Geologic Map of the Cerro del Grant Quadrangle, Rio Arriba County, New Mexico

By

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New Mexico Bureau of Geology and Mineral Resources
Open-file Digital Geologic Map OF-GM 87

Scale 1:24,000

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SUMMARY OF FINDINGS
TO ACCOMPANY GEOLOGIC MAP OF THE
CERRO DEL GRANT QUADRANGLE

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ABSTRACT

Cerro del Grant 7.5-minute quadrangle lies in Rio Arriba County, north-central New Mexico. It encompasses an area in the northern Jemez Mountains adjacent to the north rim of the Valles Caldera. The area occurs at the juncture of the Naciemiento uplift, the Espanola basin of the Rio Grande rift, and the northern Jemez volcanic field. Sedimentary rocks distributed in the quadrangle include shale, sandstone, conglomerate, evaporite deposits, and chert of Late-Triassic to late-Tertiary age. These strata dip gently to the east and are overlain by Pliocene volcanic rocks of andesitic to rhyolitic composition erupted between 14 Ma and 1.2 Ma. Lobato andesite and dacite (7-14 Ma) underlie the northern part of La Grulla Plateau. Volcanic activity in the Jemez Mountains was concurrent with late-Miocene early-Pliocene rift development. Early Lobato andesite flows issued eastward onto an east-sloping surface underlain by Santa Fe Group sandstone from a shield cone at Encino Lookout. Lobato andesites (7.85 Ma) were intruded by dacite at this location. Tschicoma andesites and dacites overlie the Lobato Formation and occur as extensive flows, domes and shallow intrusives on La Grulla Plateau. Lower member 2-pyroxene Tschicoma andesites cover most of the plateau. Upper member Tschicoma dacite domes and limited flows (7.35 Ma) are distributed on the east margin of La Grulla Plateau near Canones Creek. Structural control of dacite eruptions is apparent. Quaternary ash-flows of the Bandelier Tuff (1.6 MA to 1.2 Ma) once mantled all underlying strata in the quadrangle but now occur in local remnant outcrops after extensive Pleistocene erosion. Two distinct episodes of tectonic movement are noted. One system of north-trend high angle faults displaces pre-Tertiary rocks and is associated with Laramide uplift in the Nacimiento Mountains. A second system is comprised of high-angle, curvilinear faults associated with the western margin of the Espanola basin and has been dated between 7.4 Ma and 7.8 Ma. Eruptive centers appear to have been fixed along faults of the latter type. Post-volcanic fault reactivation caused escarpment development along Cerro Valdez and disintegration of the shield cone at Encino Lookout.

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1.0 INTRODUCTION

This report summarizes the main findings and conclusions determined during geologic field investigations and mapping of the Cerro del Grant (CdG) quadrangle in Rio Arriba County, north-central New Mexico. It is presented to the New Mexico Bureau of Mines and Mineral Resources in fulfillment of 2003-2004 NM State Mapping Contract for completion of the accompanying Geology of Cerro del Grant 7.5-minute quadrangle, herein enclosed as one inked mylar copy, one colored paper, and two uncolored paper copies. Additional documentation includes attached, rock unit descriptions, correlation diagram of map units, and geologic cross sections.

The CdG quadrangle lies within the limits of 36°00’00” to 36°12’30” North Latitude and 106°30”00” to 106°37’30” West Longitude. The map area is made up of high sub-alpine plateaus cut by narrow canyons with moderately to steeply inclined side-wall slopes. Local topography has moderate to locally steep vertical relief with elevations ranging from approximately 7,300 ft above mean sea level (msl) near the mouth of Coyote Canyon, to 10,472 ft msl at the summit of Cerro del Grant. The terrain is generally forested with ponderosa pine and aspen; however, broad open meadows extend over large areas of La Grulla Plateau.

1.1 GEOLOGIC SETTING

The Cerro del Grant quadrangle occurs at the junction of the Jemez Mountains and Espanola Basin of the Rio Grande Rift physiographic provinces. It is bordered on the west by the Nacimiento Mountains, a Precambrian-cored uplift of Laramide age. The eastern flank of the uplift is underlain by Mesozoic sedimentary rocks that are exposed in Coyote Canyon, in the western part of the quadrangle. Local Mesozoic rocks were affected by episodes of early to mid-Cenozoic crustal downwarping, basin development and non-marine sedimentary deposition followed by normal faulting associated with late-Tertiary regional extensional stresses and development of the Rio Grande rift. The Jemez volcanic lineament, a major notheast-trending fault zone and alignment of Miocene to Quaternary volcanic centers from central Arizona to southeast Colorado (Goff et al., 1989), intersects the western margin of the Rio Grande rift approximately 1 km south of the quadrangle area.

The region became the locus of volcanic activity during formation of the Jemez volcanic field beginning in the late-Tertiary. Early stages of volcanism were dominated by effusive eruptions and deposition of abundant coalecsing and overlapping lavas ranging from mafic to intermediate in composition that issued from local eruptive centers. Culminating catastrophic eruptions occurring at the beginning of the Quaternary from the center of the volcanic pile resulted in the deposition of a series of rhyolitic ash-flow (ignimbrite) sheets and that mantled underlying strata over a broad area. Sudden evacuation and collapse of the magma chamber the created the 15-km-diameter Valles caldera (Gardner, et al., 1996) bordering the southern edge of the CdG quadrangle. Extensive Pleistocene weathering and erosion removed all but local remnants of the ignimbrite layer, exposing a present-day landscape underlain by lavas, vents, domes, and shallow volcanic intrusives. Broad areas of La Grulla Plateau and adjacent areas are covered with locally thick colluvium.

1.2 PREVIOUS INVESTIGATIONS

Earliest research on rocks of the Tewan (Jemez) Mountains of New Mexico began with Hayden (1869), Iddings (1890), and Darton (1928). These studies were followed by field mapping and research on the sedimentary and volcanic rocks occurring in the northern Jemez region by Bryan (1938), Smith (1938), and Church and Hack (1939).

Volcanic stratigraphy in the Jemez Mountains has been studied by Smith (1938), Griggs (1964), Ross et al. (1961), and Bailey et al. (1969). Smith et al. (1970) published a definitive geologic map and advanced the understanding of the volcanic stratigraphy of the Jemez Mountains. Stratigraphic nomenclature of the Bandelier Tuf was redefined by Broxton and Reneau (1995). Field investigations and research on the volcanic stratigraphy and resurgence aspects of the Valles caldera were undertaken by Gardner and Goff (1996).

Studies of Rio Grande Rift basins, and the Espanola Basin in particular, were undertaken by Galusha and Blick (1971), Manley (1978), and Kelley (1952, 1978) who defined stratigraphic nomenclature of the Santa Fe Group. Broomfield (1977) mapped structure and volcanic stratigraphy of the Canones Quadrangle to the northeast of the CdG quadrangle. Woodward and Timmer (1979) mapped sedimentary and volcanic rocks, and structure on the eastern flanks of the Nacimiento uplift in the Jarosa quadrangle, west of the CdG area. Lawrence (1979) mapped volcanic and sedimentary rocks and basin-marginal structures in the Cerro del Grant quadrangle as well as a portion of the Youngsville quadrangle, to the north of the CdG map area. Singer (1985) and Singer and Kudo (1986) conducted field investigations on La Grulla Plateau and published findings on the evolution of andesitic magmas relative to Polvadera Group rocks. Gardner and Goff (1996) mapped volcanic stratigraphy and structure of the northern Valles Caldera, to the south of the CdG quadrangle.

1.3 FIELD AND LABORATORY METHODS

Geologic mapping was performed on a scale of 1:24,000 using the Cerro del Grant U. S. Geological Survey (USGS) 7.5-minute topographic map as a base for plotting field data. Survey methods included the use of a Garmin eTrex Venture Global Positioning System (GPS) personal navigator to determine station locations based on the 1000-meter Universal Transverse Mercator (UTM) grid system. A Brunton compass was used to measure bedding and structural attitudes. Analysis of aerial photographs, at a scale of approximately 1: 28:000 was performed to identify structural trends and determine the extent of surficial deposits.

Petrographic analyses were performed on thin sections prepared for selected rock samples collected in the CdG area using a Leitz polarizing microscope. Results are extracted from Lawrence (1979) and are presented in Appendix C. Nine wet chemical whole-rock analyses were performed at the chemistry laboratory of the Geology Department at the University of New Mexico for selected CdG volcanic rock samples. The results, taken from Lawrence (1979), are summarized in Table 1.

2.0 STRATIGRAPHY

The CdG quadrangle is underlain by sedimentary and volcanic rocks of Mesozoic to Quaternary age. In general, sedimentary rock units of Late-Triassic to Pliocene age, occupying roughly 30 percent of the quadrangle, are distributed in the western and northwestern parts of the map. Tertiary volcanic rocks that locally comprise the northwestern margin of the Jemez volcanic field, underlie the remaining portion of the map. Significant portions of the quadrangle area are covered by unconsolidated Quaternary alluvium, colluvium, and landslide deposits. Stratigraphic units, from older to younger, are summarized in the following sections Descriptions of map units identified in the CdG quadrangle are listed in Appendix A. Correlation of units is shown graphically in the diagram of Appendix B. Supplemental whole-rock chemical analytical results and petrographic descriptions for selected CdG volcanic rocks are extracted from Lawrence (1979) and presented in Table 1 and Appendix C, respectively.

2.1 MESOZOIC ROCKS

Mesozoic sedimentary rocks are exposed in the canyon sideslopes of Coyote and Upper Coyote Creeks in the western and northwest parts of the CdG quadrangle and include marine and non-marine shales, sandstones and limestones of Triassic, Jurrassic, and Cretaceous age.

Chinle Formation

The oldest rocks in the CdG area are Upper-Triassic nonmarine sandstone and ferruginous shale of the Chinle Formation, including the Poleo Sandstone and overlying Upper Shale (also known as the Petrified

Forest Member) Members, respectively (Stewart et al., 1972). The Chinle Formation is exposed near the mouth of Coyote Canyon where its exposed thickness is as much as 50 m.

Entrada Sandstone

Yellowish to orange-tan eolian sandstone of the Upper-Jurrasic Entrada Sandstone (Gilluly and Reeside, 1928) appear in prominent cliff exposures near the mouth of Coyote Canyon in the northwest corner in of the CdG area. It is in apparent conformable contact with the underlying Upper Shale Member of the Chinle Formation. The Entrada Sandstone occurs on the east side of Coyote Creek where it is in fault contact with the Poleo Sandstone. It has an estimated local thickness of nearly 70 m.

Todilto Formation

Gypsiferous evaporite deposits and basal limestone making up the Todilto Formation (Tanner, 1974) of Late-Jurrasic age occurs as a conspicuous thin layer that conformably overlies the Entrada Sandstone. The Todilto is distributed as a narrow band roughly parallel to, and east of, Coyote Creek. Its local thickness is estimated to be approximately 25 m.

Morrison Formation

Upper-Jurassic non-marine shales, sandstones, and lacustrine deposits of the Morrison Formation (Flesch, 1974) crop out in a nearly continuous band on the east and northeast sides of Coyote Creek and Upper Coyote Creek, respectively. Three members of the Morrison Formation were locally recognized but are shown as an undivided map unit. These include, from older to younger, the Recapture Shale, the Brushy Basin Shale, and the Jackpile Sandstone Members. The slope-forming Recapture Shale is comprised of banded, gray very fine grained sandstone with interbedded maroon shale that unconformably overlies the Todilto Formation. The Brushy Basin Member is formed of interbedded light-colored sandstone and dark shale. The Jackpile Sandstone is a white, locally conglomeratic quartzose sandstone and conspicuous cliff former. Total thickness of the of the Morrison section in the CdG area is estimated to be approximately 240 m.

Dakota Sandstone

The cliff-forming Dakota Sandstone of Early to earliest Late Cretaceous age (Grant and Owen, 1974) is distributed in a prominent, continuous narrow outcrop pattern on the east side of Coyote Creek, from Upper Coyote Creek to the north edge of the map. The Dakota is comprised of fine-grained quartzose marine sandstone and locally interbedded dark gray carbonaceous shale. The unit conformably overlies the Jackpile Sandstone of the Morrison Formation. Its estimated thickness in the CdG area is approximately 70 m.

Mancos Shale

The Upper-Cretaceous Mancos Shale (Smith et al., 1961) occurs locally as an erosional remnant conformably overlying the Dakota Sandstone in the northwest part of the CdG quardangle. It is comprised of slope-forming, dark gray and brown, calcareous shale with local thin fossiliferous (i.e., pelecypods and brachiopods) limestone interbeds. Its estimated thickness ranges from 0 m to 60 m. An extensive pre-Tertiary erosional interval following uplift of the Nacimiento Mountains resulted in an irregular surface of low to moderate relief that is superimposed on the Dakota and Mancos formations and upon which sedimentary rocks of Tertiary age were unconformably deposited.

2.2 TERTIARY SEDIMENTARY ROCKS

Tertiary sedimentary rock units are distrubuted in a discontinous band, mainly in the western part of the CdG quadrangle, extending from Upper Coyote Creek northward and along the western edge of Mesa Lagunas and Banco Largo. Limited exposures also occur in the extreme northeast corner of the map, along Canones Creek. They are comprised of non-marine shale and mudstone, sandstone, and conglomerate deposited in a series of superposed basins during early- to late-Tertiary time.

El Rito Formation

Brick-red, slope-forming micaceous siltstone and mudstone, interbedded fine- to medium-grained arkosic sandstone, and basal quartzite conglomerate making up the El Rito Formation were deposited unconformably on the Dakota Sandstone and Mancos Shale. The age of these sediments is regarded as early Tertiary, possibly Eocene (Smith, et al., 1961). Exposures of the El Rito are rare and the map outcrop pattern is inferred from sparce float indications. Its thickness is probably variable and estimated to be no more than 65 m.

Abiquiu Formation

Smith (1938) assigned the name Abiquiu Tuff for volcaniclastic sediments occurring in the near Abiquiu, New Mexico. The term Abiquiu Formation has been used by Smith et al. (2002) for these same rocks deposited in a pre-Rio Grande rift basin during Oligocene-early Miocene time. The Abiquiu Formation in the CdG quadrangle is a complex sequence of mappable subunits that include: (1) lower pink-brown coarse conglomerate and arkosic sandstone containing Precambrian quartzite, igneous and metamorphic crystaline, and limestone clasts, (2) a thin layer of chert and siliceous limestone, and (3) upper whitish fine to medium-grained tuffaceous and volcaniclastic sandstone. Smith et al. (2002) refers to these subunits informally as the lower, Pedernal [formerly the Pedernal Chert of Church and Hack (1939)], and upper members, respectively. The Abiquiu Formation occurs in a similar distribution pattern to that of the El Rito Formation upon which it was unconformably deposited. The Abiquiu Formation is estimated to be 200 m to 270 m thick in the CdG quadrangle. The three members were mapped individually.

Ojo Caliente Sandstone

The Ojo Caliente Formation of the Santa Fe Group crops out mainly in the extreme northeastern part of the CdG area. Minor exposures occur on Mesa Lagunas and along Canones Creek. The Ojo Caliente Sandstone locally consists of pink to tan-colored, moderately indurated, fine-grained feldspathic sandstone. These sediments, of eolian origin (Galusha and Blick, 1971), were deposited unconformably on the upper member of the Abiquiu Formation within the Abiquiu embayment of the Espanola Basin during Miocene time. The unit is considered to have a variable thickness across the CdG area in the map and apparently thins considerably westward approaching the western margin of the Espanola basin beneath La Grulla Plateau. Its maximum thickness is estimated to be 70 m to 100 m in Canones Creek canyon.

2.3 TERTIARY VOLCANIC ROCKS

The CdG quadrangle lies adjacent to the north rim of the Valles caldera. Tertiary volcanic rock units underlie the central, eastern, and southwestern parts of the map and genreally form local regions of higher elevations. Volcanic rocks ranging from mafic to felsic compositions occur as lavas, volcanic vents, shallow intrusives, and ash-flow tuff deposits on La Grulla Plateau and adjacent highlands. The vast majority of the volcanic units belong to the Polvadera (2.0 –7.0 Ma) and Tewa Groups (0–1.45 Ma) as defined by Bailey (1969), Smith et al. (1970), Griggs (1964), Goff et al. (1989), and Gardner et al (1986). A limited outcrop of Keres Group (7.0-10.4 Ma) andesite occurs in the extreme southeast corner of the map.

Basalt

Small basalt outcrops were noted in Canones Creek canyon and in the Four Hills area of La Grulla Plateau. The former occurs in two thin, parallel flows which appear to be enclosed by Ojo Caliente Sandstone of the Santa Fe Group. A second olivine-phyric basalt is expressed as a thin layer of angular boulders overlying quartzite-granite conglomerate of the lower member of the Abiquiu Formation. This basalt flow(?) is overlain by Tschicoma andesite in the Four Hills area on La Grulla Plateau.

Paliza Canyon Andesite

A small outcrop of Paliza Canyon andesite (8.0 Ma) (Gardner et al., 1986) is well exposed in the northern wall of the Valles caldera in the extreme southeast edge of the CdG quadrangle. The andesite at this locality is coarsely porphyritic, pyroxene-bearing, and strongly altered in part. It is overlain by 2-pyroxene Tschicoma andesite.

Lobato Formation – Andesites of La Grulla Plateau and Banco Largo

Bailey et al. (1969) named the Lobato Basalt for mafic and intermediate rocks of the Polavdera Group that occur widely in the northern Jemez volcanic field. Lobato Basalt age dates range roughly from 7 to 14 Ma (Gardner et al., 1986). The term Lobato Formation is used for purposes of mapping in the CdG quadrangle for rocks that include basalt, andesite, and dacite in northern La Grulla Plateau.

Lobato andesites underlie the northern part of La Grulla Plateau where they occur as a series of gently east-dipping flows and thin intercalated scoria-pyroclastic layers unconformably deposited on Ojo Caliente Sandstone of the Santa Fe Group. The Lobato section is well exposed north and south of Encino Lookout in a 70-meter-high, northeast-trending escarpment where as many as five successive andesite flows, each with a 2- to 3-m-thick basal interval of pyroclastic material, are recognized (Lawrence, 1979). The flow sequence is locally cut by two pipe-like vertical columns consisting of ferruginous breccia. Banco Largo, an extensive lowland area of hummocky terrain immediately west of the lookout, is underlain by additional andesite flow remnants and pyroclastic debris. Banco Largo and Encino Lookout are the site(s) of alternating explosive and effusive andesite eruption and represent a shield cone (McDonald, 1972). Lavas poured out and spread eastward away from local vents. The Lobato section is estimated to be approximately 70 m thick at Encino. The shield cone centered on Banco Largo was subsequently dissected and exposed by post-Lobato tectonic activity.

Lobato andesite is generally weakly porphyritic, with phenocrysts of plagioclase, pyroxene and olivine in an aphanitic groundmass. Three samples were collected from the Lobato andesite section at Encino Escarpment for whole-rock and petrographic analysis. Results are listed in Table 1 (Lawrence, 1979). Analyses representing lower to upper flows in the sequence (samples CG-060, CG-063, and CG-026) range from 56.4 to 59.5% SiO_2 and indicate basaltic andesite to andesite compositions (Le Maitre, 2002). Singer (1985) obtained a K-Ar date of 7.85 Ma from an upper Lobato andesite flow near Encino Lookout. Petrographic analyses for selected Lobato andesite rock samples are presented in Appendix C.

Table 1. Whole-rock Geochemical Analyses for Selected Volcanic Rocks of the Cerro del Grant Quadrangle, New Mexico

Location	Tla, Encino Escarpment	Tla, Encino Escarpment	Tla, Encino Escarpment	Tta, Cerro Valdez	Tta, Cerro Pelon	Ttd, Barrancones Hill	Qbt, Tshirege Member Upper Coyote Creek
Approximate UTM Grid Coordinates Loacation	0360365. 3999390	0360480. 3999360	0359225. 3997700	0357220. 3989265	0356340. 3988040	0362620. 3993175	0354185. 3992660
Sample Number	CG-060	CG-063	CG-026	CG-054	CG-056	CG-072	CG-084
Si0	56.38	58.27	59.52	60.73	60.98	65.14	76.34
$Ti0_2$	1.00	1.00	0.79	0.79	0.79	0.60	0.09
$A1_20_3$	16.60	15.95	15.47	15.57	16.40	15.85	12.10
Fe_20_3	1.86	3.02	2.84	4.08	3.35	2.56	0.98
Fe0	5.16	3.63	3.54	2.15	2.26	1.21	0.23
Mn0	0.12	0.11	0.10	0.10	0.08	0.07	0.06
Mg0	5.42	4.65	3.94	2.46	2.40	1.36	0.09
Ca0	6.60	6.20	5.98	5.25	5.25	3.40	0.40
Na_20	3.74	3.90	3.87	4.03	4.05	3.96	4.35
K_20	1.88	2.16	2.37	2.74	2.80	3.43	4.39
P_20_5	0.32	0.30	0.30	0.33	0.31	0.22	0.02
Sr0	0.07	0.07	0.07	0.07	0.07	0.06	0.00
H_20^+	0.39	0.53	0.54	0.49	0.45	1.48	0.48
H_20^-	0.06	0.18	0.33	0.34	0.30	0.17	0.09
Total	99.59	99.97	99.65	99.13	99.49	99.51	99.63

Note: Tabulated results from Lawrence (1979). Samples CG-060 and CG-063 were collected from Encino escarpment north of Encino Lookout, on the Youngsville 7.5-minute quadrangle.

Lobato Formation – Dacite of Encino Lookout

Porphyritic Lobato dacite intruding Lobato andesite flows and breccia deposits was interpreted as an endogenous dome (Singer, 1985). The intrusive body is roughly 300 m wide by 100 m high and is well exposed in the vertical cliff face of Encino Escarpment. A small dike of apparent similar composition intrudes remnant Lobato andesite flows on Banco Largo. Petrographically the dacite is porphyritic, with phenocrysts of plagioclase, augite, hypersthene, and minor biotite in a cryptocrystalline "felted" grondmass od plagioclase and minor opaqes. Analyses of Lobato dacite range from 63.4 to 64.0% SiO_2 (Singer, 1985).

Tschicoma Formation

Andesites and dacites of the Tschicoma Formation are the most voluminous of all volcanic rocks in the CdG quadrangle. These units are widely distributed on La Grulla Plateau and underlie significant areas on the plateaus east of Canones Creek. The Tschicoma Formation was described by Griggs (1964) as primarily dacite. Smith et al (1970) recognized the diversity of Tschicoma rock types that occur as massive flows and domes in the northern Jemez Mountains but lumped lithologies ranging from dacite to quartz-latite as a single unit. Geologic mapping in the CdG quadrangle for the present study has succeeded in breaking out heretofore unrecognized andesitic and dacitic terranes on La Grulla Plateau. Two mappable Tschicoma units are present: (1) lower, coarsely porphyritic, 2-pyroxene andesite and (2) overlying, fine-grained and coarsely porphyritic horblende- and horblende-biotite dacite. Tschicoma age dates range roughly from 3 Ma to 7 Ma (Gardner et al., 1986).

Tschicoma Formation – Andesites of La Grulla Plateau

Tschicoma andesite flows, domes, and shallow intrusives occur throughout the central part of the CdG qauadrangle and underlie most of the highland terrain of La Grulla Plateau. This voluminous and widely dispersed unit has previously not been recognized as a significant member of the Tschicoma Formation. Tschicoma andsite flows appear to have issued from several sources on, or near, La Grulla Plateau. Inferred eruptive centers include those at Cerro del Grant, Cerro Pavo, and apparent vents making up the Four Hills complex in sec. 4 and 5, T. 22 N., R. 4. E. It is likely that additional andesite eruptive centers existed in the highlands south of CdG quadrangle prior to catastrophic eruption and caldera collapse.

Good exposures of Tschicoma rocks are rare on La Grulla Plateau because of extensive weathering and erosion that have occurred since their emplacement. Andesite flows are well exposed in vertical section along the escarpment of Cerro Valdez on the west edge of the plateau, as far south as Upper Coyote Canyon. In this area, the Tschicoma flows are estimated to be approximately 70 m thick; however, an eastward thickening of the section is apparent where andesites may reach more than 150 m thick in vicinity of Canones Creek. Tschicoma outcrops along Canones Creek are generally poor due to extensive colluvial cover.

Tschicoma andesites are distinctive in that they are light gray, very coarsely porphyritic, with phenocrysts (commonly making up 40–50% or more by volume) that are comprised of euhedral to resorbed, zoned plagioclase, hypersthene, augite, and minor bitotite. Two samples of Tschicoma andesite were collected for analysis (Lawrence, 1979): one from Cerro Pelon (CG-056) and one from a lower flow near the base of Cerro Valdez (CG-54). Nearly identical analyses for the two samples range from 60.7 to 61.0% SiO_2 (Table 1). Abundant xenoliths characterize the andesite of Cerro Pelon. Because of its conspicuous linear morphology and strong vertically jointed exposures at its north end, Cerro Pelon is interpreted to be a plug or fisher vent from which andesite flows at Cerro Valdez were erupted. Appendix C presents petrographic analyses (Lawrence, 1979) for selected Tschicoma andesite rock samples.

An anomalous dark colored, fine-grained flow, up to 15 m thick, caps the east-northeast-trending hill at the south edge of the CdG quadrangle at UTM coordinates of 0356642.3985403. The morphology of this hill suggests an association with ring-fractures of the Valles caldera. The rock is dark gray, vesicular, weakly porphyritic, and has phenocrysts of fine plagioclase, pyroxene, and olivine enclosed in an aphanitic groundmass. No petrographic or chemical data are available for this rock and therefore it is preliminarily assigned as undivided Tschicoma andesite.

Tschicoma Formation – Dacites of East La Grulla Plateau

Tschicoma dacites are distributed uniquely in the eastern part of the CdG quadrangle. There is a preferred north-south alignment of dacitic rocks that occur as domes and associated flows of limited areal extent along a trend marked by the eastern boundary of La Grulla Plateau and Canones Creek. Invariably, these overlie Tschicoma andesites through which they appear to have extruded. Inferred local dacite eruptive centers occur at Hill 33 (i.e, sec, 33, T.21 N., R. 4 E.), the south side of Cerro del Grant, Cerro Pavo, the Four Hills area, and Barrancones Hill (immediately north of Barrancones Creek in sec. 32 and 33, T. 22 N., R. 4 E.). A fine-grained dacite occurring at the south edge of the CdG quadrangle appears to originate from Cerro de la Garita, or another vent south of the map area. Singer (1985) obtained a K-Ar age date of 7.35 Ma from a sample of the dacite outcropping at Four Hills south (i.e., southernmost of the four dome-shaped hills), at approximate UTM coordinates 0362500.3993260.

Tschicoma dacites in the CdG area are lithologically diverse and include both fine-grained and coarsely prophyritic varieties of hornblende- and hornblende-bitotite-bearing rocks. Tschicoma dacites were lumped as an undivided unit for mapping purposes. Hornblende-bitotite rocks of Barrancones Hill was sampled for whole-rock chemical analysis (Lawrence, 1979). Sample CG-072 (Table 1) yielded 65.1% SiO_2 and indicates that Barrancones Hill is underlain by dacite (Le Maitre, 2002). Coarsely porphyritic dacite of Four Hills south contains medium-grained phenocrysts of plagioclase, hornblende, and biotite. Analysis of this dacite yielded 66.1% SiO_2 (Singer, 1985). The dacite of Cerro Pavo is strongly flow-banded, weakly porphyritic and contains fine phenocrysts of plagioclase, augite, hypersthene, and oxyhornblende in a cryptocrystalline to glassy groundmass (Lawrence, 1979). Whole-rock chemical analysis of Cerro Pavo dacite yeilded 69.8% SiO_2 (Singer, 1985). No data are available for coarsely porphyritic hornblende-biotite dacites occurring at Hill 33 and on the south side of Cerro del Grant. No data are availbale for the fine-grained pyroxene-hornblende dacite of Cerro de La Garita. Petrographic analyses for selected Tschicoma dacite rock samples (Lawrence, 1979) are presented in Appendix C.

2.4 QUATERNARY ROCKS

Quaternary rock units in the CdG quadrangle include rhyolitic ash-flows of the Bandelier Tuff and unconsolidated surficial sediments, including alluvium, colluvium, and landslide deposits.

Bandelier Tuff

The Bandelier Tuff, first described by Smith (1938) and later Griggs (1964), is the oldest and most voluminous of the rocks that make up the Tewa Group. Bailey et al. (1969) reorganized Bandelier Tuff stratigraphy and formally subdivided it into two ash-flow members, each with a pumiceous tephra deposit at its base. Broxton and Reneau (1995) formalized Bandelier Tuff stratigraphic nomenclature as used in mapping the CdG quadrangle. The lower Otowi Member includes the basal Guaje Pumice Bed. The upper Tschirege Member includes the Tsankawi Pumice Bed at its base Subunits of the Bandelier Tuff have been dated at 1.6 Ma for the Otowi Member and 1.2 Ma for the Tschirege Member (Izett and Obradovich, 1994). Volcaniclastic sediments of the Cerro Toledo Interval, representing a roughly 400,000-year period of erosion and detrital deposition, locally separate the two tuff members.

The Otowi and Tshirege Members are both present in the CdG quadrangle. Outcrops are concentrated on the east side of the quadrangle, primarily in positions of relatively low elevation in and near the side-slopes of Canones Creek. Bandelier Tuff outcroppings adhered to subvertical canyon walls attest to a pre-Bandelier paleotopographic surface of extensive canyon development and relatively high relief. Canones Creek had accomplished significant erosion and downcutting of its drainage in essentially its present location at the time of the Otowi eruptions. Canones Canyon was in-filled by initial air-fall deposits (Guaje Pumice Bed) and subsequent voluminous welded ash-flows. During the 400,00-year eruptive hiatus following Otowi Member emplacement, Canones Creek drainage was again incised along its original (and present) trajectory leaving remnants of Otowi ash-flow tuff locally in place near the canyon rim. Tschirege air-fall and ash-flow eruptions appear to have in-filled Canones Creek drainage to a maximum extent. Undoubtedly, all rock units underlying La Grulla Plateau were covered by thick ash-flow layers. Nevertheless, virtually all Bandelier deposits were stripped from the highlands of La Grulla Plateau during extensive Pleistocene erosion.

A broad area in the southwest corner of the CdG quadrangle is underlain by Tshirege Member ash-flow deposits at least 60 m thick. Limited exposures of basal Tsankawi Pumice Bed and underlying Otowi Member also occur here. Extending northward, isolated Tshirege remnants occur in Coyote Canyon where they overlie the Morrison, Dakota, and Abiquiu Formations.

Otowi Member

The Otowi Member of the Bandelier Tuff crops out in remnant exposures on the west slopes of Canones Creek, in the northeast corner of the CdG quadrangle, where its inferred thickness is approximately 100 m. No evidence of the basal Guaje Pumice Bed section was noted. Extensive Otowi ash-flow remnants were mapped on both sides of Canones Creek canyone, as far south as sec. 28, T. 21 N., R. 4 E.

Otowi ash-flows tuff is weakly to partly welded, crystal-bearing, and characterized by locally abundant intermediate to mafic xenoliths and dark-colored pumice fragments. At UTM grid location 0364015.3992121, near the head of Canones Creek, the Otowi Member is weakly welded, contains less than 10% quartz, sanidine and mafic (pyroxene?) phenocrysts; 30-40% light- to dark-gray, intermediate volcanic lithic fragments; abundant undeformed devitrified pumices; and has a characteristic vuggy texture. Petrographic descriptions of Otowi Member samples are presented in Appendix C.

Tshirege Member

The Tshirege Member of the Bandelier Tuff is more widely distributed area than its lower counterpart.in the CdG quadrangle. It crops out extensively along the canyon rims of Canones Creek and covers a broad area in the southwest corner of the map. The Tsankawi Pumice Bed is exposed near Canones Creek, in the SE¼ NW¼ sec. 27, T. 22 N., R. 4 E., as a 1-m-thick deposit of white, well-sorted, pumice lappilli and nonwelded intergranular white ash. At the head of Canones Creek, at UTM location 0364698.3992630, typical Tshirege ash-flow tuff is charcterized as light pinkish gray, moderately welded, crystal-rich, and contains up to 30% by volume phenocrysts of quartz, sanidine; devtrified pumice (1%) and dacite lithics (1-2%) in a matrix of moderately welded very fine grained ash. The Tshirege Member in this area has an estimated thickness of 70 m. Densely welded Tshirege Member ash-flow tuff in Upper Coyote Canyon was sampled for whole-rock chemical analysis (Lawrence, 1979) and was reported to have a concentration of 76.3% SiO_2 (Table 1). Petrographic analyses for selected Tschirege Member samples are presented in Appendix C.

Colluvium and Landslide Deposits

Broad areas of the CdG quadrangle are covered with unconsolidated colluvium. Widely distributed colluvial deposits on La Grulla Plateau and along the western base of the escarpment of Cerro Valdez and Encino Lookout indicate extensive Pleistocene erosion of local volcanic highlands. Tschicoma andesite boulder colluvium of La Grulla Plateau, in the NW¼ sec. 8, T. 21N., R. 4 E., is inferred to be up to 35 m thick. Extensive colluvial cover on the canyon slopes of Canones Creek, and elsewhere throughout the CdG quadrangle, obscure unit contacts and relationships.

Many of the colluvium deposits along Coyote Creek are considered to be true landslides based on morphology. These are composed of locally derived sedimentary and volcanic debris and may be as thick as 25 m.

Alluvium

Alluvium in the CdG quadrangle consists of clay, silt, sand and gravel deposits, as much as 5 m thick , that are confined to very narrow bands associated with active and intermittent streams. Alluvium includes organic-rich sediments associated with bogs meadow areas on La Grulla Plateau.

3.0 STRUCTURE

Structure in the Cerro del Grant quadrangle is characterized by rocks that mostly exhibit gentle dip attitudes to the east, toward the axis of the Rio Grande Rift (Lawrence 1979). Structural deformation superimposed on these east-tilted strata is dominated by high-angle faults that displace all map units older than the Tschicoma Formation. The majority of faults have an indicated downward motion to the east, as shown in the cross sections A-A' and B-B' (Appendix D). Two periods of fault movement are indicated and are herein discussed as fault sets 1 and 2. Folds in the CdG area are small-scale, local structures related to drag movement along faults.

3.1 FAULT SET 1

Fault set 1 consists of a zone of north-south aligned, high-angle faults exposed mainly in the northwestern CdG area. Vertical displacements along set 1 structures generally range from approximately 33 m to 100 m, based on field observations and estimates of apparent stratigraphic separation. A major fault projected along the axis of Coyote Creek locally juxtaposes the Poleo Sandstone Member of the Chinle Formation against Morrison Formation sandstone has an inferred vertical separation conservatively estimated at more than 300 m.

Set 1 structures clearly displace Cretaceous and older strata but indicate no apparent deformation of overlying rocks in the northern part of the quadrangle. Mostly pre-El Rito movement, likely associated with regional deformation during the Laramide orogeny, is therefore implied for set 1 structures. Local late-Tertiary reactivation of parts of these faults can be inferred, particulary in vicinity of Cerro Valdez and Cerro Pelon.

3.2 FAULT SET 2

Fault set 2 consists of closely spaced, northeast-trending normal faults primarily exposed in the northern and northeast CdG area. Many have been traced northward in the Youngsville quadrangle along curvilinear trajectories that veer progressively to the northeast (Lawrence, 1979) in defining the western structural boundary of the Espanola Basin. Vertical displacements along faults of set 2 are generally estimated to range from approximately 15 m to 100 m and mainly indicate a sense of downward movement to the east. Faults showing a down-to-the-west sense of motion are also present. A major basin-marginal fault of this group places Dakota Sandstone against downwardly displaced Ojo Caliente sandstone in the Youngsville and demonstrates an inferred stratigraphic separation of at least 400 m.

Set 2 faults commonly show post-Lobato andesite movement; however, their southern traces are frequently covered by Tschicoma andesite flows on La Grulla Plateau that show little evidence of structural displacemment. Based on K-Ar dates obtained for an upper Tschicoma andesite flow and Tschicoma dacite dome, Singer (1985) placed constraints on the age of set 2 faulting activity as between 7.85 and 7.35 Ma, or mid-Pliocene in age.

The plan-view geometric pattern of set 2 faults that pass through Banco Largo and La Grulla Plateau suggests that some structures may intersect north-south aligned faults of set 1 in the areas of Cerro Valdez and Mesa Laguna. It is likely that stresses associated with the younger fault set may have been taken up by the pre-existing faults, causing a local change in trajectory. This phenomenon may account for the apparent reactivation of set 1 faults projected toward Cerro Pelon.

3.3 CALDERA MARGIN FAULT

An east-northeast trending fault occurs along upper Rio Cebolla in the southwest corner of the CdG quadrangle. It displaces Tshirege Member ash-flow tuff in sec. 33, T. 21 N., R. 3 E., with an estimated 33 m of stratigraphic separation and is downthrown on its southern side. This fault roughly parallels the margin of the Valle Grande and likely is structurally related to ring fractures that define the north caldera wall.

3.4 STRUCTURAL CONTROL OF VOLCANIC CENTERS

There is substantial evidence to indicate that faults associated with the east margin of the Nacimiento uplift and western boundary of the Espanola Basin have had an influence on the locus of volcanism in the Cerro del Grant quadrangle. Virtually all of the individual domes and eruptive centers of La Grulla Plateau are spatially aligned with north- and northeast-trending high-angle normal faults. Many of these structures are shown to have cut Lobato andesite flows with an inferred vertical displacement of as much as 50 m (Lawrence, 1976). These faults (i.e., set 2) have been traced northward and have curvilinear configurations, veering progressively to the northeast as shown on the Youngsville quadrangle (Lawrence, 1979). Projected to the south, these structures in general are covered by Tschicoma andesite flows exhibiting little, if any, indication of structural displacement.

The dissected Lobato andesite shield cone and intrusive dacite of Encino Lookout is intersected by curvilinear faults that appear to locally control the geometry of the escarpment. Banco Largo, at the base of the escarpment, is underlain by jagged outcrops of andesite lava and pyroclastic debris (Singer, 1985) that constitute the remnants of the volcano now severely deformed as a result of tectonic movement. Aerial photographs clearly show a prominent structural grain imposed on these rocks reflecting the general pattern of local curvilinear faults. Such structures acted as conduits for upwelling Lobato magmas that migrated to the surface and vented as alternating effusive and explosive events in constructing the shield cone. Subsequent post-Lobato reactivation of these same faults resulted in the dissection and nearly complete disintegration of the eruptive complex

Primariily on the basis of geomorphic expression, the dome-shaped hills of Cerro del Grant and Cerro Pelon are interpreted to represent eruptive vents. Both are apparent sources of effusive Tschicoma andesitic eruptions to the paleo-surface atop La Grulla Plateau. The apparent volcanic plug forming Cerro Pelon presents a north-south aligned linear morphology that suggests structural control in relation to faults of similar orientation (i.e., set 1). These structures, primarily exposed in the northwest part of the map area, project southward are inferred to have structural control on the north-south alignment of the escarpment at Cerro Valdez. Post-Tschicoma movement along one or more of these high-angle normal faults is therefore implied.

The eastern edge of La Grulla Plateu is bounded by the north- to northeast-trending incised canyon of Canones Creek. The southerly projection of post-Lobato, high-angle-normal faults (set 1) appears to exert structural control on this drainage. A prominent alignment of late Tschicoma domes and localized volcanic flows on the west side of Canones Creek is coincident with this fault trend. Andesite of Cerro del Grant forms the most conspicuous of the domes. Post-andesite dacite domes and lavas are identified at Hill 33, Cerro Pavo, Four Hills, and Barrancones Hill. Evidence for significant post-Tschicoma movement on set 1 faults that project along this volcanic trend is lacking. Nevertheless, a structural zone of weakness along this trend is strongly implied.

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