This structure is of presumed Laramide age as it is typical of Rocky Mountain uplifts all along the front ranges. Essentially flat lying Paleozoic

sedimentary rocks of the Great Plains to the east are folded into a monoclinal flexure with a steep to overturned limb that parallels the fault. Amount of throw on the fault/monocline is estimated to be 1000 meters based on restorable cross section, but significant right lateral strike slip on the fault was also likely (ref).

The Manzano normal fault is the rift –bounding fault forms the west margin of the mountains. It is concealed by thin Tertiary/Quaternary deposits, but we estimate a throw of about 1500 meters based on restorable cross sections. Paleozoic and Mesozoic strata are inferred to form a "bench" on the downthrown side based on projecting outcrops and structural styles northwards (and down) into the line of cross section from the Los Pinos Mountains to the south (Myer et al., 1986). Normal slip on the Manzano fault is assumed to decrease south towards Abo Arroyo.

PROTEROZOIC METAMORPHISM

The regional metamorphic grade in much of the quadrangle, between the Monte Largo shear zone and the Priest pluton, is amphibolite grade. Northwest of the Monte Largo shear zone, the rocks are greenschist grade. Mafic assemblages include actinolite (not hornblende), chlorite, sodic plagioclase, epidote quartz and white mica, suggesting temperatures of $<500^{\circ}$ C. Between the shear zone and the contact aureole, rocks contain hornblende and plagioclase suggesting metamorphic conditions $> 500^{\circ}$ C. The contact aureole of the Priest pluton is defined by two isograds that have been documented by Thompson (1993). These isogrades separate the aureole into three zones: the garnet zone, the staurolite zone and the sillimanite zone. The boundary between the garnet zone and the staurolite zone represents the reaction garnet +chlorite \rightarrow biotite+ staurolite (the staurolite-in isograde). The boundary between the staurolite zone and the

sillimanite zone is represented by the reaction of andalusite \rightarrow sillamanite and is also the temperature at which potassium feldspar is first seen in pelitic rocks (called the second sillimanite isograd ~650°C).

Foliation- porphyroblasts relationships support the interpretation that amphibolite grade temperatures were probably achieved prior to the emplacement of the Priest pluton. For instance, there are kyanite inclusions within contact metamorphic andalusite porphyroblasts. Some garnet grains have stuarolite inclusions. There is field evidence for two generations of staurolite, one that contains the S2 foliation and another that does not. However, most of the mineral are contact minerals that grew at ca. 1430 Ma, during development of the S3 cleavage. Post-emplacement retrograde metamorphism is documented by pseudomorphs of staurolite replaced by sericite, chlorite and some alteration of plagioclase to muscovite. These observations suggest late stage hydration of earlier assemblages, probably during waning stages of pluton emplacement.

ACKNOWLEDGEMENTS

Funding for this project was provided by the STATEMAP program in conjunction with the New Mexico Bureau of Geology and Mineral Resources. Access for mapping in the Becker quadrangle was facilitated by a research permit from the Sevilleta preserve.

REFERENCES

- Bachman, G. O., and Mehnert, H.H., 1978, New K-Ar dates and the late Pliocene to Holocene geomorphic history of the central Rio Grande region, New Mexico: Geological Society of America, Bulletin, v. 89, p. 283-392.
- Baer, S., 2004, Geologic and tectonic evolution of the Manzano Peak Quadrangle, Manzano Mountains, New Mexico [M.S. thesis]: University of New Mexico.
- Baer, S.H., Karlstrom, K.E. and Bauer, P. (2002) New Mapping from the Manzano Peak Quadrangle, central New Mexico. GSA Abstracts with Programs.

- Bates, R.L., Wilpolt, R.H., MacAlpin, A.J., and Vorbe, G., 1947, Geology of the Gran Quivira Quadrangle, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 26, 49 p.
- Bauer, P. 1982. Precambrian geology and tectonics of the southern Manzano Mountains, central New Mexico. New Mexico Geological Society Guidebook, 33rd Field Conference. Albuquerque Country. p. 211-216.
- Bauer, Paul w. 1983. Geology of the Precambrian rocks of the southern Manzano Mountains, New Mexico. [Master Thesis] University of New Mexico.
- Bauer, P. W., Karlstrom, K. E., Bowing, S. A., Smith, A., and Goodwin, L. B., 1993, Proterozoic plutonism and regional deformation—new constraints from the southern Manzano Mountains, central New Mexico: New Mexico Geology, v. 15, no. 3, p. 49–55.
- Behr, R.A., 1999, Structural and Thermochronological constraints on the movement history of the Montosa Fault, Central New Mexico. [M.S. Thesis]: New Mexico Institute of Mining and Technology, 129 p.
- Bowring, S.A., Condie, K., and Sumner, W., 1983, Geology and U-Pb geochronology of Proterozoic rocks in the vicinity of Socorro, New Mexico: New Mexico Geological Society Guidebook 34, p. 137-142.
- Cape, C.D., McGeary, S., and Thompson, G.A., 1983, Cenozoic normal faulting and the shallow structure of the Rio Grande rift near Socorro, New Mexico: Geological Society of America Bulletin, v. 94, n. 1, p. 3-14.
- Connell, S.D., McIntosh, W.C., Rogers, S., 2002, Geology of Trigo Canyon, Valencia County, New Mexico-uplift constraints for the southern Manzano Mountains [abstract]: New Mexico Geology, v. 24, n. 2, p. 60.
- Gile, L.H., Hawley, J.W., and Grossman, R.B., 1981, Soils and geomorphology in the Basin and Range area of southern New Mexico-Guidebook to the Desert Project: New Mexico Bureau of Mines and Mineral Resources, Memoir 39, 222p.
- Johnson, S. E., 1986, Structural analysis and interpretation of an apparent Precambrian angular unconformity, central Manzano Mountains, New Mexico: New Mexico Bureau of Mines and Mineral Resources, v. 8, no. 3, Pg. 45-50.
- Karlstrom, K. (compiler), et al., 1994, Geology of the Bosque Peak 7.5-minute quadrangle, Torrance, Bernalillo, and Valencia Counties, New Mexico: New Mexico Bureau of Mines and Mineral Resources Open-File Digital Map Report 24.
- Karlstrom, K., Amato, J., Williams, M., Heizler, M., Shaw, C., Read, A., and Bauer, P., 2004, Proterozoic tectonic evolution of the New Mexico region: A Synthesis, *in* Mack, G, and Giles, K., eds., The Geology of New Mexico: A Geologic History, Special Publication II, 1-34.
- Karlstrom, K.E., Baer, S., and Connell, S.D., 2003, Geology the Manzano Peak 7.5-min. quadrangle, Valencia and Torrance Counties, New Mexico, New Mexico Bureau of Geology and Mineral Resources, scale 1:12,000.
- Karlstrom, K.E., Connell, S.D., Rogers, S.A., and Crawford, E.B., 2001, Geology of the Capilla Peak 7.5-minute quadrangle, Torrance and Valencia Counties, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Open-file Geologic Map 27, scale 1:12,000.
- Karlstrom, K. E., Cather, S.M., Kelley, S.A., Heizler, M.T., Pazzaglia, F.J., and Roy, M., 1999, Sandia Mountains and Rio Grande rift: Ancestry of structures and history of deformation: New Mexico Geologic Society Guidebook 50, in press.

- Karlstrom, K. E., Dallmeyer, R. D., and Grambling, J. A., 1997, ⁴⁰Ar/³⁹Ar evidence for 1.4 Ga regional metamorphism in New Mexico: Implications for thermal evolution of lithosphere in the southwestern USA: Journal of Geology, v. 105, p. 205–223.
- Karlstrom, K.E. (compiler) et. al. (2001) Geologic of the Capilla Peak 7.5- minute quadrangle Torrance, and Valencia Counties, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Open-file Report OF-GM 27.
- Kelley, V. C., 1977, Geology of the Albuquerque basin, New Mexico: New Mexico Bureau of Mines and Mineral Resources Memoir 33, 60p.
- Kluth, C. F. and Coney, P. J., 1981, Plate tectonic of the ancestral Rocky Mountains: Geology, v. 9, p. 10–15.
- Kues, B.S., 2001, The Pennsylvanian system in New Mexico overview with suggestions for revision of stratigraphic nomenclature: New Mexico Geology, v. 23, p. 103-122.
- Lee, W.T., and Girty, G.H., 1909, The Manzano Group of the Rio Grande valley, New Mexico, U. S. Geological Survey Bulletin 389, 141 p.
- Lucas, S.G. and Ziegler, K.E., 2004, Permian stratigraphy in the Lucero uplift, central New Mexico, *in* Lucas, S.G. and Ziegler, K.E., eds., Carboniferous-Permian transition at Carrizo Arroyo, central New Mexico, New Mexico Museum of Natural History and Science Bulletin 25, p. 71 82.
- Myers, D.A., 1977, Geologic map of the Scholle quadrangle, Socorro, Valencia, and Torrance Counties, New Mexico: U.S. Geological Survey Map GQ-1412.
- Myers, D.A., McKay, E.J., and Sharps, J.A., 1981, Geologic map of the Becker quadrangle, Valencia and Socorro Counties, New Mexico: U.S. Geological Survey Map GQ-1556.
- Myers, D. A., and McKay, E. J., 1972, Geologic Map of the Capilla Peak quadrangle, Torrance and Valencia Counties, New Mexico: U.S. Geologic Survey, Geologic Quadrangle Map GQ-1008, scale 1:24,000.
- Myers, D. A., and McKay, E. J., 1971, Geologic map of the Bosque Peak quadrangle, Torrance, Valencia, and Bernalillo counties, New Mexico: U.S. Geological Survey Miscellaneous Investigations Series Map I-948.
- Myers, D. A., Sharps, J. A., and McKay, E. J., 1986, Geologic map of the Becker SW and Cerro Montoso Quadrangles, Socorro County, New Mexico: U.S. Geological Survey, Geologic Quadrangle Map I-1567.
- Needham, C.E. and Bates, R.L., 1943, Permian type sections in central New Mexico: Geological Society of America Bulletin v. 54, p. 1653-1668.
- Osburn, G. R., and Chapin, C. E., 1983, Nomenclature for Cenozoic rocks of the northeast Mogollon-Datil volcanic field, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Stratigraphic Cahrt 1.
- Reiche, P., 1949, Geology of the Manzanita and north Manzano Mountains, New Mexico: Geological Society of America Bulletin, v. 60, no.7, p. 1183–1212.
- Scott, L.A. and Elrick, M.B., 2004, Cycle and sequence stratigraphy of Middle Pennsylvanian (Desmoinesian) strata of the Lucero basin, central New Mexico, *in* Lucas, S.G. and Ziegler, K.E., eds., Carboniferous-Permian transition at Carrizo Arroyo, central New Mexico, New Mexico Museum of Natural History and Science Bulletin 25, p. 31-42.
- Shastri, L., 1993, Proterozoic Geology of the Los Pinos Mountains, central New Mexico: Timing of plutonism, deformation, and metamorphism [M.S. thesis]: University of New Mexico, 81 p.

- Stark, J.T., 1956, Geology of the south Manzano Mountains, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bulletin 34, 46 p.
- Stark, J.T. and Dapples, E.C., 1946, Geology of the Los Pinos Mountains, New Mexico: Geological Society of America Bulletin, v. 57, p. 1121-1172.
- Thompson, A. G., Grambling, J. A., DallMyers, D. R., 1991, Preterozoic History of the Manzano Mountains, central New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin no. 137, p. 71-77.
- Thompson, A.G., Grambling, J.A., Karlstrom, K.E., and DallMyers, B.D., 1996, Thermal evolution of Proterozoic middle crust during and following 1.4 Ga pluton emplacement, Manzano Mountains, New Mexico: Pluton-enhanced 4 kb metamorphism, rapid decompression, and retrograde history: Journal of Geology, v. 104, p. 583-598.
- Thompson, A.G. and Barnes, C.G. 1999. 1.4 Ga paraluminous granites in central New Mexico: Petrology and geochemistry of the Priest pluton. Rocky Mountain Geology. v. 34. pp.223-243.
- Timmons, J.M., Karlstrom, K.E., and Kirby, E., 1995, Geology of the Monte Largo Hills area, New Mexico: Structural and metamorphic study of the eastern aureole of the Sandia pluton: New Mexico Geological Society Guidebook 46, p. 227-232.
- Williams, M. L., Karlstrom, K. E., Jercinovic, M. J., Stevens, L., 2001, Microprobe Monazite Geochronology from the Manzano Mountains, New Mexico: Distinguishing Stages in a Long-Lived and Reactivated Orogen. (Abs.): Geological Society of America with programs, v.33, no. 5, pg. A-5.

BECKER QUADRANGLE DESCRIPTION OF MAP UNITS

NEOGENE (QUATERNARY AND PLIOCENE) UNITS

Alluvium of Abo Arroyo

Fluvial and alluvial deposits derived from the ancestral and modern Abo Arroyo. Deposits unconformably overlie the Santa Fe Group and interfinger with local stream alluvium derived from the margins of Los Pinos and southern Manzano Mountains. Gravel contains abundant, rounded to subrounded orthoquartzite and limestone with lesser amounts of reddish-brown sandstone and minor schist.

- **Qaa:** <u>Abo Arroyo alluvium, active (upper Holocene to historic)</u> Brown to reddish-brown (5-7.5YR 5/4), moderately sorted, clast-supported, pebble- to cobble gravel. Commonly contains cobble and boulder bars that are approximately 20 m wide and 40-50 m long. Deposit contains scattered boulders up to about 1 m maximum diameter. Gravel is predominantly subrounded quartzite and limestone with subordinate reddish-brown sandstone and minor schist Underlies active drainage of Abo Arroyo. No soil development was recognized, but deposit contains disseminated calcium carbonate cement. Base was not observed.
- **Qaay:** <u>Abo Arroyo alluvium, younger terrace deposit (Holocene to latest Pleistocene(?))</u> Reddish-brown (5YR 5/4-4/4), medium-bedded, fine- to medium-grained silty sand and clay with scattered lenses of pebble gravel. Lower part of unit is slightly better cemented and locally forms weak buried soil with Stage I carbonate morphology. Unit forms broad, low-lying terrace about 2 to 3 m above local base level. Very weakly developed soil with weak filamentous Stage If pedogenic carbonate morphology. Deposit base is locally exposed at mouth of Abo Canyon, where it is up to 3 m in thickness.</u>
- Qaam: Abo Arroyo alluvium, intermediate terrace deposit (late Pleistocene) Light-brown (7.5YR 6/4), pebble gravel and pebbly sand. Sand is poorly sorted, fine- to very coarse-grained sand. Unit forms discontinuous, intermediate terrace about 10 m above the floor of Abo Arroyo. Weakly developed soil exhibit Stage I to II pedogenic carbonate morphology. Unit is locally subdivided into slightly older deposits based on inset relationships. Base not exposed, but deposit is at least 1 m thick.
 - Qaamo: <u>Abo Arroyo alluvium, older subunit of intermediate terrace deposit (middle</u> <u>Pleistocene</u>) — Pink to pinkish-white and reddish-brown (7.5YR 7/4-8/2 & 5YR 5/4), pebble and cobble gravel. Unit forms highest terrace in Abo Arroyo and is recognized as low-lying gravels that sit about 2 m above the top of the intermediate terrace deposit (**Qaam**). Soils are well developed and exhibit t least Stage III pedogenic carbonate morphology. Gravel commonly contains remnants of thin to moderately (1-3 mm) thick carbonate coatings.
- **Qpa:** <u>Abo Arroyo alluvium, oldest piedmont-slope alluvium (middle or lower(?) Pleistocene)</u> — Low relief, fan-shaped unit discontinuously exposed along northern and southern

margins of the Abo Arroyo valley. Reddish-brown to light-brown (5YR 4/4 to 7.5YR 6/4) pebble to cobble gravel containing subrounded to subangular orthoquartzite, reddishbrown sandstone, schist, and sparse granite, rounded limestone, and yellowish-brown guartzose sandstone. Poorly exposed slopes along margins of Abo Arroyo valley contain scattered clasts that are commonly coated with 1-4 mm thick carbonate rinds, suggesting the presence of at least Stage III+ carbonate morphology. Deposit surface is about 18 m above the floor of Abo Arroyo. Gravels are commonly less than about 25 cm in diameter. Limestone clasts are commonly deeply pitted. Deposit surface commonly mantled by thin (<50 cm) veneer of brown (7.5YR 5/4) fine- to medium-grained silty to clayey sand with scattered gravels. Unit is inset by terrace deposits of Abo Arroyo and tributary stream deposits derived from the southern Manzano and northern Los Pinos Mountains. Deposit likely formed highest level of aggradation of the ancestral Abo Canyon fan, prior to incision of the Abo Arroyo valley. Deposits are commonly overlain by a thin, discontinuous veneer of loose, brown eolian sand that is generally less than 0.5 m thick. Base is exposed along flanks of Abo Arroyo near the western margin of map area, where it is 4.5 m thick.

Piedmont-slope alluvium

Alluvium associated with non-incised valleys. Typically recognized as alluvial fans that grade to high-level surfaces and are not integrated with Abo Arroyo. Gravels reflect upland drainage composition.

- **Qp:** <u>Piedmont alluvium, undivided (Holocene to Pleistocene)</u> Undivided piedmont alluvium. Surface contains weakly developed soils with Stage I carbonate morphology and bury older deposits. Commonly recognized as low rounded hill on low-gradient piedmont slope. North of Abo Arroyo, deposits contain variable proportions of quartzite and granite with minor schist. To the south, deposits contain quartzite and metamorphic clasts. Base not exposed.
- **Qpy:** <u>Piedmont alluvium, younger deposits (upper Pleistocene to Holocene)</u> Light-brown to brown (7.5YR 5/4-6/4), weakly consolidated, poorly sorted, pebbly to cobbly sand and gravel. Deposits commonly contain matrix-supported gravelly sand with local clast-supported gravel lenses. Beds are commonly 30-50 cm in thickness and form a stack of sand and gravel that commonly have scoured basal contacts and buried, weakly developed soils exhibiting Stage I pedogenic carbonate morphology. Deposits are at least 2 m thick and typically overlie older, paler colored, alluvium containing well developed calcic soils. Forms slightly to moderately dissected surfaces. Deposits are inset against intermediate piedmont alluvium of unit Qpm. Deposits are commonly overlain by a thin, discontinuous veneer of brown eolian sand.</u>
- **Qpm:** <u>Piedmont alluvium, intermediate deposits (middle Pleistocene)</u> Pink (7.5YR 7/4), poorly sorted, moderately consolidated pebble to cobble conglomerate and pebbly sand. Unit forms broad alluvial fans whose toes are commonly buried by younger piedmont alluvium. Base not exposed. Commonly buried by younger piedmont and stream-valley alluvium at western fronts of the Manzano and Los Pinos Mountains. Deposits are locally</u>

divided into at least three subunits based on surface morphology (as inferred from aerial photographs) and inset relationships.

- **Qpm3:** <u>Piedmont alluvium, younger subunit (middle Pleistocene)</u> Pink to brown (7.5YR 7/4-5/4), poorly sorted, moderately consolidated pebble to cobble conglomerate and pebbly sand. Unit forms broad alluvial fans that are inset against older piedmont deposits of units Qpm1 and Qpm2. Soils exhibit moderately to weakly developed Stage II to III carbonate morphology. Deposit is at least 1.5 m thick.
- **Qpm2:** <u>Piedmont alluvium, intermediate subunit (middle Pleistocene)</u> Strong-brown to very pale-brown (7.5YR 5/6, 10YR 8/2), poorly sorted cobble to boulder gravel. Soils exhibit moderately developed Stage II to III carbonate morphology and deposits commonly overlie older, paler-colored alluvial deposits. Deposit is at least 2-3 m thick near the front of the Los Pinos Mountains.
- **Qpm1:** <u>Piedmont alluvium, older subunit (middle Pleistocene)</u> White to pinkish-white (10YR 8/1 7.5YR 8/2), poorly sorted cobble gravel. Soils are well developed and exhibit Stage III+ carbonate morphology. Schist and granite clasts are commonly weathered and split. Schist clasts are commonly rubefied with reddish-brown (5YR 5/4) color. Constructional bar-and-swale topography is very subdued to not present on deposit surface. Gravels are commonly 5-10 cm in diameter and range up to about 50 cm in diameter. Base not exposed, but exposures near the front of the Los Pinos Mountains indicate deposit thickness is greater than 3 m.</u>
- **Qpo:** <u>Piedmont alluvium, older (lower(?) to middle Pleistocene)</u> Poorly sorted, poorly to moderately consolidated and calcium carbonate cemented sand. Contains strongly developed soils with Stage III+ carbonate morphology. Deposit surfaces are highly dissected and are locally preserved in the Blue Springs and Abo Arroyo drainages. Deposits lie up to 15-20 m above Abo Arroyo. May be correlative to uppermost Santa Fe Group basin fill (Sierra Ladrones Fm). Deposits are locally 3 m thick

Tributary stream-valley alluvium

Tributary stream-valley alluvium graded to modern and former levels of Abo Arroyo, but is derived from mountain-front drainages of the Los Pinos and southern Manzano Mountains. Stream-terrace deposits typically have an elongate planform shape and are associated with major tributaries to the Rio Grande. Gravels reflect upland drainage composition. Alluvium north of Abo Arroyo typically contains a mixture of granite and metamorphic rocks. Deposits south of Abo Arroyo are dominated by metamorphic rocks.

Qa: <u>Stream alluvium, undivided (upper Holocene to historic)</u> — Brown (7.5YR 4/4), medium- to very coarse-grained, poorly to moderately sorted, poorly consolidated pebble- to cobble gravel with local accumulations of cobbles and small boulders and gravel bars. Gravels in most drainage courses contain angular to subangular quartzite, schist, granite and sandstone. Gravels are commonly pebbles, but range to over 40 cm in diameter. Soil development is very weak to nonexistent with disseminated carbonate cement. Deposit underlies narrow to broad streams that are inset against low terrace deposits. Base not observed.

Qay: <u>Stream alluvium, undivided (uppermost Pleistocene to Holocene)</u> — Brown (7.5YR 5/4), poorly to moderately sorted, poorly consolidated light-brown and light reddish-brown to gray-brown pebble and cobble conglomerate and sand with minor accumulations of boulders. Soil development is very weak with Stage I to II pedogenic carbonate morphology. Unit forms broad valley fills that are inset against units Qpa and grade towards low-lying terraces of Abo Arroyo (Qaay). Estimated thickness is probably less than 4 m.

Artificial Fill and Mass-movement deposits

Surficial deposits are the name given to a group of generally thin sediments associated with mass movement and eolian processes. This category also includes sand and gravel deposited by mountain-front streams that are not integrated with entrenched tributary drainages to the Rio Grande.

- **af:** <u>Artificial fill (historic)</u> Dumped fill and areas affected by human disturbances. These areas include large quarry excavations and railroad grades. Unit delineated where deposits or disturbed areas are areally extensive.
- **Qae:** Eolian sand, alluvium, and colluvium, undivided (Holocene to upper Pleistocene) Brown (7.5YR 5/2-5/4), unconsolidated, poorly sorted and stratified, fine- to mediumgrained sand and silty sand with scattered pebbles. Forms relatively thin, discontinuous veneer over broad low-relief surface. Deposits are typically less than 0.5 m thick.
- **Qca:** <u>Colluvium and alluvium, undivided (Holocene to upper Pleistocene)</u> Brown (7.5YR 5/4), poorly consolidated, poorly sorted and stratified, fine- to coarse-grained, clast- and matrix-supported deposits derived from a variety of mass-movement hill-slope processes, including debris flow, shallow slump and creep. Clasts are typically angular and composition generally reflects local provenance. Colluvium is common on hillslopes, but is differentiated where areally extensive. Colluvium is commonly less than 1 m thick. On dip-slopes of Paleozoic units, colluvium is commonly less than 0.3 m thick.</u>
- **Qls:** <u>Landslide deposits (Pleistocene)</u> Poorly to well consolidated and very poorly sorted, sand, breccia. Formed by mass-movement, commonly along steep hill slopes. Arrows indicate direction of movement.

Santa Fe Group

QTsp: <u>Sierra Ladrones Formation, deposits of ancestral Abo Arroyo (middle Pleistocene to</u> <u>Pliocene)</u> — Reddish-brown (5YR 4/4) massive silty clay. Upper boundary with pebble gravel contains an eroded soil with light reddish-brown to pink (65YR 6/4-7/4) silty clay with Stage III+ pedogenic carbonate morphology. Gravels of unit Qpa may be part of this deposit, but these gravels have been included with the alluvium of Abo Arroyo pending further work on the adjacent Black Butte and Turn quadrangles. Interpretations of deep seismic reflection profiles and gravity data suggest that low-density basin-fill may be less than 1 km thick west of the front of the Los Pinos and southern Manzano Mountains (cf. Cape et al., 1983). These deposits may only occupy a small thickness of the Santa Fe Group stratigraphic succession exposed on the map area.

OLIGOCENE UNITS

To: Volcanics Undivided (Oligocene)

White to pinkish-gray, moderately to poorly sorted, moderately consolidated, fine- to very coarse-grained sandstone with scattered volcanic pebbles and cobbles. Also contains interbedded rhyolitic tuffs and basalt and basaltic andesite flows. Correlates to the Spears Formation and Oligocene volcanic rocks of the Mogollon-Datil volcanic field. Unit is at least 350 m thick.

MESOZOIC UNITS

Kth: Tres Hermanos Formation (Upper Cretaceous)

Uppermost beds are about 40 ft (12 m) pale-brown to dusky yellow shale that contains fish scales. Middle beds consist of shelly coquinoid conglomerate containing clams, snails, and shark teeth; grayish-orange and gray shale, siltstone, and fine-grained sandstone; at top of middle sequence of beds is a 5 ft (1.5 m) thick moderate brown coquina of *Crassostrea soleniscus*, identified by W. A. Cobban, USGS (written commun., 1981). Lower beds are very pale orange to moderate-brown, medium-to coarse-grained sandstone and conglomerate that locally contains fossil wood. Entire sequence includes probable equivalents of Dakota Sandstone and Mancos Shale. About 760 ft (230 m). (Description from Myers, Sharps, and McKay, 1986).

Trd: Dockum Formation (Upper Triassic)

Upper beds are poorly exposed red siltstone and shale; middle beds, fine-grained, moderate-red crossbedded sandstone that forms ledges and cliffs; lower beds are grayish-red to moderate-red siltstone and fine-grained sandstone. May be equivalent to Chinle Formation. About 180 ft (54 m) thick. (Description from Myers, Sharps, and McKay, 1986).

PALEOZOIC UNITS

Ps: San Andres Limestone (Lower Permian)

Upper beds, about 26 ft (8 m) of moderate reddish-brown siltstone and fine-grained sandstone; may be equivalent to Bernal Formation of Bachman (1953). Grayish- to very pale orange, light-gray to medium-light-gray, and brownish-gray fetid limestone comprises the bulk of the San Andres; may be gypsiferous near top; lower beds are sandy. Pinkish-gray to grayish-orange well-sorted, fine-to medium-grained quartz sandstone near middle. In vicinity of Gibbs Place, upper beds are mostly gypsum. About 164 ft (50 m) thick. (Description from Myers, Sharps, and McKay, 1986).

Pg: Glorieta Sandstone (Lower Permian)

Reddish-brown, grayish-orange, and yellowish-orange, fine-to medium-grained, well-sorted quartz sandstone. Typically forms cliffs or very steep slopes; beds as much as 10 ft (3 m) thick. Thickness ranges between 150-190 ft (46-58 m). (Description from Myers, Sharps, and McKay, 1986).

Py: Undivided Yeso Formation (Lower Permian)

Formation consists of orange sandstone and siltstone; white gypsum; and yellowish-gray gypsiferous limestone and sandstone. (Description from Myers, Sharps, and McKay, 1986).

Pyjc: Joyita Sandstone and Canas Gypson Members of the Yeso Formation (Lower Permian)

Joyita Sandstone Member is grayish-orange to moderate-reddish-brown siltstone and finegrained sandstone; lower part is gypsiferous and is gradational from underlying Canas Member. About 120 ft (37 m) thick. Canas Gypsum Member is poorly exposed grayish-white gypsum with thin beds of gypsiferous siltsone near middle of member. Because of generally poor exposures and difficulty in locating contacts in most of the map area, the Canas Member and overlying Joyita Member were mapped as one unit. Joyita is about 240 ft (74 m) thick. (Description from Myers, Sharps, and McKay, 1986).

Pyt: Torres Member of the Yeso Formation (Lower Permian or Leonardian)

Poorly exposed gypsum with interbedded limestone lenses. Gypsum is bedded and weathers very light gray. Limestone lenses are up to 5 feet (1.5 m) thick and weathers light-olive gray. Base of member mapped at base of gypsum. Lower 100 feet (31 m) exposed in southeast part of quadrangle; upper beds not present in quadrangle.

Pym: Mesa Blanca Sandstone Member of the Yeso Formation (Lower Permian or Leonardian)

Thin-bedded, fine-grained sandstone and siltstone. Weathers pinkish-gray, pale-red, reddish brown to white. Trace fossils observed on bedding surfaces along with ripple marks and cross bedding. Associated soil is orange to pink. Unit forms gentle slopes and undulating terrain. About 250 feet (76 m) thick.

Pa: Abo Formation (Lower Permian or Leonardian and Wolfcampian)

Overall finer-grained than lower part of Abo Formation (Pal), and composed of thin – to thickbedded micaceous siltstone and fine-grained sandstone. Upper portion contains sandstone and occasional granule conglomerate interbedded with siltstones and mudstones. Weathers light red and pale reddish brown, with local white and green oxidation/reduction spots. Cross laminae, ripple-marks, mudcracks and interbedded paleosols observed. Fossil plant debris and some bioturbation present. Uppermost 20-30 feet (6-9 m) interbedded with light orange-tan sandstones similar to those in the Yeso Formation. About 450 feet (137 m) exposed in southeastern portion of quadrangle. Thickness ranges from about 420 ft (125 m) to 775 ft (235 m).

Pal: Lower Abo Formation (Lower Permian or Leonardian and Wolfcampian)

Base of unit mapped at top of last laterally extensive marine limestone of underlying Bursum Formation; unit disconformably overlies Bursum Formation. Basal contact is poorly exposed and covered by Quaternary deposits. Unit is coarser grained and darker in color than the upper portion of the overlying Abo Formation, weathers dark purple to dark reddish brown and is coated by abundant desert varnish. Contains poorly sorted medium- to coarse-grained, cross-bedded, thick-bedded sandstones (arkosic wacke to wacke) to granule conglomerates. May contain calcite cement. Sandstone beds are more laterally continuous than those of underlying Bursum Formation. Basal sandstone may contain 10 cm limestone clasts. Rare thin lenses of thin (<20 cm thick) nodular bedded, poorly exposed, unfossiliferous (non-marine?) limestone beds at base. Unit is thin (<50 feet) and only present in the southeastern portion of the quadrangle, but is thicker and more pervasive in adjoining Scholle quadrangle. Unit is not regionally extensive, as it does not occur in the Lucero uplift region, ~80 km across the Rio Grande Rift (Lucas and Ziegler, 2004).

Pb: Bursum Formation of the Madera Group (Lower Permian)

Base of unit mapped as last appearance of well-exposed cherty limestone from uppermost IPm-5, which is typically overlain by <5 m of cover followed by 1-2 m thick coarse-grained reddish arkosic sandstone with irregular bottom contact. In northern quarter of quadrangle, basal sandstone thins and is eventually replaced by gray-white crinoid packstone. Limestone beds overlying this basal sandstone (skeletal wackestone-lime mudstones) are thin (< 2m) and contain fusulinids Triticites creekensis Thompson and Leptrotriticites sp. (Myers, 1977), finely abraded or large, intact gastropods, ramose bryozoa, crinoids, and bivalves, and rare small chert nodules (<2 cm). Middle portion of unit composed of interbedded fine-to coarse-grained cross-bedded sandstone (lithic to arkosic wacke and arkose) that may contain calcite cement, occasional granule-pebble conglomerate, red mud-shale, and micaceous siltstone; thickness of sandstone beds varies laterally. Top of unit composed of well- to poorly-exposed < 16 feet (5 m) thick light gray, thin bedded, nodular, fossiliferous limestone bed (skeletal wackestone) that contains small (1 mm thick) stringers of red sandstone, bivalves, crinoids, fenestrae, and fusulinids (Scwagerina pinosensis Thompson) sp. (Myers, 1977). Sandstone weathers reddish-brown to purplish-brown; limestone weathers olive-gray; shale and siltstone weather red. About 150 - 250 feet (46-76 m) thick.

IPM-5 through IPM-1: Informal map units within the Wild Cow Formation (Lower Permian, Upper and Middle Pennsylvanian) of the Madera Group

Informal map units within the Wild Cow Formation as previously mapped by Myers (1977) and Myers et al. (1981). Units broken out into three intervals that contain cliff-forming limestone (IPM-5, IPM-3, and IPM-1) interbedded with two slope-forming siliciclastic-dominated intervals (IPM-4 and IPM-2). Contains fusulinids of Virgilian, Missourian, and Desmoinesian ages (Myers, 1977).

PIPum: Upper Madera Group Formations

Includes IPm-5 through IPm-2, which are described below

IPm-5: (middle and upper part of La Casa Member of Myers et al., 1981) (Upper Pennsylvanian -Virgilian)

Base of unit mapped at base of first cliff-forming limestone overlying slope-forming IPm-4. Cliff- and slope-forming interval composed of three distinctive, mappable, thick (~3-8 m) limestone cliffs separated by ~10-25 m-thick slope-forming intervals. Lower limestone cliff (~4 m) composed of thick-bedded limestone (skeletal wackestone) with laterally continuous dark chert band at base (<10 cm thick) and capped by meter-scale cross-bedded limestone or cross-bedded, laterally discontinuous sandstone. Middle limestone (~3 m; skeletal wackestone) contains irregular –shaped dark chert nodules in upper 2 meters. Upper limestone (~8 m; skeletal wackestone) contains large irregular-shaped light gray chert nodules. Upper 10's of meters of unit composed of recessed, 1-m thick limestone beds containing abundant dark brown chert nodules that weather light tan. Limestones contain phylloid algae, bivalves, crinoids, brachiopods, and abundant bioturbation. Slope-forming intervals composed of interbedded green and purple micaceous siltstone, sandstone, and mudstone. *Triticites creekensis* Thompson? fusulinids present (Myers, 1977). Approximately 250 feet (76 m) thick.

IPm-4: (Pine Shadow Member and lower La Casa Member of Myers et al., 1981) (Upper Pennsylvanian – Virgilian)

Base of unit mapped at the top of the last limestone cliff in underlying IPm-3. Slope-former (poorly exposed) composed of interbedded sandstone, siltstone, and mudstone with occasional laterally discontinuous limestone beds. A thick sandstone interval (10's m thick) is present just north of gas pipeline road in middle of quadrangle and southern part of quadrangle. Mud-siltstones contain ripple laminations and soft sediment deformation. Plant debris and cross-bedding observed in some sandstone beds. Base of unit marked by distinctive thin (<1 m) orange dolomite bed overlain by white sandstone (quartz arenite). Approximately 560 ft (170 m) thick. Thickness varies laterally within map area by 9 m and is thinner to north (Myers, 1977).

IPm-3: (upper part of Sol se Mete Member of Myers et al., 1981) (Upper Pennsylvanian – Missourian)

Base of unit mapped at base of first limestone cliff overlying covered interval in lower portion of Sol se Mete Member (IPm-2). Thin- to thick-bedded cliff-forming limestone (wackestone through grainstone) containing three persistent, mappable cliffs: 1) lower limestone that contains dark chert bands (0.5 m long, <20 cm thick), 2) middle limestone interbedded with orange-weathering silty limestone and sparse chert bands, and 3) thick-bedded upper limestone with distinctive orange-brown mottling in upper 2 meters. Fossils include gastropods, bryozoan, rugose corals, phylloid algae, brachiopods, and abundant bioturbation. Approximately 65 ft thick (20 m).

IPm2: (lower portion of Sol se Mete Member of Myers et al., 1981) (Upper Pennsylvanian – Missourian)

Base of unit mapped as top of last limestone bed in underlying Los Moyos Limestone. Slopeformer (poorly exposed) interpreted to be fine-grained siliciclastic deposits (siltstone) interbedded with limestone beds (mudstone through grainstone) with marl interbeds, rip-up clasts, and plane laminations, and laterally discontinuous white and green sandstones with local granules (subarkose) (1-2 m thick). About 100 ft thick (30 m).

IPm1: (Los Moyos Limestone) (Middle Pennsylvanian – Desmoinesian)

Basal contact with underlying Sandia Formation placed at the base of the first limestone bed. Medium- to thick-bedded, cliff-forming limestones (lime mudstones through skeletal wackestones and grainstones). Individual limestone beds 1- 2 m thick. Contains dark chert in small pods (<5 cm) in lower 40 meters, middle 20 meters, and in uppermost limestone bed. Minor amounts of interbedded sandstone (quartz arenite through micaceous lithic wacke), quartz and feldspar granule conglomerate, and poorly exposed siltstones and mudshales. Fossils include bivalves, bryozoa, crinoids, fusulinids, chaetetids, and abundant bioturbation obscuring primary sedimentary structures. Weathers medium gray. About 560 ft thick (172 m).

IPs: Sandia Formation (Middle Pennsylvanian)

Interbedded sandy, fossiliferous limestones, shales, siltstones, sandstones, and conglomerates. Fossil types include marine fossils and plant debris. Limestone in upper part weathers light- to medium-gray with dark brown chert. Basal beds are orthoquartzitic quartz-pebble conglomerates with angular pink feldspar grains. Upper contact with Wild Cow Formation gradational and placed at last sandstone bed. Lower contact is fault contact with Precambrian rocks. About 600 feet (183 m) thick.

PROTEROZOIC UNITS

Xu: Proterozoic Undivided

Includes all units listed below

Xlp: Los Pinos Granite

Pink, weathers red, massive, medium- to coarse-grained, microcline + orthoclase + quartz + albite granite. Interspersed with hornblende dikes.

Xbsu: Blue Springs Upper Schist

Green to white, chlorite + muscovite schist. The apparent uppermost unit of the Manzano Peak (F2) synclinorium, found east and northeast of the Los Pinos granite (Xlp) in the eastern region of the quadrangle. Equivalent to the Metaclastics Series pCm of Myers and McKay (1974).

Xbr: Blue Springs Rhyolite

Black and brown to gray with lenticular quartz-feldspar pink colored stripes within darker layers. Interpreted as a metarhyolite due to the presence of potassium feldspar in the felsic lenses and a geochemical composition close to rhyolite. Equivalent to the part of pCa, the argillite of Myers and McKay (1972), named the Blue Springs Quartzite (bq1) by Bauer (1983).

Xbs: Blue Springs Schist Green to white, garnet + chlorite + quartz + muscovite schist. Crenulated with well preserved garnet. Equivalent to the part of pCa, the argillite of Myers and McKay (1972) and the Sais Quartzite (sq3) of Bauer (1983).

Xbq: Blue Springs Quartzite Member (of Blue Springs Schist)

Thinly-bedded, medium-grained quartzites, interbedded with chlorite-muscovite schist and quartz-muscovite schist. Partly equivalent to Sais Formation and lower part of the Pine Shadow Springs of Myers and McKay (1972); mapped as Blue Springs Formation (bs1) by Bauer (1983).

Xsq: Sais Quartzite

Thinly-bedded, reddish, schistose quartzite. Bedding planes commonly show mica concentrations. Grains size ranges from very fine to coarse sand. Primary structures include preserved cross bedding. Originally called the White Ridge and Sais quartzites of Myers and McKay (1972), called the White Ridge Quartzite 2 (wq2) of Bauer (1983).

Xes: Estadio Schist marker unit

Coarse-grained, staurolite + garnet + biotite schist. Shows multiple episodes of deformation and contains local crenulation cleavage and at least three generations of foliation. Probably originally deposited as a mudstone layer within the sandstone. Equivalent to the Lower part of the Pine Shadow Springs of Myers and McKay (1972); called the White Ridge schist (ws1) of Bauer (1983).

Xwq: White Ridge Quartzite

Coarse-grained, impure, orange to gray, thinly-bedded, aluminous quartzite. Fairly immature metasedimentary rock with well preserved cross bedding. Cross- bedding indicates overturned bedding. The upper part of the unit has a distinctive red, andalusite + muscovite, foliated, schistose layer. Part of the Lower part of the Pine Shadow Springs of Myers and McKay (1974); called the White Ridge Quartzite 2 (wq2) of Bauer (1983).

Xa: Abajo Schist

Schistose metasedimentary rocks intruded by or interlayered with mafic meaigneous dikes and flows. The metasedimentary rocks are rich in staurolite, garnet and amphibole porphyroblasts. Possible protoliths could be siltstones. Correlated with the Lower part of the Pine Shadow Springs of Myers and McKay (1974). Euivalent to units A,B,C of Parchman (1976) and Bosque metasediments of Edwards (1976).

Xla: Abajo Lithic Arenite

Composed of a variety of metasedimentary rocks including meta-pelites, meta-arkose and impure quartzite. The chlorite schist, and some quartzites interbedded with metarhyolite are thinlybedded; more massive, quartzite domains are locally dominant. Locally, garnet staurolite schist and may be related to the intrusion of gabbroic dikes (now amphibolite). Compositional layering (S_0) is commonly preserved and is generally at low angle to dominant schistosity (S_1) . Correlated with the lower metaclastic series of Reiche (1949) and the lower part of the Pine Shadow Springs and Flaggy Schist zones of Myers and McKay (1972, 1974). Equivalent to units A,B,C of Parchman (1976) and Bosque metasediments of Edwards (1976).

Xa: Amphibolite

Black to dark green, fine-to coarse-grained amphibolites with varying amounts of macroscopic white plagioclase that ranges in texture from salt and pepper to smeared-out shear banding. Coarse-grained metadiorites are present locally. Mafic units have apparent widths up to 150+m and may thicken, thin, fork, and pinch out along strike. Equivalent to the pCb "basic schist" of Myers and McKay (1972). May be confused with the intrusive gabbro described above, but some units may be part of the supracrustal sequence. These were mapped as Basic Schist and Mixed Flow units by Myers and McKary (1972) and as non-rhyolitic components of the Sevilleta Formation Formation by Bauer, 1983.

Xsr: Sevilleta Metarhyolite

Felsic, meta-igneous rocks with quartz and feldspar phenocrysts. Generally pink to gray, blockyfracturing, porphyritic aphanites with quartz and feldspar clasts ~1mm in diameter. Texture ranges from thin, well developed compositional banding to massive. Planar features, such as ~1mm-~5cm flow bands or shear bands, are common and range considerably in thickness. Quartz veins, pegmatite and massive schistose units are present locally and generally parallel foliation. Equivalent to the Sevietta metarhyolite of Reiche (1949) and Myers and McKay (1972). Subdivided as follows:

Xsru: Upper metarhyolite member

Brown to pink, finely-banded sericitic metarhyolite; 0.5-3.5mm feldspar and quartz crystals.

Xsrm: Middle metarhyolite member

Dark gray to black, finely-banded rhyolite; 0.5-2mm angular to rounded quartz clasts.

Xsrl: Lower metarhyolite member

Medium gray to black, dense, finely-banded metarhyolite; speckled with 1.0-2.5mm white feldspar crystals.

Xsrh: Hornblende schist member

Olive to dark-green, aphanitic, vesicular, flow-banded rock. Gneissic with feldspar augen in places. Interfingers with metarhyolite members (Xsru, Xsrn, Xsrl) and merges with overlying Abajo Lithic Arenite unit (Xla).

Correlation of Map Units





