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Produced by the Canyons Focus Area for the
Analysis and Assessment Focus Area

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1.0 INTRODUCTION

Los Alamos National Laboratory (the Laboratory) is located approximately 35 mi northwest of Santa Fe, New Mexico, on the Pajarito Plateau, the expanse of deeply dissected Bandelier Tuff lying between the Jemez Mountains on the west and the Rio Grande on the east (see Figure 1.0-1). The preliminary hydrogeologic atlas for the Laboratory area comprises an unbound set of 25 maps and this report documenting the decisions made in their design and construction. More specifically, this documentation describes the intended purpose and scope of the atlas, describes the data used in its preparation, gives the specifications for the various maps included in the preliminary version, and discusses its availability.

1.1 Purpose of the Atlas

"Hydrogeology" has been defined as "the science that applies geologic methods to the understanding of hydrologic phenomena" (May 1976, 63988). Hydrogeologic studies are critical to the environmental restoration (ER) efforts at the Laboratory; therefore, hydrologists, modelers, and environmental scientists at the Laboratory need various kinds of geologic information for their work. Maps showing the subsurface geology are especially useful in predicting drilling conditions, describing hydrostratigraphic units, formulating conceptual hydrogeologic models, and discretizing numerical models.

At least three types of subsurface maps are needed to minimally characterize the geologic setting of an area: one each showing structure (elevation) at the top, depth to the top, and thickness of major units (Stone 1999, 63990). Additionally, maps showing water levels and the geology at the regional piezometric surface help the user conceptualize the hydrologic system and identify data gaps. Both geologic and hydrologic maps support groundwater-modeling efforts.

The purpose of the hydrogeologic atlas is twofold. First, the amount of previous geologic work done at the Laboratory is considerable, but the results are scattered in numerous reports. A preliminary three-dimensional (3-D) sitewide geologic model for the Laboratory area was constructed in 1996 (Vaniman et al. 1996, 63991) to evaluate and integrate the available data, as well as support visualization and modeling activities. Although the 3-D model is available in electronic form and thus is compatible with modeling needs, it is difficult to provide hard-copy 3-D visualizations; therefore, traditional two-dimensional (2-D) paper maps are needed. Second, many ER activities at the Laboratory require the formulation of a sound conceptual hydrogeologic model. The hydrogeologic atlas was developed to serve as the basis for a single, consistent conceptual hydrogeologic model for the Pajarito Plateau.

1.2 Scope of the Atlas

The preliminary atlas includes a topographic map of the Laboratory area; a thickness map for the Tshirege Member of the Bandelier Tuff; a series of three maps (structure, depth, and thickness) for each of seven underlying geologic units (see Figure 1.2-1); a regional piezometric surface map; and a geologic map drawn at the regional piezometric surface. (There is only one map for the Tshirege Member of the Bandelier Tuff because that stratigraphic unit lies at or very near the surface; therefore, structure would be the same as topography and depth would be essentially zero.)

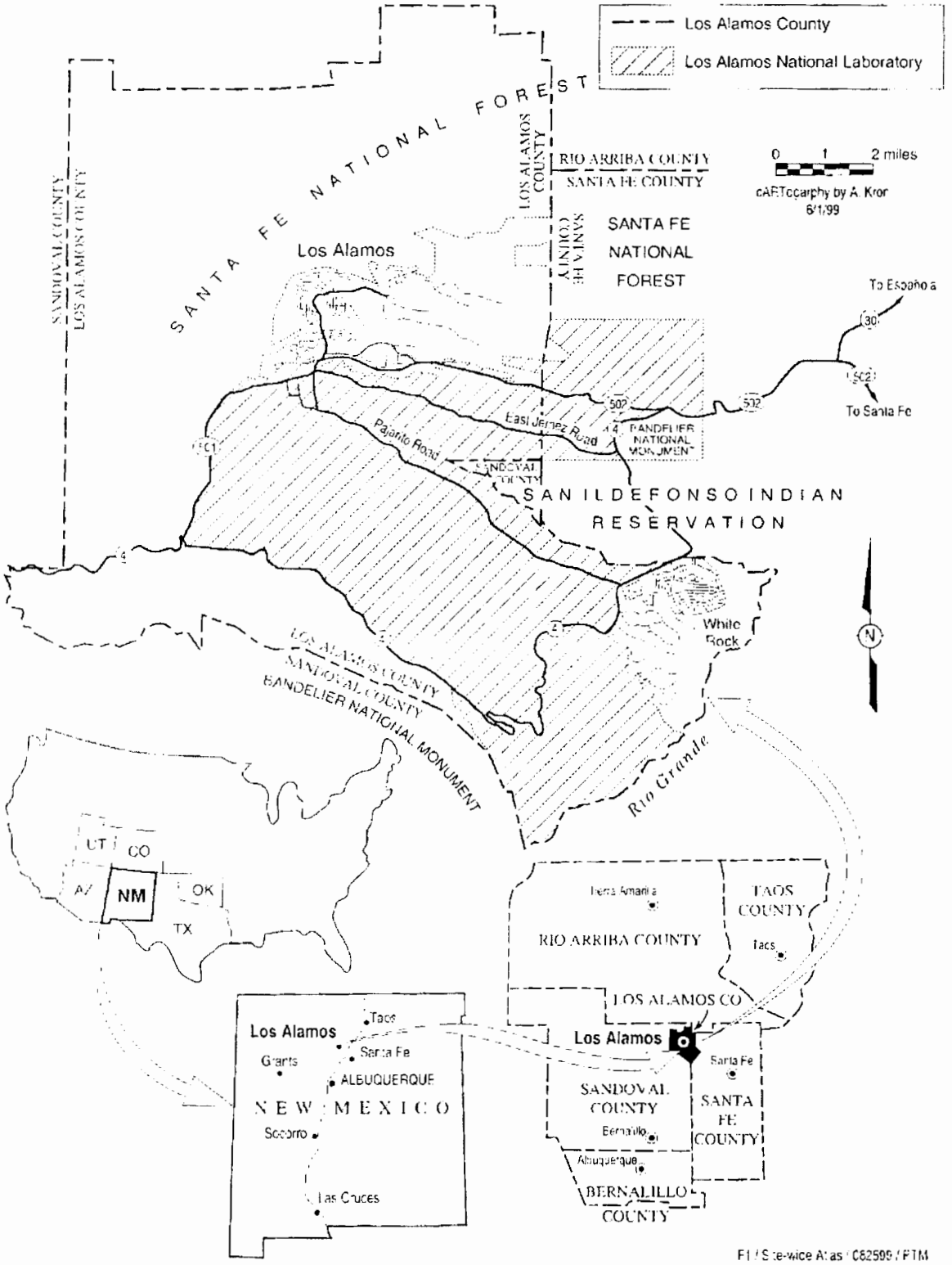


Figure 1.0-1. Location of Los Alamos National Laboratory

Preparation of such an atlas requires that limits be set on space, time, and detail. In terms of limiting space, there must be geographic boundaries. Because the subsurface geologic maps are based on data in the 3-D geologic model, the model boundaries become the atlas boundaries. The atlas is thus limited to the Laboratory and its immediate vicinity. In terms of limiting time, only data already in the Laboratory's 3-D geologic model (1998 version) were used. Thus, geologic and regional water-level data for characterization wells R-9 and R-12 are included, but data for R-15 and R-25 are not (except water level for R-25). However, like the geologic model, the atlas is in electronic form, and the maps will be updated annually as new data warrant and become available. In terms of limiting detail, the initial atlas includes maps for only the basic geologic units (see Figure 1.2-1). That is, the formal members of the Bandelier Tuff are included, but not the various subunits within those members as recognized at the Laboratory. Plans to expand the atlas to incorporate such additional information are discussed in Section 5.0, Further Work.

2.0 GEOLOGIC DATA USED

Modeling stratigraphic units at the Laboratory is difficult because the geologic framework of the Pajarito Plateau is complex. A given stratigraphic unit may contain other stratigraphic units or subunits. For example, the Puye Formation includes the Totavi Lentil and intertongues with both the Tschicoma Formation and Cerros del Rio basalt.

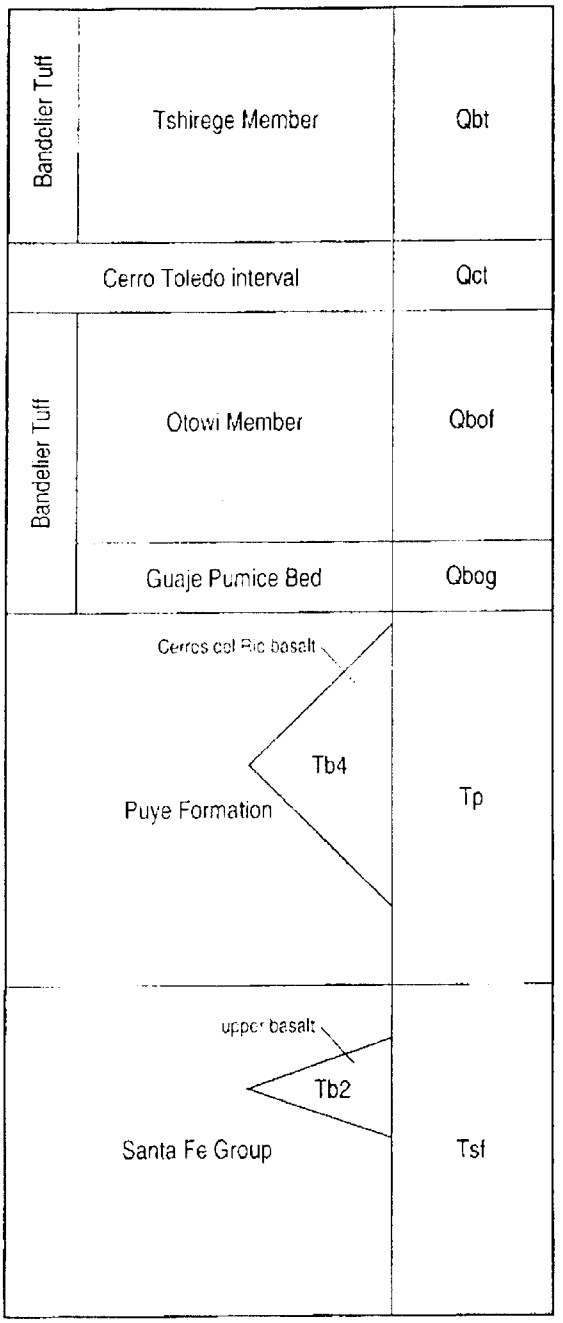
Stratigraphic units covered by this preliminary atlas include the Tshirege Member of the Bandelier Tuff; the Cerro Toledo interval; the ash flow unit in the Otowi Member of the Bandelier Tuff; the Guaje Pumice Bed in the Otowi Member; the Cerros del Rio basalt; the Puye Formation (including the Tschicoma Formation and Cerros del Rio basalt); the upper basalt of the Santa Fe Group; and the Santa Fe Group proper (see Figure 1.2-1).

2.1 Source

A considerable amount of geologic information for the Laboratory area has been collected over the years from outcrops as well as from various observation, test, and water-supply boreholes. Geologic maps exist for different areas at different scales. Purtymun (1995, 45344) compiled most of the subsurface data from Laboratory boreholes and wells.

Laboratory geologists have reviewed and synthesized existing information into the 3-D sitewide geologic model (Vaniman et al. 1996, 63991). The model is the result of integrated analysis of field mapping and borehole logging over the past 40 years. The 1998 version of the sitewide geologic model (Cole et al. 1998, 63987) provides the information that is contoured on the subsurface geologic maps in the preliminary atlas. That reference should be consulted for geologic data associated with specific wells shown on the subsurface maps in the atlas.

The geologic model consists of stratigraphic surfaces (bases or lower contacts) of volcanic and sedimentary units and subunits of regional extent as well as geologic surfaces (tops and bottoms) of localized volcanic flows or sedimentary packages of limited extent. The preliminary atlas portrays 8 of more than 20 modeled surfaces, focusing on major stratigraphic units, especially those of potential hydrologic significance.



F2 / Site-wide Atlas / 082799 / FTM

Figure 1.2-1. Geologic units used in the preliminary hydrogeologic atlas

2.2 Quality

The sitewide model has evolved and improved over the past four years, reflecting the enlarged information base as well as improved data-analysis techniques. The current model exhibits the application of a mix of computer-modeling methods, with knowledge-based bias and intervention supplied by the geologic staff, where appropriate. Additional information about the 3-D geologic model is available in internal Laboratory reports by Cole et al. (1997, 59974; 1998, 63987).

The quality of the geologic data used in the atlas is dependent upon the available geologic control. For some areas, densely spaced, high-quality data allow for a very accurate rendition of geologic conditions. For other areas, data are sparse and of lower quality so that the model is more schematic. In addition to the wells shown as control points on the subsurface maps, there are surface control points (outcrops) that are not shown in the atlas. However, these are clearly used and available in the sitewide model.

3.0 HYDROLOGIC DATA USED

Various kinds of hydrologic observations have also been made at the Laboratory over the years. Some of these are included in the report by Purtymun (1995, 45344). Other observations were published in various reports by the US Geological Survey.

3.1 Source

The only hydrologic parameter presented in this initial version of the atlas is water level. Most of the data used are from the Laboratory's Water Quality and Hydrology Group's (ESH-18's) water-level network for 1996. The source of other water-level data used is discussed in Section 4.6, Map of the Regional Piezometric Surface. Efforts are under way to construct a database for hydrogeologic information from the Laboratory area, and as other types of data are compiled into the database, they will be incorporated in updates of atlas maps.

3.2 Quality

The 1996 water-level data used were collected using transducers in accordance with the ESH-18 standard operating procedure, Pressure Transducer Installation, Removal and Maintenance (December 1998). The measurement intervals range from yearly to hourly, depending on the well. The 1991 data (used for the LA series wells) were collected by means of a steel tape or electric sounder using standard methods.

4.0 MAP SPECIFICATIONS

Several design decisions were made to facilitate the usefulness of the atlas:

1. All the maps are presented on the same base, thus eliminating the need for the user to adjust to different scales or reference information for the different parameters.

2. Each of the three types of subsurface geology maps is contoured in its own unique color so the user can readily identify the kind of map being viewed. That is, the contours on all the structure maps are purple, those on all the depth maps are green, those on all the thickness maps are red, and those on the water-level map are blue.

3. Labels for the wells from which information was used on a particular map, as well as that information, are printed in the same color as the contours so they may be readily located.

The jagged or angular nature of the contours in places is an artifact of the technique used to develop the geologic surfaces in the sitewide geologic model. Some surfaces are represented by triangular irregular networks (TINs) rather than by interpolated surfaces generated through techniques such as kriging or inverse-distance weighting. The TIN model provides a faceted (multi-planar) surface. Contours of such surfaces are composed of straight-line segments, each representing the crossing of an inclined triangular surface (i.e. linear interpolation of the triangular vertices). The TIN model is useful if there are discontinuities in the surface, such as faults or paleocanyons, because internal breaklines for the surface can be specified.

4.1 Base Map

The design of the base map involved considerations of convenient map size and inclusion of sufficient familiar features to ensure that users can readily orient themselves. A convenient map size was assumed to be one that would fit on an ordinary desk yet be large enough to present available data and be easily read. The scale selected,1:36,000, provides for such a map size. To permit easy orientation, major roads, townsites (residential streets), drainages (canyons), major faults, and the wells for which data exist in the 3-D geologic model are shown. The state-plane-coordinate system is also provided for reference.

Data from two basic sets of wells were used in constructing various maps in the atlas. One set includes the wells from the 3-D geologic model used for the subsurface maps. The other set includes the wells for which there are regional water levels as used for maps of the piezometric surface and of the geology at the piezometric surface. Both sets are also shown on the topographic map for reference. The legends of these maps show how the two types of wells are denoted.

4.2 Topographic Map

A topographic map of the Laboratory is included for three reasons. First, it shows the familiar geomorphic features and thus facilitates orienting the user on the plateau. Second, it is the best way to determine whether a given well of interest is on a mesa or in a canyon. Third, it complements all the other maps that strictly show characteristics of geologic units lying some distance below the ground surface. Data that are used come from the 1-ft digital elevation model, created by Greg Cole from the digital contour results of the ER aerial survey conducted in 1991 by Merrick and Company. The contour interval is 50 ft.

Comparing a given subsurface map with the topographic map enables the user to locate outcrop areas. For example, if elevations on the structure map for a given geologic unit are the same as those on the topographic map in the same area, the unit is cropping out there.

4.3 Structure Maps

The structure maps show contours for the elevation of the top of the major rock units, based on the best information available as of the date of the atlas. Data for the structure maps come from the elevations of geologic contacts in the 3-D geologic model. The contour interval is 100 ft for all of the structure maps.

Most of the maps show a general easterly decline in elevation of the top of the subject unit. This is generally a reflection of deposition on an east-sloping surface rather than tectonic dip. Structure contours are closely spaced in some areas because of faulting or paleotopography. Where this occurs in the western part of the map, it is a reflection of the Pajarito fault scarp. In the southeast, closely spaced structure contours represent the presence of a paleocanyon.

4.4 Depth Maps

The depth maps show the contours for the distance below the ground surface to the top of the major rock units, based on the best information available as of the date of the atlas. Data for the depth maps come from subtracting the elevation of the top of the unit from the ground-surface elevation at the well site. The contour interval is 200 ft for all depth maps.

Because depth depends on topography (units are deeper beneath mesas and shallower beneath canyons), the contours mimic those on the topographic map.

4.5 Thickness Maps

The thickness maps show contours of the drilled thickness of major rock units, based on the best information available as of the date of the atlas. Tectonic dip is presumed to be minimal, and no attempt was made to correct for it. Data for the thickness maps come from subtracting the elevation of the top of the underlying unit from the elevation of the top of the target unit. Thickness varies from unit to unit; therefore, the contour interval varies from map to map.

Thickness shown is a result of original depositional thickness, minus any removal of the unit by post-depositional erosion. Thus, areas of greater thickness are places where either more material was originally deposited or less material was removed by erosion before deposition of the overlying unit.

As would be expected, wells do not fully penetrate the deepest geologic unit covered by the atlas (the Santa Fe Group), and contouring thickness is inappropriate. Nonetheless, the partial thicknesses observed are minimum values and provide useful information. Thus, values are given for this unit on Map 23 but they are not contoured.

4.6 Map of the Regional Piezometric Surface

The water-level map shows contours for the approximate elevation of the top of the regional saturated zone (the piezometric surface). Such water levels were determined in wells tapping the deep regional aquifer in the Laboratory area, based on the best information available as of the date of the atlas. The map is essentially a modification of as-yet-unpublished mapping by W.D. Purtymun and S.G. Mclin in 1998 for Los Alamos County water-resource purposes. The main modifications include the extension of their contours to the Guaje Canyon wells; the use of 1991 data for the LA series wells to permit contouring in that area; the use of river elevations to control contouring there; and the addition of the R-9, R-12 and R-25 (1998) data.

Data from the White Rock Canyon springs were not used in the water-level mapping because the springs are elevated above the Rio Grande and are believed to yield water that has become perched above the regional zone of saturation. This may be due to some upgradient splitting of the regional groundwater flow around the Cerros del Rio basalt resulting in discharge at both spring and river positions (Stone 1996, 63989).

Ideally, a regional water-table map depicts the elevation of the top of the unconfined saturated zone, and a potentiometric surface map depicts the elevation to which water will rise in wells tapping a confined zone of saturation. Where the saturated zone is unconfined in one part of the area and confined in another, the more general terms "water-level" or "piezometric surface" are applied. In practice, however, water levels measured in wells do not precisely represent either the top of the saturated zone or the potentiometric surface but vary from them because of well depth and screen length.

Water level varies with well depth because of vertical hydraulic gradient. Groundwater moves from positions characterized by high hydraulic head to those of low hydraulic head. In groundwater-recharge areas, where the vertical gradient is downward, values of isopotentials (contours of equal hydraulic head) intersected by the well decrease with depth. Thus, the deeper the well, the deeper the water level. The reverse is true in groundwater-discharge areas, where vertical gradient is upward. In that case, the value of isopotentials penetrated by the well increase with depth: the deeper the well, the shallower the water level. Only in areas characterized by neither recharge nor discharge (i.e., isopotentials are vertical and thus parallel to the wells) is the same water level obtained regardless of well depth.

Water level varies with screen length because the screen length determines how many isopotentials the well is open to. The best water-level data are obtained in tubes open only at the bottom (piezometers) because they interrogate head at only a single point. In contrast, the water level obtained from any well with a screen is a composite of all the heads in the interval the well is open to. Although water-level data from wells with short screens are better than those from wells with long screens, they are still composites. The wells used for the piezometric surface map are those tapping the deep aquifer. Most such wells are part of the water-supply system and have very long screens to optimize production. Thus, water levels obtained in them are composite values.

As groundwater moves generally perpendicular to water-table or potentiometric contours, water-level maps are commonly used to evaluate flow direction. However, in view of the inadequacies discussed above, it should be obvious that such maps are only approximations. Therefore, decisions or calculations based on water-level maps can be misleading, and they should be used with caution. Nonetheless, the water-level map presented gives a general picture of the piezometric surface and of groundwater flow direction as conceptualized for the Laboratory area. Interestingly, it differs little from the often-cited map compiled by Purtymun (1984, 6513), except near the Rio Grande, because he used the White Rock Canyon springs to control placement of contours on the east edge of the map.

4.7 Map of the Geology at the Piezometric Surface

The map of the geology at the piezometric surface shows what stratigraphic unit is present at the top of the regional saturated zone or potentiometric surface at various places across the area, based on the best information available as of the date of the atlas. It was constructed by progressively intersecting surfaces for the top and bottom of each geologic unit covered in this preliminary atlas with the regional piezometric surface. The standard colors assigned to geologic units in the 3-D model are used on this map for consistency.

When the water table or potentiometric surface has a different slope than that of the associated geologic units, different units lie within the saturated zone at different places. As the slope of the water table beneath the Pajarito Plateau is steeper than the dip of most geologic units, saturated units are geologically older (deeper) in a downgradient direction. Knowing what material is saturated in an area facilitates the assignment of hydraulic properties to cells during groundwater modeling.

5.0 FURTHER WORK

The development of this atlas is scheduled to proceed in three phases:

1. construction of a preliminary version (documented here),
2. expansion of that version in FY 2000, and
3. annual updates thereafter.

Although the preliminary version has been described in previous sections of this documentation, a brief summary of the planned expansion and updates may also be of interest to atlas users.

The expansion will consist of the addition of things that could not readily be incorporated in this preliminary atlas, in view of data, time, or funding constraints. For example, the subsurface maps will be redrawn using the 1999 sitewide geologic model. Furthermore, subsurface maps were constructed only for the major geologic units, as they are the ones most frequently used in hydrogeologic work at the Laboratory. However, data also exist in the 3-D geologic model for many of the smaller subdivisions of these units. For completeness, structure, depth, and thickness maps should be constructed for them as well. A surface geologic map of the entire Laboratory area would be useful, but its construction necessarily awaits release of recent mapping of the Puye Quadrangle. Cross sections in selected areas would provide another perspective on the subsurface geology. Also, it would be useful to show the existing hydraulic property data, but this was deferred until these data have been compiled. Such compilation will be necessary for their input to the hydrogeologic database, and mapping should be easier once that has occurred. Addition of a stippled pattern to the piezometric surface map to indicate areas of known perched groundwater would also be useful. Such data are currently being compiled. Finally, the expansion will include the tasks necessary to make the atlas available on-line.

The 3-D geologic model and the atlas will be updated annually as necessary to incorporate data from new wells, especially those installed under the Hydrogeologic Workplan (LANL 1998, 59599). For example, if the new data change the 3-D geologic model, the subsurface maps must be modified. Similarly, the water-level map should be revised as new data points are added. Whenever the atlas is updated, the documentation will be revised as well. Only this version will carry the qualifier "Preliminary." Subsequent versions can be identified by the dates on the maps and revised documentation.

Obviously any improvements in the sitewide geologic model also improve the atlas. For the 1999 geologic model, the TIN surfaces are being reanalyzed in order to present more-realistic and visually appealing maps.

6.0 AVAILABILITY OF THE ATLAS

Hard copies of the preliminary atlas are being distributed only to those persons most actively involved in hydrogeologic work at the Laboratory (drilling wells, interpreting hydrologic data, modeling groundwater systems, overseeing environmental activities, etc.). Additional copies are available through the Laboratory's Facility for Information Management, Analysis, and Display (FIMAD).

To eliminate the need for FIMAD to plot large numbers of copies of the maps, the authors expect to eventually provide updated versions of the atlas through a web site. Use of a web site will allow for the presentation of additional data about the sitewide model, including the data set, visual presentations of the degree of fit for the data and model, geologic cross sections, and other information of interest.

The maps included in this preliminary atlas are listed below by map number, abbreviated title, and FIMAD plot identification number:

1. Topography (G107954)
2. Thickness of the Tshirege Member (G107955)
3. Structure on top of the Cerro Toledo interval (G107956)
4. Depth to top of the Cerro Toledo interval (G107957)

5. Thickness of the Cerro Toledo interval (G107958)
6. Structure on top of the ash flow unit, Otowi Member (G107959)
7. Depth to top of the ash flow unit, Otowi Member (G107960)
8. Thickness of the ash flow unit, Otowi Member (G107961)
9. Structure on top of the Guaje Pumice Bed, Otowi Member (G107962)
10. Depth to top of the Guaje Pumice Bed, Otowi Member (G107963)
11. Thickness of the Guaje Pumice Bed, Otowi Member (G107964)
12. Structure on top of the Cerros del Rio basalt (G107965)
13. Depth to top of the Cerros del Rio basalt (G107966)
14. Thickness of the Cerros del Rio basalt (G107967)
15. Structure on top of the Puye Formation (G107968)
16. Depth to top of the Puye Formation (G107969)
17. Thickness of the Puye Formation (G107970)
18. Structure on top of the upper basalt, Santa Fe Group (G107971)
19. Depth to top of the upper basalt, Santa Fe Group (G107972)
20. Thickness of the upper basalt, Santa Fe Group (G107973)
21. Structure on top of the Santa Fe Group (G107974)
22. Depth to top of the Santa Fe Group (G107975)
23. Partial thickness of the Santa Fe Group (G107976)
24. Regional Piezometric Surface (G107977)
25. Geology at the Piezometric Surface (G107978)

7.0 DISCUSSION

The paucity and scattered distribution of data are limiting factors in the preparation of both the 3-D geologic model and any 2-D maps derived from it. Thus, it should be recognized that the maps presented in the atlas are necessarily schematic. As the title of this document clearly states, this atlas is preliminary. However, the maps it contains provide an excellent opportunity to review the sitewide geologic model for the ultimate benefit of both 3-D and 2-D presentations.

8.0 ACKNOWLEDGEMENTS

The authors wish to acknowledge the ER Project for providing financial support for the development of the sitewide geologic model over the past four years and to thank ER Project's Analysis and Assessment Focus Area specifically for funding the construction of this atlas. The authors are also grateful to various members of the Ground-Water Integration Team for comments throughout the project. More specifically, David Broxton (Geology and Geochemistry Group [EES-1]) and Rick Warren (EES-1) were consulted on various geologic issues while Elizabeth Keating (Geoanalysis Group [EES-5]), Stephen McLin (ESH-18), and David Rogers (ESH-18) were consulted regarding available water-level data and maps. Holly Wheeler-Benson (Hazardous and Solid Waste Group [ESH-19]), William Carey (EES-1), Carl Gable (EES-5), Stephen McLin, Lars Soholt (E/ER), and Gene Turner (US Department of Energy [DOE]) provided peer reviews of this preliminary atlas.

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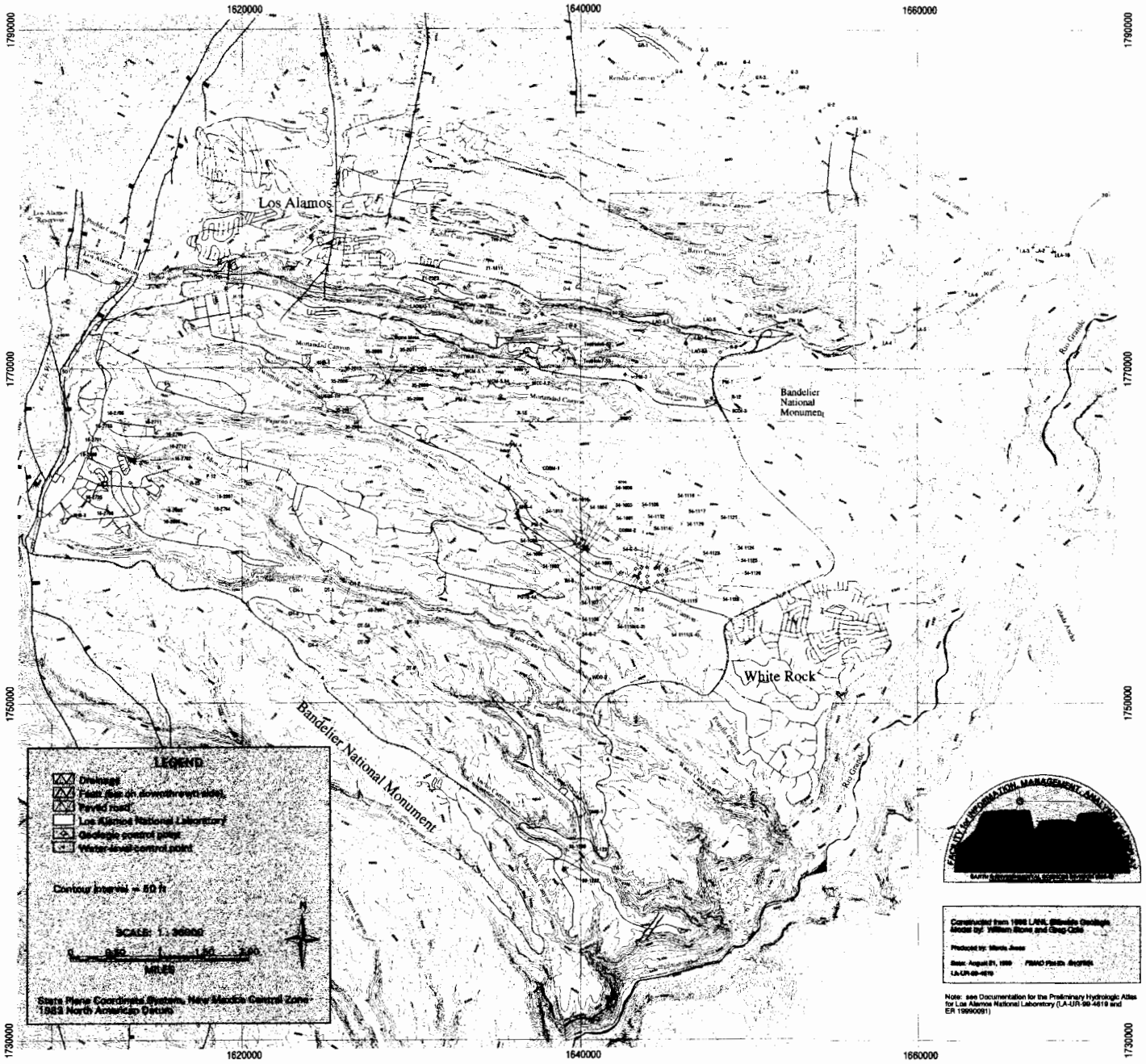
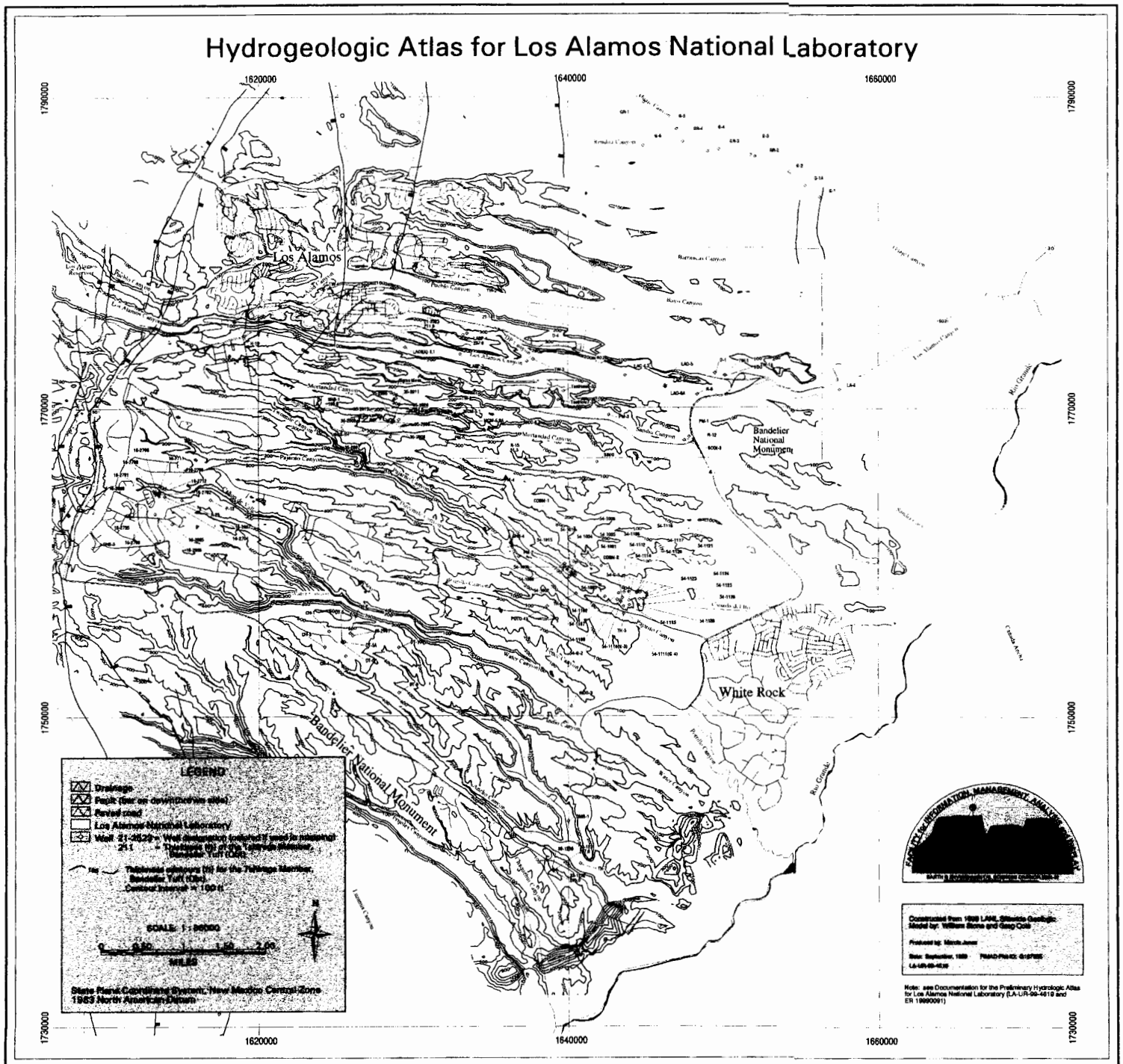
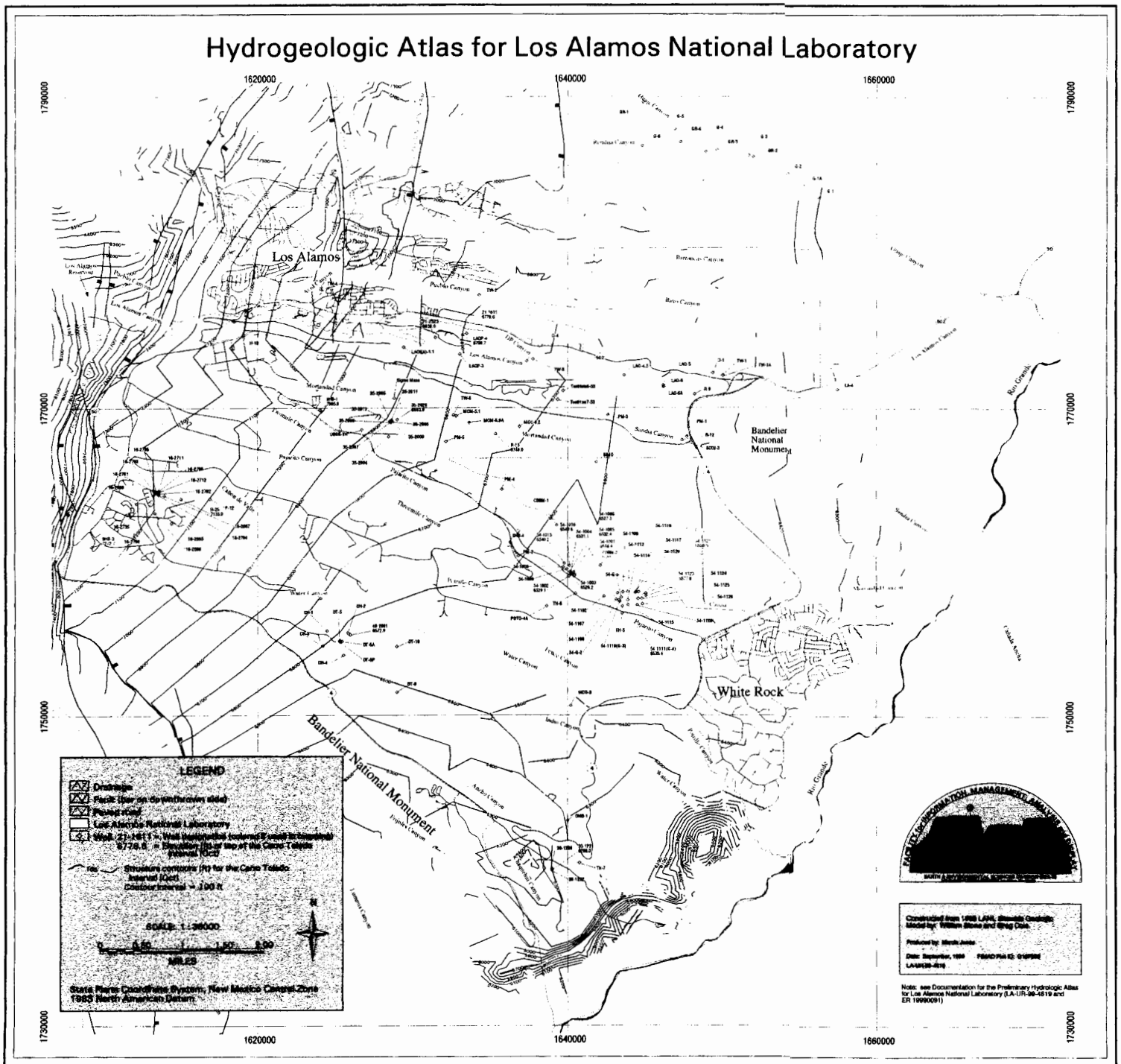
Hydrogeologic Atlas for Los Alamos National Laboratory



Map 1. Topography of the Los Alamos Area



Map 2. Thickness of the Tshirege Member, Bandelier Tuff (Qbt)



Map 3. Structure on top of the Cerro Toledo interval (Qct)

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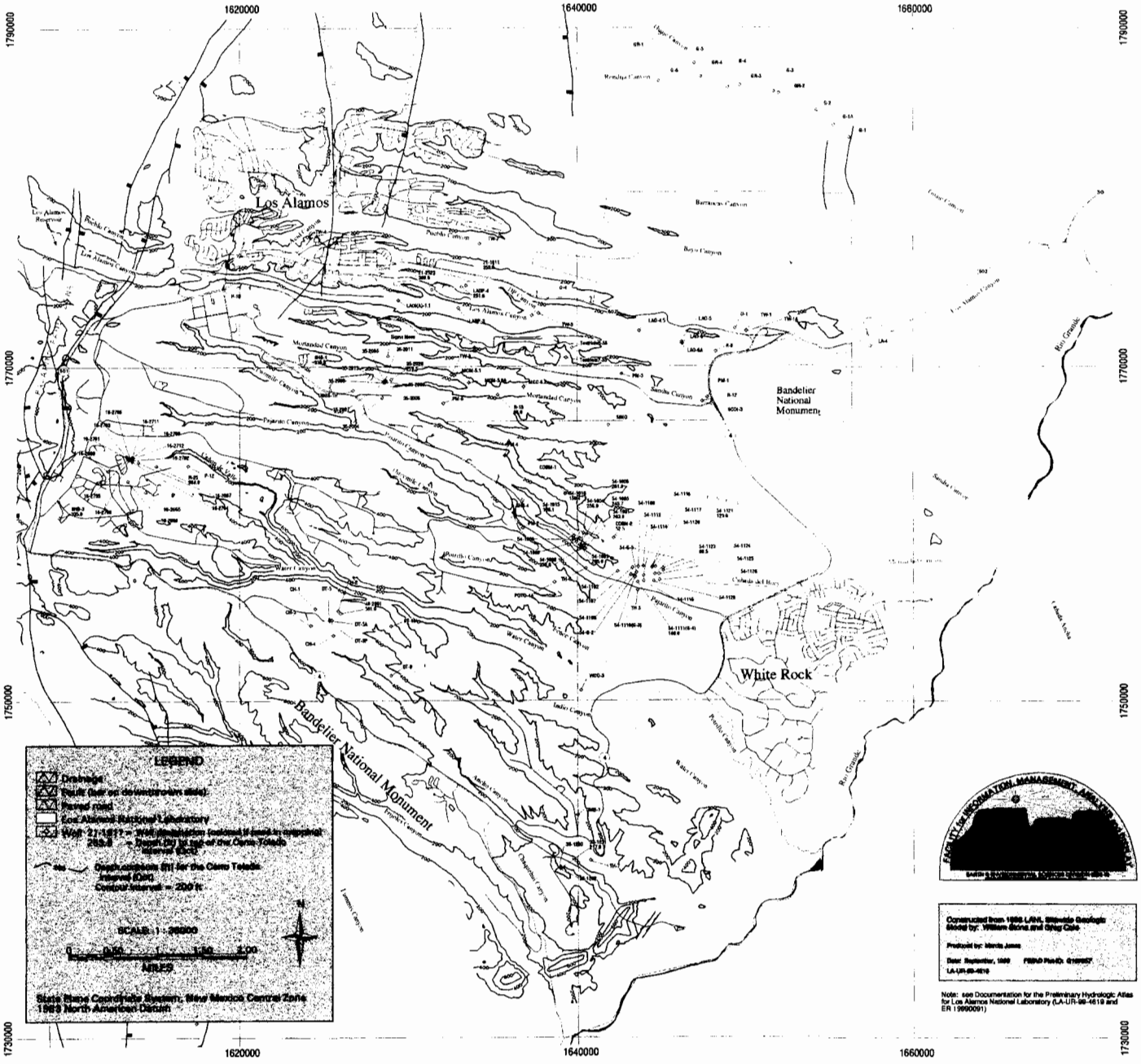
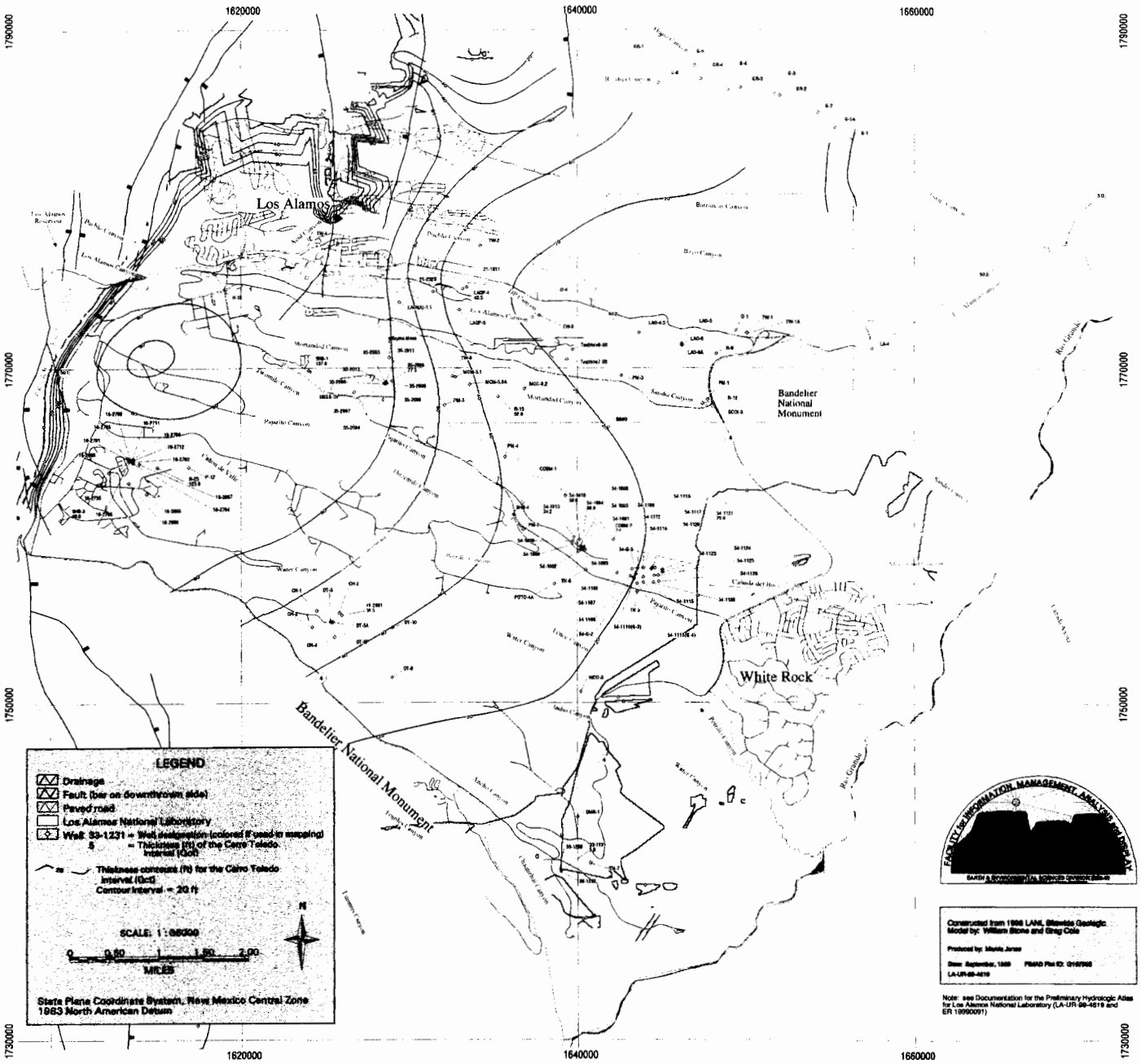
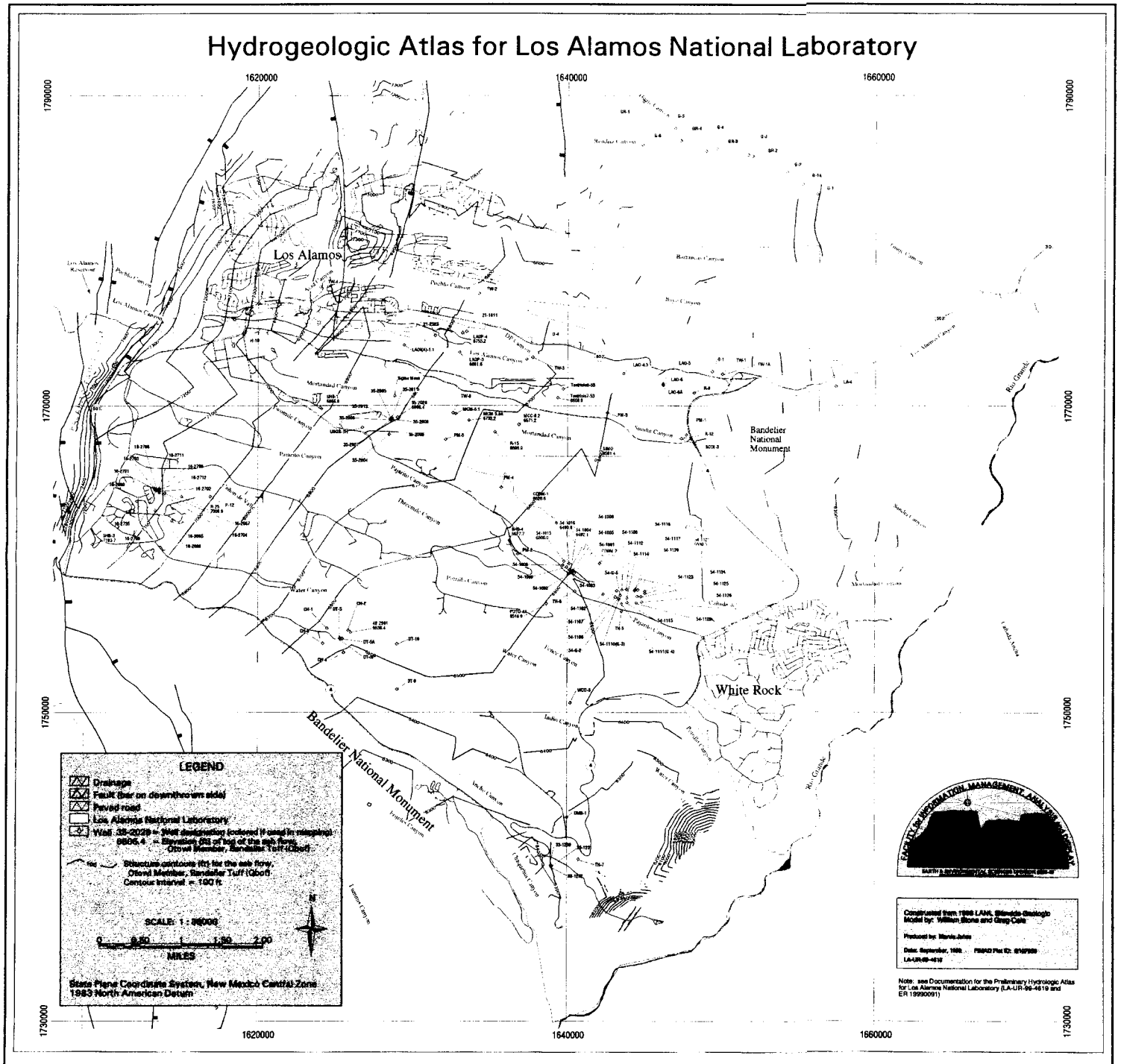


Map 4. Depth to top of the Cerro Toledo interval (Qct)

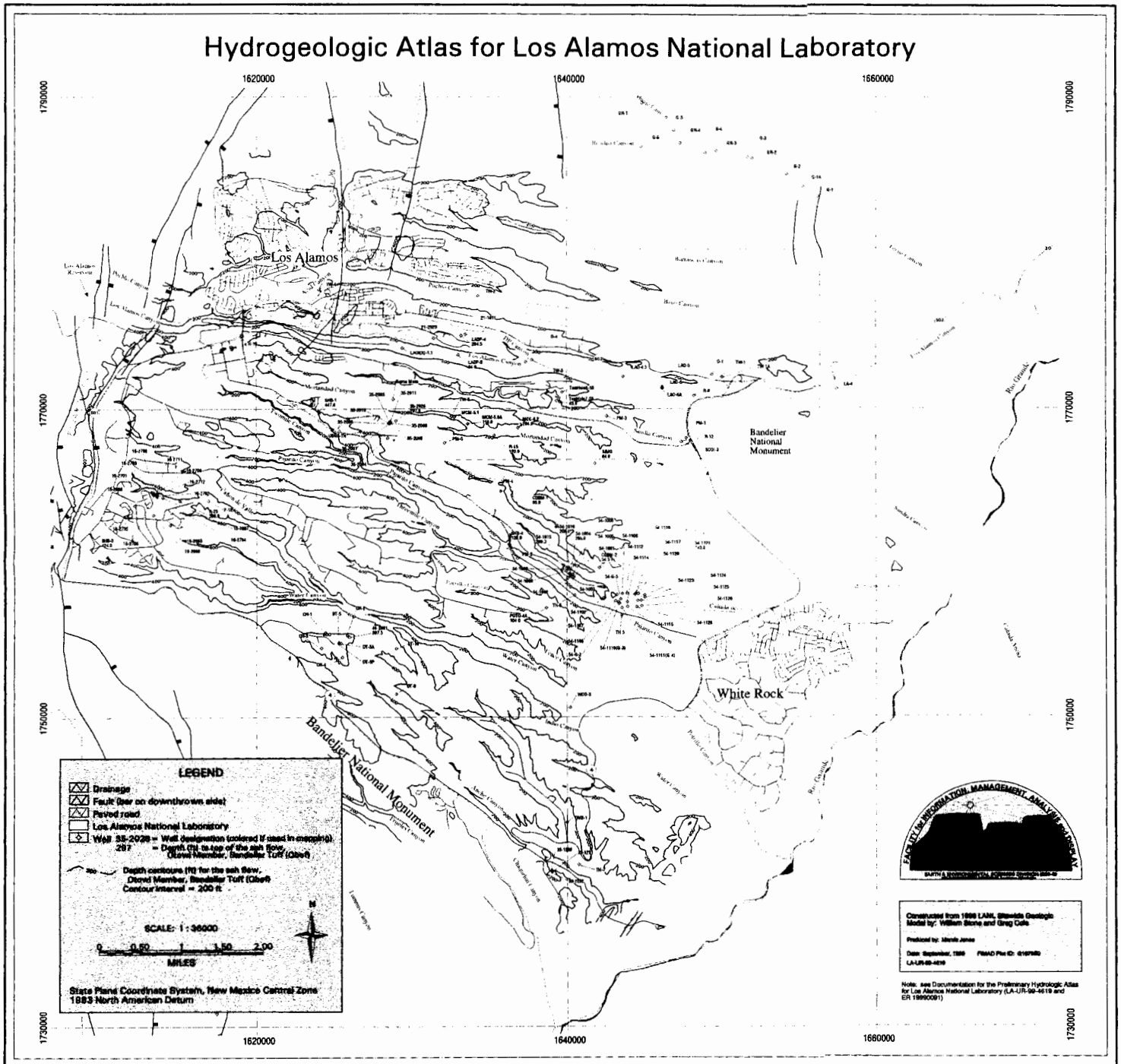
Hydrogeologic Atlas for Los Alamos National Laboratory



Map 5. Thickness of the Cerro Toledo interval (Qct)

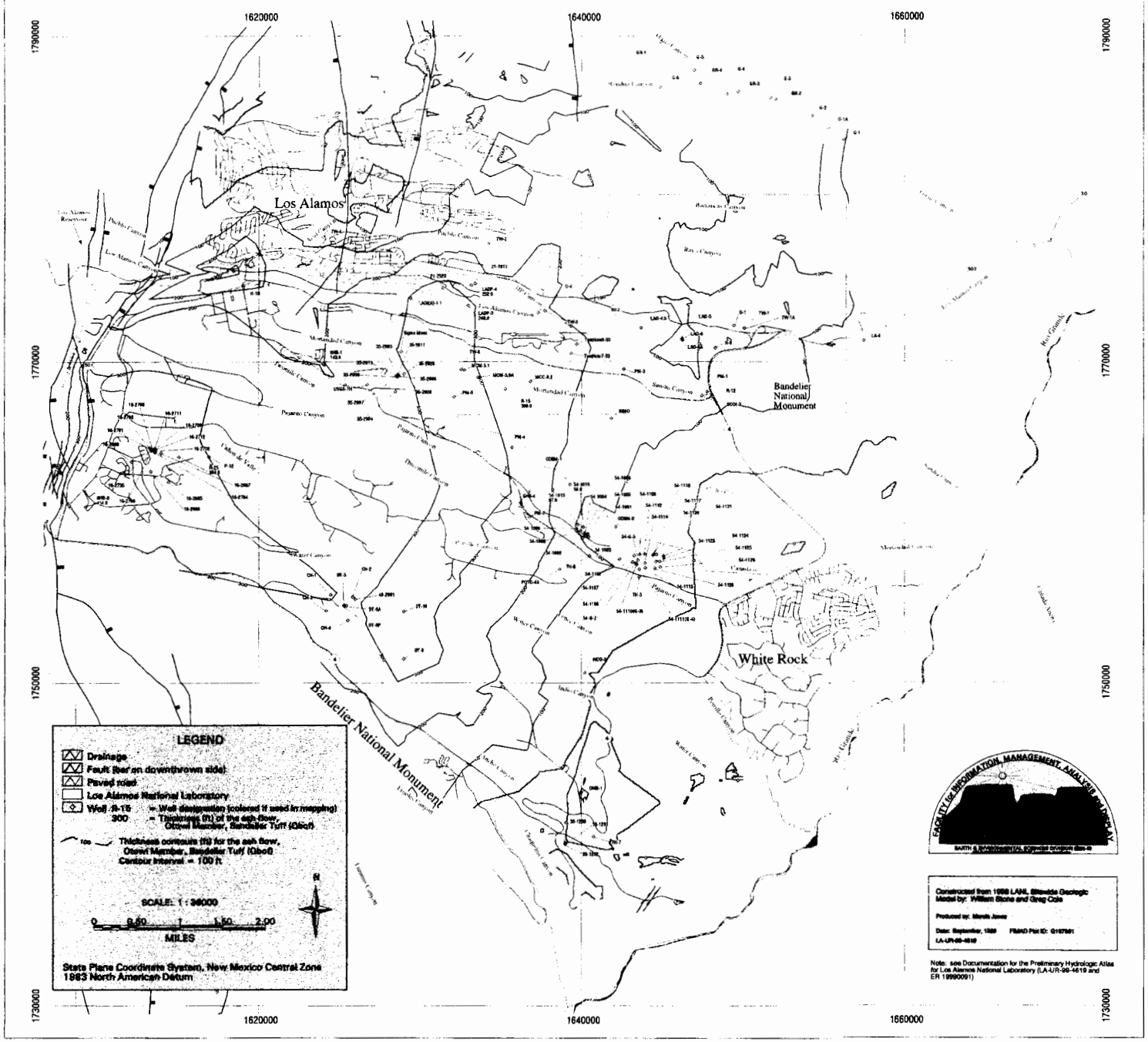


Map 6. Structure on top of the ash flow, Otowi Member, Bandelier Tuff (Qbof)



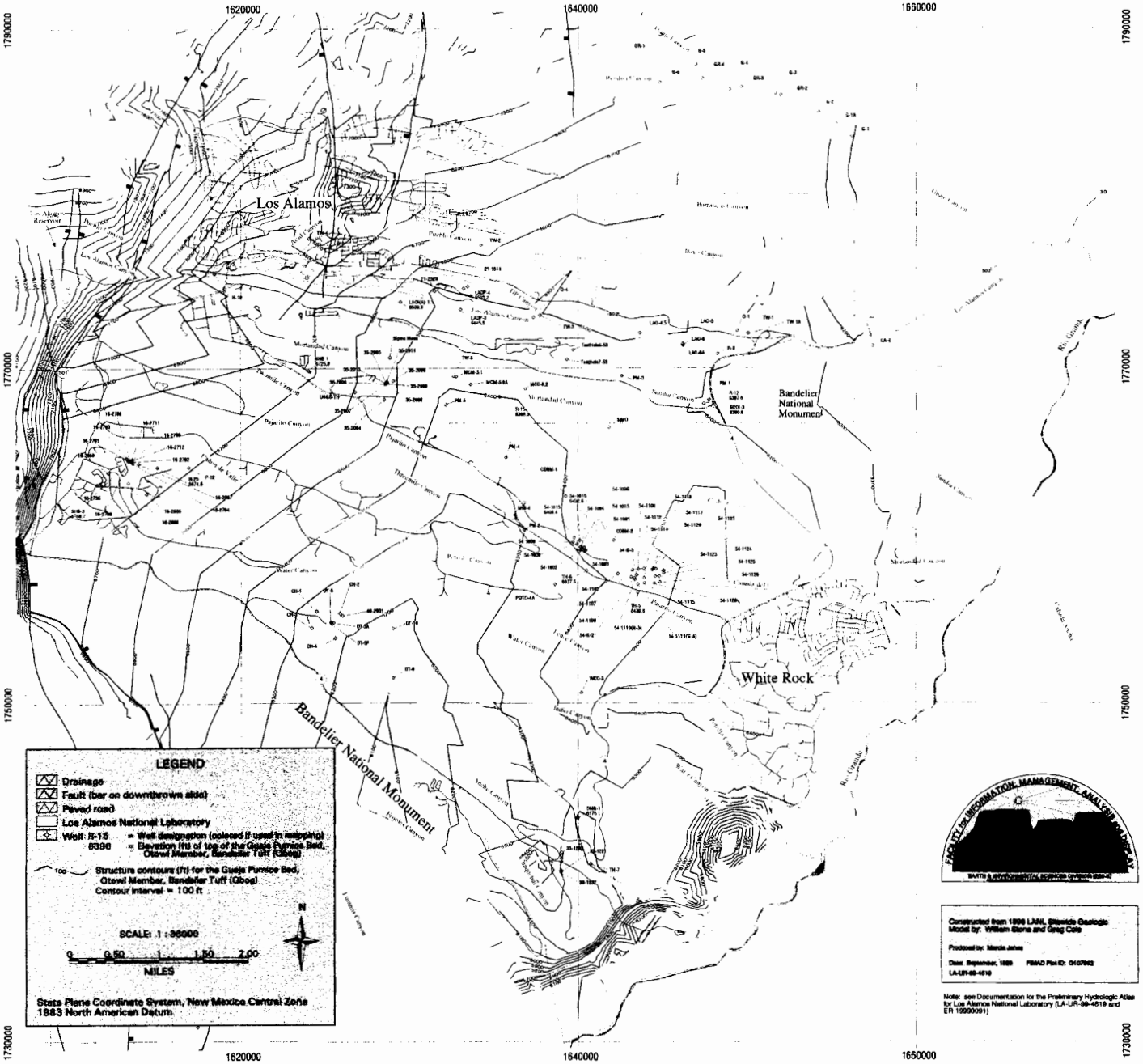
Map 7. Depth to top of the ash flow, Otowi Member, Bandelier Tuff (Qbof)

Hydrogeologic Atlas for Los Alamos National Laboratory



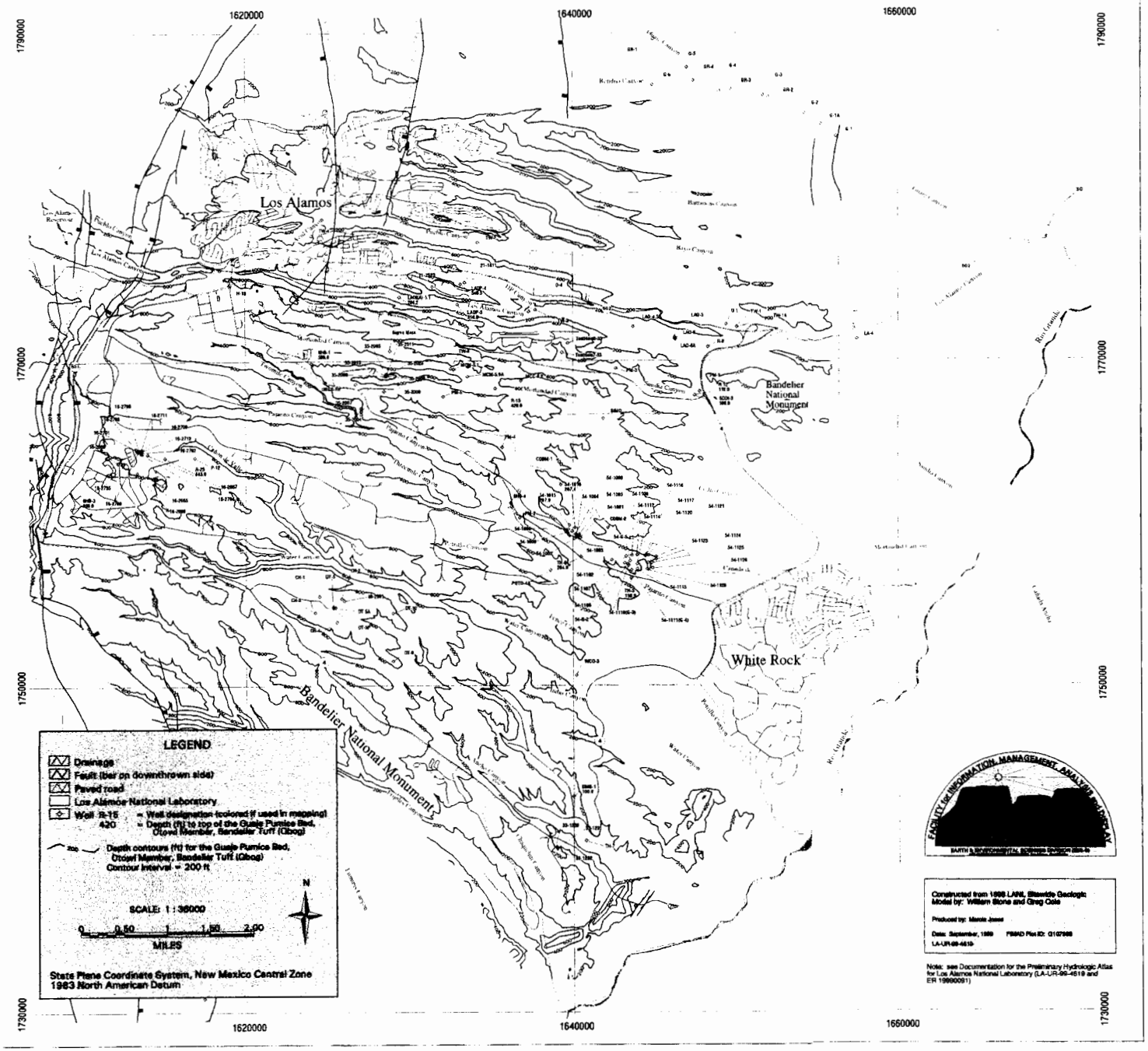
Map 8. Thickness of the ash flow, Otowi Member, Bandelier Tuff (Qbof)

Hydrogeologic Atlas for Los Alamos National Laboratory



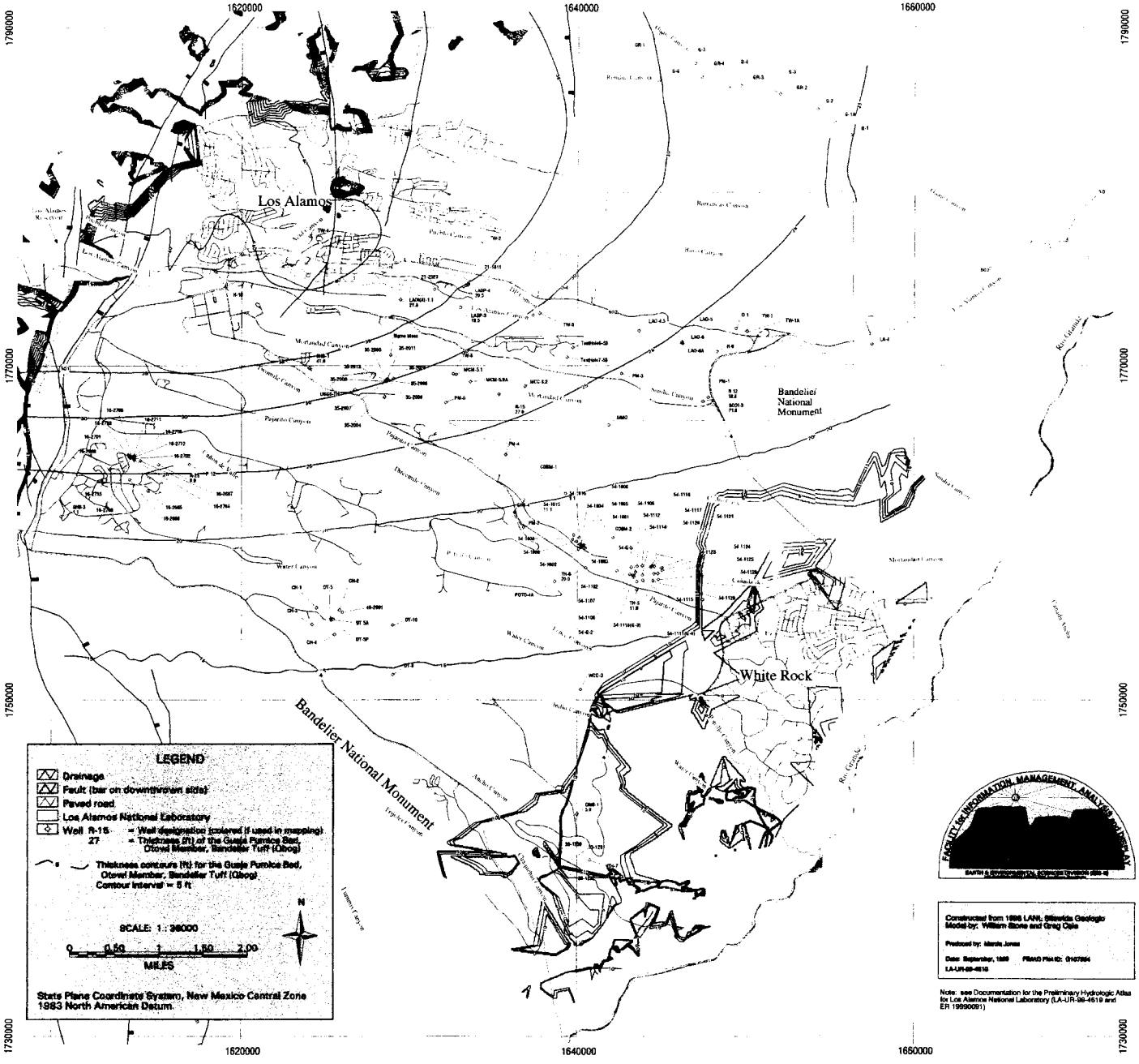
Map 9. Structure on top of the Guaje Pumice Bed, Otowi Member, Bandelier Tuff (Qbog)

Hydrogeologic Atlas for Los Alamos National Laboratory

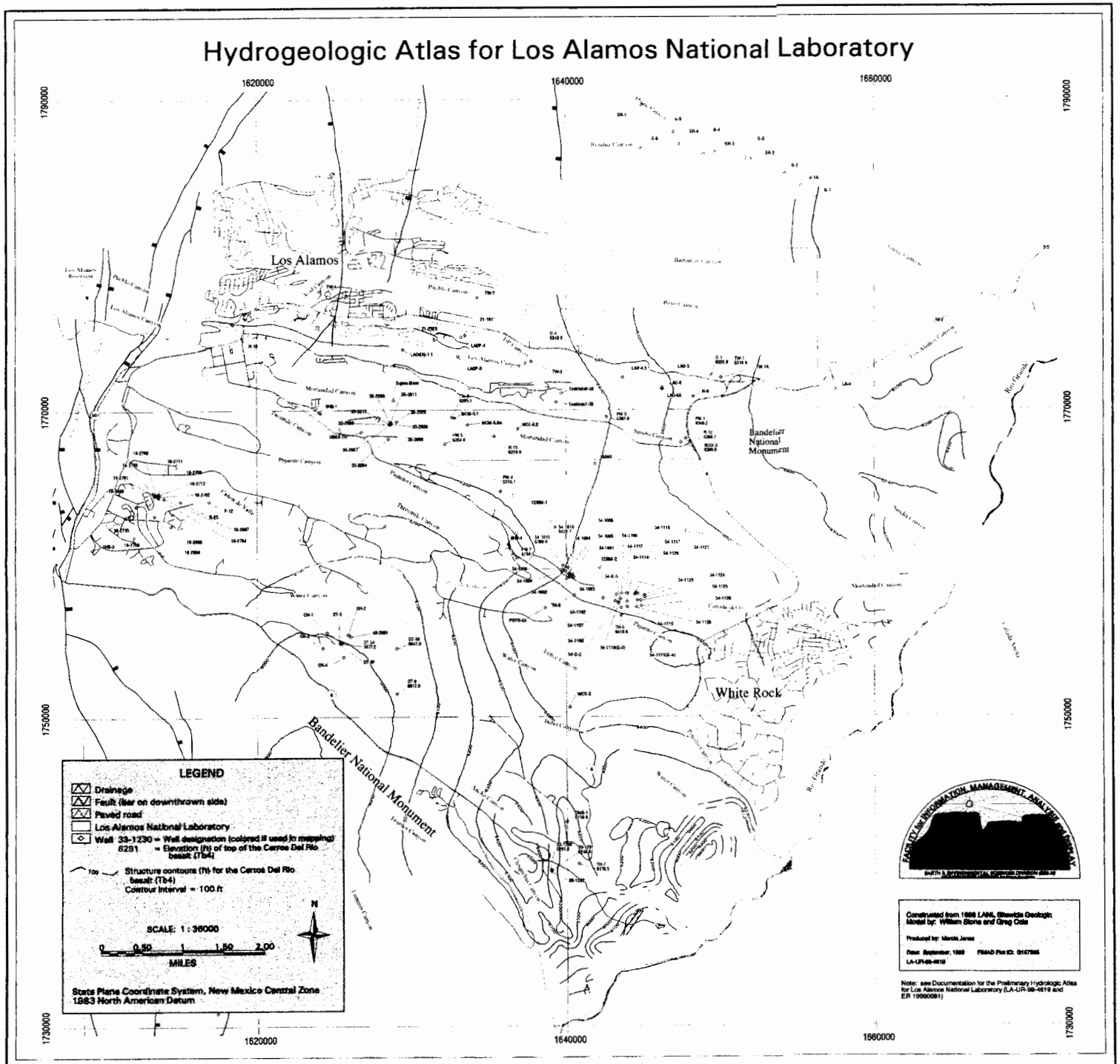


Map 10. Depth to top of the Guaje Pumice Bed, Otowi Member, Bandelier Tuff (Qbog)

Hydrogeologic Atlas for Los Alamos National Laboratory

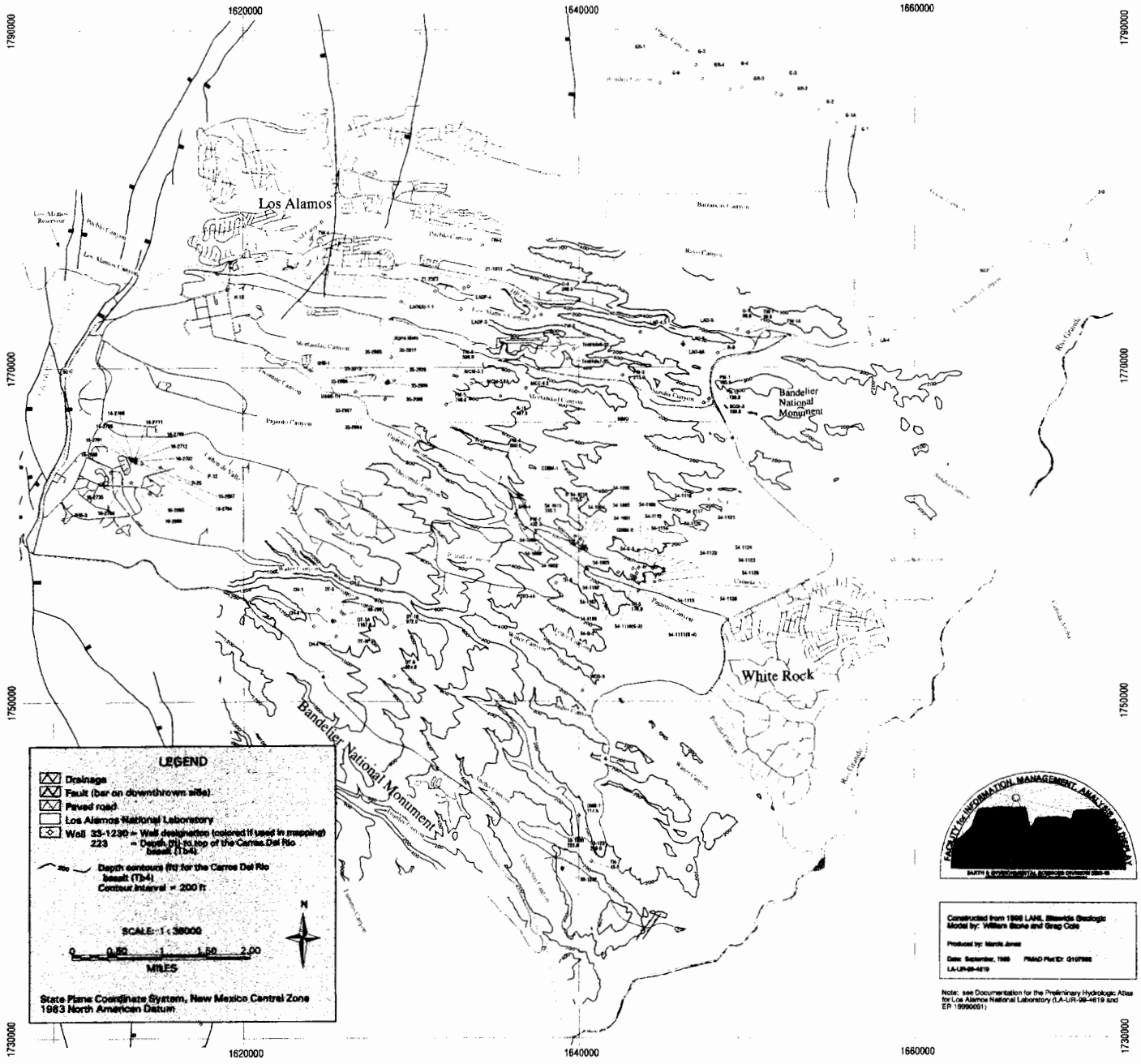


Map 11. Thickness of the Guaje Pumice Bed, Otowi Member, Bandelier Tuff (Qbog)



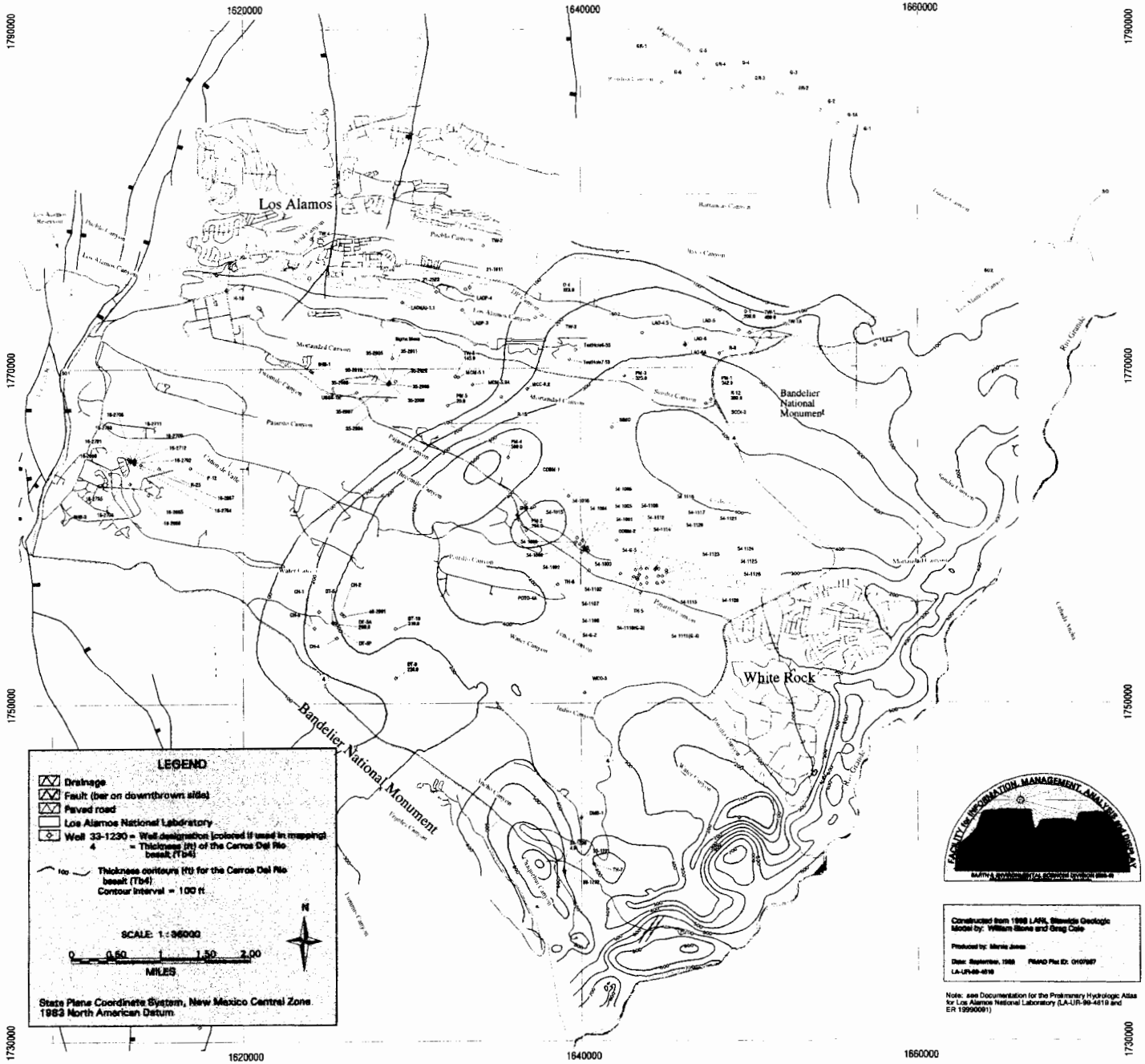
Map 12. Structure on top of the Cerros Del Rio basalt (Tb4)

Hydrogeologic Atlas for Los Alamos National Laboratory



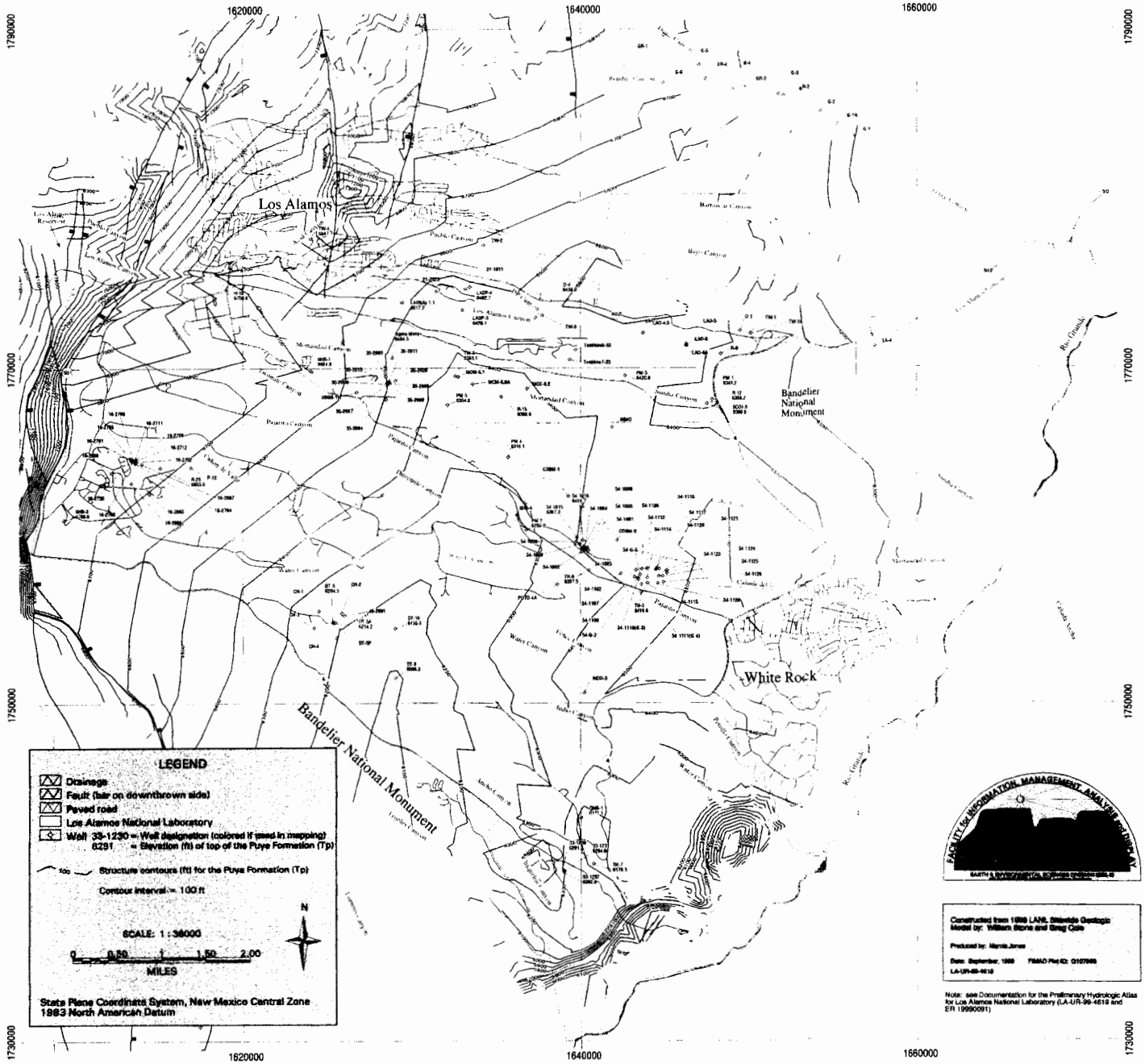
Map 13. Depth to top of the Cerros Del Rio basalt (Tb4)

Hydrogeologic Atlas for Los Alamos National Laboratory



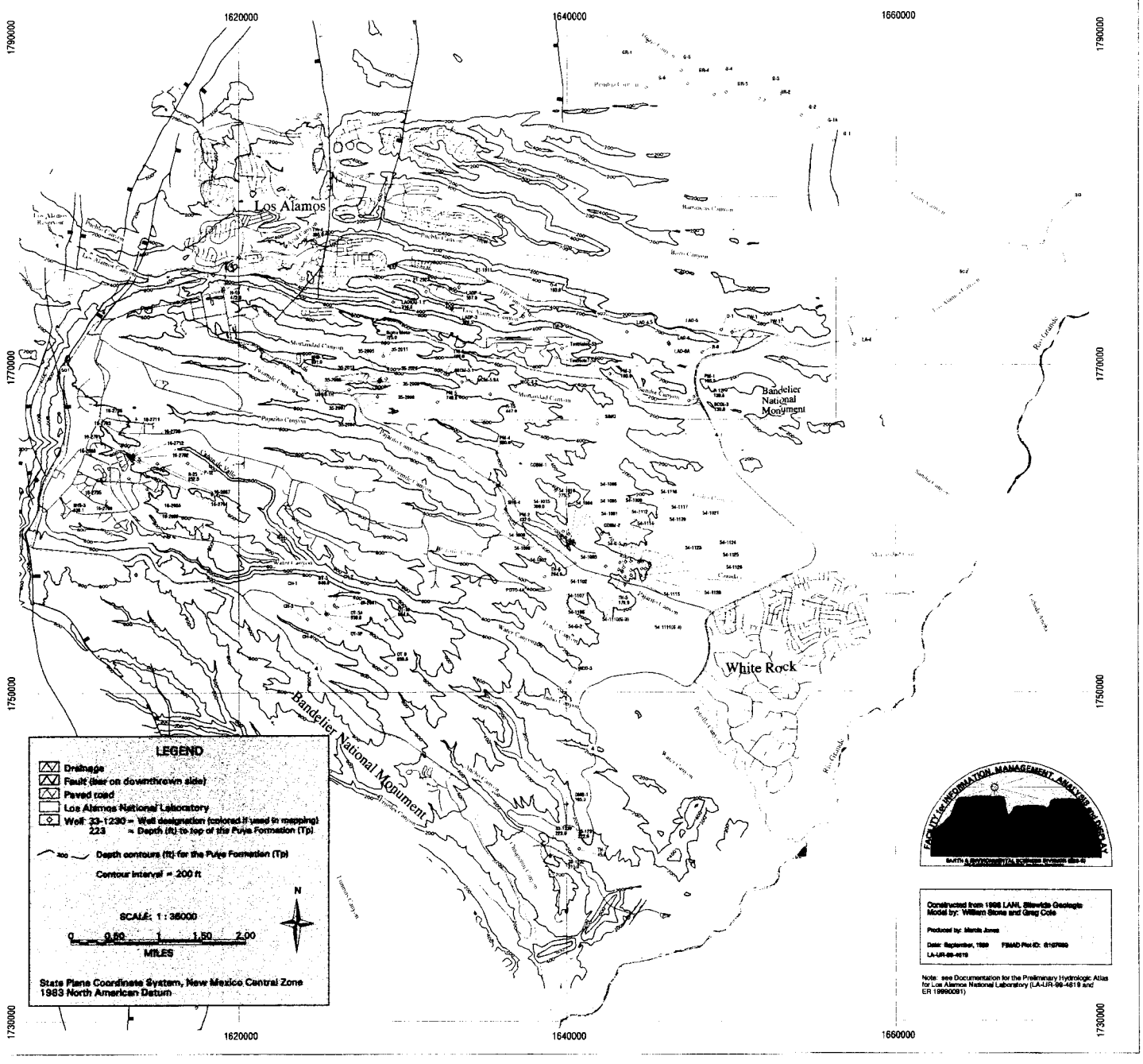
Map 14. Thickness of the Cerros Del Rio basalt (Tb4)

Hydrogeologic Atlas for Los Alamos National Laboratory

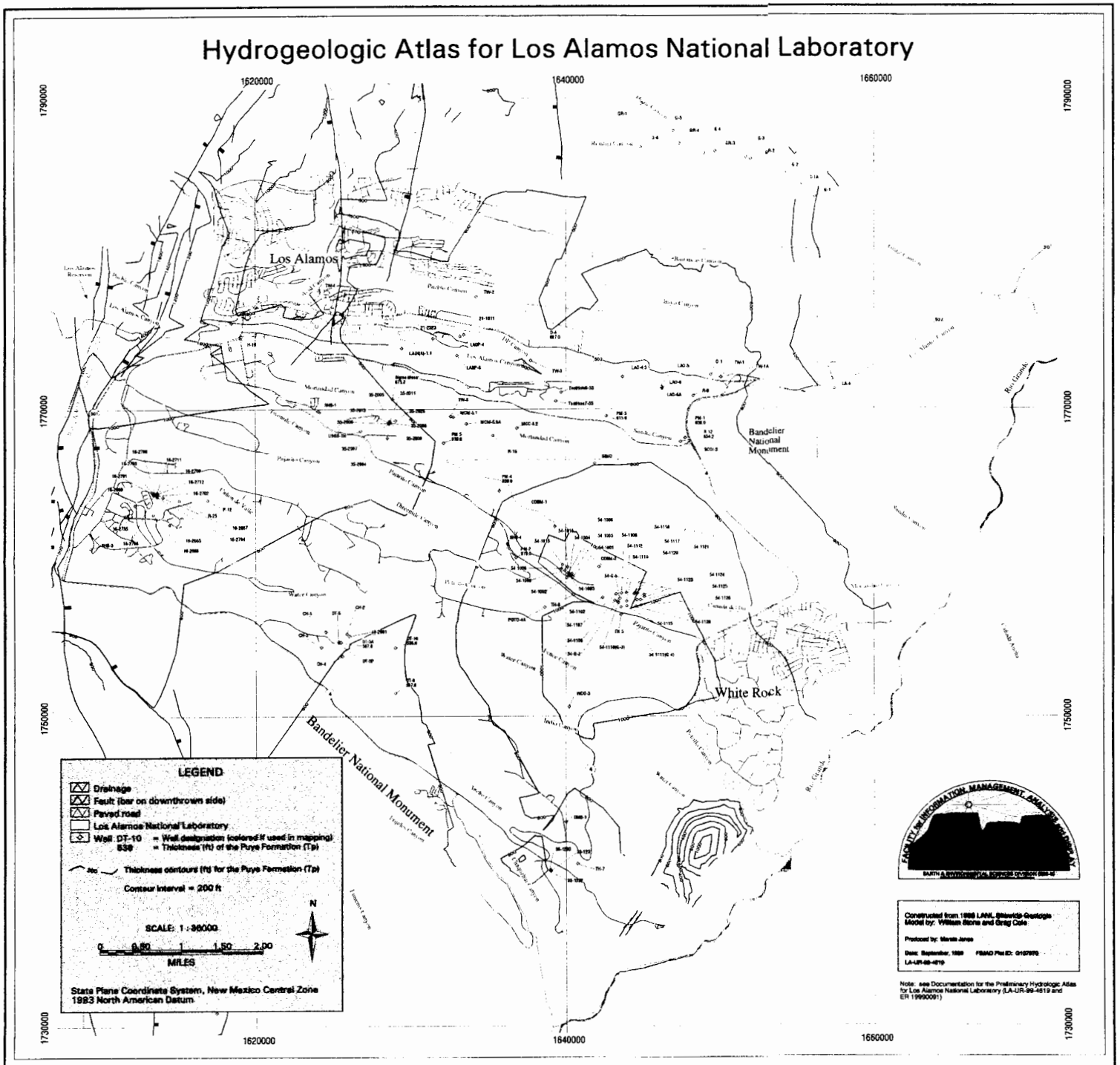


Map 15. Structure on top of the Puye Formation (Tp)

Hydrogeologic Atlas for Los Alamos National Laboratory

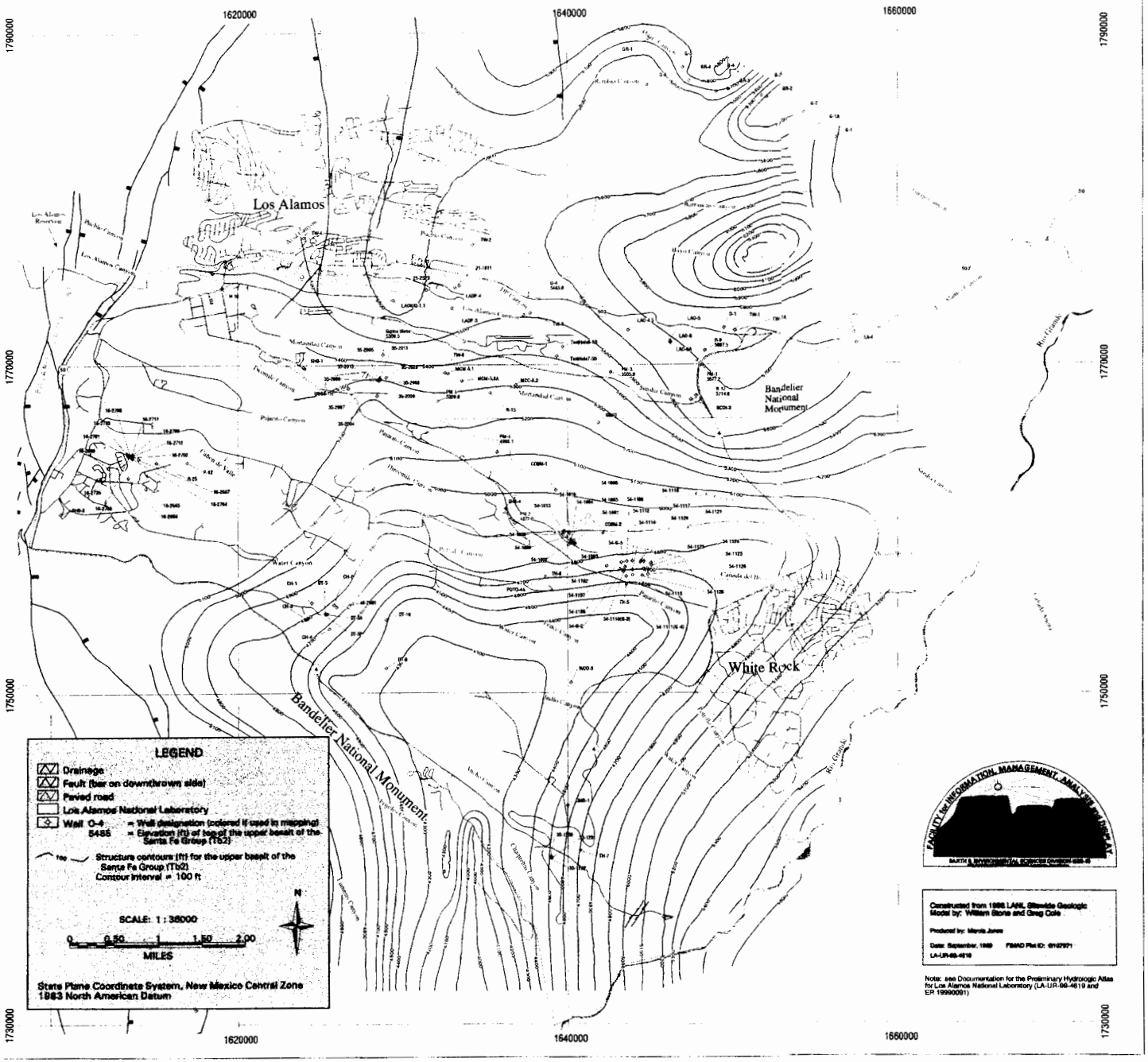


Map 16. Depth to top of the Puye Formation (Tp)



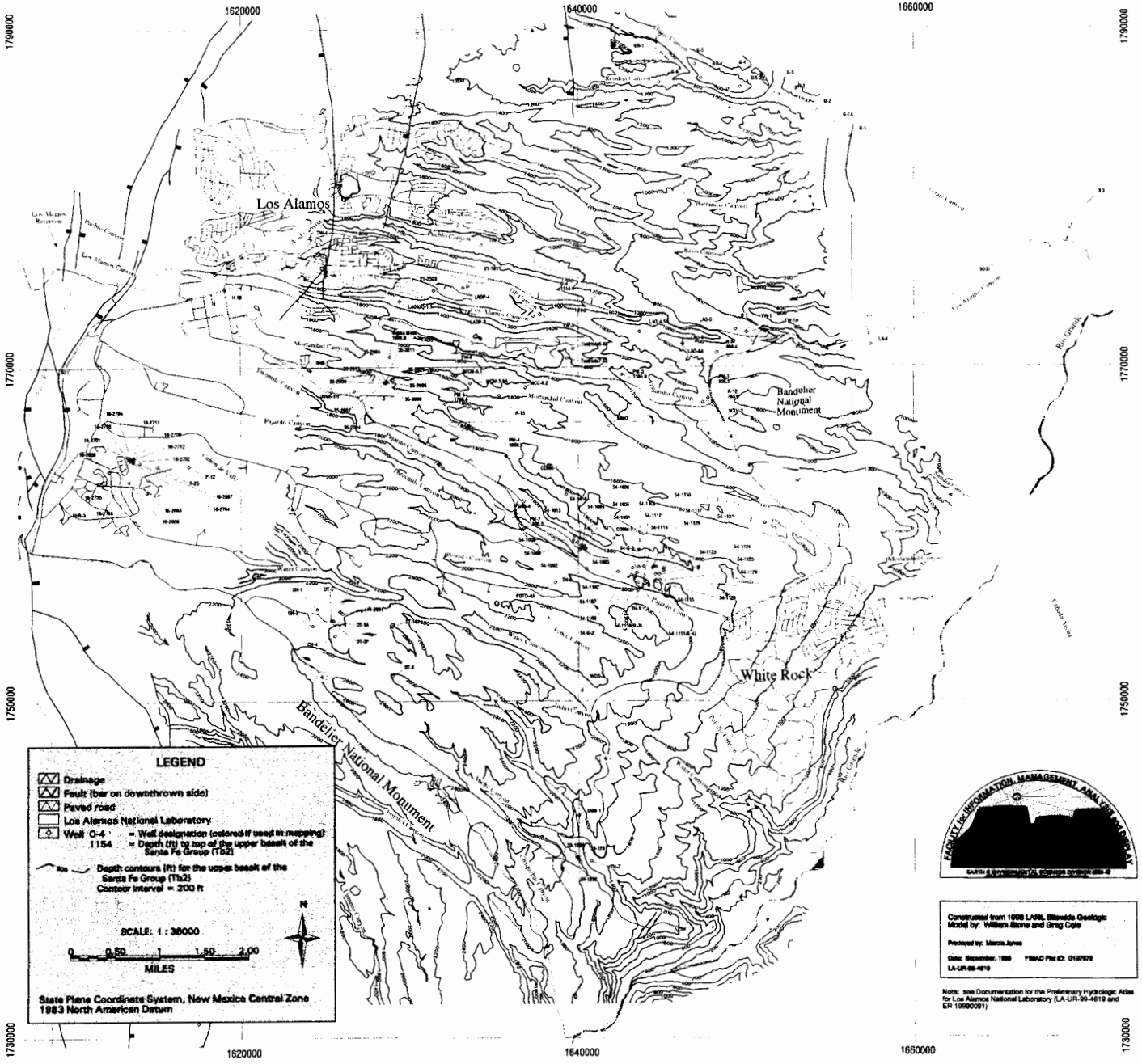
Map 17. Thickness of the Puye Formation (Tp)

Hydrogeologic Atlas for Los Alamos National Laboratory

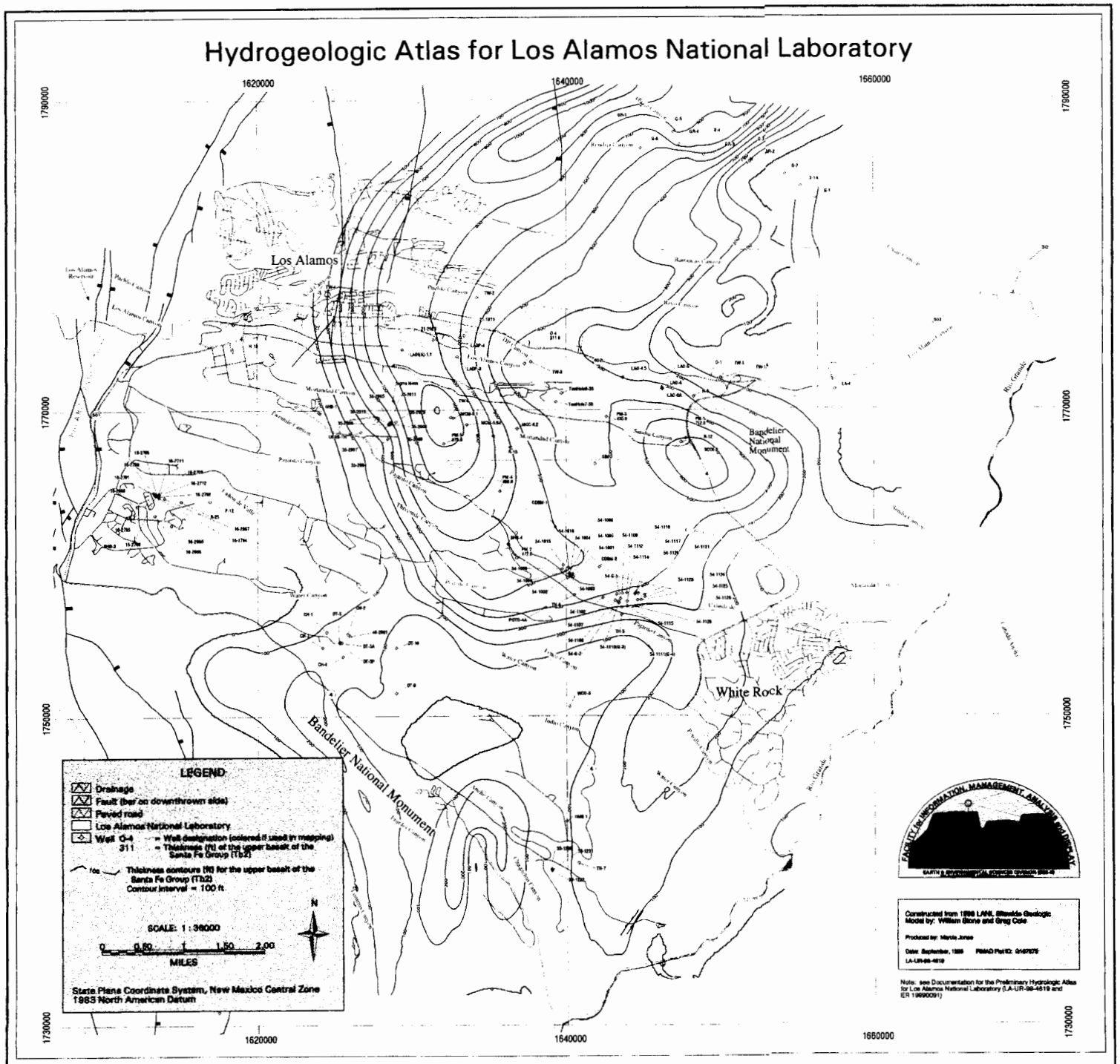


Map 18. Structure on top of the upper basalt of the Santa Fe Group (Tb2)

Hydrogeologic Atlas for Los Alamos National Laboratory

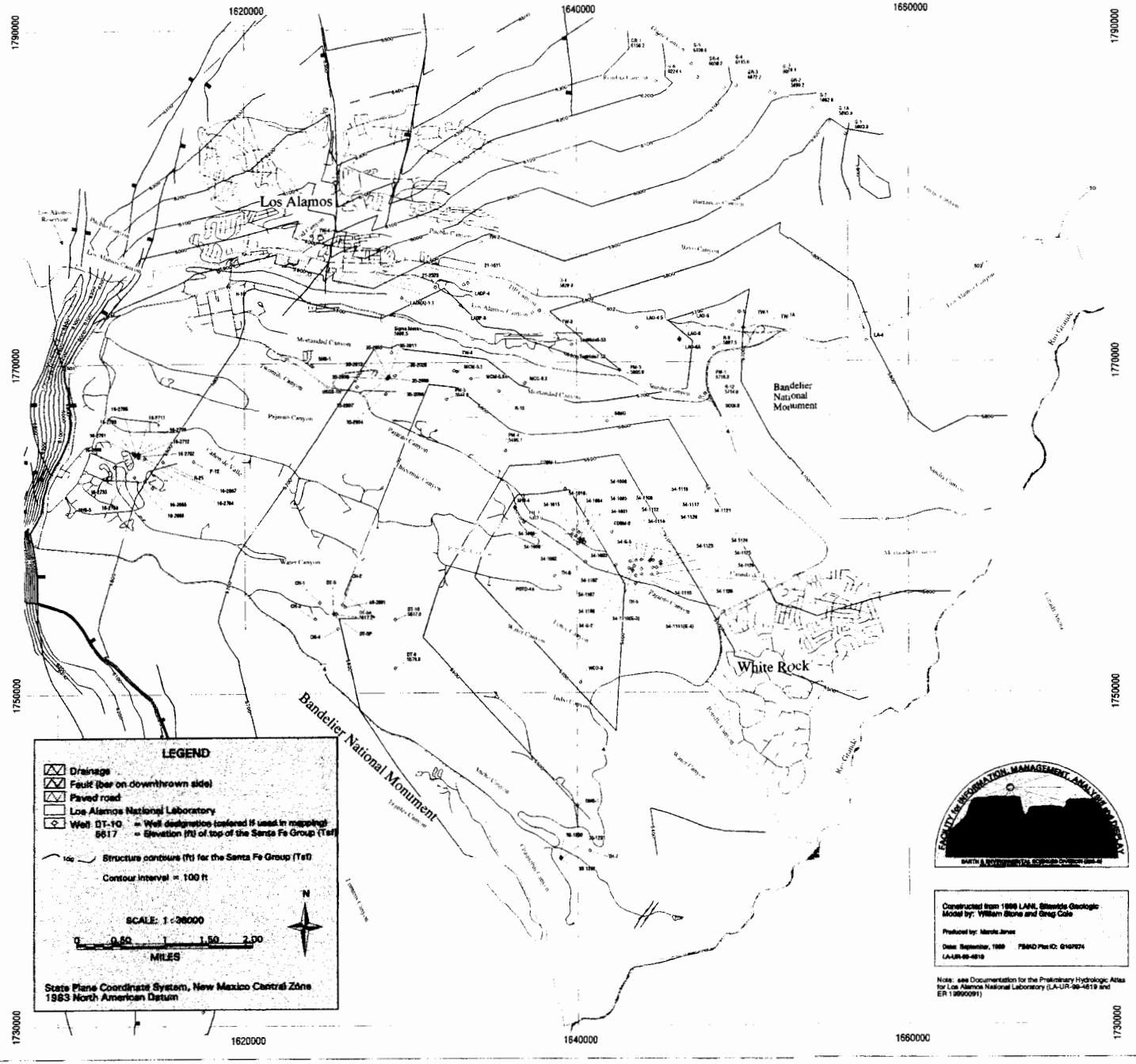


Map 19. Depth to top of the upper basalt of the Santa Fe Group (Tb2)

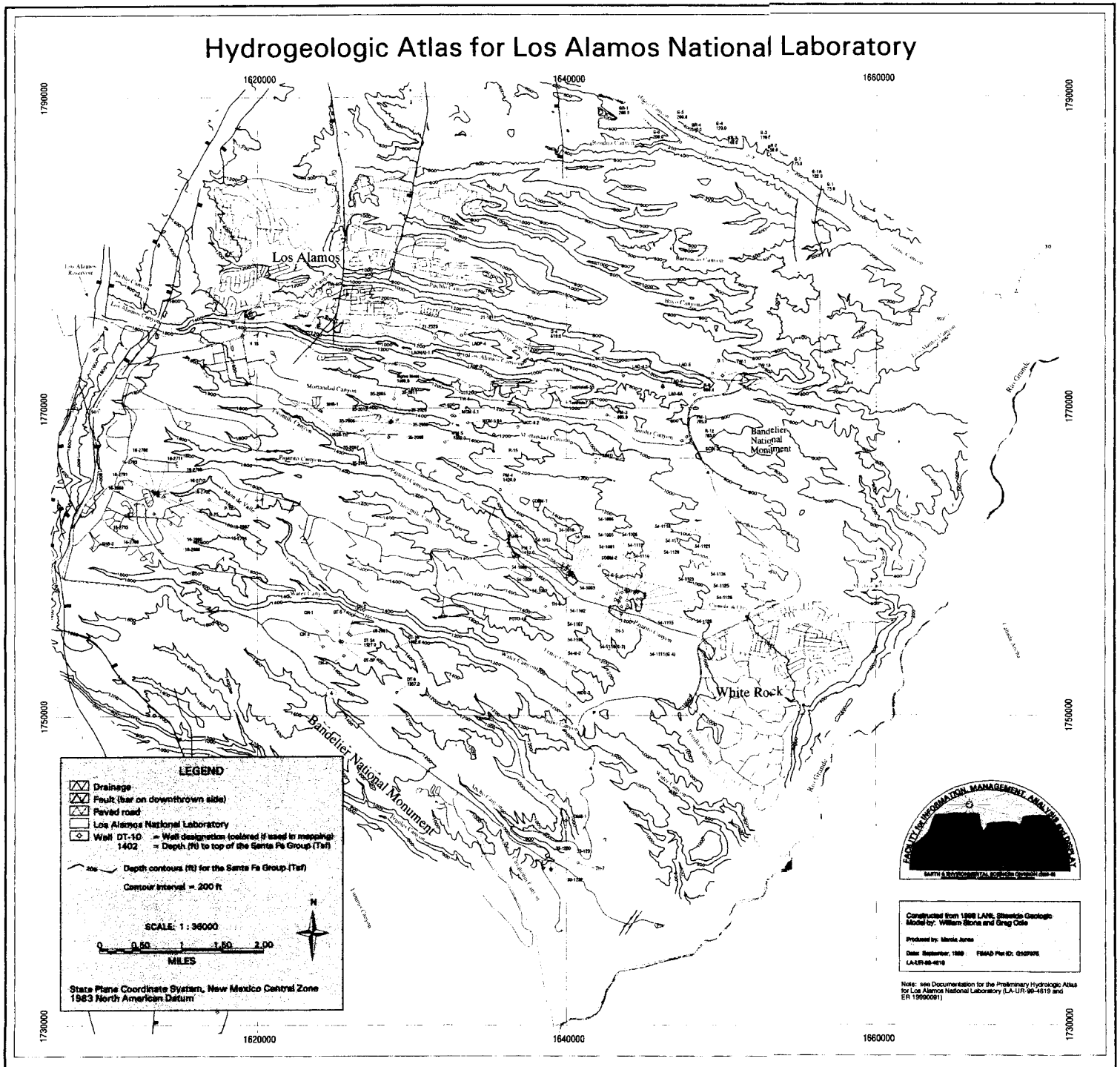


Map 20. Thickness of the upper basalt of the Santa Fe Group (Tb2)

Hydrogeologic Atlas for Los Alamos National Laboratory

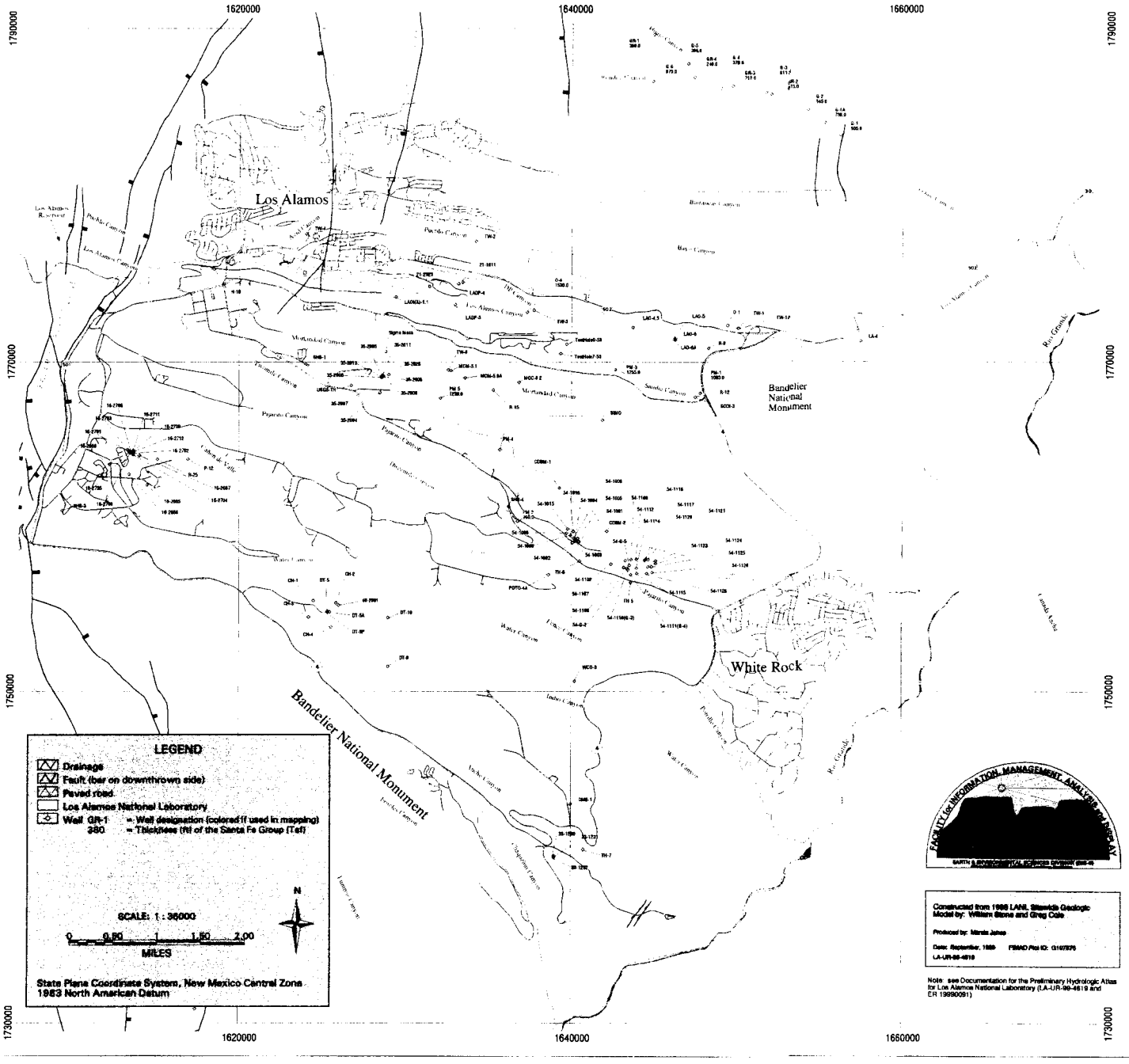


Map 21. Structure on top of the Santa Fe Group (Tsf)



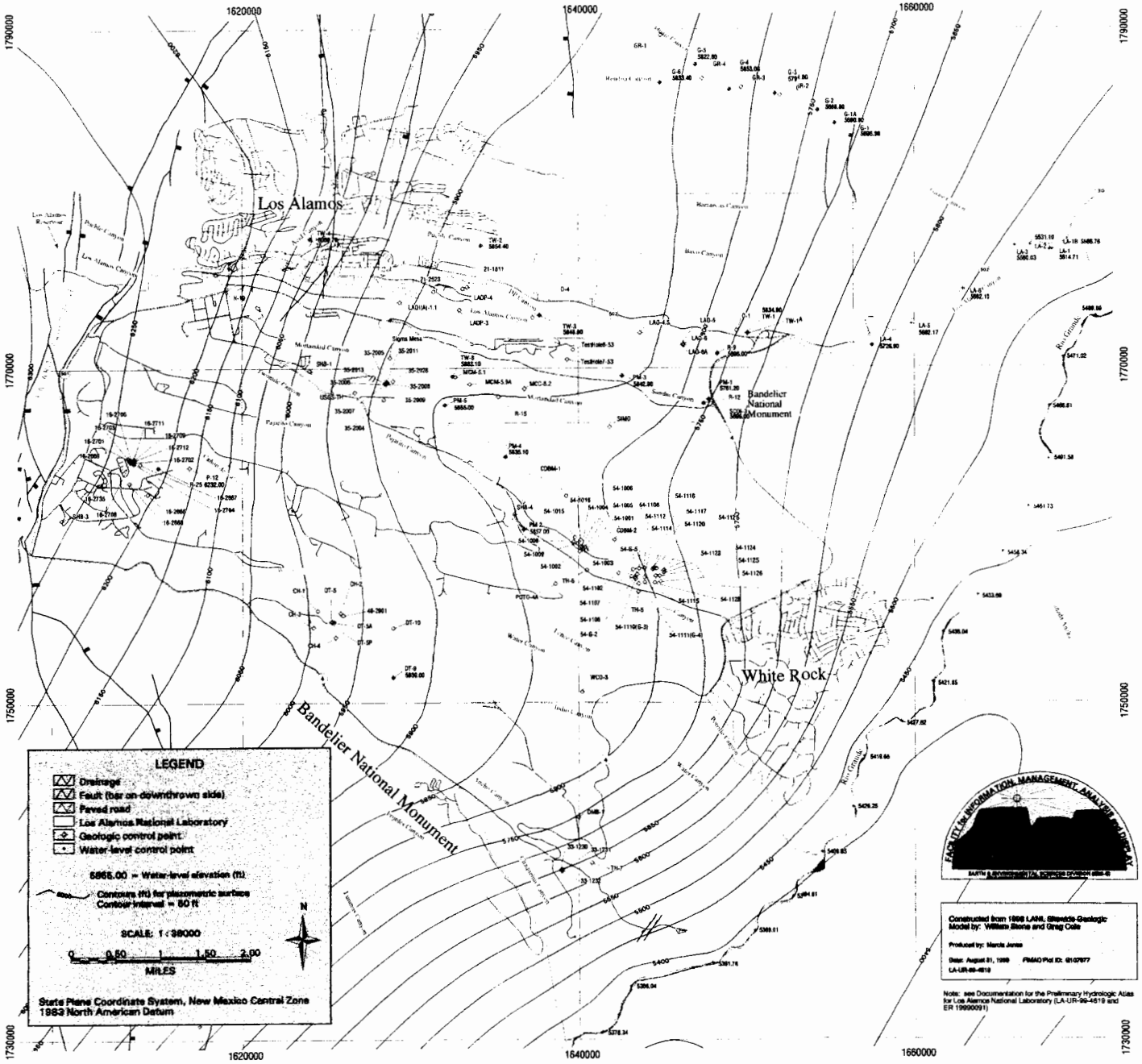
Map 22. Depth to top of the Santa Fe Group (Tsf)

Hydrogeologic Atlas for Los Alamos National Laboratory

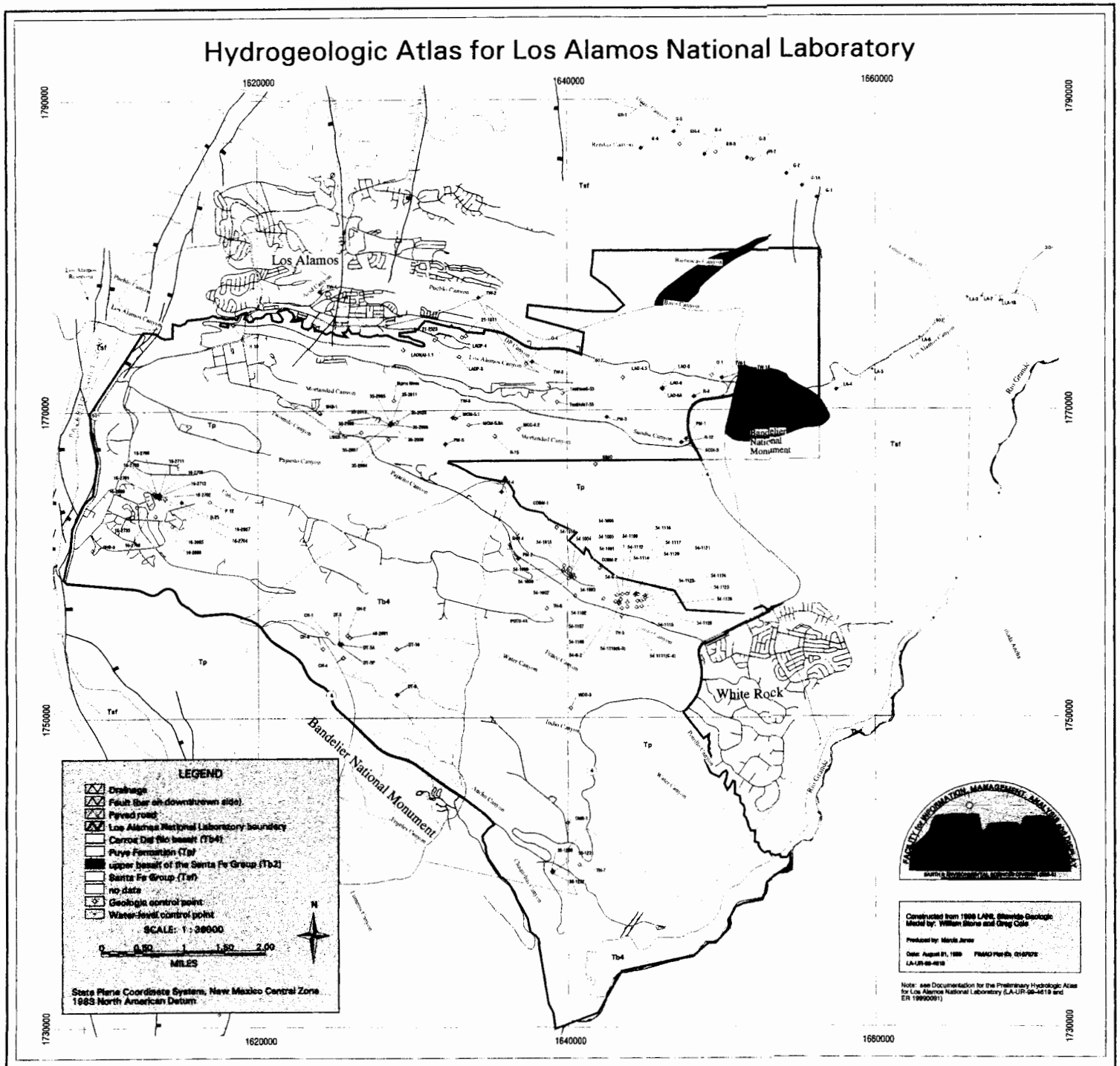


Map 23. Partial thickness of the Santa Fe Group (Tsf)

Hydrogeologic Atlas for Los Alamos National Laboratory



Map 24. Regional piezometric surface



Map 25. Geology at the regional piezometric surface