Diablo Maar Volcano

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Abstract

Diablo Canyon Recreational Area, approximately 15 miles northwest of Santa Fe, is the site of a well-preserved maar volcano that formed in close proximity to the ancestral Rio Grande approximately 2.5 Ma. Geologic mapping reveals three primary phases during the eruptive history of the volcano. Eruptions during the initial phase were phreatomagmatic, driven by explosive blasts as the rising basaltic magma encountered a significant water table in the host Tesuque Formation. These eruptions produced an elliptical tuff ring approximately 2.5 x 1.5 km in diameter, composed of greenish-brown palagonite tephra and including large blocks of Tesuque Formation sandstone/conglomerate. The eruption transitioned into a second phase once the water component was exhausted, as strombolian-style eruptions built up a significant scoria cone within the confines of the maar. Ash, cinder, scoria, bombs, and small-volume lava flows were erupted during this phase, filling in much of the maar depression as the scoria cone developed. The third and final phase of the eruption is marked by widespread intrusion of basalt, including dikes, sills, and plugs that crosscut deposits from the previous two phases. This phase produced intra-maar lava flows that formed a moat between the maar rim and the scoria cone, with at least one lava flow exiting the maar boundary to the south. As the magma influx finally waned, a funnel-shaped lava lake existed on the south margin of the maar, representing the last gasp of magmatism from the volcano. Fortuitously, the present day Cañada Ancha has carved a canyon >100 meters through the core of this solidified lava lake, exposing spectacular columnar jointed basalt. Going forward we propose the name Diablo volcano, or Diablo maar, for this volcanic vent.

Petrographic and geochemical analyses of basalts at Diablo volcano reveal them to be of uniform composition, albeit with minor variations related to contamination by xenocrystic sand grains from the underlying Tesuque Formation. Despite these accidental contaminants, the geochemical data strongly support a genetic link between all basalt samples collected within the vent area. These basalts, both intrusive and extrusive, are aphyric and exhibit a microphenocryst mineralogy of plagioclase > olivine > augite > opaque oxides > basaltic glass. One basalt lava sampled beyond the maar confines shares a geochemical signature with the Diablo basalt suite. However, an overlying basalt lava (2.49 Ma) that caps the mesa south and west of the vent, is petrographically and geochemically distinct, and is of unknown origin.

Geologic Setting

Approximately 15 miles northwest of Santa Fe on Old Buckman Road is the popular and scenic Diablo Canyon Recreation Area. Here, Cañada Ancha has carved a near-vertical canyon through >100 meters of massive columnar basalt, creating a mecca for rock climbers and a stunning backdrop for the film and movie industry. Diablo Canyon is located on the north end of the Cerros del Rio volcanic field (Figure 1), which covers an area over 700 km^2, represents at least 120 km^3 of erupted material, and is characterized by basaltic to andesitic eruptions from monogenetic vents spanning an age range of 2.7 to 1.1 Ma (Thompson et al, 2006). The bulk of the eruptions, however, occurred between 2.7 to 2.4 Ma, with more voluminous outpourings of basaltic lava transitioning to less voluminous eruptions of basaltic andesite to andesite composition. The Cerros del Rio volcanism is related to magma generation at the intersection of the Rio Grande rift and the northeast-trending Jemez Lineament (Baldridge et al., 1984; Chapin and Cather, 1994; and Laughlin et al., 1982). Initial studies by Aubele (1978, 1979), identified most of the primary flows and vents in the Cerros del Rio, including several maar craters of hydromagmatic origins. Aubele (1978) recognized a maar origin for the deposits at Diablo Canyon and postulated that the massive columnar basalts in Diablo Canyon may represent a lava pond. Geologic mapping of the White Rock quadrangle by Dethier and Koning (2007) also interpreted a maar origin for the eruptions at Diablo Canyon, including the presence of phreatomagmatic deposits and a possible lava lake.

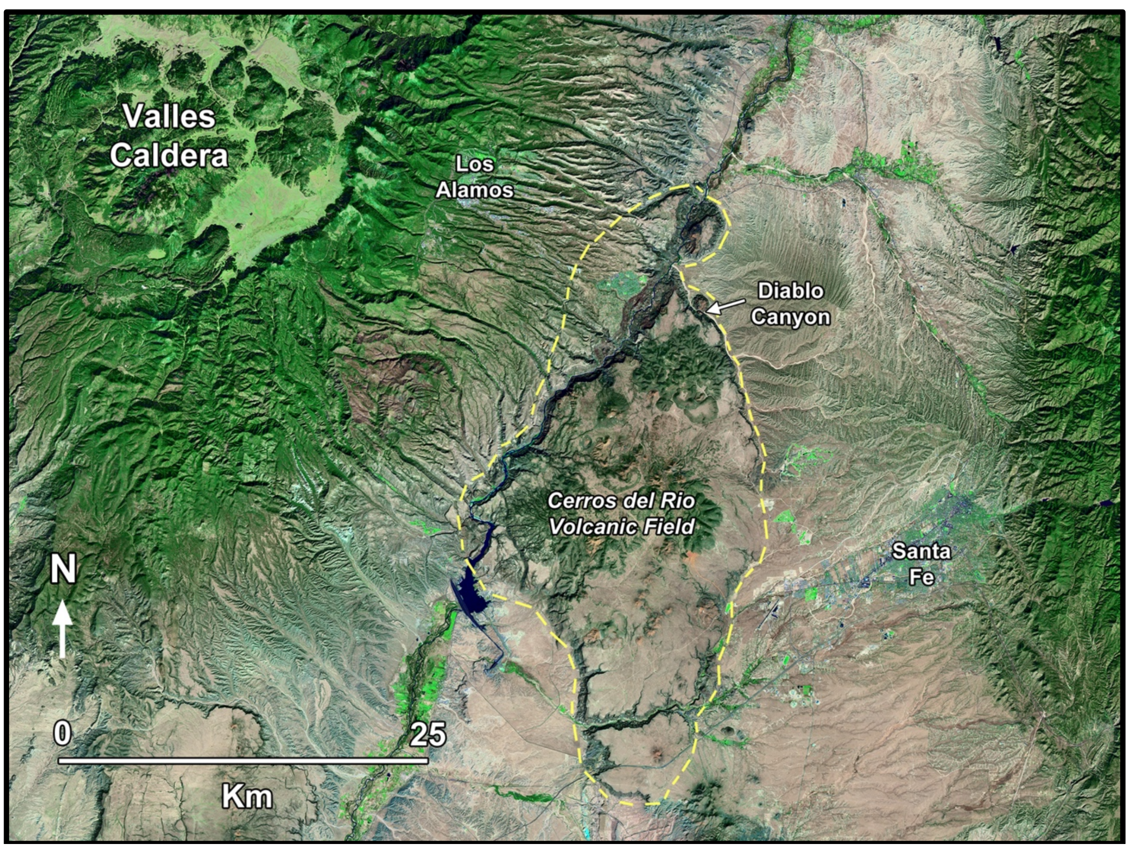

Figure 1. Satellite image showing the location of Diablo Canyon and the Cerros del Rio volcanic field (dashed yellow line).

Maar volcanoes are common in monogenetic basaltic volcanic fields where rising basaltic magma encounters a significant shallow aquifer or wetland environment (Fisher and Schmincke, 1984, fig. 9-27). Some well documented examples occur in Auckland, New Zealand, Iceland (Kereszturi et al., 2014; Thordarson and Larsen, 2007; and even New Mexico (Hoffer, 1976; Onken and Forman, 2017). Geologic mapping at Diablo Canyon reveals a classic progression of maar volcanic activity, whereby the overall explosivity of the eruptions decrease as the phreatic component is depleted. The general progression seen at Diablo volcano, where explosive phreatomagmatic activity transitions to scoria cone formation, which transitions to passive lava emission, pertains to other maar volcanoes in the Cerros Del Rio volcanic field, including Otowi Peak (Dethier and Koning, 2007) and the Montoso maar (Aubele, 1979).

Geologic Map and Units

A simplified geologic map for Diablo volcano is presented here (Figure 2), including three volcanic units related to the eruption sequence and development of the volcano (Qdv1, Qdv2, and Qdv3). A fourth volcanic unit, Qob, unrelated to Diablo volcano, is a porphyritic olivine basalt lava that caps the mesa south of Diablo Canyon. Sedimentary units that preceded maar formation, including the Tertiary Tesuque Formation (Cuarteles Member), and early deposits of the Quaternary Ancha Formation were not mapped, but essentially form the host bedrock that encircles the maar (Dethier and Koning, 2007). The dashed yellow line on the map, however, shows the approximate boundary of phreatomagmatic deposits outside the Diablo volcano of unknown origin (Qpt) above sediments of the Tesuque Formation (Ttc). Presently, the majority of the volcano forms an elliptical butte on the north side of Diablo Canyon, and contiguous exposures of all three volcanic units occur in the canyon and along the butte's western cliffs. The overall maar dimensions are ~2.5 x 1.5 km, elongated in a north-south axis. The butte's preservation is largely the result of an erosion-resistant lava (Qdv3) that rims the maar boundary. A general description of the primary rock units at Diablo Canyon is provided below.

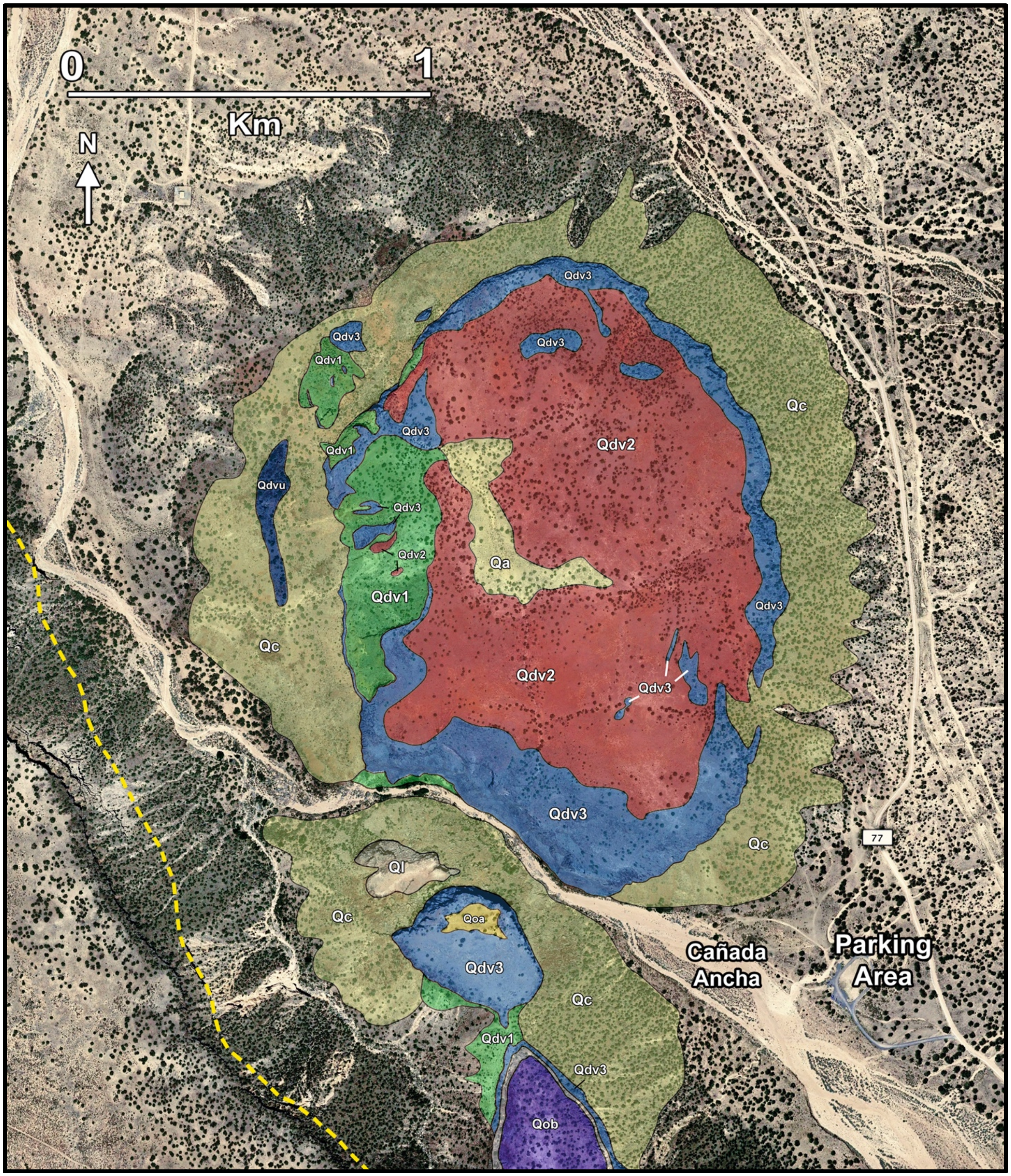

Figure 2. Simplified geologic map of Diablo volcano. Five simple observations are evident from the geologic map. 1) The oldest deposits related to the volcano, Qdv1, are best exposed along the western margin of the maar, with minor exposures in Diablo Canyon and just outside the southern maar boundary. 2) The core of the volcano is represented by Qdv2, representing deposits from a deeply eroded scoria cone. 3) A moat of basalt lava (Qdv3) encircles the scoria cone and is contiguous with a funnel-shaped lava lake in the southern portion of the maar

(approximate outline by white dashed lines). 4) Relatively flat-lying stratigraphy just south of the lava lake record outer-maar deposits, including one lava flow from Diablo volcano (Qdv3), capped by an unrelated porphyritic olivine basalt lava (Qob). 5) A small patch of ancestral Cañada Ancha gravels (Qoa) is preserved on top of lava lake basalt on the south side of Diablo Canyon, evidence for erosion of Diablo Canyon by superposition.

Map Unit Descriptions

Qa – Quaternary alluvium. Mapped only on butte mesa top, representing a thin veneer of alluvium capping scoria-cone deposits (Qdv2).

Qc – Quaternary colluvium. Mapped on steep slopes in Diablo Canyon and the maar butte north of the canyon. Includes minor landslide deposits and alluvium. Mostly covering up outer maar deposits of the Tertiary Tesuque Formation.

Ql – Quaternary landslide. Only mapped in one place on the south side of Diablo Canyon, representing a large slump block of the lava lake (Qdv3).

Qoa – Quaternary old alluvium. Only mapped in one location, resting on lava lake basalt on south side of Diablo Canyon. Unconsolidated to poorly cemented fluvial gravels on top of lava lake basalt. Clasts are dominated by sub-rounded to rounded pebbles and cobbles of Proterozoic granite and a wide variety of metamorphic rocks, including quartzite, amphibolite, and gneiss. Clast compositions are similar to modern alluvium in Cañada Ancha.

Qob – Quaternary porphyritic olivine basalt. At least two porphyritic lava flows that cap the broad mesas south and west of Diablo Canyon. Basalt includes large phenocrysts of olivine, sometimes in clots, and small phenocrysts of plagioclase. Previously dated at 2.49 ± 0.03 Ma by WoldeGabriel et al (1986). Unit is underlain by greenish phreatomagmatic tephra deposits and an outer-maar lava flow from unit Qdv3.

Qdv3 – Medium to dark gray, aphyric olivine basalt that includes intrusive dikes, sills, and plugs, and extrusive lava, including scoria-cone agglutinate, maar-filling flows, and the lava lake. One lava flow south of the maar boundary is also included in this unit. The boundary between intrusive and extrusive basalt is often blurred inside Diablo volcano, especially along the western margin of the maar where dikes connect to intra-maar lava flows. The lava lake is also ambiguous in this regard, as the upper surface is clearly extrusive (including pahoehoe textures), whereas deeper sections may be intrusive, including clear connections with dikes and sills. Petrographic examinations of this unit reveal microphenocrysts of plagioclase and olivine in a fine- to very fine-grained groundmass of plagioclase, olivine, augite, opaques, and glass.

Qdv2 - Scoria and cinder deposits associated with scoria cone development within the maar. These deposits are found mostly on top of the butte where they represent the eroded base of a scoria cone complex that formed inside the maar. Cliff exposures on the western face of the butte, however, also reveal stratified scoria and cinder tephra on top of older phreatomagmatic strata (Qdv1). These deposits show significant variations in color (red to dark gray), stratification (poorly to well stratified), and welding (poorly to highly welded). Near-vent deposits contain welded lapilli, scoria, and bomb agglutinate, with clasts ranging from subrounded cinder to large spindle-shaped bombs. Locally, small volume agglutinate lava flows are interbedded with the tephra deposits, as are a few massive, poorly-stratified basaltic tuff beds. Overall, we interpret these deposits to be consistent with a strombolian-style eruption from one or more vents within the maar confines.

Qdv1 - Phreatomagmatic deposits associated with maar formation. This unit is best exposed along the butte's west-facing cliffs, where they represent intra-maar tephra deposits. In general, this unit is comprised of stratified palagonite tephra deposits that exhibit a variety of bed forms, including inversely graded beds, planar beds, dune-like beds, and mildly cross-laminated beds. Angular unconformities are common in the phreatomagmatic sequence, reflecting complex and dynamic topographic changes within the maar throughout the eruption sequence. The ratio of juvenile to older lithic material is highly variable, although in general there is an increase in the juvenile component up section. Lithic material is mostly derived from the underlying Tesuque Formation, providing granitic and metamorphic sand and gravel. Locally, large blocks of lithified Tesuque Formation are entrained within the deposits. Juvenile materials include ash, lapilli, accretionary lapilli, bombs, and other pyroclastic fragments. Outer-maar deposits are exposed on the south side of Diablo Canyon, where they are overlain by mesa-capping lava flows.

Qdvu – Elongated ridge of intrusive basalt. Reddish-brown, slightly altered groundmass. May or may not be related to Qdv3.

Qpt – Phreatomagmatic deposits outside of the Diablo volcano south and west of Cañada Ancha. These deposits reach a thickness of ~80 meters in a tributary canyon to Cañada Ancha (see Photo 15) and include finely laminated lake sediments near the base. Possibly, an earlier maar eruption (and crater) occurred here, then filled up with tephra from the adjacent Diablo maar eruptions.

Ttc – Tesuque Formation, Cuarteles Member (Dethier and Koning, 2007). Beige to light pink sandstone with silt and gravel interbeds. Clasts include granite and metamorphic rocks derived from the Sangre de Cristo Mountains, and minor Paleozoic limestones. Pebbles are subrounded to subangular. Lenticular and trough cross-bedding common, including channel-fill complexes over 1 meter thick. Channel sands range from fine- to coarse-grained, poorly to moderately sorted, and poorly to moderately cemented. Cementation is calcium carbonate.

Diablo Maar Volcano Eruptive Model

Figure 5 displays a 6-stage working model for the origin and development of Diablo volcano. These diagrams are schematic and do not reflect the detail and intricacies of the maar formation and evolution. For example, some phreatomagmatic activity likely accompanied the widespread intrusions of basalt (Qdv3), as phreatomagmatic tephra is observed above and below the outer-maar lava flow. Although only a half dozen maars have been identified in the Cerros del Rio volcanic field (Aubele, 1979), it is almost certain that several more exist. The early phreatomagmatic phase is often buried by younger scoria cones and lava flows, and only places where deep erosion has occurred, such as along White Rock Canyon and its nearby tributaries, are these maar-related phreatomagmatic deposits exposed.

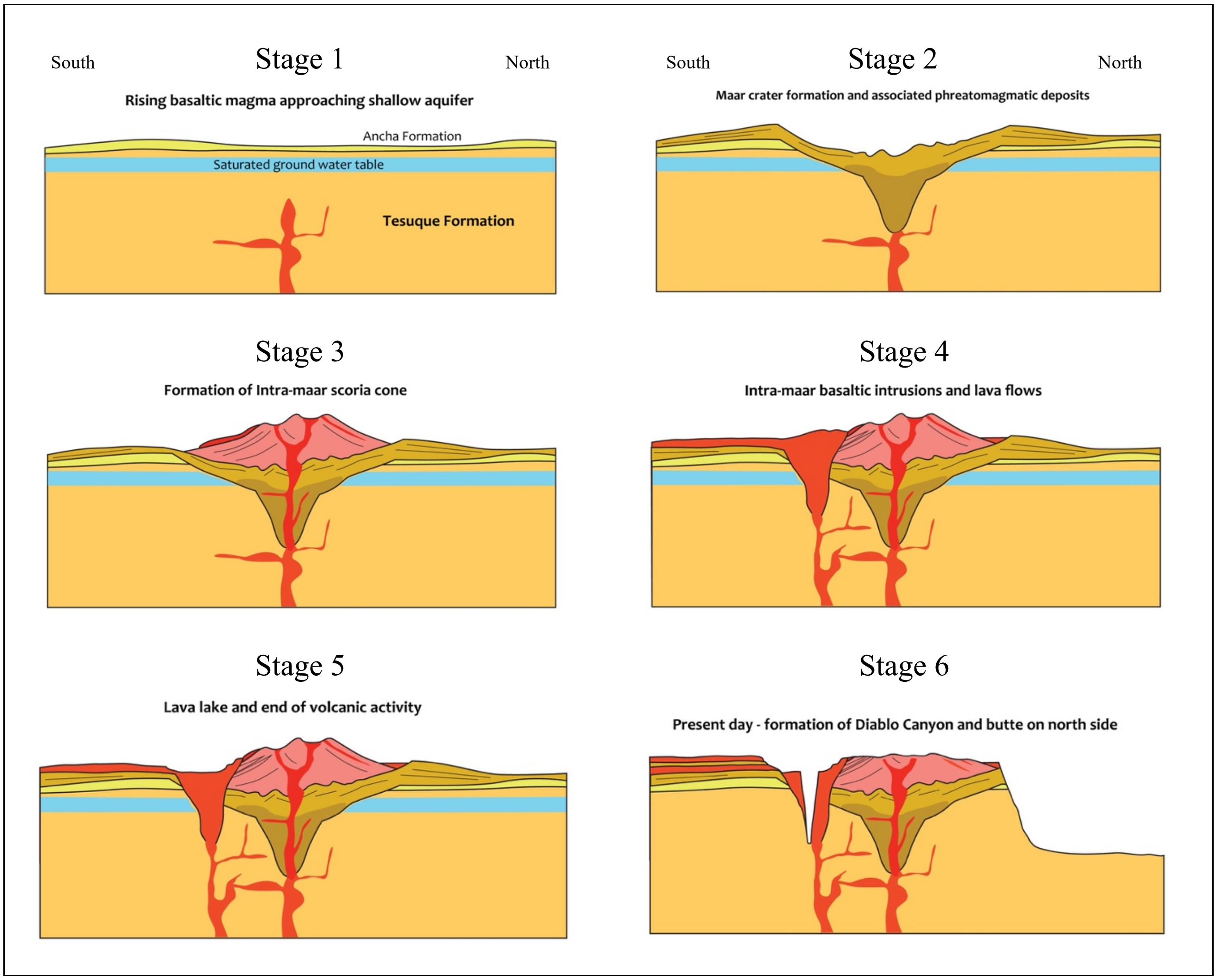

Figure 5. Eruptive model for the origin and development of Diablo volcano.

Figure 5 shows the general eruptive history of Diablo volcano based on the geologic observations given in this report. In Stage 1, at approximately 2.5 Ma rising basaltic magma approaches a shallow, saturated aquifer of the ancestral Rio Grande. At this time a thin veneer of early Ancha Formation gravels likely capped older Tesuque Formation sediments, and the ancestral Rio Grande was flowing on a relatively flat valley floor nearly 800 feet higher than its current elevation. In Stage 2, multiple eruptions occur as the rising magma interacts with the saturated ground water table. These explosive phreatomagmatic blasts form a maar crater, or tuff ring, and deposit thick tephra within the maar, and progressively thinner deposits with distance outside the maar (Fisher and Schmincke, 1984). These tephra deposits (Qdv1 in Figure 2) include a significant component of Tesuque Formation rock material, which hosted the shallow aquifer. Stage 3 begins once the ground water component has been exhausted, allowing the magma to erupt inside the maar without phreatic interaction. Strombolian-style eruptions gradually build a scoria cone within the maar confines, erupting basaltic ash, cinder, scoria, and bombs. The eruption intensity waxed and waned during this phase, and at times produced small-volume lava flows that are interbedded with tephra deposits. In Stage 4, strombolian activity subsides as widespread intrusions of basalt occur in the southern and western margins of the maar, injecting plugs, dikes and sills into the earlier phreatomagmatic and scoria deposits inside the maar. Extrusive lava flows during this stage form a moat between the scoria cone and the maar crater rim, and at least one lava flow escaped the maar confines, flowing southward onto relatively flat topography. In Stage 5, the input of basaltic magma comes to an end, with the last gasp of molten basalt forming a lava lake in the southern portion of the maar. Gradual solidification of this basalt (over many decades) produces a wide array of columnar jointing. For the last diagram, representing Stage 6, we fast forward ~2.5 Ma to the present, showing the current topographic expression of Diablo volcano. Widespread erosion in the Española Basin, driven by incision of White Rock Canyon by the Rio Grande, has resulted in Cañada Ancha carving Diablo Canyon through the core of the lava lake basalt by superposition. Most of Diablo volcano today forms a butte on the north side of Diablo Canyon, as softer sedimentary deposits north of the volcano have been deeply eroded. Prior to this erosion, however, a porphyritic olivine basalt lava capped the stratigraphic section south of the volcano.