Geology of the Vallecitos 7.5-Minute Quadrangle, Northern Jemez Mountains, New Mexico.

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Geologic Overview:

The Vallecitos 7.5-minute quadrangle lies in the northern Jemez volcanic field along the western margin of the northerly-trending Rio Grande rift. Most of the volcanic rocks within the quadrangle belong to the older part of the volcanic field (~ 3 to 13 Ma). The ignimbrites associated with the voluminous eruptions of the 1.61 Ma and 1.25 Ma Toledo and Valles calderas located just southwest of the area generally were not deposited here and thus are rarely preserved. This area represents a zone of geographic and geologic transition in the northeastern Jemez Mountains. Geographically, the transition is from spruce- and pine-forested highlands underlain by Tschicoma Formation lavas to the west (elevations >10,000 feet) to sparsely-vegetated piñon-juniper valleys on the east (elevations <7,000 feet). Geologically, this transition involves massive ~3-5 Ma Tschicoma Formation lava flows along the western boundary, including distal flows along the flanks of Tschicoma and Polvadera Peaks located to the west of the quadrangle boundary, overlapping a broad, faulted mesa of ~9-10 Ma Lobato Formation mafic lavas in the center of the quadrangle. To the east, these mafic lavas overlie rift-fill sediments of the Tesuque Formation (Santa Fe Group). North-south trending rift structures are prominent in the eastern half of the quadrangle, although most of the larger faults are down-to-the-west, offsetting thick sequences of Lobato Formation mafic lavas. Major rock units in the quadrangle include (from oldest to youngest): Chama-El Rito Member of the Tesuque Formation, Ojo Caliente Sandstone Member of the Tesuque Formation, Lobato Formation mafic and dacitic lavas, Tschicoma Formation dacitic lavas, Puye Formation fanglomerates, El Alto basalt, Bandelier Tuff, and a variety of Quaternary sediments.

Geologic mapping of this quadrangle has provided several new insights into the volcanic and sedimentary history of the region, including:

1) Improved understanding of Lobato Formation and Tschicoma Formation volcanism in the northeastern Jemez Mountains. On Lobato Mesa, lavas and other eruptive materials related to specific vents - La Sotella, La Bentolera, and Chibato – were identified and mapped. A major dacitic vent south of Rio del Oso, Los Cerritos, was also identified and mapped. The extent of one of the largest single dacite flows in the Tschicoma Formation (dacite of Mesa de la Gallina) was better defined. Several other Tschicoma lavas were also differentiated based on their hydrous phenocryst mineralogy.
2) Determination of the distribution of at least two (possibly three) voluminous dacite

flows within and capping the Lobato Formation. These flows provide key marker beds for structural offset. Dacitic to basaltic volcanism was occurring 9 to 10 Ma both in the northeastern Jemez Mountains (Lobato Formation) and in the southern Jemez Mountains (Paliza Canyon Formation).

3) Identification of numerous episodes of sedimentary and volcanic deposition on Mesa El Alto (Vallecitos) in areas previously mapped only as Puye Formation. These deposits include:
    - giant boulder conglomerates capping the Puye Formation (Ttb), possibly representing a massive rock avalanche.
    - gravels and conglomerates possibly younger than the Puye Formation but older than the Bandelier Tuff (QTg)
    - old Quaternary alluvium with abundant obsidian that may correlate with the Cerro Toledo interval.
    - small, isolated exposures of Otowi Member ignimbrite and poorly exposed mounds of reworked pumice that most likely correlate to the Guaje Pumice Bed.
    - numerous exposures of El Alto basalt, including numerous vents adjacent to, or on top of, Tschicoma Formation lavas.
4) Documentation of several major rift-related faults that traverse the quadrangle. Major faults in the quadrangle tend to be down-to-the-west, opposite to the offset of the Santa Clara fault system (which just crosses the southeastern edge of the quadrangle). Where possible, the amount and timing of fault displacement was determined. Some faults were clearly active during Lobato Formation mafic volcanism, as lava flows filled paleovalleys adjacent to active fault scarps.
5) Discovery of small-volume tephra and ignimbrite deposits likely related to Tschicoma Formation volcanism. A new age analyses of 4.01 Ma indicates that these units are related to Tshicoma Formation eruptions (Table 1)
6) Extension of the known outcrop extent of Tesuque Formation deposits, and differentiation of the Ojo Caliente Sandstone Member (Tsto) from the Chama-El Rito Member (Tstc) in the process of mapping.
7) Identification of old gravel deposits (Tog) that may precede the Puye Formation; these gravels are more closely related to Lobato Formation volcanic activity.

View looking north across the Rio del Oso drainage. The mesa on the left is the east end of Lobato Mesa, capped by flows of Lobato Formation basalt. The light-colored areas on the slopes of the mesa are Ojo Caliente Sandstone.

View from the west side of Lobato Mesa looking southwest toward Tschicoma Peak. The aspen-covered high ridge in the center of the photograph is the dacite of Mesa de la Gallina flow. The flat area in the foreground is Mesa El Alto.

Unit Descriptions

Qal – Alluvium. Late Pleistocene to Holocene. Alluvial deposits in modern drainage bottoms and elevated basins. Deposits include gravel, sand, and silt. Holocene terrace deposits less than 2 meters above drainage bottoms are included. Alluvium on Mesa El Alto contains abundant quartz and sanidine crystals from Bandelier Tuff, while alluvium in the canyon along the Rio del Oso is dominated by fluvial clasts of Tschicoma Formation dacite (**Tt**) and Lobato Formation basalt (**Tlb**). Obsidian fragments are common. Maximum thickness can exceed 4 meters.

Qtal - Undifferentiated terraces and alluvium in modern stream drainages. Late Pleistocene to Holocene. Obsidian fragments are common..

Qc/Qclb – Colluvium. Late Pleistocene to Holocene. Poorly sorted talus, debris, and colluvium in wedge-shaped deposits on hill slopes. Numerous hill slopes beneath mesas of Lobato Formation basalt (**Tlb**) are covered by basalt colluvium (obscuring the underlying bedrock); mapped only in a few locations (**Qclb**) but relatively extensive on the flanks of elevated Lobato Formation mesas. Similar colluvial deposits occur along the edges of Tschicoma Formation dacite flows (**Tt**). Thickness can locally exceed 5 meters.

Qt/Qtg – Terrace deposits. Late Pleistocene to Holocene. Alluvial deposits near the margins of modern streams or older perched floodplain deposits. Mapped only in a few locations. Most are fill terrace deposits of sand, silt and gravel < 10 m above modern drainages. Coarser gravel terraces along Rio del Oso canyon are mapped as Qtg. Maximum thickness is <5 meters.

Qes – Eolian deposits reworked by sheetwash. Late Pleistocene to Holocene. Poorly bedded fine-grained sand and silt preserved sporadically on terraces, in broad valleys, and on mesa tops. Although no sedimentary structures could be identified, these deposits appear to be primarily eolian in origin and reworked by sheetwash. The units often cap older alluvial deposits. Generally less than 1 meter in thickness.

Qav – Rock avalanche deposits. Late Pleistocene to Holocene. Chaotic, angular debris emplaced during a single detachment event from a steep slope or cliff, generally lacking a sedimentary matrix. Mapped only in a few locations. Thickness can exceed 10 meters.

Qls – Landslides. Pleistocene to Holocene. Unsorted, chaotic debris emplaced during a single detachment event from a steep slope or cliff, generally containing a sandy matrix. Also, slump or block slides, especially along the flanks of high mesas where Lobato Formation basalts cap older Santa Fe Group sediments. Fan-shaped deposits occur where debris spread out on valley floor. Thickness can exceed 20 meters.

Qbt – Upper Bandelier Tuff, Tshirege Member. Quaternary. White to orange non-welded to welded ash-flow tuff containing abundant phenocrysts of quartz and sanidine. Ash-flow tuff beds consist of multiple flow units in a compound cooling unit with thin surge beds (less than 0.5 meters thick) locally exposed. Exposures in the field area are limited to outcrops on the Santa Clara Reservation north of Santa Clara Canyon. Erupted at approximately 1.25 Ma during the formation of the Valles Caldera (Phillips, 2004). Maximum thickness is approximately 40 meters.

Qcpc?– Cerro Toledo Formation, Pueblo Canyon Member. Quaternary. Older alluvial deposits of gravel, sand and silt that may correlate with Cerro Toledo (Qct) interval deposits in adjacent quadrangles. Dominant clast lithology varies on location, but is typically Tschicoma dacite (Tt) or Lobato basalt (Tlb). These deposits typically contain obsidian clasts, presumably originating from the Toledo embayment or domes of El Rechuelos rhyolite from the Polvadera Peak quadrangle to the west. Quartz and feldspar crystals of Bandelier Tuff are also common, especially in ant mounds capping these deposits. Maximum thickness is approximately 10 meters.

Qcpc – Cerro Toledo Formation, Pueblo Canyon Member. Quaternary. Alluvial deposits of gravel and sand containing abundant clasts of obsidian. Mapped only where overlain by the Tshirege Member of the Bandelier Tuff (Qbt). Maximum thickness is 5 meters.

Qbo – Bandelier Tuff, Otowi Member. Quaternary. White to beige poorly-welded ash-flow tuff containing abundant pumices with phenocrysts of quartz and sanidine and sparse mafic phenocrysts. Moderate to abundant lithic fragments (5-15%), primarily of andesitic or mafic lavas. These deposits occur only as isolated, thin exposures in Mesa El

Alto west of Lobato Mesa. Although no primary exposures of the basal Guaje Pumice were observed in the quadrangle, mounds of pumice (Qbp) typically occur adjacent to these thin tuff deposits. The Otowi Member erupted at approximately 1.61 ± 0.01 to 1.62±0.04 Ma (Izett and Obradovich, 1994; Spell et al., 1996) during the formation of the Toledo caldera. Two dates on pumice and tuff in this area yield slightly older, but statistically overlapping ages (1.68 ± 0.04 and 1.72 ± 0.04 Ma; Table 1). Maximum thickness is approximately 4 meters.

Qbg – Bandelier Tuff pumice deposits. Quaternary. Mounds and poorly-exposed strata of reworked Bandelier Tuff pumices. The lack of primary Bandelier Tuff deposits in the area make it difficult to determine whether this is Guaje or Tskankawi pumice. Most likely these deposits are reworked Guaje Pumice Bed tephra, due to their association with thin Otowi Member tuff deposits (see above). Maximum thickness is approximately 15 meters.

QTg – Alluvial deposits that range from sandy gravels to coarse boulder conglomerates. Late Tertiary to Early Quaternary. These deposits may correspond with Puye Formation fanglomerates (**Tp**), but where mapped, are of uncertain age. Dominant clasts are typically Tschicoma dacite (**Tt**) or Lobato basalt (**Tlb**). Deposits mapped along the western flank of Lobato Mesa (mixed with Lobato basalt colluvium) may represent a basin fill maximum (~8100 foot elevation). Locally, dacitic tephra (**QTp**) is found within these deposits, although outcrops are rare. Obsidian fragments are rare if present at all. Maximum thickness is 5 meters.

QTp – Dacitic pumice deposits, slightly reworked. Late Tertiary to Early Quaternary. Phenocrysts include biotite and hornblende. Mapped in a small region adjacent to QTg deposits at the south end of Vallecitos de los Chamisos. Maximum thickness is 1 meter.

Tp/Tpb – Puye Formation fanglomerates. Pliocene to Early Pleistocene. Sands, gravels and conglomerates derived from nearby highlands of Tschicoma Formation dacite (**Tt**) and Lobato Formation basalt (**Tlb**). Also includes a bouldery unit 10-15 meter thick east of Polvadera Peak that may have been deposited by a rock avalanche (**Tpb**) . Individual blocks can exceed 5 meters across. Locally, dacitic tephras and thin pyroclastic flow deposits (less than one meter thick) occur within the sediments. Reworked tephras, silts and fine- to medium-grained sands of this unit occur beneath the dacite of Mesa de la Gallina (**Ttg**) along Gallina Creek (roadcuts on FR-144). In general, however, Puye Formation deposits are poorly exposed in the quadrangle, and often occur as rounded fluvial clasts of surface colluvium. Maximum thickness is approximately 25 meters.

Tt/Tt1/Tt2/Ttpd/Tt3/Ttp/Ttg – Tschicoma Formation. Late Miocene to Late Pliocene. Light gray to dark gray, moderately to coarsely porphyritic lavas of dacitic composition in the Vallecitos quadrangle (Figure 1). This formation includes thick, overlapping flows and high-aspect ratio domes. Age analyses for Tschicoma lavas in the northern Jemez Mountains range from ~ 5 to 3 Ma (Goff et al. 1989, Table 1). Most of the flows in the quadrangle were undifferentiated, mapped as **Tt** or are broadly grouped by age (Tt1-3).

Tt1 is an older sequence of domes and flows, including plagioclase-dominated flows with both hydrous (biotite + hornblende) and non hydrous mineralogy. Age dates from these flows imply ages greater than 4.5 Ma. In the NE quadrant these older flows and domes are mostly dacitic to rhyodacitic, with abundant phenocrysts of plagioclase, biotite and hornblende with minor amounts of pyroxene.A few of the larger flows characterized by abundant phenocrysts (20-35%) including hydrous mafic minerals, such as biotite and hornblende..

Tt2 deposits include dacites commonly containing cognate clots of more mafic magmas (vesicular basaltic andesite) ranging in size from 2 to 25 cm. These flows represent an age span between 4.5 to 3.2 Ma.

Ttpd flows include dacite and rhyodacite (undivided) in the Tschicoma Peak area including the northern rim rocks of the Toledo embayment and Chicoma (or Tschicoma) Peak to the west of the quadrangle**.** These massive to sheeted, coarse porphyritic lavas have abundant phenocrysts of plagioclase, and variable quantities of phenocrysts of biotite, hornblende, and rare clinopyroxene. The younger lavas may contain of sanidine and quartz and 2 to 25 cm, elliptically-shaped inclusions of mafic composition; $^{40}Ar/^{39}Ar$ dates are 4.29 to 4.46 Ma (Kempter et al., 2007); maximum exposed thickness >500 m.

Tt3 is a lobe coming from the west sourced on Polvadera Peak that is the youngest of the Tshicoma lavas; this porphyritic dacite has plagioclase as the dominant phenocyrst.

Other flows that lack these distinctive hydrous minerals are typically dominated by plagioclase phenocrysts, often including plagioclase megacrysts that exceed one cm in length. Only a few of these flows were mapped separately (**Ttp**).

One of the largest single flow units of the entire Tschicoma Formation occurs in the southwest corner of the quadrangle where a broad, northeast-sloping surface known as Mesa de la Gallina represents the surface of this massive flow, covering more than 10^2 kilometers. The flow, informally named the dacite of Mesa de la Gallina (**Ttg**) is dated at 3.90±0.15 and 4.29±0.49 Ma (Goff et al., 1989, Table 1) and originated from the northeast side of Tschicoma Peak. Forest Road 144 traverses the upper surface of the flow as it ascends Tschicoma. The flow contains abundant phenocrysts (25-35%), including biotite and hornblende. Plagioclase phenocrysts are abundant but typically small to medium in size (less than 0.5 cm). The flow is often highly flow-banded, including spectacular flow contortions along its margins. To the north the Gallina flow overlies older plagioclase-rich, mafic-pheonocryst-poor Tschicoma flows and is bordered by the Rio del Oso. To the west, the Gallina flow overlies fine- to medium-grained fluvial deposits of the Puye Formation, exposed along FR 144 in Gallina Creek. The maximum thickness of Tschicoma lavas in the quadrangle occurs in upper Gallina Creek, exceeding 500 meters.

WoldeGabriel et al. (2006) dated a lower dacite flow and an upper dacite flow in Tschicoma Formation in Santa Clara Canyon just north of the quadrangle boundary. The $^{40}Ar/^{39}Ar$ age of the higher flow on the north wall of the canyon is 3.79±0.17 Ma and a topographically lower flow on the south side of the canyon is 4.39±0.13 Ma. The sample from the north wall is porphyritic with phenocrysts of plagioclase, hornblende and biotite.

The sample from the south side is very porphyritic with plagioclase, quartz, and little biotite.

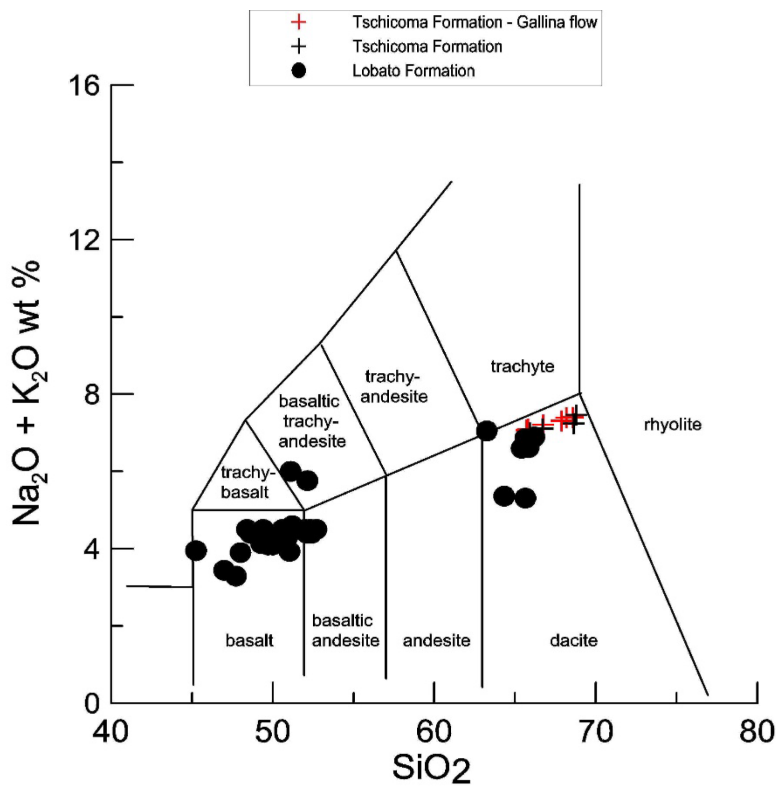

Figure 1. Total alkali-silica diagram showing the geochemistry of the Lobato Formation and Tschicoma Formation in the Vallecitos quadrangle. The IUGS classification of volcanic rocks (after LaBas et al., 1986) is plotted for reference. Data from Goff et al. (1989); Justet (2003); Wolff et al. (2005), and WoldeGabriel et al. (2006).

Tog – Near source alluvial and colluvial deposits, possibly corresponding with older Puye Formation. Late Miocene to Late Pliocene?. The deposits include angular to subrounded blocks of Lobato-age dacitic and mafic lavas and are perched at higher elevations than other Puye fanglomerates (up to 8100 feet). Maximum thickness is approximately 50 meters.

Tlb/Tlbi/Tlbc/Tlbs/Tlb1/Tlbb/Tlbp/Tlbo – Lobato Formation. Miocene. These deposits represent a wide variety of mafic lava flows, including basalt, basaltic andesite, basaltic trachyandesite (Figure 1), and associated deposits. Undivided flows (**Tlb**) represent the majority of this unit in the quadrangle. These lavas are black to gray, sparsely to moderately porphyritic, containing phenocrysts of plagioclase, olivine, ± clinopyroxene in a variety of groundmass types. Flows are typically massive and flow banded with brecciated lower and upper surfaces. Thin fluvial sandstones that occur locally between mafic lavas across Lobato Mesa may correspond with the Ojo Caliente sandstone member (Tsto) described below. Intrusive facies (**Tlbi**) occur as fine- to medium-grained dikes and crystalline gabbroic sills or plugs. One of these gabbros is well exposed along Forest Road 144 as it first enters the quadrangle from the east. In

Cañada Almagre along the eastern boundary of the quadrangle a spectacular combination dike/sill intrudes the Chama-El Rito member (Tstc), the sill forming a resistant floor in part of the valley bottom. This intrusion, dated at 9.74±0.21 Ma, is offset by the Cañada del Almagre fault (Koning and Kempter, 2007). Scoria and cinder deposits (**Tlbc**) occur in several places in the quadrangle but are only mapped in a few areas where nearby vents are suspected. Mafic lavas on the west side of Lobato Mesa are differentiated based on phenocryst content. Those with abundant olivine phenocrysts (typically altered to iddingsite) are identified as Tlbo, while a younger series of olivine-poor, plagioclase-rich lavas are mapped as Tlbp. A prominent dike flanked by cinder deposits of this later unit is located immediately south of Cerrito del Chibato (mapped as **Tlbi** and **Tlbc**). On the eastern flank of Lobato Mesa, three groups of mafic lavas are distinguished that overlie undifferentiated Tlb lavas. These include olivine-phyric basalts of La Sotella shield (**Tlbs**) that contain 2-15% 1-8 mm euhedral plagioclase phenocrysts overlain by basaltic lavas containing 2-10% phenocrysts of 1-3 mm mafic phenocrysts (olivine±pyroxene) mapped as Tlb1. The youngest lavas occur at the southern portion of the mesa, erupted from a vent near La Bentolera. These distinctive lavas (**Tlbb**) have a crystalline matrix and are nearly aphyric, containing 0-2% phenocrysts (and xenocrysts) of pyroxene, pyroxene-olivine aggregates, quartz and potassium feldspar. Rare granitic xenoliths also occur in this unit. Mafic lavas of Lobato Mesa were primarily emplaced over a 1.5 Ma span (9.0 to 10.5 Ma), with the bulk of the eruptions occurring between 9.5 to 10 Ma (Table 1).

In contrast, Lobato Formation basalt and basaltic trachyandesite exposed in Santa Clara Canyon are generally older (10.16 to 13.13 Ma) and are less voluminous compared to the unit on Lobato Mesa, consisting of thin flows interbedded with the Santa Fe Group (WoldeGabriel et al., 2006). The 5 to 7 m thick mafic flows in Santa clare Canyon are interbedded with altered volcaniclastic deposits, sandstone, and pumice beds. The basalts are fine-grained. The interbedded sequence of sediment and basalt is capped by a vesicular, porphyritic, purple-gray andesite flow with phenocrysts of palgioclase and altered mafic minerals. Maximum thickness exceeds 200 meters on Lobato Mesa.

Tld1/Tld2 – Lobato Formation dacite lavas. Miocene. At least two large volume dacitic lavas were erupted during Lobato Formation volcanic activity in the quadrangle (Figure 1). The younger lava, Tld1, was erupted from a vent source at Los Cerritos in the southwest area of the quadrangle and covers at least 3 km2, flowing in a northeasterly direction. The lava is beige in color, fine-grained with 2-6% phenocrysts of plagioclase and minor hornblende. A brecciated, block and ash-flow horizon is locally exposed in lower and distal portions of the flow. This flow caps all Lobato mafic lava flows erupted from the Los Cerros shield to the east. An age of 9.6±0.15 Ma (Goff et al., 1989) for this unit provides an upper age limit for Lobato-age volcanic activity in this area of the quadrangle. The flow also provides a superb stratigrahic marker for a major down-to-the-east fault that offsets the flow by at least 100 meters along its eastern edge. Older dacitic flow(s) (Tld2) are intercalated with Lobato mafic lavas. These flow(s) are similar in appearance to younger Tschicoma dacite lavas (Tt), moderately to coarsely porphyritic with 20-25% phenocrysts of plagioclase (up to 0.7 cm), biotite and hornblende. Three isolated exposures of these lavas are exposed near Los Cerritos with another group of exposures in Rio del Oso at the south end of Lobato Mesa. In this area Lobato mafic lavas underlie and overlie the porphyritic dacite. Maximum thickness of Tld1 is exceeds 100 meters, Tld2 is approximately 75 meters.

Tsto – Ojo Caliente Member, Tesuque Formation of the Santa Fe Group. Miocene. Light brown to light pink fine- to medium-grained sand, subrounded to rounded, moderately to well sorted. Planar sand sheets to high-angle crossbeds of eolian origin (suggesting a prevailing paleowind direction to the northeast. Thin fluvial layers occur in the upper portions, containing rounded pebbles of various volcanic lithologies and lesser quartzite and granite. This unit is generally weakly consolidated and seldom outcrops where overlain by Lobato mafic lavas. Its presence often indicated by tan quartz sand amongst basalt colluvium, along with occasional fluvial pebbles. On Lobato Mesa, fluvial sandstones containing abundant clasts of Lobato mafic lavas may correspond to Ojo Caliente sandstone. The age of the Ojo Caliente sandstone is interpreted to range from 13.4 to 12.5 Ma (Koning et al., 2007). Maximum thickness in the quadrangle (along the eastern margin of Lobato Mesa, is approximately 275 meters.

Tstc – Chama-El Rito Member, Tesuque Formation of the Santa Fe Group. Miocene. Light pink to reddish brown floodplain deposits of siltstone, mudstone, fine-grained sandstone and thin channels of low-angle crossbedded channel gravels. In contrast to the Ojo Caliente member which tends to have massive, poorly-consolidated eolian sandstone beds, the Chama-El Rito sediments tend to be moderately consolidated, with alternating planar to low cross-stratified beds of varying shades of pink to brown. Fluvial channels contain rounded volcanic pebbles of intermediate and felsic composition, poorly to moderately sorted. These channels are typically cemented by calcium carbonate. The age of the unit is 18 to 13.4 Ma (Koning et al., 2007). Maximum thickness of the deposit, approximately 100 meters, is exposed in the northeastern corner of the quadrangle.

Geologic History

The basic stratigraphy for rock units in the Jemez Mountains was established by Bailey et al. (1969) and Smith et al. (1970). Further refinement of the volcanic stratigraphy was presented by Gardner et al. (1986) and Gardner and Goff (1996). Structural studies relevant to the Vallecitos quadrangle include Aldrich (1986) and Aldrich and Dethier (1990).

The oldest rocks in the quadrangle belong to the Chama-El Rito and Ojo Caliente members of the Tesuque Formation. These two members underlie most of the Abiquiu embayment (Kelley, 1978) and represent Rio Grande Rift-fill sediments during the Miocene. The Chama-El Rito member consists of siltstones, mudstones and fluvial gravels indicative of a relatively low energy floodplain environment of deposition. Volcaniclastic pebbles and gravel occur throughout the unit, possibly derived from the Latir volcanic field – or from sources now buried beneath the southwestern Taos plateau (Koning, pers. comm). The age of the Chama-El Rito is considered to span from 18-13.4 ma Ma (Aldrich and Dethier 1990). The overlying Ojo Caliente Sandstone Member consists primarily of massive medium-grained sand of eolian origin, representing a vast erg that covered much of the northern Jemez area between 13.4 to 12 Ma in this particular area (Tedford, 1981). Thin lenses of fluvial gravel occur in the upper Ojo Caliente Sandstone, dominated by volcanic clasts of uncertain provenance (possibly early volcanic rocks of the Jemez Mountains), and lesser amounts of quartzite and granite most likely derived from areas to the north, including the Tusas Mountains.

Early volcanism in the northeastern Jemez Mountains is recorded by preservation of thin 12.5 to 13 Ma flows in Santa Clara Canyon. A strong episode of mafic volcanism then affected the area between ~10.5-9 Ma (Table 1), forming Lobato Mesa and the Clara Peak center south of Rio del Oso. This episode of mafic volcanism appears to have affected a broad region, extending south to basalts of Chamisa Mesa in the southern Jemez Mountains. Interlayered with Lobato basalt flows are thin sediments of eolian and fluvial origin that may represent continued Ojo Caliente deposition in the area during Lobato volcanism. Most of the Lobato Formation vents and dikes in the area are aligned roughly north-south, parallel to structural trends. Some of these structures appear to have been active during this time period, as some basalt flows dramatically thicken in paleovalleys adjacent to fault scarps.

Dacitic volcanic activity, though less voluminous, also affected the area during this time. At least one large dacitic flow is interbedded with mafic lavas (exposed in Rio del Oso Canyon), although its source vent is unknown. This flow (along with a few other isolated exposures) are strikingly similar in appearance to later Tschicoma-style volcanism, including similar porphyritic textures with large phenocrysts of plagioclase and lesser amounts of biotite ± hornblende. Capping the Lobato Formation sequence is a large dacite center south of Rio del Oso Canyon (Cerritos). This eruptive center issued a fluid, low-aspect ratio lava that flowed to the northeast, capping a thick package of mafic lavas and lapping onto the Los Cerros basaltic cone to the east. This dacite is fine-grained with few phenocrysts (plagioclase and hornblende), unlike later Tschicoma-age dacites. A brecciated horizon occurs in several areas, possibly represented a widespread block and ash flow event during the eruptive process. Locally, a few old gravel deposits occur in the Vallecitos quadrangle, including a crater-like feature at Los Cerritos. These coarse gravels are perched at a much higher elevation that the subsequent Puye Formation, and are comprised of angular to sub-rounded Lobato mafic and dacitic lavas.

The next important phase of volcanic activity began with Tschicoma-style volcanism, beginning approximately 3 to 5 Ma in the northeastern Jemez Mountains. Although predominantly dacitic in composition, rhyodacites and rhyolites were all erupted in the northeastern Jemez Mountains between ~5-3 Ma (Goff and Gardner, 2004). Accompanying this volcanic activity was deposition of fanglomerate sediments of the Puye Formation. Most of the Tschicoma Formation lavas in the Vallecitos quadrangle represent distal flows from major vents just to the west, including the highest and third highest peaks in the Jemez Mountains (Tschicoma and Polvadera Peaks). These flows were primarily erupted between 5-3 Ma. The largest single flow in the quadrangle (and one of the largest dacite flows in all of the Jemez Mountains, covering at least 10^2 km), was erupted from the northeast side of Tschicoma Peak at 3.9±0.15 Ma (Goff et al., 1989). The northeastward-sloping surface of this flow (informally named dacite of Mesa de la Gallina) spread across the post-Lobato surface. As the flow fanned out, it covered older Tschicoma Formation lavas, Lobato Formation basaltic lavas, and early Puye Formation sediments.

Puye Formation sediments are preserved in many areas of the quadrangle, especially adjacent to the steep flow margins of the Tschicoma Formation lavas. Much of the aggradation occurred after the eruption of the dacite of Mesa de la Gallina, as this dacite is a common component in many of the sediments. Adjacent to Lobato Formation highlands, however, clasts of Tschicoma Formation dacites decrease significantly, replaced by clasts of mafic lavas. In Mesa El Alto (Vallecitos), at least 30-40 meters of Puye Formation is preserved. Along the southwestern flank of Lobato Mesa, remnants of old QT gravels (possibly Puye) can be found at elevations up to 8100’, suggesting that sediment fill in the valley was once much greater than at present. However, this perched elevation can be partly the result of Pliocene-Pleistocene faulting along the western margin of Lobato Mesa. Near the abandoned village of Rechuelos, a major fault juxtaposes Puye Formation sediments with Lobato mafic lavas, showing an estimated 20 meters of displacement post-Puye.

Intercalated with the Puye gravels are thin (typically less than one meter thick) tephra and pyroclastic flow deposits related to Tschicoma volcanism, containing dacitic pumices with biotite and hornblende. The coarsest Puye deposits in the quadrangle, including massive boulder conglomerates (individual boulders up to 5 meters across) occur near the top of the present day Puye surface where Rio del Oso exits the Tschicoma highlands and just east of Vallecitos Corrales east of Loma Parda. The depositional mode of emplacement of these massive boulder conglomerates is difficult to interpret. Possibly they represent large scale debris flows off the adjacent Tschicoma highlands, although there is very little matrix material within the deposit. More detailed studies of these deposits is needed to better understand their true origin.

Capping the Tschicoma lavas in Mesa El Alto is the El Alto Basalt, erupted from a series of vents near Rincón de Mora and Los Cerritos. This pulse of basalt volcanism occurred between 3.2-2.8 Ma (Baldridge et al., 1980) in the northern Jemez, although only one eruptive phase is interpreted for the Vallecitos area. The basalt flowed northwards, filling the ancestral Abiquiu Creek valley and capping Ojo Caliente sandstone (preserved now along Mesa de Abiquiu).

The youngest volcanic rocks in the quadrangle are related to the eruptions of the Bandelier Tuff. Both Otowi and Tshirege members occur in the quadrangle, although no primary deposits of Tshirege Member were found north of Rio del Oso. Thin (less than one meter thick), isolated exposures of Otowi Member ignimbrite occur in Mesa El Alto (Vallecitos). These patchy remnants of tuff are white to beige, highly pumiceous and contain a moderate amount of lithics. The tuff is typically moderately welded, containing abundant quartz and sanidine phenocrysts. Still, the overall appearance of the tuff is unlike typical Bandelier Tuff. Most likely, very distal clouds of the Otowi pyroclastic flow settled in this valley, forming only thin layers of tuff in locally conducive environments. For the Tshirege Member, however, normal voluminous flows traveled down the ancestral Santa Clara Canyon, and are now preserved on mesas just north of the canyon on the Santa Clara Reservation. To our knowledge, no Tshirege Member tuff is preserved in Mesa El Alto, although well preserved Tsankawi tephra and Tshirege tuff is preserved just a few kilometers east of the quadrangle boundary on Forest Road 27 (south side of Cerro Pelon).

A variety of young alluvial deposits are preserved in Mesa El Alto, and further study of this area is recommended to better understand the unique history of deposition and erosion in this valley. Besides remnant Otowi Member tuff exposures, numerous mounds and poorly-exposed tephra occur in the valley. Several occur in the vicinity of the tuff outcrops, suggesting a connection between the two (most likely Guaje pumice). In many places old Quaternary alluvium caps Puye deposits. These deposits are at least post-Otowi age, containing abundant crystals of Bandelier Tuff and obsidian fragments that are likely related to Cerro Toledo obsidian domes prior to the Valles Caldera eruption. Without Tshirege Member tuff preserved in the valley, however, the age of these alluvial deposits is unclear. If they are older than Tshirege then they could be classified as Cerro Toledo interval deposits.

One unsolved mystery is the omnipresent obsidian found throughout the Mesa El Alto valley. Although likely of human distribution, its abundance as fragments on the surface is extraordinary. In many places, the distribution pattern seems random and ubiquitous, atypical of an archaeological origin. In these areas the fragments are highly angular yet appear unworked (by human hands/tools), and display no significant evidence of fluvial transportation. They occur predominantly at the surface and are especially abundant capping old Quaternary gravels and Puye Formation gravels adjacent to Tschicoma flow margins. A more detailed study of the obsidian throughout Mesa El Alto is highly recommended. What is the true distribution of obsidian in the valley? What are the obsidian sources (Rechuelos domes, Cerro Toledo domes)? Can sediment packages be distinguished by the composition of obsidian clasts? Was the obsidian distributed by human or geologic processes - or both?

Forest Road 144 Geologic Road Log to Vallecitos: Española to Tschicoma Peak

0.0 Begin at the intersection of Paseo de Oñate (Hwy 285) and Fairview (east) / Industrial Park Road (west). Turn west onto Industrial Park Road.

0.2 mi. Right turn onto Calle de Merced

0.4 mi. Calle de la Merced merges with Forest Service Road 144 and turns left. Proceed west on the unpaved Forest Service road.

0.6 mi. Pass a water supply well for the city of Española.

0.8 mi. Road turns slightly left. Ahead is a view of the Jemez Mountains. We are driving on a thin (~3 m thick) terrace, composed of volcaniclastic alluvium derived from the Jemez Mountains.

1.2 Descend into Arroyo del Gaucho.

1.5 We are driving on a surface graded to the top of the Qtcg2 terrace deposit of Koning and Manley (2003). The Qtcg1 (highest) terrace deposit forms much of the low hill to the immediate right.

1.8 Roadcut on the right exposes quartzite-rich, axial fluvial gravel, associated with terrace Qtcg1, unconformably overlying the Ojo Caliente Sandstone Member of the Tesuque Formation.

2.0 We are driving on an erosional surface on top of Qtcg1.

2.4 The road drops about 20-40 ft onto a topographic saddle. The cliffs located 1 mile to the south are on Santa Clara Reservation land (permission needed to access). These cliffs consist of grayish gravel of the Puye Formation underlain by orange to pinkish Vallito Member of the Chamita Formation. Beds of the main coarse white ash zone are interbedded in the Vallito Member (12.0-13.0 Ma; Koning et al., 2005b; Koning and Manley, 2003).

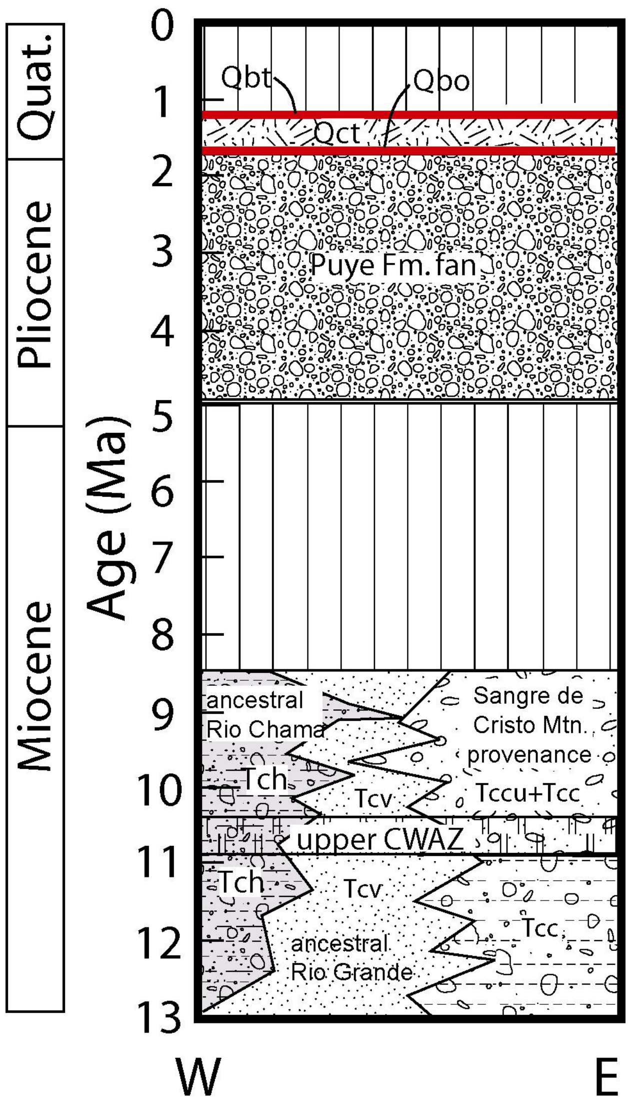

Figure 2. Ages and stratigraphic relations among the rock units exposed just west of Española. The vertical lines denote unconformities. Modified from Broxton and Vaniman (2005) and Koning (2007). Qbt = Tshirege Member, Bandelier Tuff; Qct = Cerro Toledo Formation; Qbo = Otowi Member, Bandelier Tuff; Tch= Hernandez Member, Chamita Formation, Santa Fe Group; Tcv = Vallito Member, Chamita Formation, Santa Fe Group; Tccu+Tcc = Cuarteles Member and interbedded Cuarteles and Cejita members, Chamita Formation, Santa Fe Group; Tcc= Cejita Member, Chamita Formation, Santa Fe Group. CWAZ = coarse white ash zone.

2.6 Good exposure of a thick conglomerate bed of Cejita Member of the Chamita Formation overlying 20 cm of Cuarteles Member sandstone and 6 m of claystone across the arroyo to the south.

To the right, roadcuts reveal brown mudstone beds that are overlain by ~2 m of pinkish, granite-bearing Cuarteles Member of the Chamita Formation. The Cuarteles Member is sharply overlain by pebbly sandstone and pebble-conglomerate channel-fill. The lower

80 cm of this channel-fill belongs to the Vallito Member of the Chamita Formation(mixed Paleozoic, quartzite, and volcanic clasts), which is overlain by 1.7 m of the Hernandez Member of the Chamita Formation. This contact is likely an unconformity because of its scoured nature, the thinness of the Cuartles Member here compared to that found to the north and south, and the lack of a gradation zone between the three members. The Cuarteles Member is~10.5-11.0 Ma and the overlying Hernandez Member is ~ 9.5-10.0 Ma. The Hernandez Member contains, among other things, clasts of dark gray, greenish gray, and dark brown andesite-dacite clasts that. Koning and Aby (2005) interpret that the Hernandez Member represents an ancestral Rio Chama.

3.1 Puye Formation conglomerate overlies stata of the Cejita Member of the Chamita Formation. The latter contains a 20 cm-thick bed of tephra (8.0-8.5 Ma; Koning et al., 2005a) . Notice the significant scour of the Puye Formation basal contact.

The Puye Formation here is Pliocene age (5-2 Ma) and contains diverse clasts of Tschicoma Formation dacite lavas and Lobato Formation basalts.

3.5 The road climbs onto a pediment surface developed on top of the Puye Formation. Several strands of the east-down Puye fault zone (2.2 km wide) offset this surface.

3.7 East-facing fault scarp of the Puye fault zone.

3.9 East-facing fault scarp of the Puye fault zone.

4.3 Good exposures of Puye Fm. in roadcut. The fault scarp on the east side of the outcrop is associated with the Puye fault zone.

4.6 We are on a broad surface developed on the Puye Formation. Straight ahead stands Tschicoma Peak. This peak is a remnant of a Tchicoma Formation dacitic eruptive center. To the northeast of the peak, capping a topographic bench, lies a Bandelier Tuff deposit. The Santa Clara fault offsets this bench on its east side.

5.8 Road on left enters pumice mine, which is on Santa Clara Reservation land. The pumice is mined by Richard Cooke of Española. No entry without permission.

6.5 Stop 1. Nice view of pumice mine along fence just 30 yards south of road. Guaje Pumice Bed tephra (~3 m) is overlain by Otowi Member ignimbrite. Remnants of the Otowi ignimbrite are locally preserved, where the ignimbrite filled small paleovalleys in the upper portion of the Puye Formation fan. Although the Guaje tephra blanketed the entire region, its preservation was largely dependent on preservation of the capping Otowi ignimbrite, as is the case at this mine. The large hill to the north of the road is Cerro Roman, composed primarily of Lobato Formation basalt. West of Cerro Roman is Clara Peak, formed by erosion of Lobato Formation basalt that caps the Ojo Caliente Sandstone Member of the Tesuque Formation. The Santa Clara fault trends WSW-ENE in front of Cerro Roman, parallel to the Embudo fault system to the north. To the southwest, this fault bends southward, connecting up with the Pajarito fault system. This major fault has offset the Lobato Formation basalt by at least 400 m in this area. Road 144 can easily be seen climbing the south side of Clara Peak heading into the northern Jemez highlands.

7.2-7.3 Cross the degraded scarp associated with the Santa Clara fault.

8.2 Nice exposures of Otowi Member ignimbrite overlain by pediment gravel in roadcut on the left.

8.3 Road to the right leads into the Ram Das Puri community.

8.6 Pediment gravel above Otowi Member ignimbrite on the left side of road. The pediment gravel contains diverse clasts of Tschicoma Formation dacites and Lobato Formation basalt. Obsidian and flow-banded rhyolite clasts are common, presumably shed from rhyolite domes that existed in the Toledo embayment between the Toledo and Valles caldera eruptions 1.6 to 1.2 million years ago. After the road turns northwards, finer eolian sands and silts overlie the pediment gravels (road can get very muddy when wet!).

8.9 Otowi Member ignimbrite on the right.

9.4 At the road bend, we cross the northern strand of the Santa Clara fault. This is the fault strand which offsets the Bandelier Tuff to the southwest (noted in mile 4.6). To the east, this fault is interpreted to bend right (eastward) and strike along the southern foot of Cerro Roman.

9.5 Calichified landslide deposit of Lobato basalt capping Ojo Caliente Sandstone deposits in the roadcut on the right. Note large (~1 meter) slab of Ojo Caliente in landslide. This landslide is exposed in roadcuts for the next 0.3 miles. We are now on the up-thrown footwall of the Santa Clara fault.

9.8 Good exposures of pink sandstone of the Chama El Rito Member (Tesuque Formation) on the right. We cross a southeast-down fault between here and mile 9.5.

9.9 A fine white ash bed within the Chama-El Rito Member is in the roadcut on the right.

10.1 The Chama-El Rito Member here consists of very pale brown to pink beds that are thin to thick, tabular to lenticular. It is composed primarily of fine- to medium-grained sandstone, with minor siltstone beds. The lack of coarse-grained sediment and the lack of cross-stratification sets >20 cm-thick suggests a relatively sluggish, sand-dominated, broad drainage on a basin floor during this time and concomitant low slip rates along the Santa Clara fault.

10.3 The south tip of the east-down Cañada del Almagre fault is about a km north of this point.

10.5 Drainage on right side of road shows Chama El Rito extending upwards at least 60 meters sbove the road, and underlies approximately 20-30 m of Ojo Caliente Sandstone. Locally, the contact of the Lobato Formation basalt on Santa Fe Group sediments occurs at 7,700-7,800 feet.

11.4 Outcrop of Lobato Formation basalt in roadcut (may be part of a slump deposit).

11.7 Good exposures of Lobato Formation basalt flow

11.8 Contact on the right between Lobato basalt flow (east side) and intrusive gabbro (west side) with a fine-grained chill margin for the gabbro. For the next 0.5 miles, exposures of gabbro occur. The gabbro is fine to medium grained with interlocking phenocrysts of plagioclase, pyroxene and olivine. Higher in the intrusion the gabbro has medium to coarse grained lenses that become light gray (as the abundant plagioclase phenocrysts increase in size). The chemical composition of the gabbro is 50% silica.

11.9 Enter the Vallecitos 7.5 minute quadrangle.

12.1 Possible contact between gabbro and older lava flow

12.3 Contact between gabbro (east side) and red, oxidized, near-vent tephra deposits (west side). These cinder and spatter deposits dip steeply to the west and were likely erupted from a nearby vent.

12.4 Lobato basalt flow on top of tephra deposits

12.7 Road widens Multiple thin basalt flows capping the Clara Peak Lobato sequence with brecciated flow bases and tops. All flows dip 8-15 degrees to the west, due in part to original deposition and in part to later faulting.

12.8 Stop 2. Road widens at high point of curve. Pull over (but not too close to the edge!). Viewpoint provides a broad vista of the Española valley and the Jemez Mountains. WNW View: On the western horizon are Tschicoma and Polvadera Peaks, large dacite centers active between 5-4 Ma. The entire Jemez skyline, extending southwards to Pajarito Mountain (ski slopes visible) are part of this volcanic episode characterized by voluminous silica-rich lavas erupted in the northeastern Jemez throughout the Pliocene. Contemporaneous with the extrusion of these massive lavas was the aggradation of the broad Puye fanglomerate, composed dominantly of fluvial sands, gravels and conglomerates. The gradual slope leading up towards Tschicoma Peak is the Gallina lava flow, a massive, singular flow erupted ~4 Ma (visited later in the log). Hills in the foreground (east of the Gallina flow) are related to the Cerritos dacite, a Lobato-age volcanic center that erupted a widespread fine-grained dacite lava at ~9.6 Ma, capping the Lobato basaltic sequence in this area (also visited later in the log). South of Tshicoma Mountain is Santa Clara Canyon, precipitously carved into thick Tschicoma lavas. Quaternary Bandelier Tuff (Tshirege Member) can be seen forming a bench on the north side of the canyon, and is preserved as an erosional butte (Peñasco Blanco) in front of the Gallina flow. The entire Jemez skyline, extending southwards to Pajarito Mountain (sky slopes visible) are part of this voluminous silica-rich lava eruptive episode in the northeastern Jemez throughout the Pliocene. Contemporaneous with the extrusion of these massive silica-rich lavas is the broad Puye fanglomerate, composed dominantly of high energy fluvial sands, gravels and conglomerates. South View: The town of Los Alamos can be seen to the south with the Sandia Mountains forming the skyline above. St. Peter's Dome, a dominantly andesitic center active in the Miocene (part of the Paliza Canyon Formation), is in the right foreground of the Sandias. The Santa Clara fault scarp is conspicuous in the foreground, curving southwards as it joins with the Pajarito fault system. On the south side of Santa Clara Canyon, the scarp offsets a large Tschicoma flow lobe (west side) with Puye Formation (east side). Within Santa Clara Canyon the fault juxtaposes Puye Formation (east side) with Santa Fe Group (west side). On the north side of the canyon, where the fault begins to curve to the northeast, the scarp offsets the Puye Formation (both sides of fault) by ~100 meters. ESE View: Santa Clara Canyon is easy to follow as it strikes almost due east across the Puye fan. Also easy to spot is the pumice mine visited at Stop 1, a broad white patch (representing cleared land and pumice tailings) on the north side of the canyon. Hummocky landslide blocks of Lobato basalt can be seen along the base of Clara Peak and Cerro Roman.

12.8 to 13.5 Road begins to descend through Lobato Formation basalts in roadcuts all dipping to the southwest. Views to the NNW of Lobato Mesa, containing numerous basaltic volcanic centers.

13.5 A significant fault occurs across the valley to the west, downdropping the eastern (Clara Peak) side. The ridge across the valley (foot wall) is Lobato Formation basalt capped by the ~9.6 Ma dacite lava of the Cerritos center to the west. This lava has been downdropped by >150 on this, the hanging wall of the fault. The flows dip west.

13.8 Outcrops of dacite lava on left side of road. Although this lava is topographically low, it clearly lapped onto the preexisting Clara Peak shield volcano, with no overlying basaltic lavas. Faulting has then tilted the western flank of the Clara Peak shield volcano (and capping Cerritos dacite) by 5-12 degrees.

13.9 Fault parallels road on the west side. Intersection of Forest Road 144 with Forest Road 145, which leads to the top of Clara Peak. Continue straight on FR144.

14.2 Colluvium adjacent to fault on left side of road. Basalt crops out upslope.

14.4 Road crosses to the west of the fault. Exposures of Lobato Formation basalt on the left side.

14.6 Bend in road providing nice views to the north of Rio del Oso Canyon and Lobato Mesa. Also evident is the northward continuation of the Cerritos fault as it heads into Rio del Oso Canyon. The southwestern-dipping grassy mesas on the footwall of the fault are composed of relatively thin Cerritos dacite capping Lobato Formation basalts. A small outcrop of Lobato Formation basalt is on the left side of the road.

14.8 Lobato Formation Cerritos dacite caps basalt

15.0-15.2 Good outcrops of Lobato Cerritos dacite on left side of road.

15.3 Limited exposure of Lobato Formation coarse-grained dacite, which is similar in appearance to younger Tschicoma Formation dacites.

15.3-15.7 Lobato Formation porhyritic dacite

15.8 Puye Formation fills in paleovalleys that developed around the Lobato Formation flows

16.7 Road to right heads down into Rio del Oso Canyon. Cross cattle guard.

16.8 Tschicoma Formation coarse-grained dacite flows on left side of road.

17.2 Fine- to medium-grained alluvial deposits of Puye Formation beneath the dacite of Los Posos.

17.4 Gallina Creek

17.6 Good exposures of laminar beds of silt, sand and gravel containing Tschicoma Formation lava clasts beneath the impressive cliffs of the dacite of Mesa de la Gallina, a flow in the Tschicoma Formation, on left side of road. The distinctive flow of the dacite of Mesa de la Gallina is typically flow banded and contains 25-40% phenocrysts , including medium-sized plagioclase crystals and abundant small to medium-sized biotite and hornblende. This flow forms the Mesa de la Gallina surface that the road will climb for the next several miles.

17.8 Puye Formation exposures buried by colluvium.

17.85 Forest Road to Mesa El Alto and Abiquiu to right. **Continue straight.** The road follows the distal edge of the Gallina flow for the next 0.6 miles.

18.1 East dipping Lobato Formation Basalt flows dip into the fault across the valley.

18.9 Outcrop of Gallina flow on left side.

19.2 180 degree bend in road. Road ascends the Gallina flow surface for the next several miles.

20.9 Views of Clara Peak to left.

21.0 View down Rio del Osa Canyon to left.

21.5 Vista of Clara Peak, the Rio del Oso valley, and Lobato Mesa. Note the east-tilted fault blocks and the intervening valleys on Lobato Mesa.

22.0 Views of El Alto Mesa and the eastern edge of the Colorado Plateau. The cliffs on the west side of the meadow are the dacite of Mesa de la Gallina.

27.4 Cattleguard.

28.9 Optional Stop. Rock Glacier on Polvadera Peak. Turn right onto a two-track road that heads toward Polvadera Peak. A high clearance vehicle is recommended for this road.

29.05 Park in the large meadow and walk east toward the ridge line to reach the southernmost extent of a rock glacier. Walk northward along the western margin of the rock glacier to view more of this feature. The rock glacier blocks are tabular and are composed of Tschicoma Formation lava with phenocrysts of plagioclase and pyroxene. The tabular blocks are locally imbricated. indicating flow toward north. The lava is underlain by dacitic pumice and Tchicoma Formation dacite with phenocrysts of plagioclase, pyroxene, hornblende and biotite.

Rock glacier.

Turn around and retrace the route back to FR144.

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