#66782

Released in 1999 (LA-UR-00-2056)

Title:
Revised Site-Wide Geologic Model for Los Alamos National Laboratory (FY99)

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Abstract:

A completely revised digital geologic (FY99) model has been developed for Los Alamos National Laboratory. This model extends all contact surfaces to the site-wide model boundaries and where appropriate it resolves inconsistencies among pre-Bandelier flow units, removes the Tb3 basalt unit from the model, and adds a hydrologically distinct transition unit, Qbt3t, to the model. The model incorporates all new drilling data available by the end of FY99 (30 September 1999), previous mapping to the southwest of the Laboratory in the Dome Lookout area, new data from the Seismic Hazards Project, and new map data in the western Los Alamos townsite area. Special efforts were made to carefully model (in 3D) the lower Tschicoma flow, which underlies the townsite and western edge of the Laboratory, and the hydrogeologically important Puye Formation and "Chaquehui" subunit/facies. Results of the more detailed 3-D analysis, which are based on sparse data, indicate that axial gravel facies of the Puye and Santa Fe Formations may create hydrologically conductive, north-south trending zones within the water table.

Summary:

A consistent process was used in the generation of all contact surfaces for the FY99 site-wide, hydrogeologic model. The process consisted of the following for each surface:

1) Creation of a plot showing the location of ALL contact data points: color-coded to reflect their misfit to the existing FY98 model and with different symbols to reflect the original data sources

2) Hand-contouring of the data set by a professional geologist familiar with the tectonic history of the region;

3) Digitizing of contours, generally at a scale of 1:24,000 but also at a scale of 1:12,000, with expected digitizing errors of < .02", reflecting actual ground errors of < 40' and < 20' respectively;

4) Creation of gridded surfaces using the Topogrid module of Arc/Info with input data consisting of digitized contours, drill hole contact intersections, and other "exact" contact points located by Global Positioning Satellite systems;

Received by ER-RPF
AUG 31 2000

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5) Conflict resolution to remove inconsistencies, improper intersections of surfaces, or stratigraphic inconsistencies; sometimes necessitating a return to step 2 of the process, and

6) Minor corrections/distortions to/of the model to allow generation of a consistent and coherent set of surfaces within the StrataModel software (normally accomplished at the same time as step 5.

Stratigraphic units include flows of the Bandelier Tuff (and intercalated Cerro Toledo Formation), as well the older Puye and Santa Fe units. These units are defined by their basal contacts. Flow units located within the pre-Bandelier sedimentary stratigraphic units, including the Tschicoma latite flows and Middle Miocene to Late Pliocene basalts, are identified by top and bottom contacts. These pre-Bandelier flow units consist of multiple flows intercalated with sediments. The top contact of this suite and flow units is defined by the top of the uppermost flow unit. The bottom contact reflects the bottom of the lowest flow unit. The unit isopach reflects thickness of the unit plus the thickness of the intercalated sediments. Top and bottom contact surfaces for these flow units were usually obtained through determination of either the top or bottom surface, and isopachs.

Greg Cole produced preliminary pre-Tshirege surfaces (Qct and older/lower, including basalts and older flow units). Bill Carey produced preliminary Tshirege surfaces (including a new Qbt3t surface). Both geologists worked together through steps 5 and 6 to produce the final surfaces. Bill Carey did the appropriate integration of this site-wide model into the Española Basin-wide model.

Details of Revised 3-D Model:

The following descriptions are taken from the **model_desc table** of the 3-D geology database. Electronic versions of these tables are available at the Facility for Information Management, Analysis, and Display (FIMAD) at LANL.

Tb1:

Contacts for Tb1 (Santa Clara Canyon Basalt) have been identified in the G-, and GR-series wells in Guaje Canyon as well as in well O-1. All contacts in Guaje Canyon wells that were previously identified in the FY98 model as Tb2 (Bayo Canyon Basalt) contacts based on their spatial position are now considered as representing Tb1 flows, based on recent age dating by Giday WoldeGabriel (WoldeGabriel et al., in preparation).

All but the O-1 occurrences of this unit are intercalated with what has been identified as upper Santa Fe Group, Chaquehui sediments (Tsfuv). The Tb1 flow of Well O-1 occurs within the Tesuque Formation of the Santa Fe Group (Tsfu). If the well logging for Well O-1 is correct, then deposition of the Tesuque and Chaquehui sediments was coeval.

The FY99 model for the Chaquehui sediments (or facies) indicates a major drainage separating the Tb1 occurrence in O-1 from the occurrences in Guaje Canyon. However, the elevation and thickness of the occurrence in O-1 are consistent with a model of multiple SSE trending flows originating from a center north of Guaje canyon, with a combined thickness

>1300 feet, which thin to a thickness of 12 feet in the vicinity of O-1. These flows apparently filled and ultimately crossed the paleodrainage. The FY99 model represents the Tb1 flows as two distinct bodies, whose elevations and isopachs follow a single modeled flow trend, but are separated by the axis of the postulated paleodrainage due to probable fluvial erosion and removal of Tb1 within the paleochannel.

Tb2:

Contacts for Tb2 (Bayo Canyon Basalt) have been identified in outcrops at Bayo Canyon to the north and Ancho Canyon to the south, as well as in drill holes within an area bounded by Los Alamos and Pajarito canyons in the middle of the Laboratory. All contacts in Guaje Canyon wells that were previously identified in the FY98 model as Tb2 (Bayo Canyon Basalt) contacts based on their spatial position are now considered as representing Tb1 flows, based on recent age dating by Giday WoldeGabriel (WoldeGabriel et al., in preparation).

Observed elevations and thicknesses of this unit are consistent with contiguous flows toward the south from a source to the north. The modeled basalt source was arbitrarily located at the head of Pueblo Canyon, approximately 2 miles north of the greatest observed unit thickness (basalt and intercalated sediments) of 975 feet in well PM-5, and in the vicinity of possibly active faults of the Pajarito fault system. The current data set provides few constraints for this unit north of Los Alamos Canyon except for its presence in outcrops in Bayo Canyon and its absence in Guaje Canyon further north. The model also lacks constraints to the west and new data development in this area is unlikely. Its observed presence or absence in White Rock Canyon currently defines the eastern/southeastern extent of the unit. Drilling logs from the Buckman Well field, could perhaps provide a validation of this assumption.

Tb3:

The basalt of Black Mesa (Tb3) was dropped from the FY99 site-wide model. Recent age dating by WoldeGabriel indicates that the basalt located at Black Mesa is contemporaneous and can be included with the Cerros Del Rio Basalts (Tb4) (WoldeGabriel et al., in preparation). The three remaining occurrences of Early Pliocene basalt, observed in wells PM-2, PM-5 and O-1 are petrologically dissimilar, and absent in all other deep wells. These occurrences may represent large cobbles in ancestral, axial river gravels (probably the Rio Grande) which were carried downstream from source areas north of the site-wide model. The 1998 model description table provides details on the petrological differences of these similarly aged occurrences.

Tb4:

The FY99 model of the Cerros del Rio Basalts (Tb4) provides only slight modification to the FY98 model as described in the model description table. The major differences include more-exact matching of drill hole data (including new data from drill hole R-15) and resolution of conflicts with other surfaces in which the top of Tb4 was constrained to be below Qbog and the bottom of Tb4 was constrained to be above Tb2. The apparent intersections that were removed in this process were most likely the result of complex depositional topographies, which were not adequately defined by the available data.

Tt1:

The FY99 model of the lower Tschicoma flows (Tt1) is a complete revision of earlier models and is based on subsurface projection of outcrop data from Griggs (1964), reassignment of Tschicoma flows in wells H-19 and TW-4 from Tt2 to Tt1, and in addition of outcrops of Tt1 at Cumbres Middle School and Pueblo Canyon, which were mapped this year by Giday WoldeGabriel (WoldeGabriel, 1999).

The mountains to the west of Los Alamos are composed of lower Tshicoma flows, and their surface is considered to represent the top of Tt1. This outcrop surface was projected eastward beneath the on lapping Puye and Bandelier units. The projected surface with added-modeled offsets representing post-depositional faulting within the Pajarito fault zone was forced to be consistent with the observed drill hole and outcrop elevations for Tt1.

Deposition of the Puye Formation was a result of the creation and erosion of the Tschicoma volcanic dome complex. The FY99 model assumes that the pre-Puye, pre-Tschicoma surface for the entire region of the site-wide model was gently dipping to the east. The base of Puye surface generated from the middle and eastern portions of the site-wide study area was therefore projected (with modeled fault offsets), into the western portion of the site. The base of Puye surface intersects the downward projection of the top of Tt1 at depth. The portion of the Puye surface intersected, beneath the top of Tt1, represents the pre-depositional surface and hence the bottom of Tt1.

Tt2:

The FY99 model of the upper Tschicoma flow(s) (Tt2) is based on only 4 occurrences of this unit: wells SHB-1, SIGMA MESA, TW-8 and PM-5. Reported occurrences in wells H-19 and TW-4 were reassigned from Tt2 to Tt1 based on new interpretations of the western Laboratory area. Nearby deep wells, which do not intersect Tt2 but intersect units stratigraphically below Tt2, include: O-4, PM-4, PM-2, DT-10, and DT-5A. These wells constrain the modeled extent of this unit in the east and south. Pre-existing Tt1 flows would have constrained the original extent of the flow(s) in the west and north. Therefore the flow(s) are modeled as pinching out against Tt1 in the north. The Tt2 flow has a fairly constant thickness of about 130 feet for the 3 drill holes in which thickness can be determined, and pinches out abruptly to the east, which may indicate some paleotopographic control of the flow distribution.

Tsfuv:

The exact nature of the hydrogeologic unit within the Santa Fe Group called the "Chaquehui" is unclear. This unit (Tsfuv) is seen only in well cuttings and is poorly distinguished from the local Tesuque Formation (Tsfu) of the Santa Fe Group (Tsf), except for the fact that it is the most productive aquifer for Los Alamos. The model treats this hydrologically important zone as a separate unit although the modelers suspect that the upper Santa Fe formation in the Los Alamos area consists of (from east to west) coeval Tesuque, Chaquehui, and Cochiti "facies" which reflect the mix of plutonic, Sangre de Christo detritus from the east; volcaniclastic Keres Group material from the west; and fluvial material from the north. The Chaquehui facies would contain significant proportions of both volcaniclastic fan deposits and fluvial material.

The Middle and Late Miocene basalt flows (Tb1, Tb2) are assumed to have been extruded onto pre-existing Santa Fe erosional/depositional surfaces during discrete time intervals. In almost all site-wide well cuttings, sediments intercalated with these flows have been identified as Chaquehui (Purtymun, 1995). Only in Well O-1 have intercalated sediments been identified as Tesuque (Tstu). For this reason, the modeled boundaries of Tsfuv incorporate all Tb1 and Tb2 flows except for a small flow modeled in the environs of O-1. The boundary of the Chaquehui could easily be extended eastward to encompass the O-1 basalt occurrence, as the assignment of Tsfu versus Tsfuv in well O-1 was probably somewhat arbitrary.

The control for the model is adequate in the north and central parts of the site-wide model to clearly define a major paleobasin (probably fluvial) that existed at the time of initiation of Tsfuv sedimentation. Definition of the basin axis to the south is less clear due to the lack of data and several options are available for continuation of the basin. The option that best fits the available control points is the most direct route to the south and agrees with basal Puye drainage flow directions of Dethier (1997). The base of Tsfuv rises steeply to the east from the basin axis and reflects canyon erosion or a possible fault scarp, or a combination of the two. A north-south trending divide is modeled to the west of the basin axis based on wells DT-5A, DT-9 and DT-10, which bottom out (TD) in Tsfuv and indicate the presence of a divide in the base of the Puye Formation (top of Tsfuv). Further to the west, there are no data and it is expected that the Chaquehui "facies" transitions to Cochiti formation (facies) which is uplifted and exposed in the Dome Lookout area to the southwest of the study area (Goff et al., 1990). Faults in the southwestern portion of the site-wide study area greatly complicate and compromise the validity of this portion of the model, which is based on minimal data.

Tp (Tpf/Tpt):

The base of the Puye Formation (Tp) is reasonably well defined in the central and eastern parts of the site-wide model by a combination of drill hole and outcrop data. The base of the Puye Formation mimics the morphology of the modeled base of the Chaquehui (Tsfuv) with a north-south paleodrainage (?) axis in the central and southern portions of the site-wide model. Extension of the paleodrainage to the north is not well defined by the line of G- and GR- wells in Guaje Canyon (which clearly defined the pre-Chaquehui paleodrainage), so the source of this drainage may be further to the east, perhaps influenced by Tb2 flows. New data from well R-25 support the modeled divide between this main paleodrainage and the Puye source area (Tt1 flows) to the west. Although the base of the Puye Formation is projected to the west edge of the site, Puye sediments would not have been deposited where the earliest Tschicoma flows (Puye source material) occur, or in uplifted regions of the Keres Volcanic center to the southwest.

There is an unresolved conflict in the FY99 model in the vicinity of the "Y" intersection of highway NM 4 and the Main Hill Road. Wells O-1 and TW-1 both contain Totavi Lentil (Puye) material. However, occurrences of Tb2 Basalt in well R-9, and in outcrop just north of the "Y" indicate a higher elevation for the base of the Puye Formation at those well locations. The basal Puye is modeled as lapping against the pre-existing Tb2 flows, resulting in a "hole" in the modeled basal Puye unit in this region in conflict with the existing data at O-1 and TW-1. Pre-existing drainage topography and/or faulting could be used to develop a more complex model, which would fit these two drill holes. Incorporation of new mapping of the Puye Quadrangle by Dethier (in press) may provide resolution to this inconsistency. Other holes in the modeled Puye surfaces occur within the southern portion of the Pajarito Fault system where Puye

materials may not have been deposited, and in the vicinity of White Rock Canyon where Puye is assumed to truncate against Tb4 Basalt flows.

The Puye Formation consists of fanglomerate material shed from the Tschicoma volcanic complex to the west, axial river gravels, and some lakebed sediments. Waresback (1986) proposes a Totavi "Formation" for the axial river gravels, and would restrict the Puye Formation to the marginally derived fanglomerate material of the Tschicoma volcanic complex. In the model, the axial gravels of the ancestral Rio Grande would have been deposited throughout the deposition of the Puye Formation and would interfinger with the fanglomerate material as well as Cerros del Rio Basalt flows. However, the basal portion of the Puye in most of the cuttings collected within the site has been mapped as Totavi Lentil (Tpt). Only in one well in Guaje Canyon and in some White Rock Canyon outcrops, is Puye Fanglomerate (Tpf) identified below Tpt. Due to the difficulty of portraying an interfingered Tpt surface, and in accordance with the current interpretations of well data, the Totavi Lentil (Tpt) is modeled as the base of the Puye Formation.

The modeled base of the fanglomerate portion of the Puye Formation (Tpf) was obtained by adding Tpt isopachs to the base of the Puye (Tpt). The model of Tpt isopachs in the FY99 model contains significantly more detail than previous models. In the past, due to the heterogeneity of reported thicknesses for these gravels (ranging from 0 - 160'), a simple model of smoothed, averaged thickness was adopted. For the FY99 model, an attempt was made to exactly contour (by hand), the highly variable measurements, biasing the contour trends in the direction of expected paleodrainage. For example, thick axial gravels measured (north to south) from wells GR-4 (130'), O-4 (98'), and PM-4 (120') lay within the trend of the pre-Puye paleodrainage, so contouring was biased to conform to this paleodrainage if the data would permit such an interpretation. Paleo-flow indicators (Dethier, 1997) support such an isopach model.

Qbo (Qbof/Qbog):

The modeled base of the Otowi Member of the Bandelier Tuff (Qbo) is based on a large set of well cutting and outcrop observations. This surface was carefully re-contoured for the FY99 model, incorporating new data and insuring consistency with well observations. Isopachs of the basal Gauje Pumice Bed (Qbog) were recontoured based on twelve well observations, and result in minor changes to previous models. The isopachs of Qbog were added to the base of Qbog (base of Qbo) to provide the base of the Otowi ash flow (Qbof). The contoured base of Qbog reflects most pre-depositional features such as the cinder cones associated with the Cerros del Rio basalts (Tb4). Projected Qbog surfaces onlap the Tschicoma flows (Tt1, Tt2) and the Bayo Canyon Basalt (Tb2) and are clipped by these surfaces.

Qct:

The modeled base of the rhyolite and sediments of the Cerro Toledo interval (Qct) is based on 11 well observations. While the basic trend of the surface is similar to earlier models, some local changes are quite significant. The maximum thickness of Qct for the FY98 model was restricted to 90 feet. The recent drilling results from R-25 (125' of Qct) confirm earlier results from SHB-1 (137' of Qct) and portray a much thicker unit (up to 50% thicker) for the southwest portion of the Laboratory.

Qbtt:

The modeled base of the Tshirege member of the Bandelier Tuff (Qbtt) is constrained by a large number of outcrop observations in addition to well data. The FY99 model represents a significant reworking of the FY98 contours, which were developed using the TIN option in Arc/Info. The FY98 contours were reworked to more closely follow the geologic observations and to provide a topographically more reasonable shape to the surface (i.e., the TIN contours were smoothed). The FY98 surface was extended in all directions: to the SE using data of Goff, et al. (1990) for the Dome Lookout area, to the NE, N, and NW based primarily on Griggs (1964), and to the SE based on Dethier (1997). In the SW, SE, and NW, the Qbtt was allowed to run higher than topography to reflect areas where the Bandelier Tuff is absent. In the SE, the surface was extended to reflect the trends of the paleo-Rio Grande. In the SW, the surface geometry was modified to reflect faulting mapped by Goff et al. (1990). In the north, the surface was modified to reflect faulting along the Rendija Canyon and Guaje Mountain faults and was run higher than topography in areas of Tschicoma outcrop. The final surface was created using Topogrid in Arc/Info with the contours as input and with hard constraints provided by 25 wells that penetrate the base of Qbtt. In addition, 6 wells that penetrate Qbtt were used to provide estimates for the base of Qbtt (assuming a uniform thickness of 3 feet for Qbtt).

Qbt1g:

The base of the Qbt1g was created from an isopach model for Qbtt. The new isopach model incorporates and earlier isopach model of Vaniman et al. (1996) as well as data from 25 wells that penetrate Qbtt. The resulting isopach model was smoothed and built into a surface using Topogrid. The Qbt1g surface was obtained by adding the Qbtt isopach to the base of the Qbtt unit.

Qbt1v:

The initial draft of the Qbt1v surface was created with the assumption that the thickness of Qbt1g was 50 feet. This contour coverage was modified by the available well data (30 points) and then further modified by hand contouring to honor the available outcrop data. One well data point was excluded: the contact elevation from 49-2901 is 100 feet higher than the adjacent CH-2 and indicates a thickness for the Qbt1g of 178 feet, which is greater than that in any other wells. In the final grid operations, the base of Qbt1v was forced to coincide with Qbt1g in the south (in the vicinity of the paleocanyon) and in the NW (in the vicinity of the Tshicoma outcrops) to be consistent with surface mapping.

Qbt2:

The base of Qbt2 was created as an isopach. The first draft of the isopach was created by allowing Topogrid to model the base of Qbt2 using all outcrop and well data as input. The resulting isopach map was modified to provide geologically reasonable extensions of the isopachs to the edge of the model area and to resolve conflicts among closely spaced data. In the final step, the base of Qbt2 was constructed in Topogrid with the isopach contours and the well data (44 points) as hard constraints.

Qbt3:

The base of Qbt3 was created from an isopach model for Qbt2. The isopach model was created using well data (17 data points), high-precision outcrop data (for the base of Qbt3 as referenced to the FY99 base of Qbt2: Gardner et al., 1999; Gardner et al., 1998 and outcrop data

from WoldeGabriel (1999) for the NW region. The isopachs were modified to extend to the model limits and to resolve conflicts between well and outcrop data.

Qbt3t:

Qbt3t was created from well data (21 points), high-precision outcrop data (Gardner et al., 1999) and outcrop mapping of WoldeGabriel (1999) north of the Laboratory within the town site. The resulting surface was subtracted from Qbt4 to create an isopach map. The isopach map was modified to extend to the limits of the Qbt4 outcrop area (i.e., Qbt3t only exists where Qbt4 exists) and to thin to zero thickness to the east. The modified isopach map was subtracted from Qbt4 to create a contour coverage for the base of Qbt3t and to use as input in Topogrid, along with well data and high precision outcrop data, to produce a final Qbt3t coverage. The well data include those of LANL (1998).

Qbt4:

The base of Qbt4 was created from well data (23 points, including 19 from LANL, 1998), high-precision mapping of Gardner et al. (1999), and surface mapping (WoldeGabriel, 1999). The resulting contour coverage was modified to resolve conflicts among data and limited by a model boundary for the extent of Qbt4 such that Qbt4 is not found in the eastern half of the model and does not occur along the northern edge of the model.

Qbt5:

The base of Qbt5 was created from an isopach model of Qbt4. The isopach model was created from a preliminary representation of the base of Qbt5 obtained in Topogrid using well data and surface outcrop data. The isopach model was extended to the limits of the Qbt4 surface (i.e., Qbt5 only exists where Qbt4 exists) and was further constrained so that Qbt5 does not occur much north of Los Alamos Canyon. The final surface was obtained from the isopach and was constrained with 14 well data points.

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