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Title:
Revised Site-Wide Geologic Model for Los Alamos National Laboratory (FY98)

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Abstract:

A revised digital geologic (FY98) model has been developed for Los Alamos National Laboratory. This model resolves inconsistencies that previously resulted in the intersection of stratigraphic surfaces. A major effort was also made to identify the extent of additional pre-Bandelier basalt and other lava flow units, which could have major impacts on groundwater flow. Preliminary top and bottom surfaces were created for four basalt units as well as two-quartz latite flows of the Tschicoma Formation. As these units may have a major impact on models of ground water flow, efforts are continuing on resolving surface conflict (intersection) issues among these poorly constrained units. The FY98 model is available at the Facility for Information Management, Analysis, and Display (FIMAD).

Summary:

Initial efforts in FY98 were directed toward removing remaining inconsistencies in the FY97 model (Cole et al., 1997). Quantitative predictions of drill hole stratigraphy were made for the R-9, R-12, and R-25 wells using both the FY97 and the updated FY98 models. Drilling results from the R-9 well confirmed the importance of the deeper basalts (pre-Bandelier) in any hydrogeologic model. New data to help define these deeper units were collected and include geologic age and rock chemistry data, the geologic map of the White Rock Quadrangle (Dethier,1997), and drilling results from the R- and GR-series wells.

Six basalt and latite subunits were added to the model, based upon age and chemistry: four basalts and two quartz latite (Tschicoma) flows. The basalt and quartz latite subunits are enclosed within the Puye and Santa Fe units, have irregular shapes, and are limited in geographic extent. For this reason, both top and bottom contacts are identified for these subunits. To obtain and analyze the 3-D position of contacts, unit surface and drill-hole contacts were displayed in 2-D plots as well as 3-D visualizations. The 2-D geographic plots identified elevations of surface and drill hole contacts for individual units, as well as those drill holes that were deep enough to have penetrated the unit, but did not (i.e., showing the absence of the unit). The 2-D plots were hand contoured by the authors to provide the input for creating gridded contact surfaces using Arc/Info software. More detailed analysis of the gridded contact surfaces is currently underway to resolve intersection and other issues. Additional age and chemical analyses are underway to improve the geospatial correlations upon which the contact surfaces are based.

Details of Revised 3-D Model:

Qbt3:

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Based on the recommendation of S. Reneau, the basal Qbt3 contact was modified to eliminate "negative thicknesses" of Qbt1g, and to be compatable with Qbt2 revisions of the FY98 model.

Qbt2:

Based on the recommendation of S. Reneau, the basal Qbt2 contact was modified to eliminate "negative thicknesses" of Qbt1g, to prevent intersection of structure contours with the White Rock basalt high, and to remove inconsistencies with base-Qbt3 and base-Qbt4 contours.

Qbt1v:

Based on the recommendation of S. Reneau, the basal Qbt2 contact was modified to eliminate "negative thicknesses" of Qbt1g, to prevent intersection of structure contours with the White Rock basalt high, to limit the initial extent of the unit in the White Rock area, and to correct model errors through incorporation of the SHB-1 (drill hole) contact and addition of a new 7050' contour.

Qbtt:

Based on the recommendation of S. Reneau, the base-Qbof contact obtained from the Tschicoma outcrop as mapped by (Griggs, 1964), was used to constrain the base of Qbog and the base of Qbtt as well. New estimated points for both base-Qbtt and base-Qbog were added in the NW Los Alamos area. Estimated base-Qbtt points were also created for points assigned base-Qbof elevations by D. Broxton. S. Reneau also provide a revision of the paleocanyon surface of Cole et al. (1997) through addition of a set of equally-spaced control points, interpolated/extrapolated between the preexisting points along the canyon axis.

Qct:

The apparent Qct thinning inside the 90' isopach in the western portion of the FY97 model was removed by assigning a value of 90' to everything inside this isopach.

Qbog:

Based on the recommendation of S. Reneau, the base-Qbof contact obtained from the Tschicoma outcrop as mapped by (Griggs, 1964), was used to constrain the base of Qbog and the base of Qbtt as well. New estimated points for both base-Qbtt and base-Qbog were added in the NW Los Alamos area. Estimated base-Qbog points were also created for points assigned base-Qbof elevations by D. Broxton. Additional control points were added for the base of Qbog in the northwest portion of the study area to prevent intersection of the base of Tpf and base of Qbog surfaces in the FY97 model. Approximate elevations for base-Qbog/top-Tpf in the west part of Guaje Canyon were taken directly from (Griggs, 1964).

Tb1:

Contoured top and bottom surfaces of middle Miocene basalt, here termed Middle Miocene Basalt of Santa Clara Canyon (Tb1), were developed by R. Warren from available data. Alternative models were evaluated, as discussed in this text. The surface

models considered most likely were used for the 1998 site-wide model. The unit consists of multiple flows with possible interfingering of Santa Fe Group sediments between the flow layers. The top surface represents the top surface of the uppermost flow, the bottom surface represents the bottom surface of the lowest flow. Surfaces were modified slightly during the creation of the 3-D model to remove improper unit intersections and/or stratigraphic inconsistencies.

The occurrence of middle Miocene basalt, here termed Middle Miocene Basalt of Santa Clara Canyon (Tb1), has been demonstrated by $^{40}Ar/^{39}Ar$ integrated ages of 11.7 and 12.0 Ma for 2 samples from the deepest basalt encountered inO-1 (WoldeGabriel et al., in preparation). The deepest basalts in several wells of Guaje Canyon are assigned as Tb1, based on preliminary petrographic analysis for one sample from GR3. The deepest basalt in PM-5 might also be included within Tb1, but presently is included with Tb2. The age of this basalt, 11.4 Ma, with a 2 sigma uncertainty of 0.6 Ma (WoldeGabriel et al., in preparation), lies between those of Tb1 in O-1 and all other samples of Tb2 (see discussion below). But the deepest basalt in PM-5 is closely similar in elevation to overlying flows of Tb2, and is chemically dissimilar to Tb1 in O-1. Presently, all basaltic rocks older than 10 Ma are characterized as tholeiitic basalt (WoldeGabriel et al., in preparation; Aldrich and Dethier, 1990).

North of the Pajarito Plateau, basalts with ages ranging from 7.6 to 14.1 Ma (Dethier et al., 1986; Gardner et al., 1986) are included within Lobato basalt (Smith et al., 1970), and probably represent the northern extent of a field that extends southward as Middle Miocene Basalt of Santa Clara Canyon (Tb1) and Late Miocene Basalt of Bayo Canyon (Tb2). Including published age dates for Miocene basalts north of the Laboratory with those near or within the Laboratory (WoldeGabriel et al., in preparation; WoldeGabriel et al., 1996), no major temporal gaps are apparent for basaltic volcanism between 7.6 to 14.1 Ma. Therefore, Middle Miocene Basalt of Clara Canyon (Tb1) should only be taken as a representation that Middle Miocene basalts certainly occur within subsurface of the Pajarito Plateau. Few wells penetrate depths great enough to provide control for Tb1. There is no control for the possible extent of this unit south of PM-2, to the east of the Rio Grande, or to the northwest beneath the overlying Tschicoma Formation. Additional age dating and petrographic and chemical analyses are in progress to clarify the ages and distribution of Miocene basalts in subsurface of the Pajarito Plateau.

Tb2:

Contoured top and bottom surfaces of the Late Miocene Basalt of Bayo Canyon (Tb2) were developed by R. Warren from available data. Alternative models were evaluated, as discussed in this text. The surface models considered most likely were used for the 1998 site-wide model. The unit consists of multiple flows with possible interfingering of Santa Fe Group sediments between the flow layers. The top surface represents the top surface of the uppermost flow, the bottom surface represents the bottom surface of the lowest flow. Surfaces were modified slightly during the creation of the 3-D model to remove improper unit intersections and/or stratigraphic inconsistencies.

Late Miocene Basalt of Bayo Canyon (Tb2) consists of a multitude of individual flows, generally separated by layers of sediment, with 9 individual flows recognized within the GR wells of Guaje Canyon alone. However, age dates cluster tightly for 9 samples from outcrop at the type section in Bayo Canyon, outcrop near river level in White Rock Canyon near Ancho Canyon, and wells O-4, PM-4, and R-9 (WoldeGabriel et al., in preparation, Woldegabriel et al., 1996). The range for $^{40}Ar/^{39}Ar$ ages is between 8.4 to 9.3 Ma for those 9 samples with a small uncertainty (2 sigma <0.4 Ma). The deepest basalt encountered in PM-5 provides one sample with an older age of 10.9 Ma for Tb2, as described above. All Late Miocene volcanic rocks of Tb2 have thus far proven to be basalt, both alkalic and tholeiite. As a group, these basalts are distinctively clinopyroxene-phyric, in contrast to Pliocene basalts, which invariably lack clinopyroxene phenocrysts. Thus, despite the multitude of separate flows and often thick intervening sediment, this group of basalts is considered to represent a relatively brief period of time and therefore a bona fide stratigraphic marker within the deeper parts of the stratigraphic succession beneath the Pajarito Plateau. Except for the above-mentioned outcrops, this unit is known only in subsurface near the Laboratory. South of Frijoles Canyon, exposures of older units on the western, upthrown side of the Pajarito Fault limit the southwestern extent of Late Miocene Basalt of Bayo Canyon (Tb2). North of the Pajarito Plateau, basalts of this age (Gardner et al., 1986), mapped as the Lobato basalt (Smith et al., 1970), may represent a northern extention of Late Miocene Basalt of Bayo Canyon (Tb2). There is no control on the possible extent of this unit to the east of the Rio Grande, or to the northwest beneath the overlying Tschicoma Formation.

Three linear arrays of well penetrations provide the key structural data for the base of Tb2. Wells in Guaje Canyon, which provide the densest array of data, suggest a gentle northwest paleoslope here, taken to represent the eastern side of an ancestral canyon of the Rio Grande. Contours can be extended southwestward around the middle array of wells, including PM-1, PM-3,and O-4 to project a river course southward through the southern array that includes PM-2, PM-4, and PM-5. Just northeast of the Laboratory, the topographic high for the base of Tb2 can be attributed to a topographic high from older basalt (Tb1). The southwestward drop in elevation for the base of Tb2 between the middle and southern arrays could be instead attributed to a northwest-trending fault southwest of the Bayo Canyon outcrop, and an additional northeast-trending fault northwest of this outcrop. Significant faults are rare on the Pajarito Plateau, and there is no evidence for those with a northwest orientation. But Miocene was probably a time of far greater structural activity than Pliocene. Deposits of Totavi Lentil, which mark the ancestral channel of the Rio Grande, are unknown beneath Tb2, and argue that the base of Tb2 does not represent an ancestral canyon of the Rio Grande. Perhaps environmental conditions during the Late Miocene, when the Chaquehui Formation was deposited, were not amenable to the deposition of Totavi-like deposits. During later, Pliocene time, control by the Rio Grande on both top and bottom surfaces of Pliocene Basalt of the Cerros del Rio (Tb4) is unmistakable, as described below. Although control for the pre-Tb2 surface by an ancestral canyon of the Rio Grande is considered the most plausible explanation of the structural data, structural explanations are also plausible.

Structural data for the top of Tb2 does not plausibly allow a throughgoing ancestral canyon of the Rio Grande in the same location as inferred for the base. The gentle northwest slope at the base of Tb2 within the GR wells is replaced by a steep and variable, generally southward slope for the top of Tb2. This is taken to represent the southern terminus of a sequence of flows filling the ancestral Rio Grande, forcing the river into a location more nearly coincident with its present course. These flows might extend continuously northward to those of Lobato basalt. The ancestral Rio might also have flowed east of its present course, with the trough within the southern part of the Laboratory instead representing a tributary canyon, which indeed it did in Pliocene time. But structural data for the base of Totavi Lentil shows a trough exactly coincident with the trough atop Tb2,and supports this location as the position of the ancestral Rio Grande immediately post-Tb2.

Tb3:

Contoured top and bottom surfaces of the Early Pliocene Basalt of Black Mesa (Tb3) were developed by R. Warren from available data. Alternative models were evaluated, as discussed in this text. The surface models considered most likely were used for the 1998 site-wide model. The unit consists of multiple flows with possible interfingering of Puye sediments between the flow layers. The top surface represents the top surface of the uppermost flow, the bottom surface represents the bottom surface of the lowest flow. Surfaces were modified slightly during the creation of the 3-D model to remove improper unit intersections and/or stratigraphic inconsistencies.

Early Pliocene Basalt of Black Mesa (Tb3) is assigned in only three wells,PM-2, PM-5 and O-1, and is absent in all other deep wells. In O-1, a poorly-constrained age of 4.35 Ma was determined on a questionable analysis with strongly disturbed age spectra (WoldeGabriel et al., in preparation). The sample from O-1 has a distinctive chemistry, and a very distinctive, high content of quartz phenocrysts is established by thin section examination. Sample PM-5-1110D represents a basalt with an age of 3.4+-0.4 Ma (2 sigma) that underlies latite of SHB-1. Black Mesa has been age dated by K/Ar at 4.4 Ma from a sample collected on its southwestern flank (Baldridge et al., 1980), but a sample recently collected on its northwestern flank for Ar/Ar dating lacks quartz phenocrysts in thin section. If all these samples can be related, despite some obvious differences, then structural constraints require that Tb3 has a very narrow distribution, strongly suggesting its confinement as a narrow ribbon, presumably marking the location of an ancestral stream during Early Pliocene, probably the Rio Grande. In support of this representation for Tb3, a sample of Old Alluvium from R-9, representing pre- or syn-Tb4 deposits of the ancestral Rio Grande, is dominated by clasts of quartz-rich basalt, and a large basaltic clast of Old Alluvium from R-9 shows an excellent match in chemistry to that of Tb3 in O-1. The location for R-9 is very close to the narrow ribbon that represents the location of Tb3.

Tb4:

Contoured top and bottom surfaces of the Pliocene Basalt of the Cerros del Rio (Tb4) were developed by R. Warren from available data. Alternative models were evaluated, as discussed in this text. The surface models considered most likely were used

for the 1998 site-wide model. The unit consists of multiple flows with possible interfingering of Puye sediments between the flow layers. The top surface represents the top surface of the uppermost flow, the bottom surface represents the bottom surface of the lowest flow. Surfaces were modified slightly during the creation of the 3-D model to remove improper unit intersections and/or stratigraphic inconsistencies.

Structure contours for the base of Pliocene Basalt of the Cerros del Rio (Tb4) represent the landscape prior to eruption of this unit as a multitude of basaltic to latitic flows, mostly between 2.5 to 2.8 Ma ago (WoldeGabriel et al., 1996). Four critical data require that this landscape was shaped by an ancestral Rio Grande that occupied a position indistinguishable from its present course. The base level, at somewhat less than 5260 ft, and position exactly coincident with today's canyon-ending narrows, is accurately established by ancestral gravels beneath Tb4 at Cochiti Lake. Far upstream, just northwest of Otowi Bridge, an outlier from La Mesita tops Santa Fe Group at <5740 ft. In between, a flow from La Mesita extends to <5720 ft elevation, and the base of a flow at the mouth of Water Canyon lies at 5520ft. With this base level established for the region, it is clear that low structural levels for the DT wells in the southwestern part of the Laboratory require a major drainage near the southwestern edge of Tb4, which is constrained here in its western limit by older rocks west of the Pajarito Fault. Structural data near Cochiti Lake show the widest opening coincident with the first present-day canyon downstream from Capulin Canyon, where this major tributary probably opened into the ancestral Rio. Downstream from Ancho Canyon, abundant structural data for the base of Tb4 devulges the presence of deep side canyons cut by headward erosion from the canyon of the ancestral Rio. Tb4 appears to be limited to the northwest by latite of SHB-1, based on the parallel nature of structure contours for both Tb4 andTt2. To the north, high topography was associated with Tb2, providing an effective barrier to spread of Tb4 northward.

Structure contours for the top of Tb4 are very similar to those at the base. Primary features are a deep canyon with a position indistinguishable from the present-day canyon, several well-defined constructional centers, a prominent drainage along the southwestern edge of Tb4, just east of the Pajarito Fault, deep side canyons cut by headward erosion from the canyon of the ancestral Rio, and a subsidiary channel parallel to the main channel of the ancestral Rio. The base level, at somewhat less than 5400 ft, and position exactly coincident with today's canyon-ending narrows, is accurately established by abundant structural data at Cochiti Lake. Far upstream, a flow at the mouth of Water Canyon tops at about 5650 ft, and just northwest of Otowi Bridge, an outlier from La Mesita tops at about 5800ft. Structural data near Cochiti Lake show that the widest side canyon is coincident with Capulin Canyon, where the major tributary that followed south along the east side of the Pajarito Fault probably opened into the ancestral Rio. A subsidiary channel cuts deeply across present-day Frijoles and Alamo Canyons. From contours on the base of Tb4, this channel appears to have been initially developed as a side canyon to ancestral Capulin Canyon, and then used periodically as the main canyon of the ancestral Rio was repeatedly dammed by lava flows of Tb4. The subsidiary channel is connected to the main channel along each of the present-day major northern tributaries of the Rio Grande; each of these connections probably served as a meander

during episodes of dam formation (Reneau and Dethier, 1996). Following damming, the main canyon must have quickly filled with fine sediments that would support deposition of coarse gravels found within the subsidiary channel. Most of the sediment deposited in paleo-White Rock Canyon was rapidly eroded after basalt dams were breached and the river was re-established within a later paleo-White Rock Canyon. Remnants of sediments deposited within paleo-White Rock Canyon are preserved as Old Alluvium, map unit Ta of Dethier (1997). Pronounced headward erosion from both the main and subsidiary canyons of the Rio Grande occurred in exactly the same course as modern streams, due to the great ease in headward erosion of Bandelier Tuff compared to Basalt of the Cerros del Rio.

To summarize, the surface of Pliocene Basalt of the Cerros del Rio (Tb4) represents a constructional surface with several topographic highs that represent eruptive centers: Montoso Peak, Ortiz Mountain, and La Mesita are major centers east of the Rio Grande that dominate the present landscape. The TA-33, Powerline Jump, and Tshirege Ruins centers are much more topographically subdued centers west of the Rio. Flows from these centers coalesced to stabilize the Rio within its present course. Key structural data at Otowi Bridge, the mouth of Water Canyon, and at Cochiti Lake demonstrate that the morphology of the Tb4 surface, including the present White Rock Canyon, was established early during emplacement of Tb4, and this surface has been virtually unmodified since its emplacement. This view is quite different than that presented by (Reneau and Dethier, 1996), who show a pre-Tshirege Rio Grande that was considerably higher than today's river in their Figure 9. During the emplacement of Tb4, the periodic construction of basalt dams resulted in rapid filling of paleo-White Rock Canyon with mostly fine sediment and high river levels that forced the ancestral Rio Grande into a topographically higher, parallel, subsidiary canyon. The main canyon was rapidly reestablished, the subsidiary canyon abandoned, and most of the sediment filling paleo-White Rock Canyon was rapidly eroded away. The subsidiary canyon was connected to the main canyon along courses coincident with present-day major canyons, including Ancho, Frijoles, Lummis, and Alamo, and merged with the master drainage along the western edge of the basalt field, coincident with the lower part of present-day Capulin Canyon. The Pajarito Fault provided the western barrier that established the position of this drainage, uplifting older rocks west of the fault.

The basal surface of Tb4 is very similar in gross features to its upper surface. Just prior to emplacement of Tb4, paleo-White Rock Canyon was virtually identical to the present day canyon both in relief and position, and a master drainage also flowed southward just east of the Pajarito Fault. This pre-Tb4 topography was probably shaped in most part by the previous episode of voluminous basaltic volcanism, represented by Late Miocene Basalt of Bayo Canyon (Tb2). The upper surface of Tb2 is fairly similar in form to the lower surface of Tb4, and indicates the existence of an ancestral canyon that the Rio Grande occupied during late Miocene. The presence of the Rio along its inferred course through this canyon is corroborated by a similar shape for the surface of the Totavi Lentil, which represents axial deposits of the ancestral Rio Grande. The basal surface of Tb2 is quite different than its upper surface. The basal surface is interpreted as the expression of an ancestral canyon of the Rio Grande positioned far to the west of the

present-day canyon. Presumably, this ancestral, pre-Tb2, Late Miocene canyon was shaped by even older, Middle Miocene Basalt of Santa Clara Canyon (Tb1). This hypothetical, ancestral canyon was plugged by Tb2, forcing the Rio Grande into its present position. Alternatively, the basal surface of Tb2 might reflect major faults that preceded emplacement of the unit. No Totavi-like sediments are known beneath Tb2 to support a westward location for a Late Miocene ancestral Rio Grande. Instead, the topographic trough that existed at this time is filled with the Chaquehui formation, which is a poorly-described lithology.

Tt1, Tt2:
Contoured top and bottom surfaces of the upper and lower units of the Tschicoma Formation (Tt2,Tt1) were developed by R. Warren from available data.Alternative models were evaluated, as discussed in this text. The surface models considered most likely were used for the 1998 site-wide model. The units consists of multiple flows with possible interfingering of Puye sediments between the flow layers. Top surfaces represents the top surface of the uppermost flow of each unit, bottom surfaces represents the bottom surface of the lowest flow. Surfaces were modified slightly during the creation of the 3-D model to remove improper unit intersections and/or stratigraphic inconsistencies. The units of Tschicoma Formation (upper, Tt2 and lower, Tt1) are limited in their possible extents to the southwest by the occurrence of older rocks across the Pajarito Fault. Structural control is sparse, and Tt2 may include units that differ greatly in age and in origin. Near the eastern limit of its extent, Tt2 is represented by latite of SHB-1, which has a similar age as the generally overlying Pliocene Basalt of the Cerros del Rio (Tb4), and chemically and petrographically resembles the most evolved units within Tb4 (WoldeGabriel et al., in preparation, WoldeGabriel et al., 1996). West of the Pajarito Fault, Tschicoma Formation representing Tt1 is considerably older than latite of SHB-1 (Aldrich and Dethier, 1990; Dethier et al., 1986; Gardner et al., 1986; Dalrymple et al.,1967), and very different chemically and petrographically (D. E. Broxton and R. G. Warren, unpublished data). Samples are unavailable for H-19 and TW-4, so the nature of thick Tt2 in these key wells and thick Tt1 in H-19 is unknown and will remain so until R6 and R2 are drilled. Structural data for Tt2 and Tb4 strongly suggest that latite of SHB-1 forms a flow front at its eastern limit, effectively forming a barrier to the western migration of Tb4. The unit logged as Tb4 in TW-9 has a thickness and top elevation virtually identical to the unit in PM-5 characterized by thin section petrography and by chemistry as latite of SHB-1; this interval should be reassigned as Tt2.On the other hand, the interval assigned as Tt2 in TW-3 structurally matches petrographically and chemically characterized basalt in adjacent O-4, and the interval in TW-3 should be reassigned as Tb4. Constraints for the eastern limit of Tt1 are similar as those for Tt2, and demonstrate that Tt1does not extend as far east as Tt2.

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