FOR AUDIT PURPOSES ONLY

Hydrogeologic Framework Model
for the
Saturated-Zone Site-Scale Flow and Transport Model
Draft 00D, 6/8/2000

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OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
ANALYSIS/MODEL COVER SHEET
Complete Only Applicable Items

1. QA: QA

Page: 1 of: 64

2. ☒ Analysis	Check all that apply	3. ☒ Model	Check all that apply
Type of Analysis	☐ Engineering ☐ Performance Assessment ☒ Scientific	Type of Model	☒ Conceptual Model ☐ Abstraction Model ☐ Mathematical Model ☐ System Model ☐ Process Model
Intended Use of Analysis	☐ Input to Calculation ☒ Input to another Analysis or Model ☒ Input to Technical Document ☐ Input to other Technical Products	Intended Use of Model	☐ Input to Calculation ☒ Input to another Model or Analysis ☒ Input to Technical Document ☐ Input to other Technical Products
Describe use:	analyze available surface and subsurface geologic data to construct a site-scale hydrogeologic framework model.	Describe use:	Provide hydrogeologic framework and internal geometry for development of the site-scale saturated zone flow and transport model.

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Hydrogeologic Framework Model for the Saturated-Zone Site-Scale Flow and Transport Model

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OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
ANALYSIS/MODEL REVISION RECORD

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FIGURES

FIGURES (CONTINUED)

TABLES

ACRONYMS

2D	Two-Dimensional
3D	Three-Dimensional
AMR	Analysis/Modeling Report
CAD	Computer Assisted Drafting
CRWMS M&O	Civilian Radioactive Waste Management System Management & Operating Contractor
DEM	Digital Elevation Model
DOE	U.S. Department of Energy
DTN	Data Tracking Number
ERP	Environmental Restoration Program
FEHM	Finite Element Heat Mass Model
GIS	Geographic Information Systems
GFM	Geologic Framework Model (Version 3.1)
HFM	Hydrogeologic Framework Model
NTS	Nevada Test Site
NWIS	National Water Information System
OCRWM	Office of Civilian Radioactive Waste Management
QA	Quality Assurance
QARD	Quality Assurance Requirements and Description
RMSE	Root Mean Square Error
RPC	Records Processing Center
SGM	Stratigraphic Geocellular Modeling
SZ	Saturated Zone
TBV	To Be Verified
TDIF	Technical Data Information Form
TDMS	Technical Data Management System
U.S.	United States
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
YMP	Yucca Mountain Site Characterization Project

1. PURPOSE

Yucca Mountain is being evaluated as a potential site for development of a geologic repository for the permanent disposal of spent nuclear fuel and high-level radioactive waste. Ground water is considered to be the principal means for transporting radionuclides that may be released from the potential repository to the accessible environment, thereby possibly affecting public health and safety. The ground-water hydrology of the region is a result of both the arid climatic conditions and the complex geology. Ground-water flow in the Yucca Mountain region generally can be described as consisting of two main components: a series of relatively shallow and localized flow paths that are superimposed on deeper regional flow paths. A significant component of the regional ground-water flow is through a thick, generally deep-lying, Paleozoic carbonate rock sequence. Locally within the potential repository area, the flow is through a vertical sequence of welded and nonwelded tuffs that overlie the carbonate aquifer. Down-gradient from the site, these tuffs terminate in basin fill deposits that are dominated by alluvium. Throughout the system, extensive and prevalent faults and fractures may control ground-water flow.

The purpose of this Analysis/Modeling Report (AMR) is to document the three-dimensional (3D) hydrogeologic framework model (HFM) that has been constructed specifically to support development of a site-scale ground-water flow and transport model. Because the HFM provides the fundamental geometric framework for constructing the site-scale 3D ground-water flow model that will be used to evaluate potential radionuclide transport through the saturated zone (SZ) from beneath the potential repository to down-gradient compliance points, the HFM is important for assessing potential repository system performance.

This AMR documents the progress of the understanding of the site-scale SZ ground-water flow system framework at Yucca Mountain based on data through July, 1999. The AMR documents a geometric model of the site HFM. This HFM provides a simplified 3D interpretation of the hydrostratigraphy and structure within the site SZ flow and transport model domain. This AMR documents data input, modeling methods, assumptions, uncertainties and limitations of the model results, and qualification status of the model. The primary data types from which the HFM was constructed are geologic maps and sections, borehole data, geophysical data (resistivity, seismic, magnetic and gravity), and existing geologic framework models.

The current HFM described in this report represents the hydrogeologic setting for the Yucca Mountain area that covers about 1,350 km^2 and includes a saturated thickness of about 1.5 km (Figure 1-1). The HFM extends from 533340 meters to 563340 meters (west to east) and 4046782 meters to 4091782 meters (south to north), Universal Transverse Mercator (UTM) Zone 11 (Figure 1-1). In depth, the model domain extends from the interpreted top of the water table to the base of the regional ground-water flow model (Data Tracking Number (DTN): GS960808312144.003). The domain was selected to be: (1) coincident with grid cells in the regional ground-water flow model (DTN: GS960808312144.003) such that the base of the site model was equivalent to the base of the regional model; (2) sufficiently large to minimize the effects of boundary conditions on estimating permeability values at Yucca Mountain; (3) sufficiently large to assess ground-water flow at distances 30 km down-gradient from the potential repository area; (4) small enough to minimize the number of computational nodes used in the model; (5) thick enough to include part of the regional Paleozoic carbonate aquifer; and (6) large enough to include borehole control in the Amargosa Desert at the southern end of the modeled area.

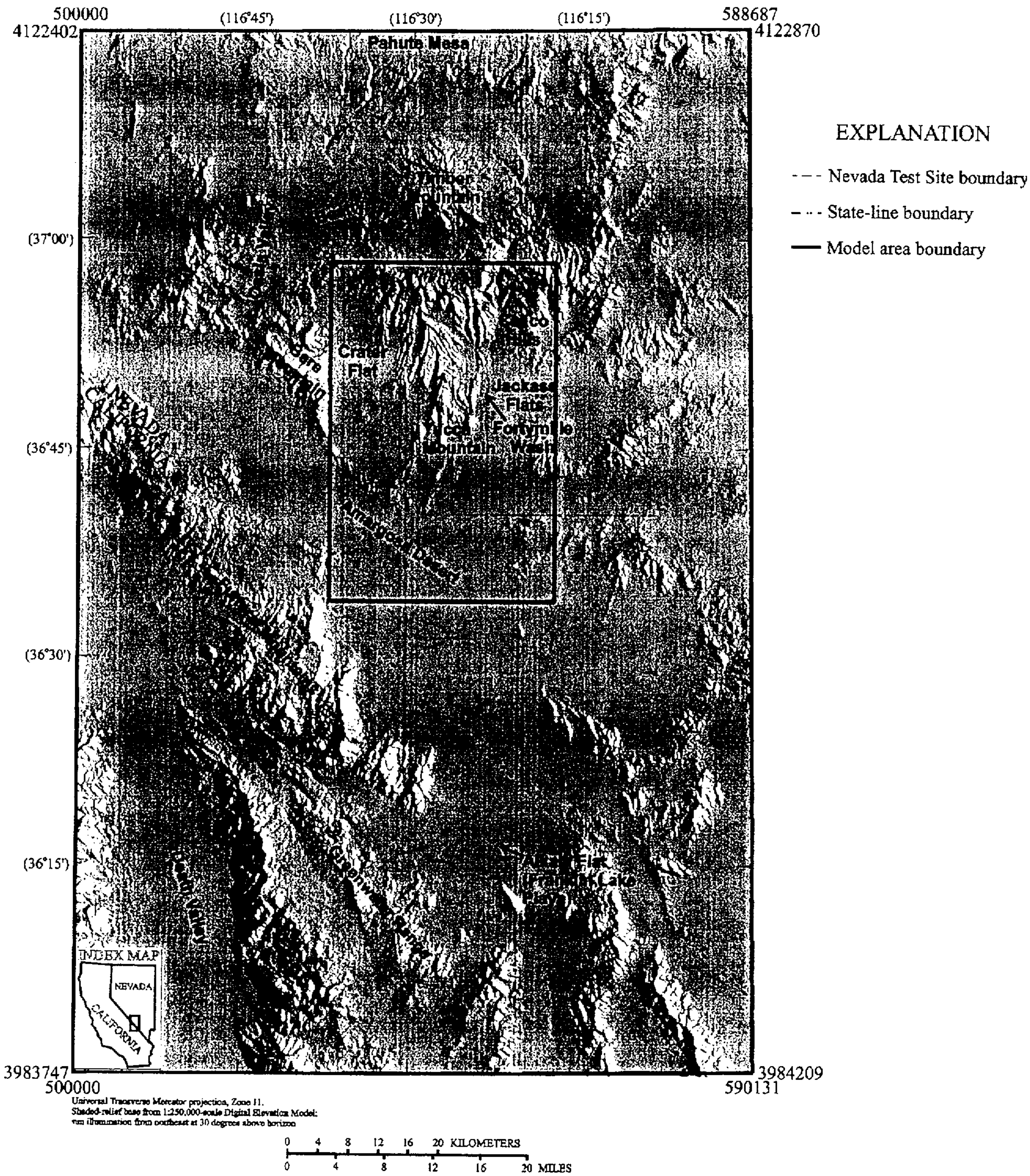

Figure 1-1. Location Map of the Study Area and Associated Geographic Features

The activities documented in this AMR were conducted in accordance with the planning requirements described in USGS (1999). The scope of this analysis includes:

- Incorporating a lower boundary consistent with that of the regional flow model that is documented by D'Agnese and others (1997). The base of this model is set equal to an altitude of 2750 meters below a smoothed version of the potentiometric surface. In general, this boundary is coincident with no vertical flow in or out of the site model area (a natural no flow boundary). See the discussion by D'Agnese and others (1997) for more details.
- Incorporating data, as available, from Nye County wells and boreholes SD-6 and WT-24.
- Incorporating a geologic map and cross sections of Yucca Mountain.
- Incorporating an updated potentiometric-surface map.

The constraints, caveats, and limitations associated with this model are discussed in the appropriate text sections that follow.

2. QUALITY ASSURANCE

The activities documented in this AMR were evaluated in accordance with QAP-2-0, *Conduct of Activities*, and were determined to be subject to the requirements of the U.S. Department of Energy (DOE) Office of Civilian Radioactive Waste Management (OCRWM) *Quality Assurance Requirements and Description* (QARD) (DOE 2000). This evaluation is documented in CRWMS M&O (1999a, b); and Wemheuer 1999 (*Activity Evaluation for Work Package WP 14012031M3*). Scientific Notebook SN-USGS-SCI-072-V2, Part B, Hydrogeologic Framework for the Site Saturated Zone Model (USGS 2000a), was kept to document the model construction process. This AMR has been prepared in accordance with procedure AP-3.10Q, *Analyses and Models*.

The work activities documented in this AMR depend on electronic media to store, maintain, retrieve, modify, update, and transmit quality affecting information. As part of the work process, electronic databases, spreadsheets, and sets of files were required to hold information intended for use to support the licensing position. In addition, the work process required the transfer of data and files electronically from one location to another. Consequently, all electronic files consisting of source data, developed model inputs, model outputs, and post-processing results were maintained and processed according to the seven compliance criteria listed in AP-SV.1Q *Control of the Electronic Management of Data* pursuant to the Work Direction and Planning Document governing these activities (USGS 1999).

3. COMPUTER SOFTWARE AND MODEL USE

The HFM was constructed using a variety of software packages including geographic information systems (GIS), database, Computer Assisted Drafting (CAD), gridding, and 3D geologic framework software. The software identified in Table 3-1 is currently being processed in accordance with Sec. 5.11 of AP-SI.1Q, *Software Management*.

Table 3-1. Software used to Support Model Development

Item No.	Software Name	Version	Software Tracking Number	Computer Platform, Operating System, Compiler	Description
1	ARCINFO	7.2.1	STN: 10033-7.2.1-00	Windows NT Workstation ver. 4	Plotting, digitizing, coordinate transformation, database, and visualization of analysis results.
2	PETROSYS	7.60d	STN: 10168-7.60d-00	Windows NT Workstation ver. 4	Gridding, contouring, plotting, and visualization of analysis results.
3	STRATAMODEL	4.1.1	STN: 10121-4.1.1-00	SGI Indigo 2 Unix Workstation	Constructing 3D HFM and visualization of analysis results.
4	ERMA SITE GEOLOGIST	6.0.1	STN: 10210-6.01.-00	Windows NT Workstation ver. 4	Tasks include creating, attributing, and manipulating 2D and 3D cross-sections; posting data with attribute symbology; generating boring logs; and posting section horizons to maps.

A brief description of how the software was used follows.

ARCINFO version 7, manufactured by Environmental Systems Research Institute, Inc. was used for plotting, digitizing, coordinate transformation, database, and visualization of analysis results. PETROSYS version 7.60d, manufactured by PETROSYS Pty. Ltd. was used for gridding, contouring, plotting, and visualization of analysis results. STRATAMODEL version 4, manufactured by Landmark Graphics, Inc., was used for constructing the 3D HFM and for visualization of analysis results. ERMA SITE GEOLOGIST, manufactured by Intergraph, Inc., was used for subsurface geological studies including data analysis, interpretation, modeling, and presentation functions. These tasks included creating, attributing, and manipulating 2-D and 3-D cross sections; posting data with attribute symbology; generating boring logs; and posting section horizons to maps.

Data from the geometric components (not process representations) of three models were used in developing the HFM (Table 3-2):

1. Yucca Mountain Site Characterization Project's (YMP's) Geologic Framework Model (GFM), Version 3.1 (DTN: MO9901MWDGFM31.000),

2. Cross sections and surfaces developed as part of the Environmental Restoration Program (ERP) for the ERP hydrogeologic framework model (DTN: GS000400002332.002)[1], and

3. The geometry of the Death Valley regional ground-water flow model (DTN: GS960808312144.003).

Table 3-2. Models used as Data Input to Hydrogeologic Framework Model

Model	Version	DTN
Geologic Framework Model	3.1	MO9901MWDGFM31.000
Environmental Restoration Program HFM	N/A	GS000400002332.002
Death Valley ground-water flow model	N/A	GS960808312144.003

Reconstruction of HFM or use of the STRATAMODEL binary format files requires STRATAMODEL software Version 4.0 or higher.

The use of input computer files in developing the HFM is summarized in Section 6 and documented in Scientific Notebook SN-USGS-SCI-072-V2 (USGS 2000a). The model input files are available from the Model Warehouse under HFM output data DTN: GS000508312332.002.

4. INPUTS

4.1 DATA AND PARAMETERS

Data feeds to the HFM include borehole lithologic logs, geologic maps, geologic cross sections, topographic information, and the GFM (DTN: MO9901MWDGFM31.000). In addition, geologic cross sections and stratigraphic surfaces developed for the DOE ERP for the Nevada Test Site (NTS) (DTN: GS000400002332.002) were added. The Death Valley regional ground-water flow model (DTN: GS960808312144.003) was used to define the lower boundary of the model. The potentiometric surface (DTN: GS000508312332.001) was used as a clipping surface to form the top of the model. The appropriateness of this data is addressed in Section 6.2 and represents the most current geologic information for southern Nevada. Input information used to develop the HFM comes from several sources. Specific input data sets and associated DTNs are listed in Table 4-1; the qualification status of the input sources are indicated in the electronic Document Input Reference System (DIRS) database.

[1] The DOE under its ERP, has made NTS the subject of a long-term investigations, in response to concerns about whether byproducts of underground testing pose a potential hazard to the health and safety of the public. As part of these investigations, the DOE has developed ground-water flow models and hydrogeologic framework models.

Table 4-1. Input Data

Data Description	Data Tracking Number
Digital Elevation Models Death Valley East Scale 1:250,000. Submittal date: 04/12/2000.	GS000400002332.001
Underground Test Area Subproject Phase I Data Analysis Task, 1996	GS000400002332.002
Water-Level Data Analysis for the Saturated Zone Site-Scale Flow and Transport Model	GS000508312332.001
A Summary of Geologic Studies Through January 1, 1983, of a Potential High-Level Radioactive Waste Repository Site at Yucca Mountain, Southern Nye County, Nevada. Submittal date: 09/17/1990.	GS900908314211.007
Lithologic and Geophysical Logs of Drill Holes Felderhoff Federal 5-1 and 25-1, Amargosa Desert, Nye County, Nevada. Submittal date: 09/08/1994.	GS940908312132.004
Major Results of Regional Geophysical Investigations at Yucca Mountain and Vicinity, Nevada. Submittal date: 01/06/1995.	GS950108314212.001
Cross-Section Data for Hydrogeologic Framework Model Construction in Intergraph Design File Format. Submittal date: Submittal date: 05/19/1995.	GS950508312333.001
Borehole Data for Hydrogeologic Framework Model Construction. Submittal date: Submittal date: 05/19/1995.	GS950508312333.002
Hybrid-Source Seismic Reflection Profiling Across Yucca Mountain, Nevada: Regional Lines 2 and 3. Submittal date: 01/10/1996.	GS960108314211.002
Hydrogeologic Evaluation and Numerical Simulation of the Death Valley Regional Ground-Water Flow System, Nevada and California, Using Geoscientific Information Systems. Submittal date: 08/29/1996.	GS960808312144.003
Geologic Map of the Yucca Mountain Region. Submittal date: 12/01/1999.	GS991208314221.001
Geologic Framework Model. Submittal date: 01/06/1999.	MO9901MWDGFM31.000

The primary input data for the HFM are stratigraphic contact data from boreholes, geologic cross sections, and the geologic map of the Yucca Mountain region, as listed in Table 4-1. The locations of the subsurface data are shown on Figure 4-1. The hydrogeologic units and faults in the area are shown on Figure 4-2.

At the time the HFM was constructed, no new lithologic data were available from the Nye County Early Warning Drilling Program boreholes or from boreholes USW SD-6 and USW WT-24. The boreholes were being drilled (or were drilled) at the time of this report, but the stratigraphic data were not available in time for model construction.

The HFM was constructed using lithostratigraphic and structural data from boreholes, surface geologic maps, inferred geologic cross sections, and geophysical surveys that constituted a necessary and minimally sufficient data set by which to construct the three-dimensional framework model at the designated scale of resolution. On this basis, these data were determined to be appropriate for their intended use in providing a geologically based geometric framework for the site-scale SZ flow and transport model.

Data qualification efforts, as needed, will be conducted in accordance with AP-SIII.2Q, *Qualification of Unqualified Data and the Documentation of Rationale for Accepted Data*, and documented separately from this AMR.

4.2 CRITERIA

This AMR complies with the DOE interim guidance (Dyer, 1999). Subparts of the interim guidance that apply to this analysis or modeling activity are those pertaining to the characterization of the Yucca Mountain site (Subpart B, Section 15), the compilation of information regarding hydrology of the site in support of the License Application (Subpart B, Section 21(c)(1)(ii)), and the definition of hydrologic parameters and conceptual models used in performance assessment (Subpart E, Section 114(a)).

4.3 CODES AND STANDARDS

No specific formally established codes or standards have been identified as applicable to the development of the HFM.

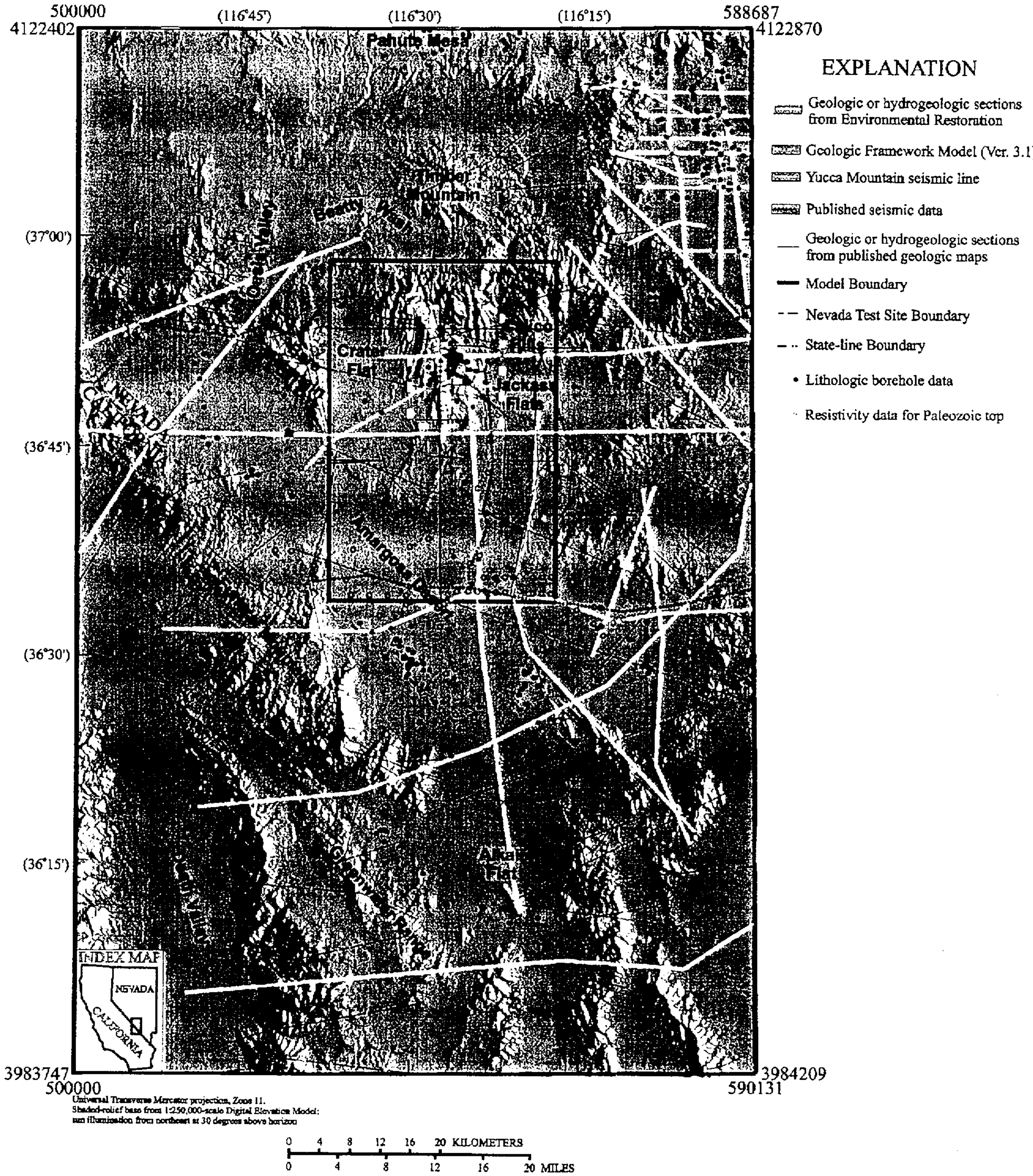

Figure 4-1. Locations for Geologic, Geophysical, and Borehole Data listed in Table 4-1 used in the Construction of the Hydrogeologic Framework Model

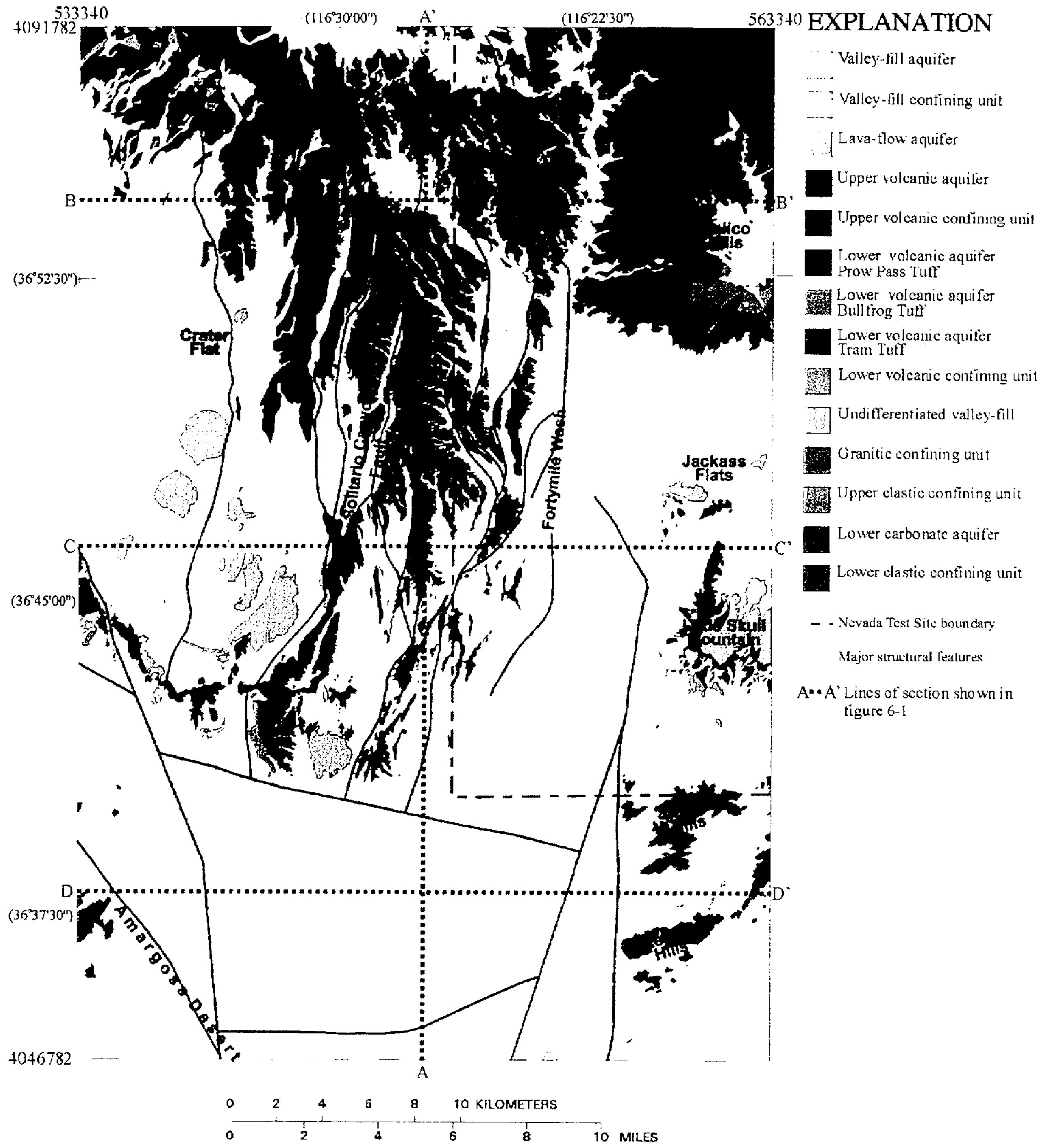

Figure 4-2. Generalized Hydrogeologic Units with Major Structural Features and Lines of Section Specific to the Site Model Area (DTN: GS991208314221.001)

5. ASSUMPTIONS

The assumptions underlying the construction of the HFM are methodological in nature and are based on the use of standard geologic techniques for the analysis, interpretation, and representation of stratigraphic and structural features within the Yucca Mountain region. Specific techniques that are assumed to be applicable and that are used throughout this AMR include the interpolation and extrapolation of stratigraphy through the use of borehole lithologic logs, geologic maps, developed geologic cross sections, and geophysical data. Standard methods were used to generate structure contour maps. Hydrogeologic units were defined on the basis of measured or inferred hydrologic properties. The use of these techniques is described in Section 6 of this AMR. The applicability of these techniques to the development of the HFM is supported by the information currently available pertaining to the geologic setting of the Yucca Mountain site and region as described in CRWMS M&O (1998, Sections 3.2, 3.5, and 3.6) and require no further confirmation.

6. MODEL DEVELOPMENT

The HFM is a representation of the hydrogeologic units and major structural features within the SZ flow system encompassed by the domain of the site-scale SZ flow and transport model. These units are subjected to different stresses and facies changes, and as a result have varying hydraulic properties. The HFM was constructed using basic inputs described in Section 4 of this AMR, including new information from the Death Valley regional ground-water flow model, an updated potentiometric-surface map, and a geologic map and geologic cross sections (DTN: GS991208314221.001). Data inputs also included data from the GFM 3.1 (DTN: MO9901MWDGFM31.000), and geologic cross sections and stratigraphic surfaces developed for the ERP for the NTS (DTN: GS000400002332.002). This section describes the HFM in terms of the hydrogeologic representation and conceptual model, data use, development of the model, model validation, and the uncertainties and limitations of the model. The approach used in this task is the compilation and interpretation of the results of existing lithologic/stratigraphic information and analyses.

The HFM is not concerned with estimating or otherwise directly addressing any of the principal factors, other factors, or potentially disruptive processes and events included within the Repository Safety Strategy (CRWMS M&O 2000a) and, therefore, is deemed to be of Level 3 importance in addressing the factors associated with the post-closure safety case. The HFM provides the geologically defined internal geometry for the site-scale SZ flow and transport process model and is considered to be appropriate for this intended application.

6.1 HYDROGEOLOGIC REPRESENTATION AND CONCEPTUAL MODEL

The geologic setting, geologic history, stratigraphy, and structure of Yucca Mountain are summarized in Luckey and others (1996, p. 7-13). Briefly, Yucca Mountain (Figure 1-1) is located in the Great Basin section of the Basin and Range physiographic province, and consists of a group of north-south-trending block-faulted ridges (Figure 4-2) that are composed of volcanic rocks of Tertiary age that may be several kilometers thick. Crater Flat, the basin to the west of Yucca Mountain, contains a thick sequence (about 2,000 m) of Tertiary volcanic rocks, Tertiary and Quaternary alluvium, and small basaltic lava flows of Quaternary age. The Solitario

Canyon fault separates Crater Flat from Yucca Mountain (Figure 4-2). West of Crater Flat is Bare Mountain (Figure 1-1), which is composed of Paleozoic and Precambrian sedimentary rocks. Fortymile Wash (Figure 4-2), a prominent topographic feature and an inferred structural trough, delimits the eastern extent of Yucca Mountain. East of Fortymile Wash are the Calico Hills, an assemblage of altered Tertiary volcanic rocks and Paleozoic sedimentary rocks. Yucca Mountain terminates to the south in the Amargosa Desert, which contains near-surface deposits of interbedded Quaternary and Tertiary alluvial, paludal, and tuffaceous sediments.

In order to represent geologic heterogeneity introduced by stratigraphy in a ground-water flow model, geologic units traditionally are simplified into hydrogeologic units on the basis of similar hydrologic properties. The rocks and surficial deposits in the vicinity of Yucca Mountain were classified into hydrogeologic units (Figure 4-2). Where possible, hydrogeologic units identified by previous investigators (Luckey and others, 1996; Winograd and Thordarson, 1975; and Laczniak and others, 1996) were used. Many of the units are not present in the model area or do not crop out at the land surface (Figure 4-2). Eighteen hydrogeologic units are present in the model area (Figure 6-1; Table 6-1). Table 6-1 summarizes the hydrogeologic units and their correlation with the different geologic units in the model area. Figure 6-1 illustrates, by way of a fence diagram, the complex 3D spatial relation among these units within the SZ of the model area.

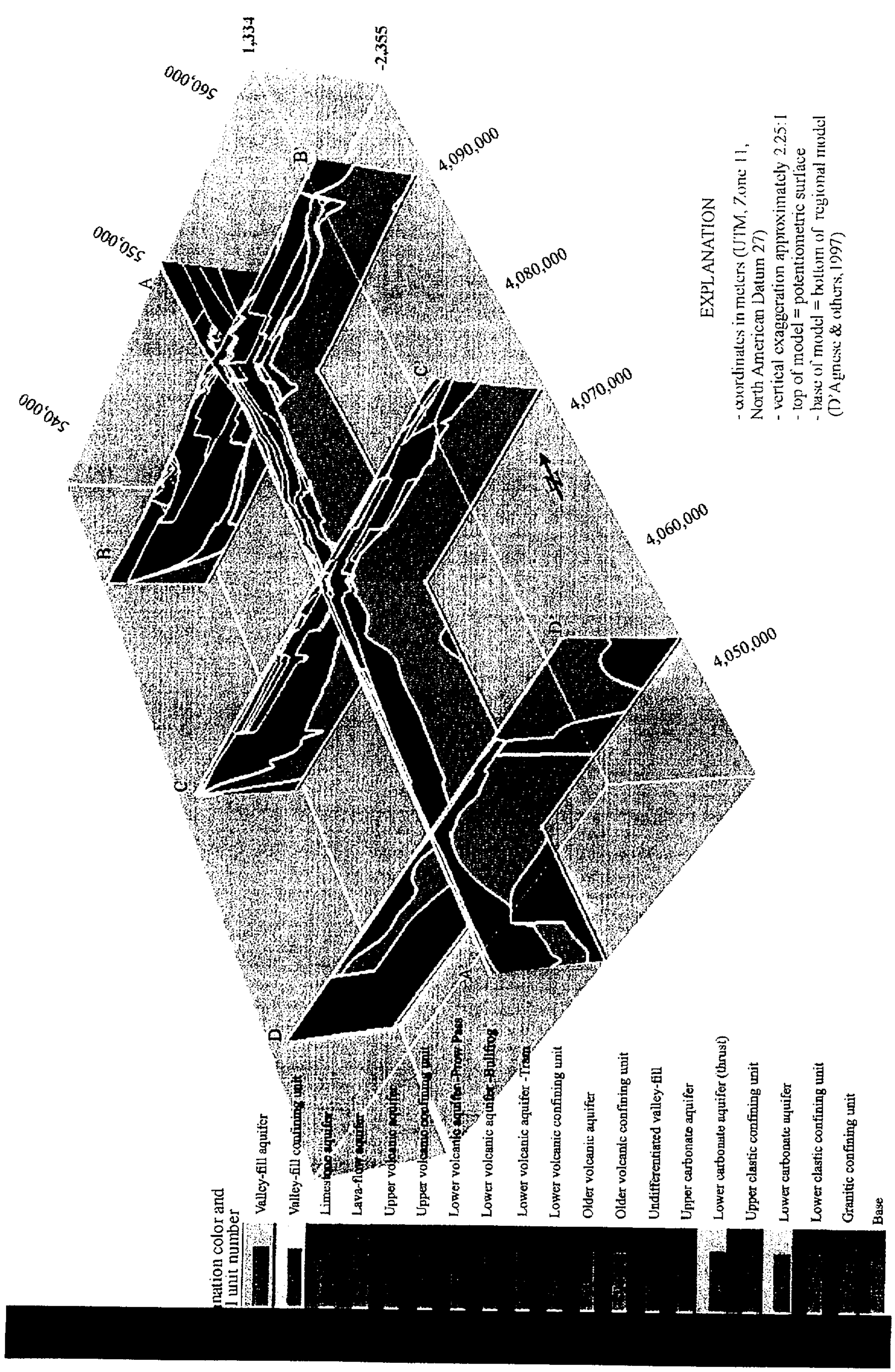
1,334
-2,355
560,000
550,000
540,000
4,090,000
4,080,000
4,070,000
4,060,000
4,050,000
A
A'
B
B'
C
C'
D
D'
EXPLANATION
- coordinates in meters (UTM, Zone 11, North American Datum 27)
- vertical exaggeration approximately 2.25:1
- top of model = potentiometric surface
- base of model = bottom of regional model (D'Agnese & others, 1997)
Valley-fill aquifer
Valley-fill confining unit
Upper volcanic aquifer
Lower volcanic aquifer -Tram
Lower volcanic confining unit
Older volcanic aquifer
Older volcanic confining unit
Undifferentiated valley-fill
Upper carbonate aquifer
Lower carbonate aquifer (thrust)
Upper clastic confining unit
Lower carbonate aquifer
Lower clastic confining unit
Granitic confining unit
Base

Table 6-1. Hydrogeologic Units, Equivalent Units, and Associated Lithologies in the Vicinity of Yucca Mountain

Hydrogeologic Unit in HFM (Age)	Equivalent Unit: Winograd and Thordarson (1975) Table 1	Equivalent Unit: Laczniak and others (1996) Table 1	Equivalent Unit: Luckey and others (1996) Table 1	Type of Deposit or Lithology	Data-Availability Rating
Valley-fill aquifer (Q, T)	Valley Fill (Valley-fill aquifer)	Alluvial deposits (Valley-fill aquifer)	Alluvium	Alluvial fan, fluvial, fanglomerate, lakebed, eolian and mudflow deposits	9.0
Valley-fill confining unit (Q, T)	Valley Fill (Valley-fill aquifer)	Alluvial deposits (Valley-fill aquifer)	Alluvium	Playa deposits	5.0
Limestone aquifer (T)	–	–	–	Lacustrine limestones, calcareous spring deposits	0.9
Lava-flow aquifer (Q,T)	Basalt of Kiwi Mesa Basalt of Skull Mountain (Lava-flow aquifer)	Basalt	–	Basalt flows, dikes and cinder cones, latite dikes	1.0
Upper volcanic aquifer (T)	Timber Mountain Tuff Paintbrush Tuff (Welded-tuff aquifer)	Thirsty Canyon Group Timber Mountain Group Paintbrush Group (Welded-tuff and lava-flow aquifers)	Paintbrush Group (Upper volcanic aquifer)	Variably welded ash-flow tuffs and rhyolite lavas (non-welded tuffs)	6.0
Upper volcanic confining unit (T)	Wahmonie Formation Salyer Formation Rhyolite flows and tuffaceous beds of Calico Hills (Lava-flow aquitard - Tuff aquitard)	Volcanics of Area 20 Wahmonie Formation (Lava-flow aquifers)	Calico Hills Formation (Upper Volcanic Confining Unit)	Rhyolite lavas, volcanic breccias, non-welded to welded tuffs, commonly argillaceous or zeolitic	1.0
Lower volcanic aquifer – Prow Pass Tuff (T)	Grouse Canyon Member Tuff of Crater Flat (Tuff aquitard)	Crater Flat Group Belted Range Group (Welded-tuff and lava-flow aquifers)	Crater Flat Group (Lower Volcanic Aquifer)	Variably welded ash-flow tuffs and rhyolite lavas	0.8
Lower volcanic aquifer – Bull Frog Tuff (T)	Grouse Canyon Member Tuff of Crater Flat (Tuff aquitard)	Crater Flat Group Belted Range Group (Welded-tuff and lava-flow aquifers)	Crater Flat Group (Lower Volcanic Aquifer)	Variably welded ash-flow tuffs and rhyolite lavas	0.8
Lower volcanic aquifer - Tram Tuff (T)	Grouse Canyon Member Tuff of Crater Flat (Tuff aquitard)	Crater Flat Group Belted Range Group (Welded-tuff and lava-flow aquifers)	Crater Flat Group (Lower Volcanic Aquifer)	Variably welded ash-flow tuffs and rhyolite lavas	0.8
Lower volcanic confining unit (T)	Local informal units of Indian Trail Formation (Tuff aquitard)	Tunnel Formation (Tuff confining unit)	Flow Breccia Lithic Ridge Tuff (Lower Volcanic Confining Unit)	Non-welded tuff, commonly zeolitized	0.8
Older volcanic aquifer (T)	Tub Spring Member (Tuff aquitard)	Volcanics of Big Dome (Lava-flow and welded-tuff aquifer)	–	Variably welded ash-flow tuffs, rhyolite lavas	0.1

Hydrogeologic Unit in HFM (Age)	Equivalent Unit: Winograd and Thordarson (1975) Table 1	Equivalent Unit: Laczniak and others (1996) Table 1	Equivalent Unit: Luckey and others (1996) Table 1	Type of Deposit or Lithology	Data-Availability Rating
Older volcanic confining unit (T)	? (Tuff aquitard)	Older Volcanics (Tuff confining unit)	--	Non-welded tuff, commonly zeolitized	0.1
Undifferentiated valley-fill (T)	Rocks of Pavits Spring Horse Spring Formation (Tuff aquitard)	Pavits Spring Formation Horse Spring Formation Paleocolluvium	--	Tuffaceous sandstone, tuff breccia, siltstone, claystone, conglomerate, lacustrine limestone, commonly argillaceous or calcareous. Sedimentary breccia.	5.0
Upper carbonate aquifer (Pz)	Tippipah Limestone (Upper carbonate aquifer)	Bird Spring Formation (Upper carbonate aquifer)	--	Limestone	0.3
Upper clastic confining unit (Pz)	Eleana Formation (Upper clastic aquitard)	Eleana Formation (Eleana confining unit)	--	Siliceous siltstone, sandstone, quartzite, conglomerate, limestone	0.5
Lower carbonate aquifer (Pz)	Devils Gate Limestone Nevada Formation Ely Springs Dolomite Eureka Quartzite Pogonip Group Nopah Formation Dunderberg Shale Bonanza King Upper Carrara Formation (Lower carbonate aquifer)	Guilmette Formation Simonson Dolomite Sevy, Laketown, and Lone Mountain Dolomite Roberts Mountain Formation Dolomite of the Spotted Range Ely Springs Dolomite Eureka Quartzite Pogonip Group Nopah Formation Bonanza King Formation Upper Carrara Formation (Lower carbonate aquifer)	Lone Mt. Dolomite Roberts Mt. Dolomite (Carbonate Aquifer)	Dolomite and limestone, locally cherty and silty	0.5
Lower clastic confining unit (Pz, pC)	Lower Carrara Formation Zabriskie Quartzite Wood Canyon Formation Stirling Quartzite Johnnie Formation (Lower clastic aquitard)	Lower Carrara Formation Zabriskie Quartzite Wood Canyon Formation Stirling Quartzite Johnnie Formation Noonday (?) Dolomite (Quartzite confining unit)	--	Quartzite, siltstone, shale, dolomite	0.8
Granitic confining unit (T)	Granitic Stocks (A minor aquitard)	Granite	--	Granodiorite and quartz monzonite in stocks, dikes and sills	0.1

(–, no units identified; hydrologic-unit names listed in parentheses; Q, Quaternary; T, Tertiary; Pz, Paleozoic; pC, Precambrian; data-availability rating (intended as a relative indicator of data availability, not to precisely estimate the spatial extent of each of the hydrogeologic units): 0.1, poor; 10.0, excellent)

The basic conceptual model used to construct the HFM is that the hydrogeologic units at Yucca Mountain form a series of alternating volcanic aquifers and confining units above the regional carbonate aquifer. Many of the formations have eroded significantly since deposition. The volcanic rocks generally thin toward the south away from their eruptive source areas in the vicinity of Timber Mountain (Figure 1-1). The volcanic aquifers and confining units are intercalated with undifferentiated valley-fill and the valley-fill aquifer to the south and southeast. Structural features define the eastern, western, and portions of the southern boundaries of Yucca Mountain (Figure 4-2). Depending upon the length of time between major volcanic eruptions, the volcanic rocks and valley-fill materials could have been deposited on either a planar surface unaffected by erosion and structural deformation, or on a pre-existing topographic surface. Depositional units that are quickly buried by subsequent deposits generally have fairly planar upper surfaces.

The geologic relations, both actual and inferred, were simplified greatly in order to accommodate computer mapping, framework modeling, and ground-water flow modeling limitations. In simplifying units, emphasis was placed on maintaining a highly generalized structural and stratigraphic framework that incorporated previously described hydrogeologic units. The following criteria were used as guidelines in the simplification process:

- Major high-angle faults were simplified and represented as individual vertical fault planes
- Geologic units were grouped into the hydrogeologic units (Table 6-1)

6.2 DATA AND MODEL SELECTION

The model is built from geologic maps, geologic sections, borehole lithologic logs, digital elevation data, and the GFM (DTN: MO9901MWDGFM31.000). Geologic information, geologic sections and stratigraphic surfaces, developed for the ERP for the NTS (DTN: GS000400002332.002), and the results of recent geologic mapping and subsequent geologic section development (DTN: GS991208314221.001) were added to the data base. Data were selected for input into the model upon completion of an extensive literature search. Where more than one geologic section exists, the newer interpretation (incorporating a newer conceptual model) was used. Hence, the data represented the most current geologic information that were available for the model area at the time of model construction. The model is a geometric model and incorporates the conceptual models of the geologic maps and sections on which it is based. If the conceptual models upon which these are built are changed, the HFM should be updated. No new conceptual models were developed as part of this process.

The base of the model was set to correspond to the base of the Death Valley regional ground-water flow model (DTN: GS960808312144.003). Each of the sequences in the model corresponds to a hydrogeologic unit. The sequences are numbered sequentially from bottom to top. The numbers representing the stacking order of the units in the site area are listed on Table 6-2. The model consists of digital files in STATAMODEL format (site125.tfm, site125.tfb, site125.scf, version 5-99).

Table 6-2. Stacking of Hydrogeologic Units

Stacking sequence	Hydrogeologic Unit
20	Valley-fill Aquifer
19	Valley-fill Confining Unit
18	Limestone Aquifer
17	Lava-flow Aquifer
16	Upper Volcanic Aquifer
15	Upper Volcanic Confining Unit
14	Lower Volcanic Aquifer –Prow Pass Tuff
13	Lower Volcanic Aquifer –Bullfrog Tuff
12	Lower Volcanic Aquifer – Tram Tuff
11	Lower Volcanic Confining Unit
10	Older Volcanic Aquifer
9	Older Volcanic Confining Unit
8	Undifferentiated valley-fill
7	Upper Carbonate Aquifer
6	Lower Carbonate Aquifer (thrust plate)
5	Upper Clastic Confining Unit
4	Lower Carbonate Aquifer
3	Lower Clastic Confining Unit
2	Granitic Confining Unit
1	Base (bottom of regional flow model)

The upper boundary of the model is clipped by the potentiometric surface. The potentiometric surface incorporates a steep hydraulic gradient in the northern portion of the site-scale model area (Figure 6-2). No other conceptual models for this gradient area are considered as part of this AMR. The potentiometric information is summarized in Section 6.3.6.

6.2.1 Intended Use and Accuracy of the Data

The site HFM was developed specifically for use as the hydrogeologic framework for the site-scale SZ ground-water flow and transport model. This HFM is intended to be converted into a ground-water flow model mesh, for use in the Finite Element Heat Mass Model (FEHM) ground-water flow and transport modeling code. Consequently, the model is highly simplified and is intended only for this specific purpose.

The model has grid cells of 125 m on a side and variable thickness. This relatively small grid spacing is predicated by flow model constraints, and is not necessarily consistent with the resolution of geologic data, especially in areas outside the immediate site area or deep in the model. In many areas, the geologic data are not detailed enough to support this grid resolution. The geologic sections used were all at a scale of 1:100,000 or larger. The data are only accurate to the scale of the hard copy of the source data being digitized. Due to the digitization process, an additional small loss in accuracy may occur. The scanning process used a resolution of 0.0013 inch. The sections were leveled and digitally referenced to the map traces. The geologic section files are referenced to their true location in UTM coordinates. The sections are labeled with the appropriate hydrogeologic unit designation. In Intergraph's ERMA software, these horizon tops are tied to the data base and tagged by color.

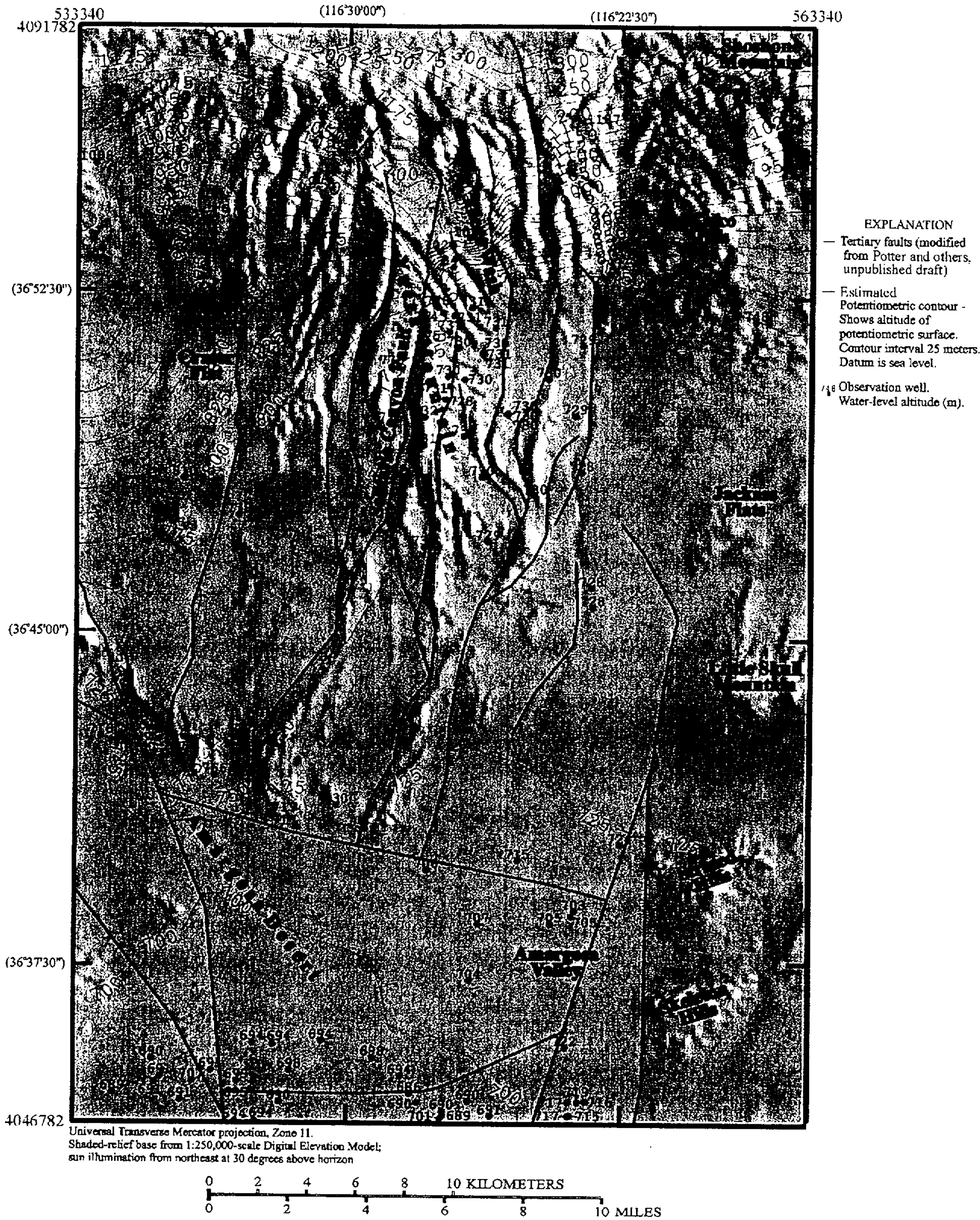

Figure 6-2. Potentiometric Surface and Location of Faults in Site Saturated-Zone Model Area (DTN: GS000508312332.001)

The borehole data accuracy depends on the initial stratigraphic picks and borehole location. In general, these are much more accurate than the geologic section data. The geographic location is given in degrees, minutes, and seconds of latitude and longitude. All of the water-level data are from the Water Level AMR (DTN: GS000508312332.001). The borehole top altitudes were estimated from the digital elevation model (DEM) for data model consistency. The elevations were derived from USGS 3-arc-second 1- by 1-degree DEM files. The published topographic maps at 1:250,000 scales show topographic elevations in feet; however, the standard DEM files define these elevations in meters. The original production objective for the 3-arc-second DEM's was to provide an absolute vertical accuracy related to mean sea level of +/- 30 meters with a 90-percent probability. This absolute vertical accuracy may be too strict as a measure of vertical accuracy; however, 3-arc-second DEM's also are defined as having a root-mean-square-error (RMSE) of elevation values equal to one-third the contour interval and no errors greater than two-thirds the contour interval. Because the source maps in this region have contour intervals of about 30 or 60 meters (100 or 200 feet), corresponding RMSE values no greater than 10 or 20 meters may be expected. The grid interpolation functions used to construct the USGS 1-degree DEM gridded elevation values may favor values corresponding to contour-line elevations. Furthermore, USGS documentation concerning DEM data files state that the relative horizontal and vertical accuracy, although not specified, will in many cases conform to the actual hypsographic features with higher integrity than indicated by the absolute accuracy. In other words, errors in the relative elevation of nearby features may be considerably less (perhaps in the order of 10 meters) than their absolute elevation accuracy relative to mean sea level.

The digital elevation data is from 1:250,000-scale topographic maps, USGS 3-arc-second 1- by 1-degree DEM files, with a grid spacing of approximately 90 m (DTN: GS000400002332.001). All 1- by 1-degree DEMs have hypsographic information consistent with the planimetric features normally found on 1:250,000-scale topographic maps. The production criteria were to provide an absolute horizontal accuracy of 130 meters circular error at 90-percent probability.

6.3 METHODS USED TO DEVELOP MODEL

To characterize the complex 3D, heterogeneous, porous, and fractured media beneath Yucca Mountain, a detailed 3D HFM was developed. The HFM was developed so that it could be converted into a tetrahedral mesh, for use in the FEHM ground-water flow modeling code. As a result, the HFM has many simplifications that may restrict its use for other applications.

The HFM is suitable only for providing a simplified internal hydrogeologic framework for the site-scale ground-water flow model. As flow modeling progresses, details such as hydraulic property variations and facies changes should be added to the HFM. Because of the grid increment, offsets across faults are much less abrupt than in reality. Hence, this HFM should only be used to depict the extent or the boundaries of the hydrogeologic units in a very general sense.

Initially, the HFM was developed for an area bounded by latitude 36°N and 37°15'N and longitude 116°W and 117°W, resulting in the identification of 18 hydrogeologic units. A subarea of this refined HFM, described in this report, is 1,350 km^2 and extends from 533,340 meters to 563,340 meters (30 km west to east) and 4,046,782 meters to 4,091,782 meters (45 km south to north), UTM Zone 11 (Figure 1-1). The subarea grid was chosen to be coincident with the Death Valley regional flow model (DTN: GS960808312144.003). The model area is larger than that of the 3D site GFM (DTN: MO9901MWDGFM31.000) (Figure 4-1), developed to support the Yucca Mountain site unsaturated-zone model, and extends deeper into the SZ than the site GFM.

Development of an HFM begins with the assembly of primary data: geologic maps and sections, borehole lithologic logs, and topography DEM. Standard GIS such as ARCINFO can manipulate each of these primary data; however the merging of these diverse data types to form a single coherent 3D digital model requires more specialized geologic modeling software.

Construction of a 3D HFM involves seven steps:

1. Geologic units are classified into hydrogeologic units based on their hydraulic properties and lateral extent. In this study, the hydrogeologic units described by previous investigators were used, as shown in Table 6-1;
2. DEM data are combined with hydrogeologic maps to provide a series of points in 3D space locating outcrops of individual hydrogeologic units;
3. Geologic sections and borehole lithologic logs are used to locate hydrogeologic units in the subsurface;
4. Geologic maps and geologic sections are used to locate faults;
5. Structure contour maps for each hydrogeologic unit are developed by interpolating both surface and subsurface positions with gridding software which incorporates unit offsets across faults;
6. An HFM is developed when the structure contour maps for the individual hydrogeologic units are combined, utilizing appropriate stratigraphic principles to control their sequence, thickness, and lateral extent; and
7. The potentiometric surface is used to clip the HFM (Water Level AMR, DTN: GS000508312332.001).

The first step was discussed previously, while the last 6 steps are discussed in the following sections. For more detailed information, the steps are described in the Scientific Notebook SN–USGS-SCI-072-V2 (USGS 2000a).

6.3.1 Surface Information

A geologic map (DTN: GS991208314221.001) for the site model area was available in digital form. The geologic units were combined into hydrogeologic units and a new hydrogeologic map coverage was created in ARCINFO. Hence, the surface hydrogeologic map (Figure 4-2) provided the "ground truth" for other model-building data and was the foundation upon which the rest of the HFM was constructed.

To define the surficial 3D extent of units exposed on the ground surface, the hydrogeologic map and the DEM were integrated in ARCINFO. The digital elevation data are from 1:250,000-scale topographic maps with a grid spacing of approximately 90 m (DTN: GS000400002332.001). The DEM defined an array of points in which each point was located by its planar (x,y) coordinates and altitude (z). Points falling within each outcrop area were tagged with the corresponding hydrogeologic unit code.

6.3.2 Subsurface Information

The geologic sections (Figure 4-1) used to construct the HFM were all at a scale of 1:100,000 or larger. The detailed stratigraphy was simplified into the appropriate hydrogeologic unit (Table 6-1). The simplified geologic sections were then digitized, merged, scaled, warped to fit their digitized traces, and accurately placed in 3D space. A data base was populated with the different hydrogeologic units. This data base was then linked to the sections by pointing to each hydrogeologic unit top and keying in the appropriate hydrogeologic unit.

Lithologic data for boreholes in the area (Table 4-1) were used to help correlate between the geologic sections. Borehole lithologic units were grouped into the appropriate hydrogeologic units (Table 6-1). In order to be consistent with the other altitude data being used, the altitude of the top of each hydrogeologic unit was determined by subtracting its depth from the altitude interpolated from the DEM at the borehole location. Where necessary units of feet were converted to meters using the following formula:

$$\text{Distance (ft)} \times 0.3048\ (\text{m/ft}) = \text{Distance (m)}$$

In the area covered by the site GFM (DTN: MO9901MWDGFM31.000) (Figure 4-1), the HFM and the GFM are consistent. The GFM was resampled to the coarser grid resolution of the HFM and only the units corresponding with the tops of the HFM were used (Table 6-3). The GFM surfaces for the Calico Hills Formation, and the Prow Pass, Bullfrog, and Tram Tuffs were used to refine the HFM grid in the area covered by the site 3D GFM (Tables 6-1 and 6-3). For each group of units in a particular hydrogeologic unit, the highest altitude from each grid was taken to represent the top of the corresponding hydrogeologic unit for that cell. Although GFM does contain gravity data to help define the top of the Paleozoic rocks, the lower carbonate aquifer was not augmented by the data from GFM. GFM also contains a surface representing the older volcanic rocks. In some areas this unit appears to equate with the older volcanic confining unit of the HFM, while in other areas it appears to be a different surface. As a result, these data also were not incorporated.

Table 6-3. Hydrogeologic Units and GFM Units

Hydrogeologic Unit	GFM Units (DTN: MO9901MWDGFM31.000)
Upper Volcanic Confining Unit	Calico, Calicobt
Lower Volcanic Aquifer – Prow Pass Tuff	Prowlv, Prowlc, Prowmd, Prowuc, Prowuv, Prowbt
Lower Volcanic Aquifer – Bullfrog Tuff	Bullfroglv, Bullfroglc, Bullfrogmd, Bullfroguc, Bullfroguv, Bullfrogbt
Lower Volcanic Aquifer - Tram Tuff	Tramlv, Tramlc, Trammd, Tramuc, Tramuv, Trambt

6.3.3 Representation of Faults and Structures

Information on faults used in the development of the HFM includes fault trace maps showing where faults intersect the land surface, and faults shown on geologic sections. Faults in the model area can dip at almost any angle, but most are high-angle faults. Given software constraints and the flow model resolution, the faulting in the area is greatly simplified. The major simplification is that nearly all of the high-angle faults are treated as vertical features.

Thrust faults were represented by repeating hydrogeologic units where these structural features were thought to be hydrologically important. Structural or stratigraphic surfaces are stored as arrays, and can not have multiple z values at one location. This means that thrust faults and mushroom-shaped intrusions can not be represented by an array. In order to deal with these problems, some simplifying techniques were used. Where units were repeated by thrust faults, two different grids were created for the same hydrogeologic unit. A unit boundary map was then added to define an outline for the perimeter of the thrust sheet. Within this boundary, hydrogeologic structural elevation values were treated as defining unique additional hydrogeologic units. Where units were continuous across this boundary, values are the same on each side of the boundary, making the boundary invisible for modeling purposes.

Due to the large number of faults in the modeled area and limitations in modeling technology, guidelines are needed to select the faults that can realistically be modeled. The fault traces from the site-area map were examined to determine which have hydrologic significance. This determination was based primarily on feedback from the users of previous model versions, but also on the importance of a fault to the HFM and SZ flow modeling. A number of faults were selected to use for offsets on the grids (Figure 6-3). For example, an area in the southwest corner of the model area influenced by thrusting was identified (Figure 6-3). This area is coincident with an area of highly fractured carbonate rock as well as an area of high hydraulic conductivity and high flow rates in the regional model (DTN: GS960808312144.003).

Although currently included as part of the Upper Volcanic Aquifer within the HFM, the Claim Canyon Caldera and the Shoshone Pluton, shown in Figure 6-3, may be associated with zones of hydrothermally altered rocks having distinctly different hydrologic properties from those nominally associated with the Upper Volcanic Aquifer. These altered zones, therefore, may be hydrologically significant in controlling ground-water flow and recharge in the northern part of the model domain. Data are lacking, however, by which to assess the potential effects of these zones of altered rocks and to incorporate these zones explicitly within the HFM. Similarly, the anomalous Fortymile Wash drainage shown in Figure 6-3 may be indicative of a structural feature that may affect ground-water flow and recharge but for which data are lacking by which to incorporate this feature explicitly in the HFM. However, partial allowance for the potential effects of these features is being incorporated into the development of the site-scale SZ flow model (CRWMS-M&O 2000b).

The Solitario Canyon, Crater Flat, Windy Wash, and Bare Mountain faults (Figure 6-3) are identified as major faults in the site-scale model region and are thought to affect ground-water flow. Where enough hydrologic data is available, other structures could be added as necessary to help calibrate the flow model.

6.3.4 Construction of Hydrogeologic Unit Structure Contour Maps

The fundamental building blocks of the HFM are structure contour maps. To construct these maps, the different hydrogeologic unit tops must be interpolated and extrapolated from the available land-surface data and throughout the subsurface between the geologic sections and boreholes. The emphasis in this step was to create structure contour maps in a consistent manner by interpolating and extrapolating from available data points. These data points included: (1) topographic elevations derived from DEM data within the outcrop areas of each hydrogeologic unit; (2) separate files defining the tops of each hydrogeologic unit supplied from the geologic sections; (3) altitudes of hydrogeologic unit tops from borehole lithologic logs, 4) geophysical evidence of unit tops from published sources, and 5) grid points from GFM. The distribution of geologic, geophysical, and borehole-data locations is shown on Figure 4-1. The data sources for developing the structure contour maps are shown in Table 6-4. Maps showing the data distribution for each unit are in Figures 6-4 through 6-20. The distribution of the valley-fill aquifer and confining unit is based only on the surface-based hydrogeologic map data shown in Figure 4-2. This unit distribution is before being clipped by the potentiometric surface. In many cases, the actual distribution of the units in the HFM is much smaller.

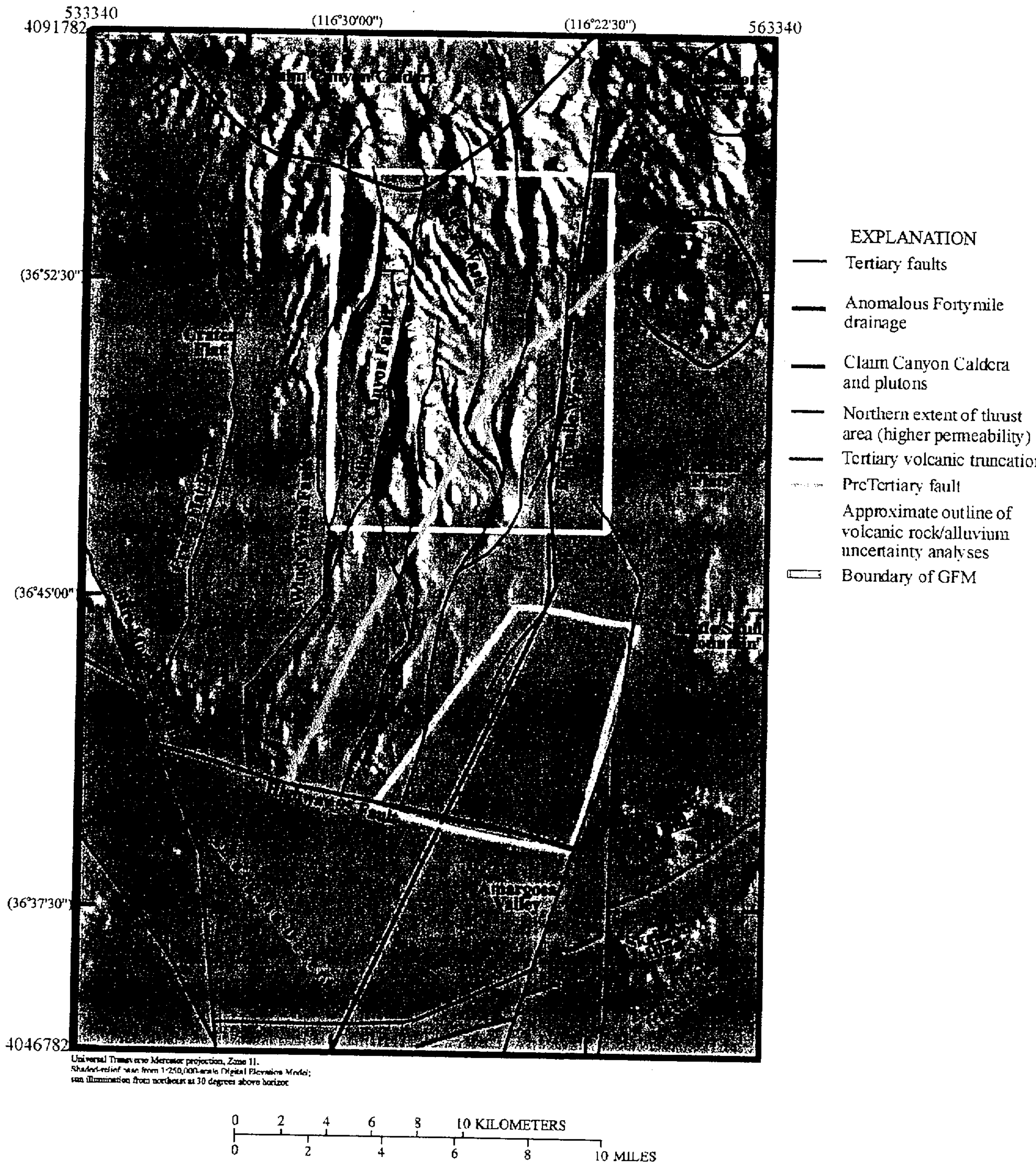

Figure 6-3. Site Saturated-Zone Model Extent and Locations of Proposed Hydrogeologic Zones and Faults (modified from DTN: GS991208314221.001)

Table 6-4. Data Sources for Hydrogeologic Units (Actual sources in Table 4-1)

Hydrogeologic Unit	Data Sources					
	Geologic Section[1]	Lithologic Log[2]	Geologic Map[3]	GFM 3.1[4]	ERP Model Geologic Section[5]	ERP Model Grid and Geophysical Data[6]
Valley-fill Aquifer			X			
Valley-fill Confining Unit			X			
Limestone Aquifer		X				
Lava-flow Aquifer	X	X	X			
Upper Volcanic Aquifer	X	X	X			
Upper Volcanic Confining Unit	X	X	X	X		
Lower Volcanic Aquifer –Prow Pass Tuff	X	X	X	X		
Lower Volcanic Aquifer – Bullfrog Tuff	X	X	X	X		
Lower Volcanic Aquifer – Tram Tuff	X		X	X		
Lower Volcanic Confining Unit	X	X	X			
Older Volcanic Aquifer	X	X	X			
Older Volcanic Confining Unit	X	X	X			
Undifferentiated Valley-Fill	X	X				
Upper Carbonate Aquifer	X	X	X		X	
Lower Carbonate Aquifer (thrust plate)	X		X			
Upper Clastic Confining Unit	X	X	X		X	
Lower Carbonate Aquifer	X	X	X		X	X
Lower Clastic Confining Unit	X	X	X		X	
Granitic Confining Unit	X	X	X			

[1] GS900908314211.007; GS950508312333.001
[2] GS940908312132.004; GS950508312333.002
[3] GS000400002332.001; GS991208314221.001
[4] MO9901MWDGFM31.000
[5] GS000400002332.002
[6] GS960108314211.002; GS950108314212.001

Construction and data source type and location of each hydrogeologic unit surface is illustrated in Figures 6-4 through 6-20. The data sources for Figures 6-4 through 6-20 are shown in Table 4–1.

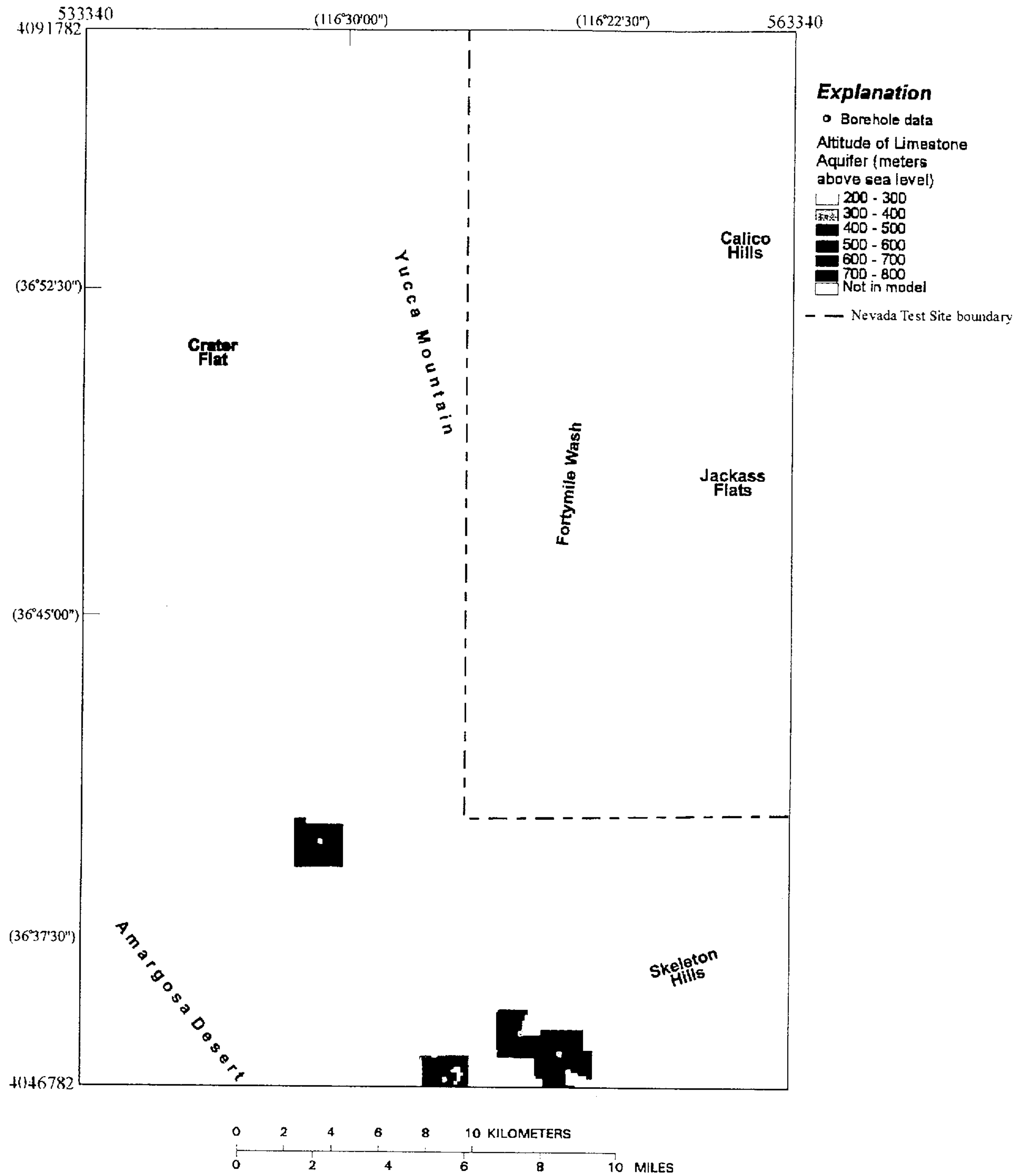

Figure 6-4. Map Showing Distribution of Limestone Aquifer and Data Distribution used to Construct Surface (Unit distribution is before clipping by potentiometric surface) (DTN: GS000508312332.002)

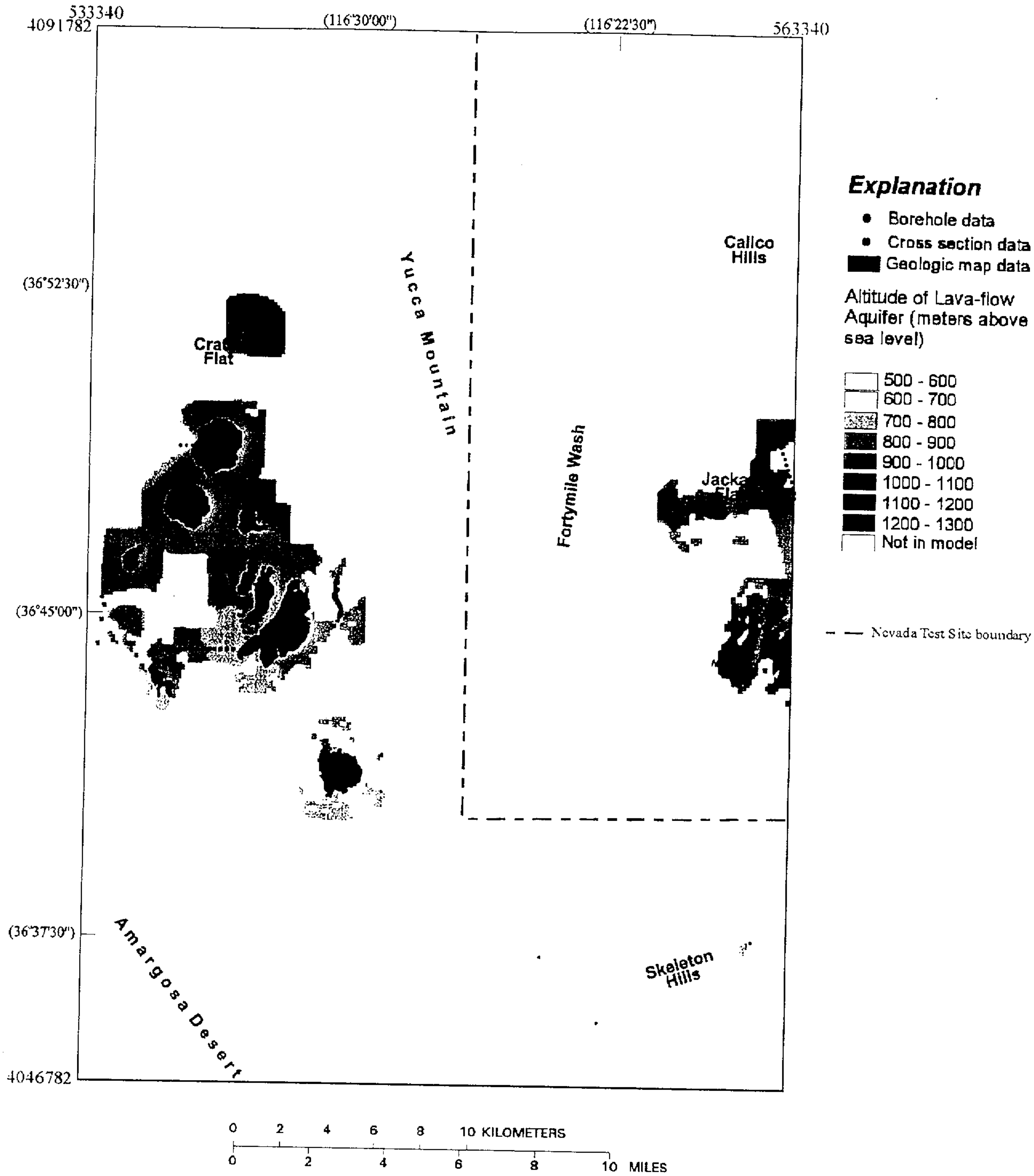

Figure 6-5. Map Showing Distribution of Lava-Flow Aquifer and Data Distribution used to Construct Surface (Unit distribution is before clipping by potentiometric surface) (DTN: GS000508312332.002)

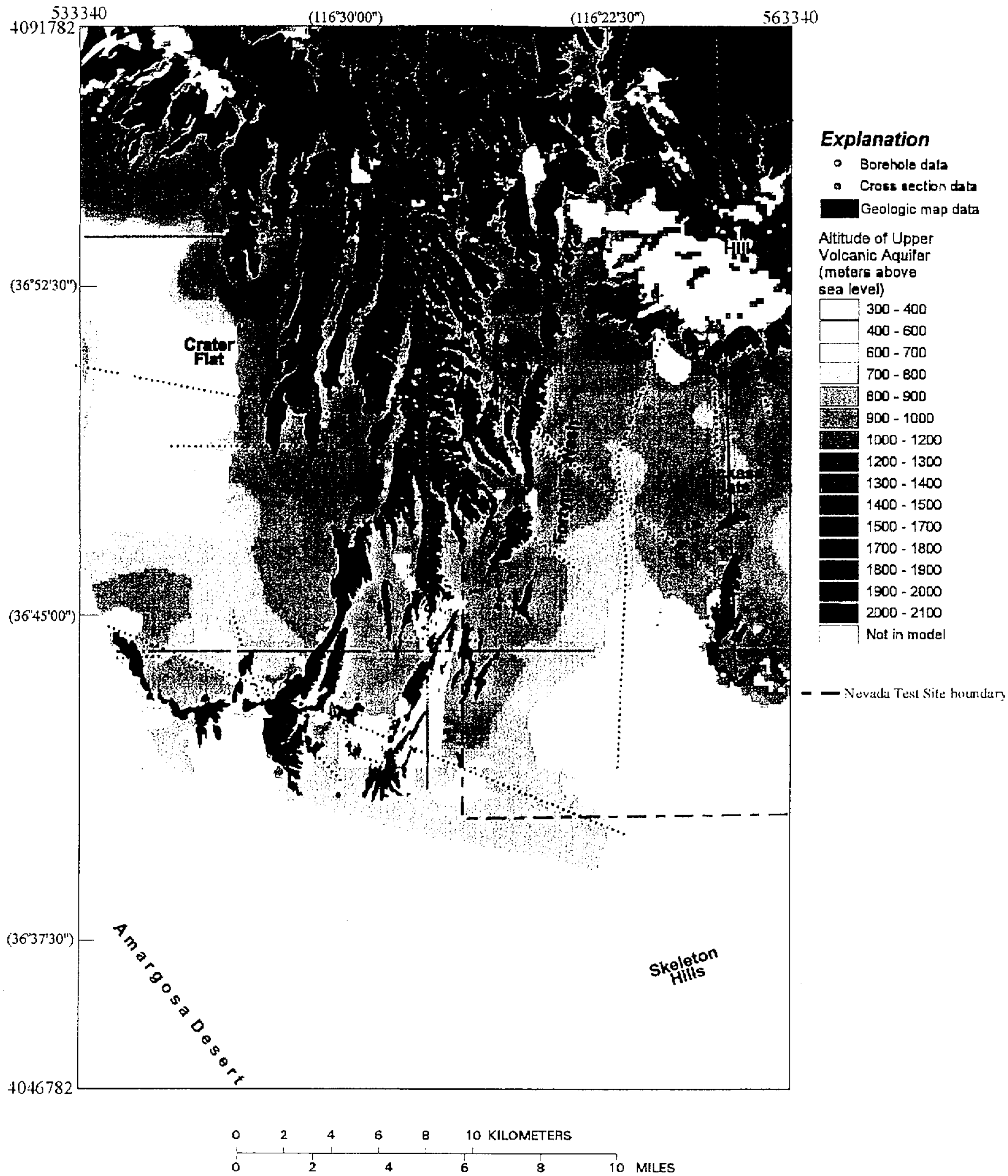

Figure 6-6. Map Showing Distribution of Upper Volcanic Aquifer and Data Distribution used to Construct Surface (Unit distribution is before clipping by potentiometric surface) (DTN: GS000508312332.002)

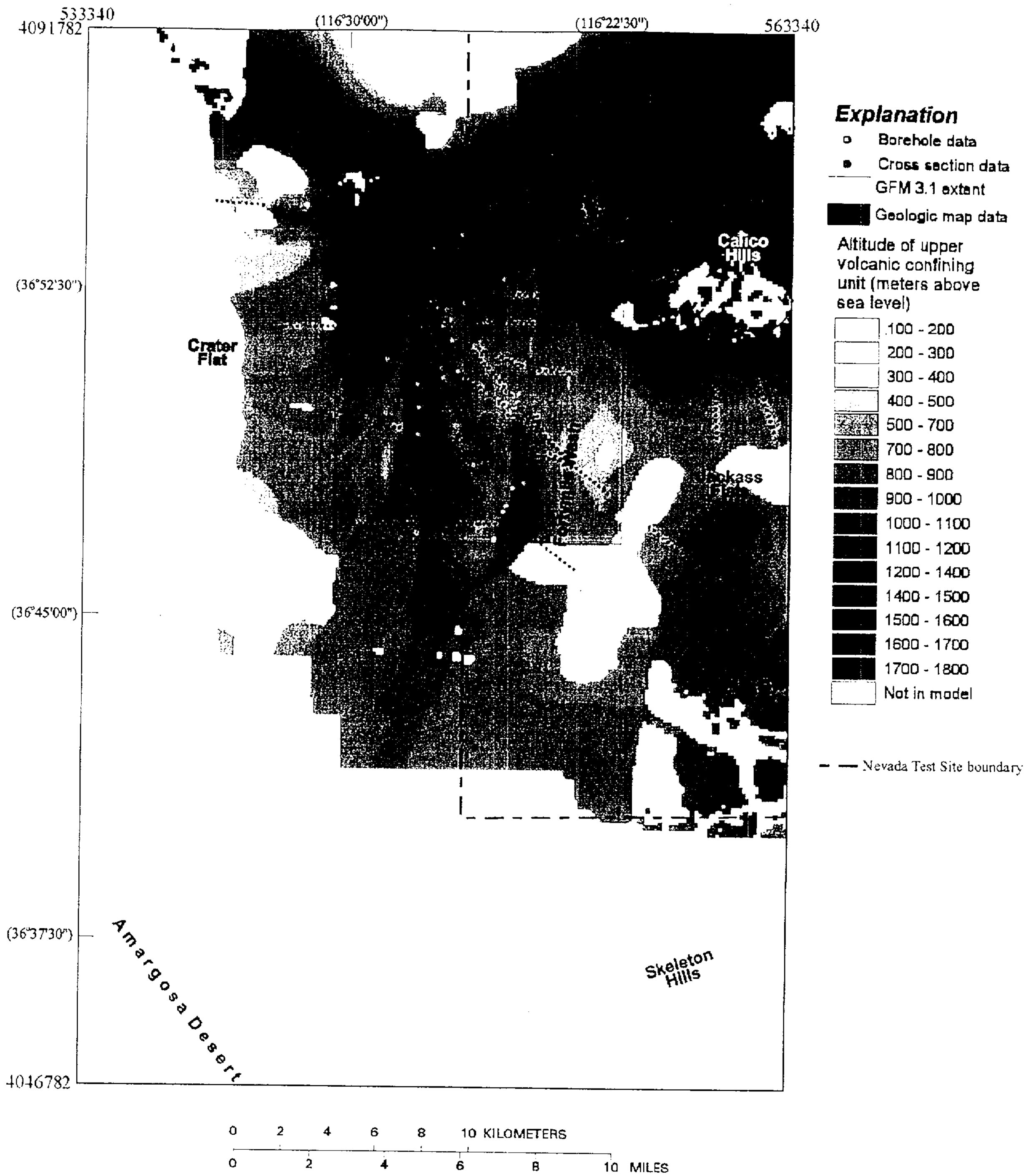

Figure 6-7. Map Showing Distribution of Upper Volcanic Confining Unit and data Distribution used to Construct Surface (Unit distribution is before clipping by potentiometric surface) (DTN: GS000508312332.002)

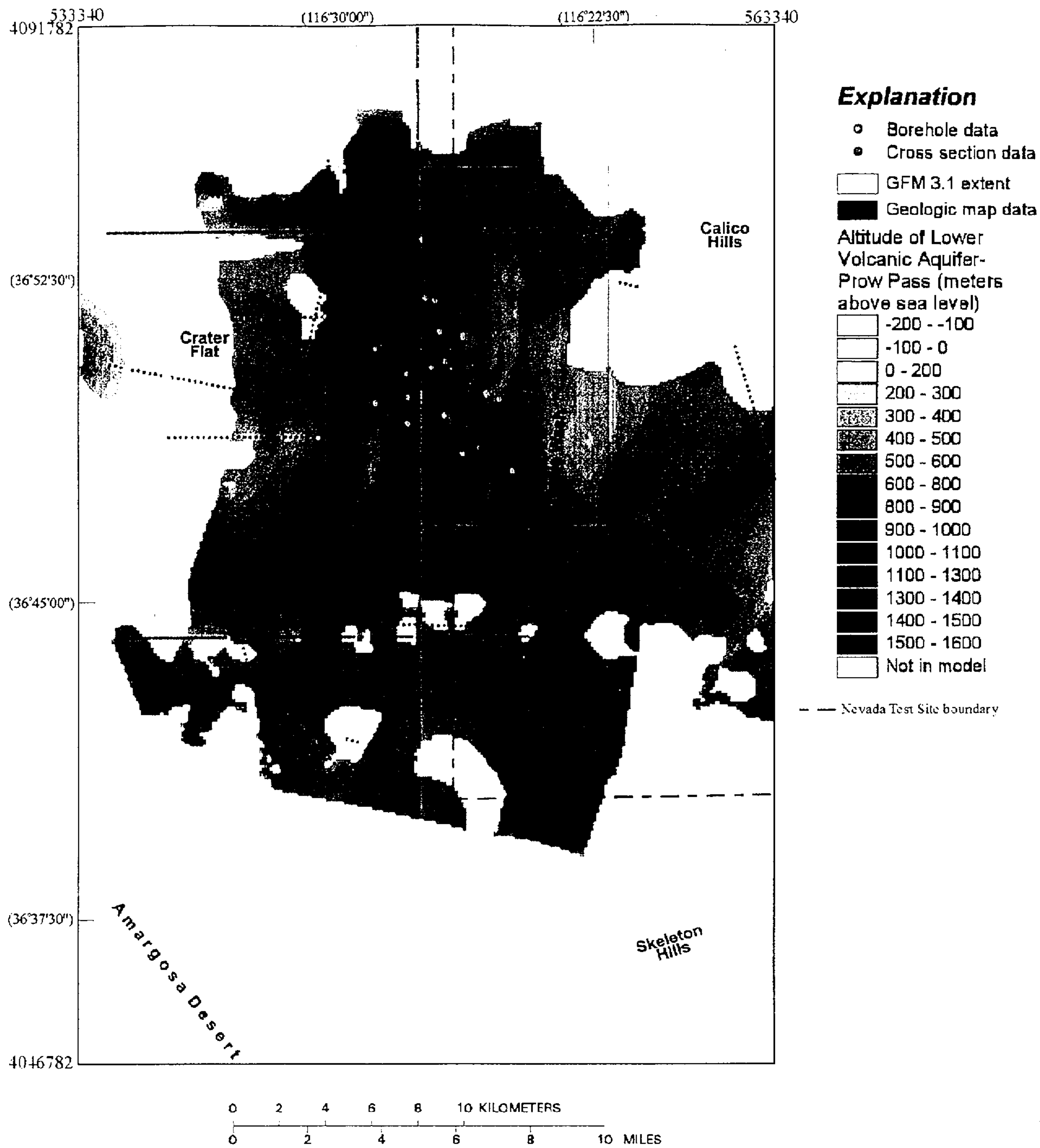

Figure 6-8. Map Showing Distribution of Lower Volcanic Aquifer (Prow Pass Tuff) and Data Distribution used to Construct Surface (Unit distribution is before clipping by potentiometric surface) (DTN: GS000508312332.002)

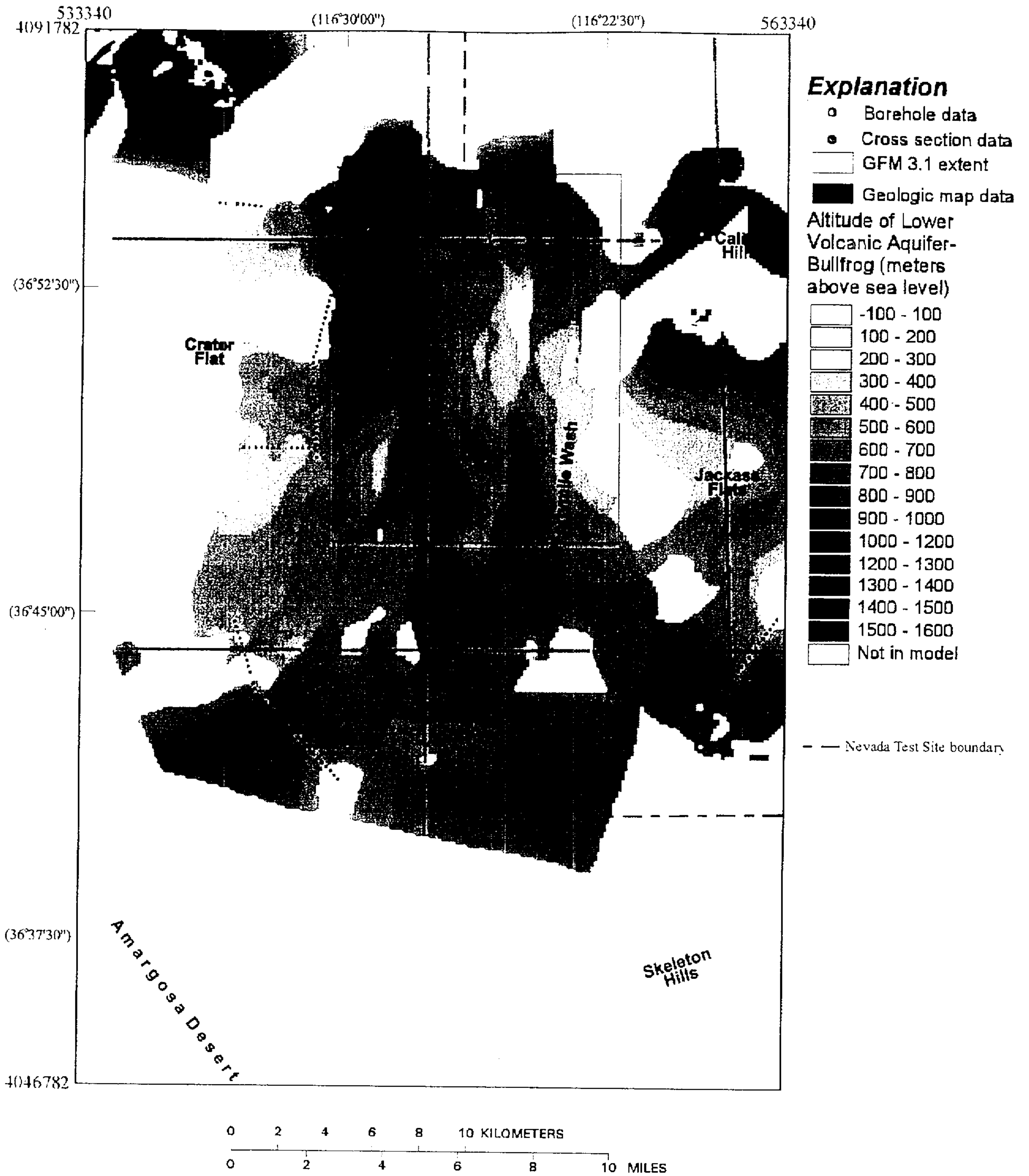

Figure 6-9. Map Showing Distribution of Lower Volcanic Aquifer (Bullfrog Tuff) and Data Distribution used to Construct Surface (Unit distribution is before clipping by potentiometric surface) (DTN: GS000508312332.002)

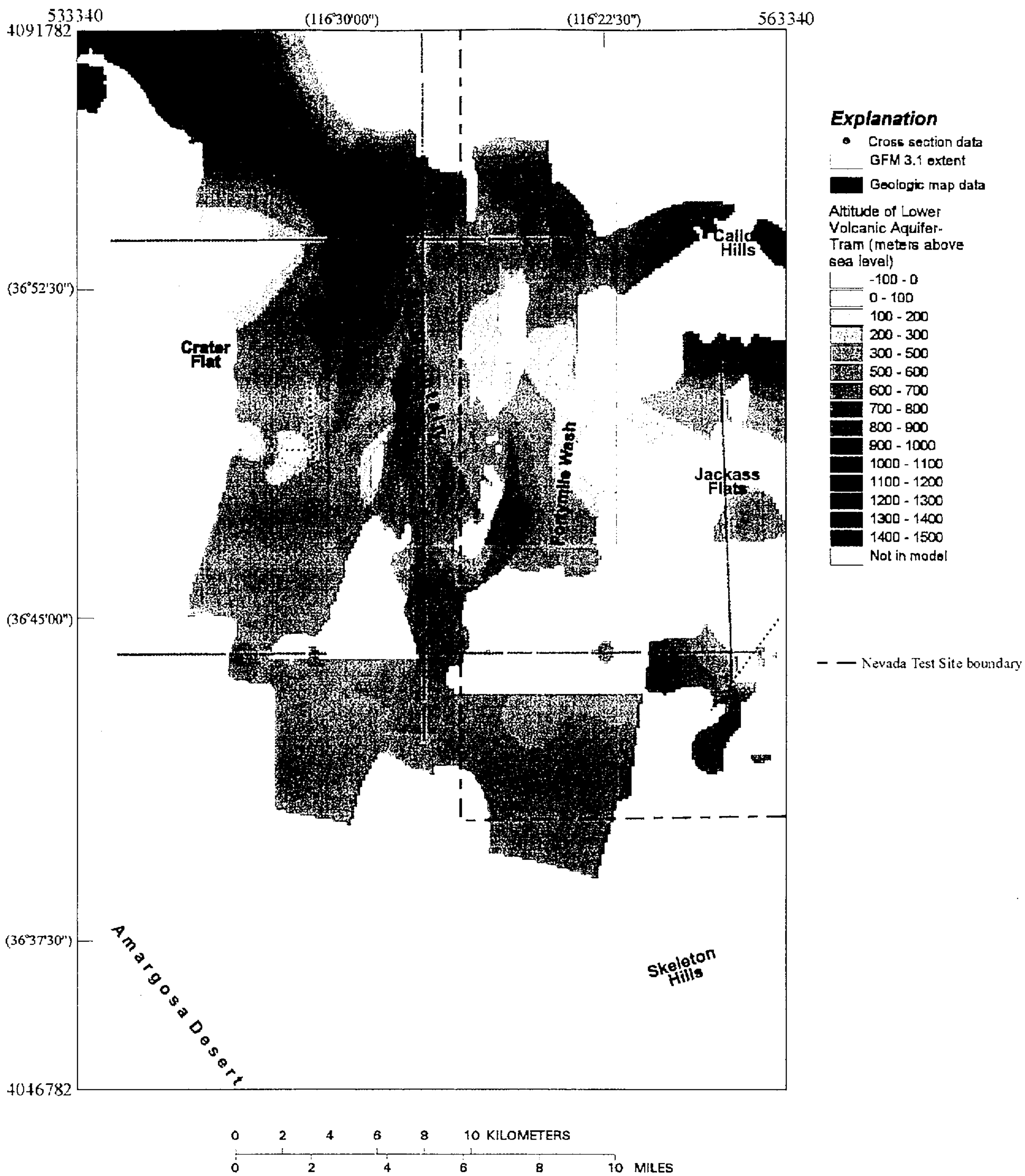

Figure 6-10. Map Showing Distribution of Lower Volcanic Aquifer (Tram Tuff) and Data Distribution used to Construct Surface (Unit distribution is before clipping by potentiometric surface) (DTN: GS000508312332.002)

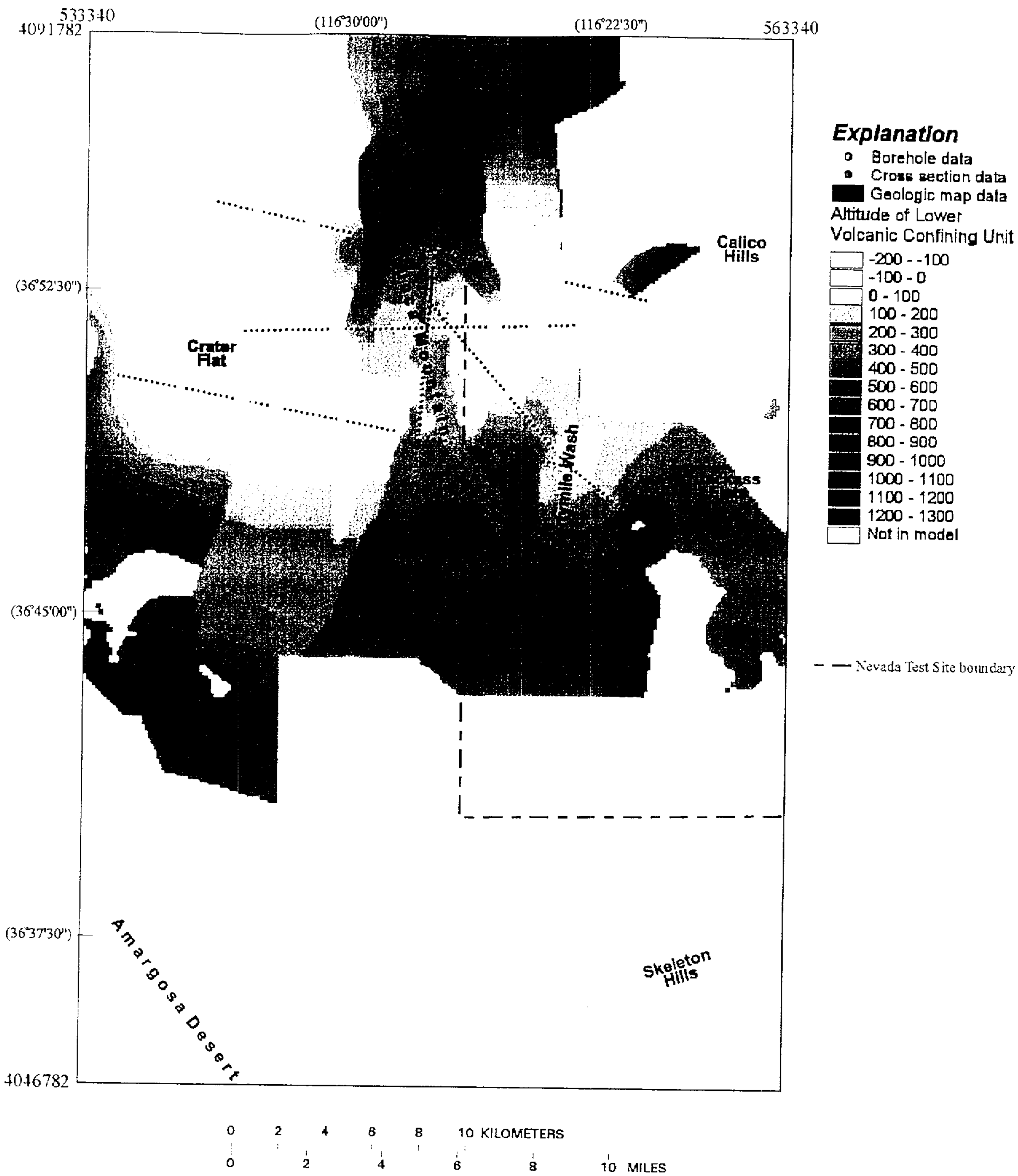

Figure 6-11. Map Showing Distribution of Lower Volcanic Confining Unit and Data Distribution used to Construct Surface (Unit distribution is before clipping by potentiometric surface) (DTN: GS000508312332.002)

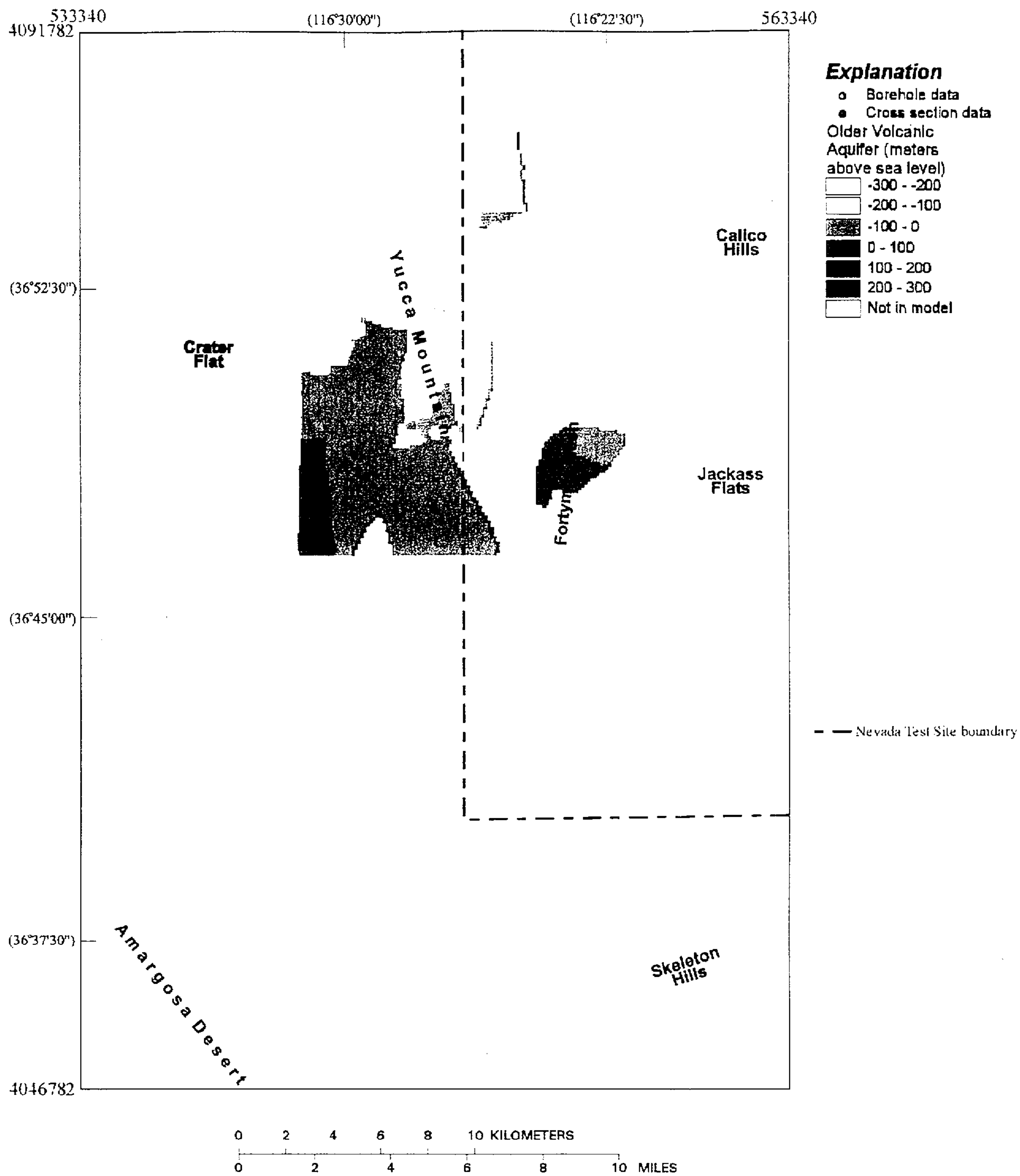

Figure 6-12. Map Showing Distribution of Older Volcanic Aquifer and Data Distribution used to Construct Surface (Unit distribution is before clipping by potentiometric surface) (DTN: GS000508312332.002)

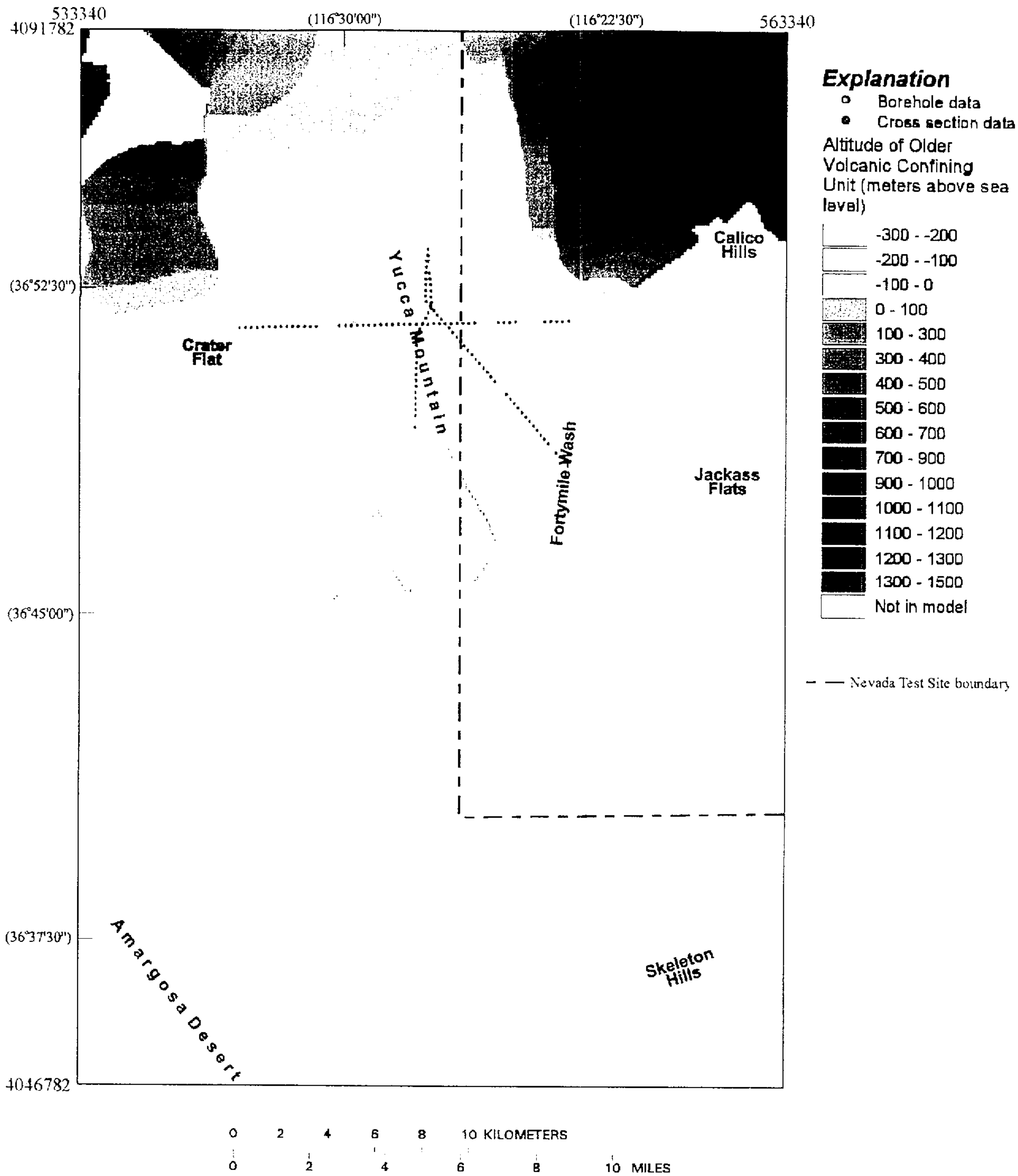

Figure 6-13. Map Showing Distribution of Older Volcanic Confining Unit and Data Distribution used to Construct Surface (Unit distribution is before clipping by potentiometric surface) (DTN: GS000508312332.002)

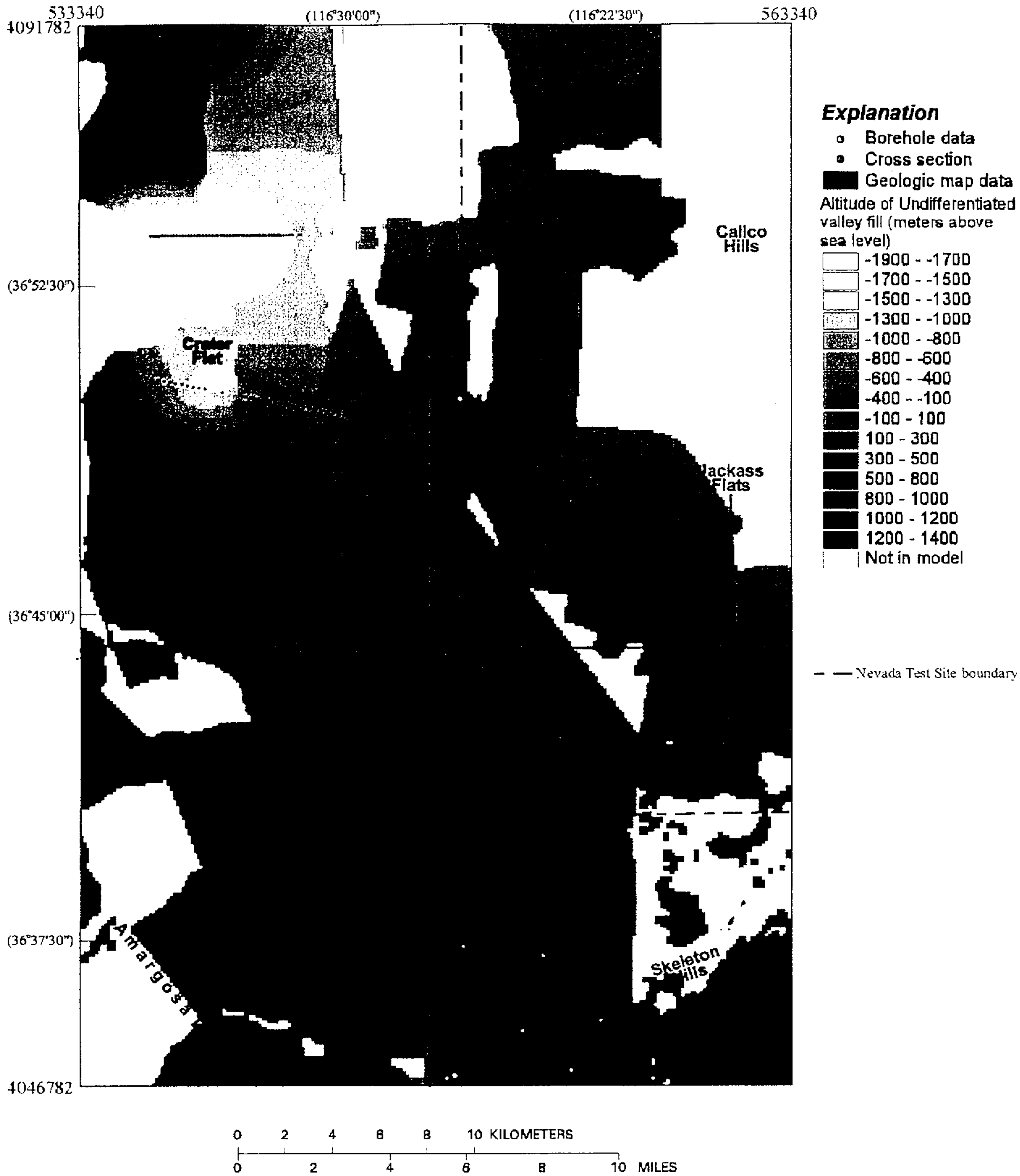

Figure 6-14. Map Showing Distribution of Undifferentiated Valley Fill and Data Distribution used to Construct Surface (Unit distribution is before clipping by potentiometric surface) (DTN: GS000508312332.002)

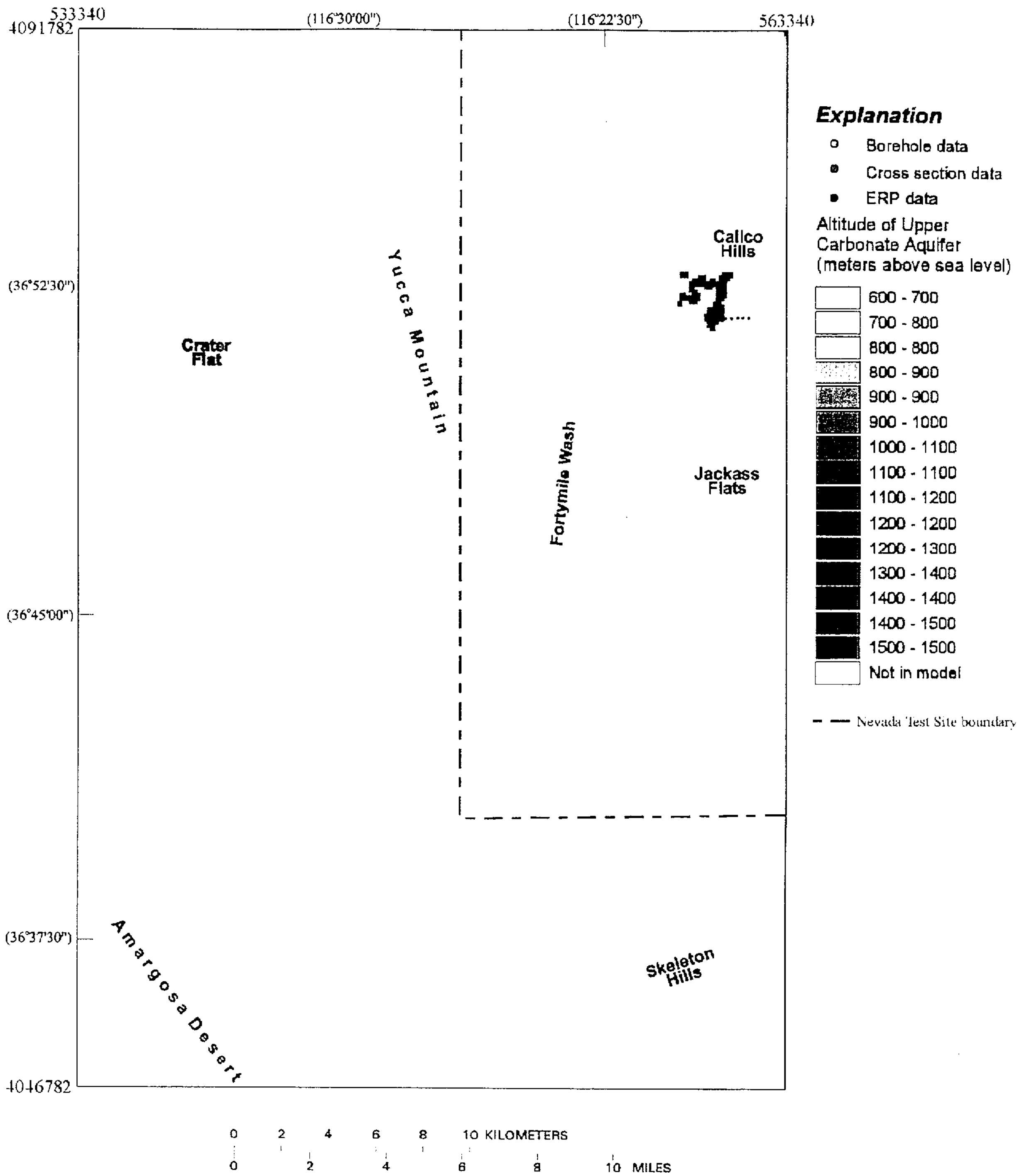

Figure 6-15. Map Showing Distribution of Upper Carbonate Aquifer and Data Distribution used to Construct Surface (Unit distribution is before clipping by potentiometric surface) (DTN: GS000508312332.002)

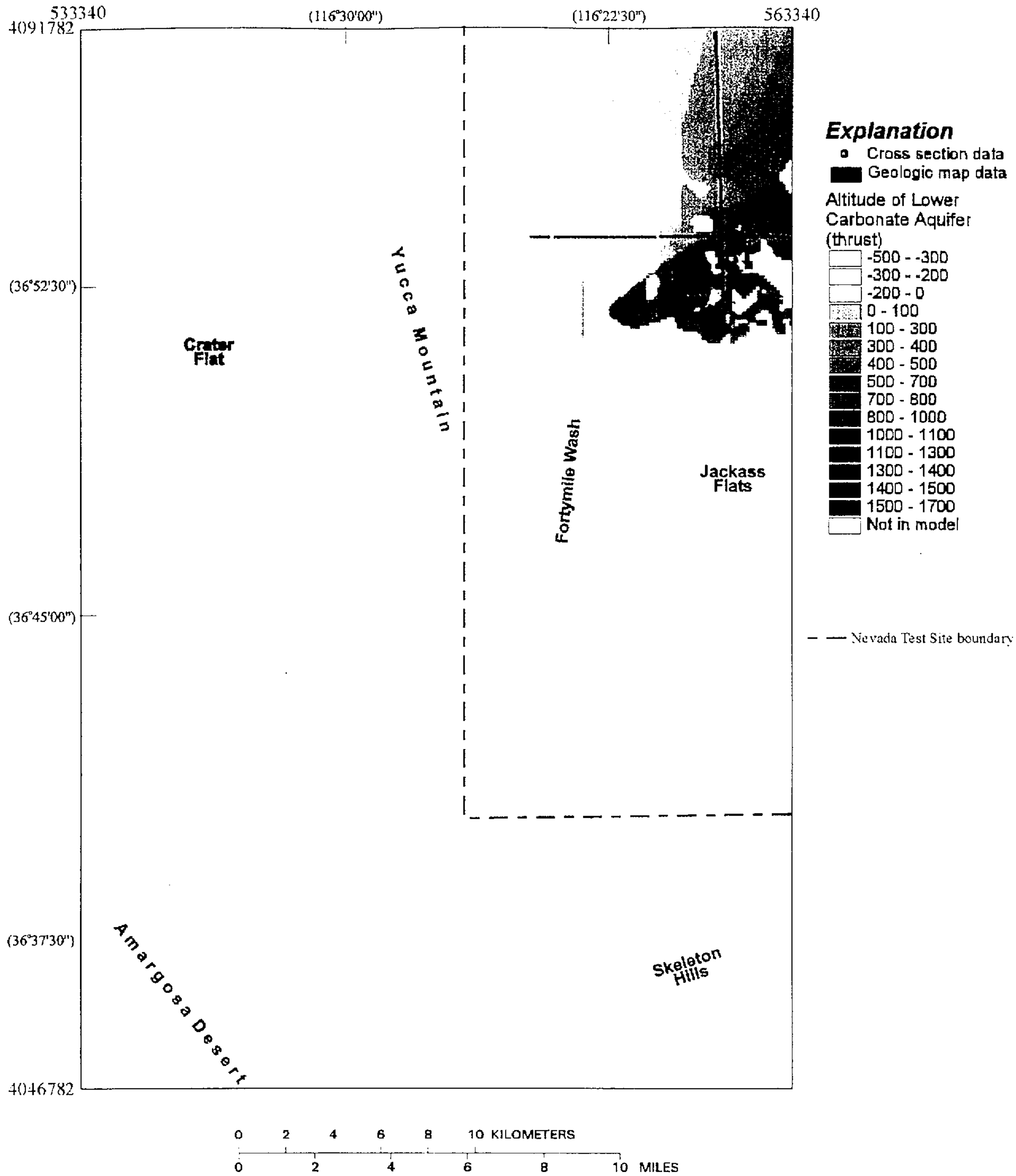

Figure 6-16. Map Showing Distribution of Lower Carbonate Aquifer Thrust and Data Distribution used to Construct Surface (Unit distribution is before clipping by potentiometric surface) (DTN: GS000508312332.002)

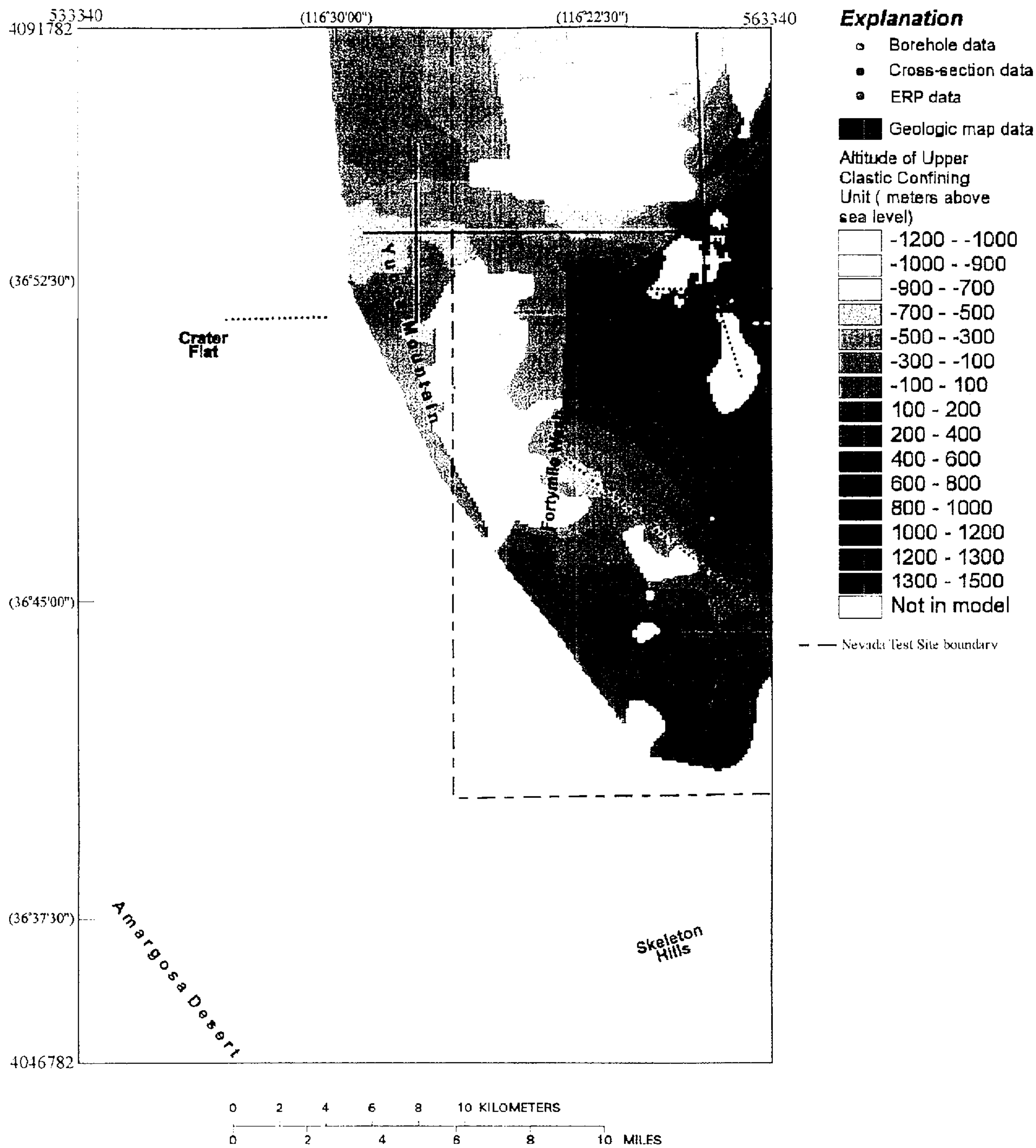

Figure 6-17. Map Showing Distribution of Upper Clastic Confining Unit and Data Distribution used to Construct Surface (Unit distribution is before clipping by potentiometric surface) (DTN: GS000508312332.002)

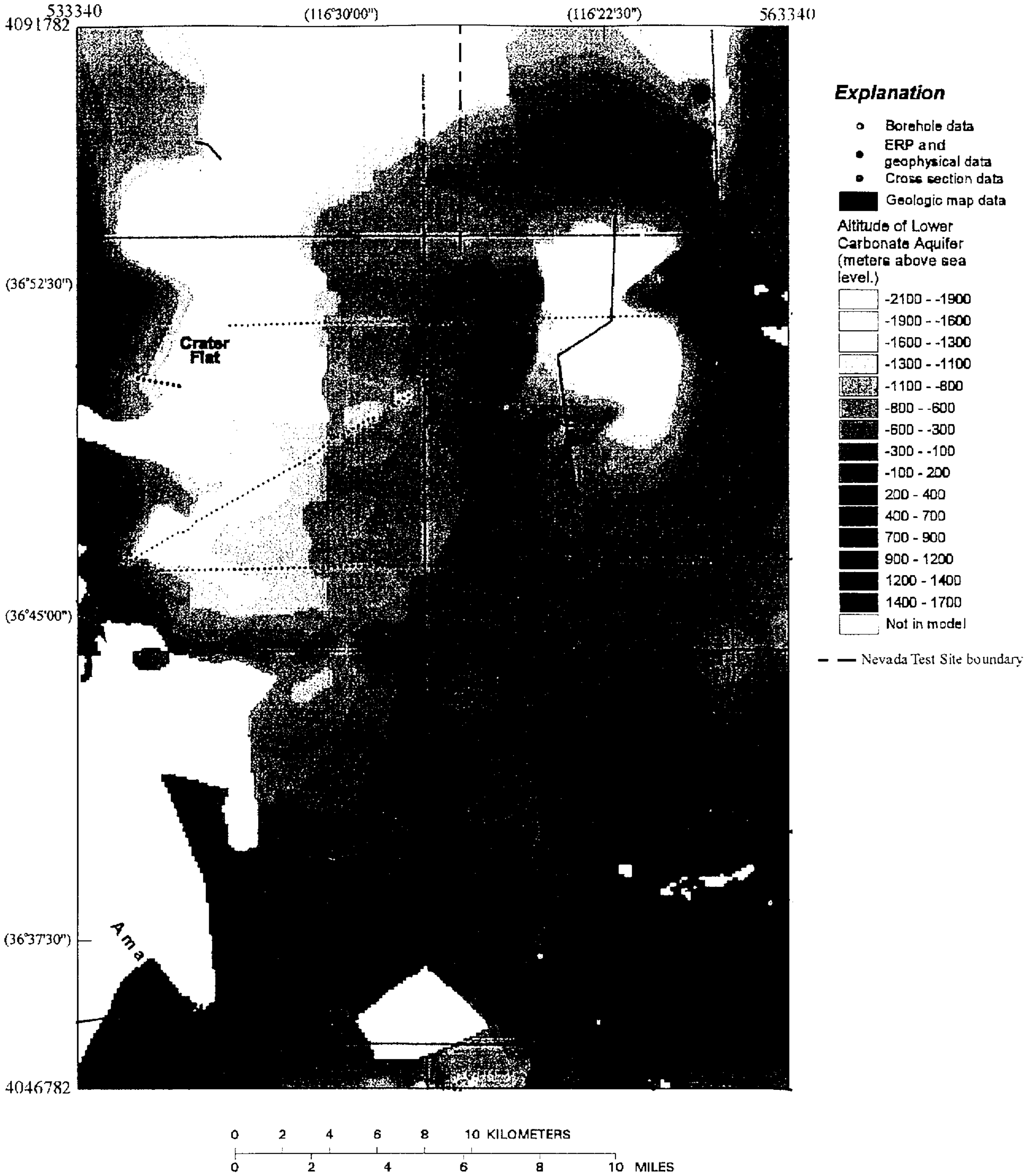

Figure 6-18. Map Showing Distribution of Lower Carbonate Aquifer and Data Distribution used to Construct Surface (Unit distribution is before clipping by potentiometric surface) (DTN: GS000508312332.002)

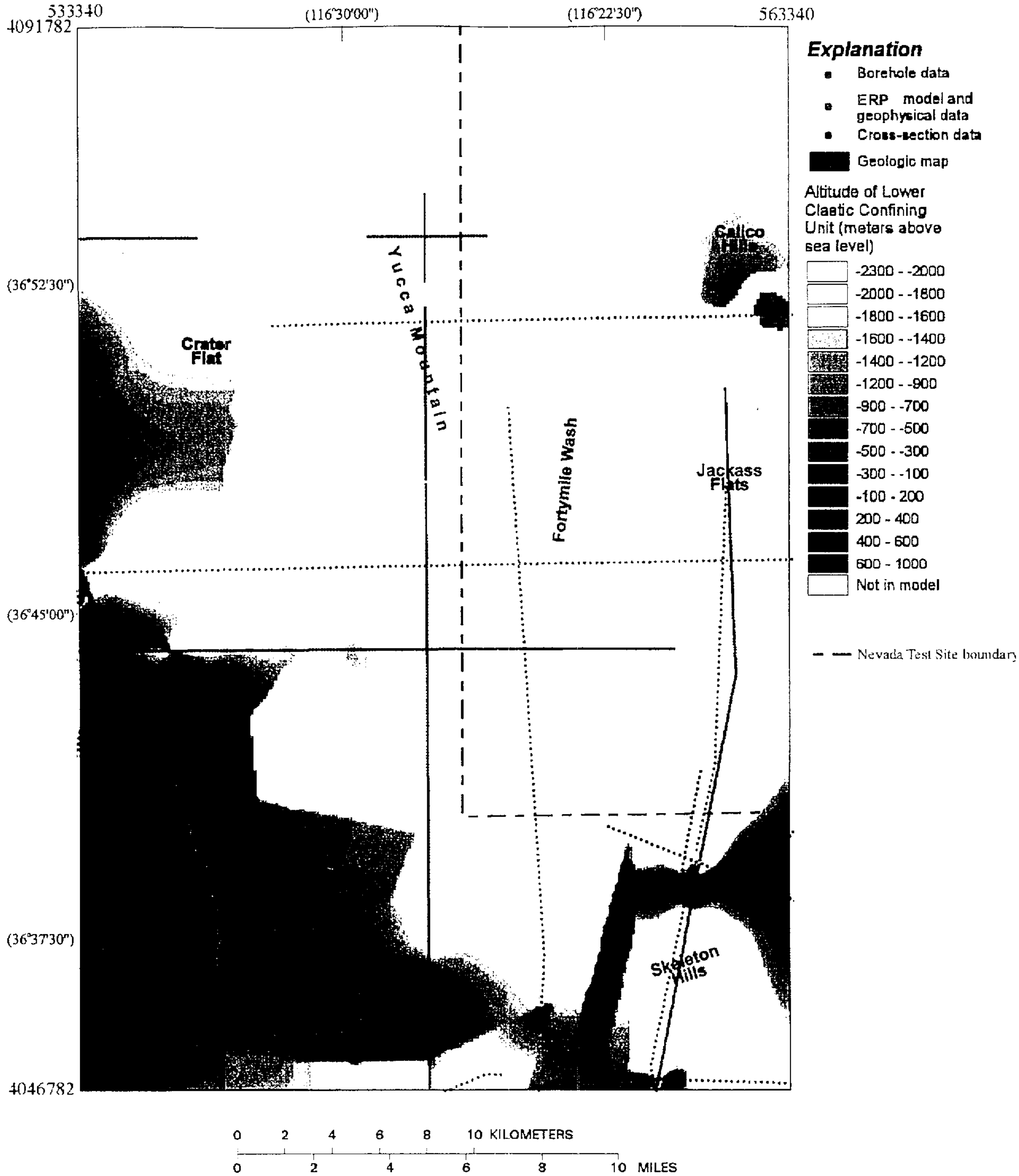

Figure 6-19. Map Showing Distribution of Lower Clastic Confining Unit and Data Distribution used to Construct Surface (Unit distribution is before clipping by potentiometric surface) (DTN: GS000508312332.002)

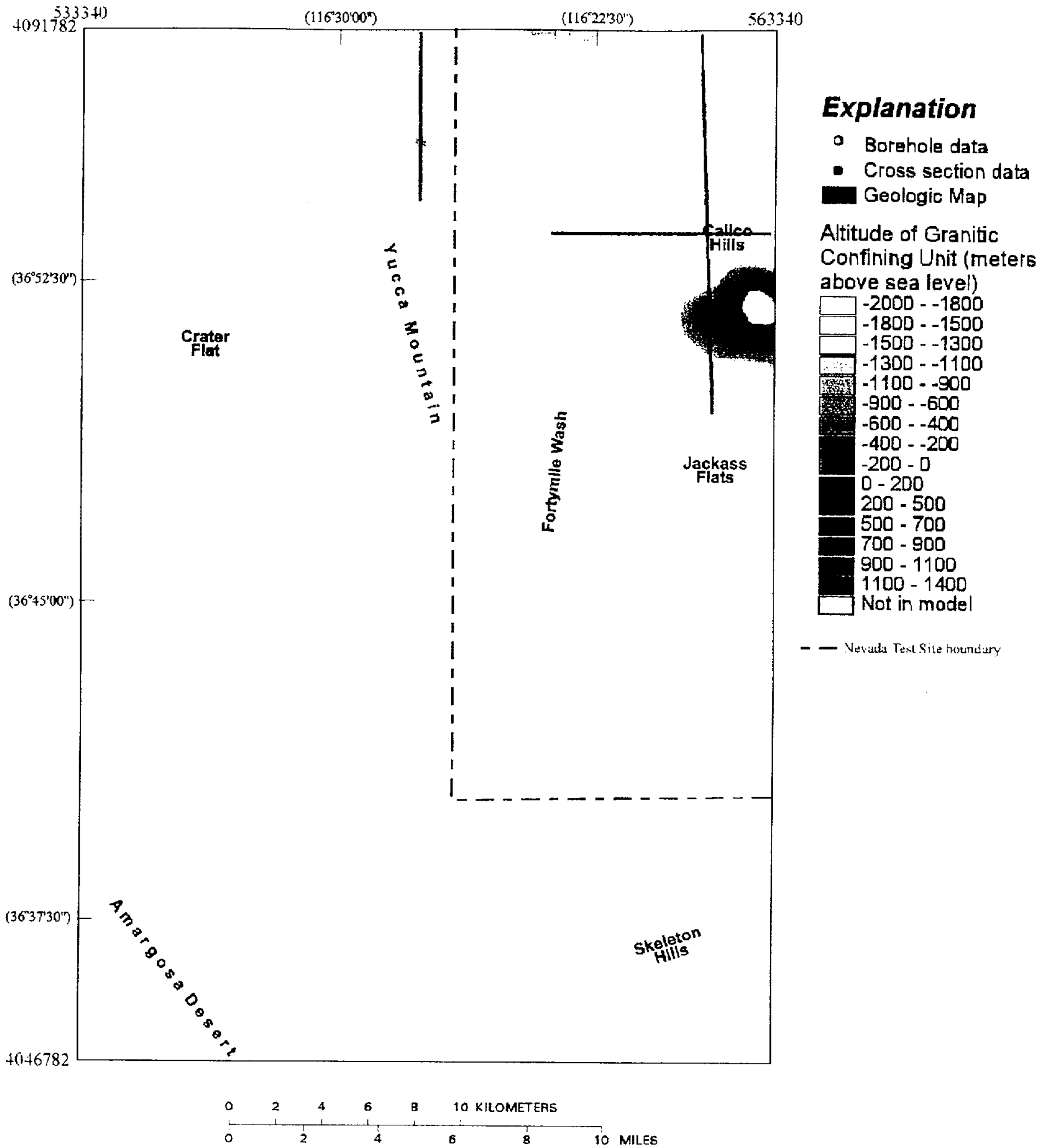

Figure 6-20. Map Showing Distribution of Granite Confining Unit and Data Distribution used to Construct Surface (Unit distribution is before clipping by potentiometric surface) (DTN: GS000508312332.002)

Gridding is the process of creating a surface grid across an area based on scattered input data. The PETROSYS gridding system and fault-handling package was used to interpolate the hydrogeologic surfaces between existing geologic sections, borehole unit tops, surface exposure points, and points from the GFM. A grid design congruent with the computational grid of the regional ground-water flow model (DTN: GS960808312144.003) was used. The HFM grid, therefore, consists of a rectangular array of nodes with a nodal spacing of 125 m, which was chosen on the basis of flow modeling requirements as opposed to the best increment to accurately represent the data. This selection resulted in grids with 240 columns and 360 rows. This grid spacing simplifies the available data near the potential repository and extrapolates from very widely spaced data in other areas of the model domain.

Many methods (both mathematical and interpretive) are available for use in creating grids. Most methods use a projected distance weighted average to obtain initial grid estimates for the input data. Once the initial estimation has been completed, the grid is allowed to converge to an optimum solution by using forced filtering. This filtering pass fills in the missing values in the grid.

A hybrid gridding technique was used to construct a continuous grid or surface for each hydrogeologic unit utilizing a set of points in x, y, z space. The hybrid method is a combination of the minimum curvature and a first order least squares. It uses first order least squares within one grid cell of a fault and minimum curvature to calculate all other nodes. In areas, such as Yucca Mountain, the results from this method may be better than those obtained using the minimum-curvature method that commonly is used in geologic modeling. In areas with heavy faulting, such as Yucca Mountain, a combination of the methods appears to honor the data more accurately.

Using a fault-handling package built into the gridding software, the fault traces (Figure 6-3) were used during the gridding procedure so that the altitude of a unit was not translated across a fault (Table 6-5). Where the grid crosses a fault, the grid is offset by the appropriate amount. The offset on the faults varies with location. Inherent in using fault traces is the simplification of these faults being traces of a vertical fault plane. Hence, the resulting structure contour maps contain a series of undulating surfaces broken by faults (Figure 6-4 through 6-20). Because the scale of the model, the intended use of the model, and data availability, grids of individual fault surfaces were not constructed. Even less is known about the dip and location of faults below the water table than the stratigraphy. Some of the offsets on the faults are preserved through changes in altitude of a given hydrogeologic unit. Given the depth to which the HFM extends and the lack of information in most of the modeled volume, this seems to be a rational simplification.

Table 6-5. Gridding Parameters

Hydrogeologic Unit	Clipping Distance (m)[1]	Faults included in gridding
Valley-fill Aquifer	62.5	No
Valley-fill Confining Unit	62.5	No
Limestone Aquifer	2000	No
Lava-flow Aquifer	2000	Yes
Upper Volcanic Aquifer	5000	Yes
Upper Volcanic Confining Unit	5000	Yes
Lower Volcanic Aquifer –Prow Pass Tuff	7500	Yes
Lower Volcanic Aquifer –Bullfrog Tuff	10000	Yes
Lower Volcanic Aquifer – Tram Tuff	7500	Yes
Lower Volcanic Confining Unit	7500	Yes
Older Volcanic Aquifer	5000	Yes
Older Volcanic Confining Unit	10000	Yes
Undifferentiated Valley-Fill	10000	Yes
Upper Carbonate Aquifer	2000	Yes[2]
Lower Carbonate Aquifer (thrust plate)	7500	Yes[3]
Upper Clastic Confining Unit	2000	Yes[2]
Lower Carbonate Aquifer	None	Yes[2]
Lower Clastic Confining Unit	None	Yes[2]
Granitic Confining Unit	6000	Yes

[1]Clipping distance is the distance beyond the data points which grid nodes are set to null values.
[2]Paleozoic fault was also included.
[3]Thrust fault unit extent was used.

Thrust faults occur in the model area, but are difficult to represent because geologic, structural, or stratigraphic surfaces stored as arrays cannot have multiple vertical coordinate (z) values. Simplifying techniques were used to handle this limitation. Where units were repeated by thrust faults, two different grids were created for the same hydrogeologic unit. Repeating hydrogeologic structural unit altitude values were treated as defining unique additional hydrogeologic unit(s). In this model, thrust faulting made it necessary for the lower carbonate aquifer to be represented by two grids.

The quality of individual structure contour maps depends on the density of the data points used to define them. Some of these hydrogeologic surfaces, such as that for upper volcanic aquifer, were relatively well defined by more than one data set (derived from surface information, lithologic logs, and geologic sections). Other structure contour maps, especially those for units with fewer outcrops, were less well defined and were extrapolated from sparse, interpretive data such as published geophysical interpretations. A relative rating of data availability for each of the hydrogeologic units appears in Table 6-1; the rating does not imply accuracy regarding the extent and location of each unit. Although the rating is subjective, it is based partially on the number of data points used to define each hydrogeologic unit.

In areas with little or no data, gridding algorithms sometimes extrapolate unreasonably. Where no geologic interpretations were available to augment the data, the problems were handled in two ways. A clipping distance (Table 6-5) was instituted that allowed the grid values to be null where the unit was thought not to exist. Otherwise, because of lack of data and to fill in between data gaps, extrapolations were kept. As constructed, these areas can be reevaluated in later versions of the HFM as new data become available, and the hydrogeologic consequences can be evaluated through flow modeling uncertainty analyses.

6.3.5 Assembling the HFM

The 3D HFM was constructed by combining the set of interpolated structure contour maps representing the tops of individual hydrogeologic units. Landmark's STRATAMODEL Stratigraphic Geocellular Modeling (SGM) is a geologic modeling software product that uses "geologic rules" to help define the geographic extent and intersection of surfaces. The SGM software has been developed for modeling a sedimentary basin environment. It allows for the specification of sedimentary depositional units (onlap and proportional units), as well as the truncation of units and faulting. Although SGM allows the incorporation of faults as individual surfaces in the sequence of events, because of the lack of geologic information at depth and complexity of the model area, this feature was not incorporated in the construction of the HFM.

SGM was not designed to handle the time stratigraphic emplacement of intrusions. To include intrusions, they must be inserted into the SGM model out of their correct stratigraphic order. The youngest intrusion must represent the oldest deposition surface. Therefore, the youngest intrusion is the first event sequence included in the SGM model. While this does not affect the resulting model, it does affect the order the units are put into the model. The following sequence was used to build the 3D HFM for the site-scale SZ flow and transport model:

1. The base of the regional flow model (DTN: GS960808312144.003) was input as an independent surface.

2. The granitic intrusions were input as the first geologic unit.

3. Next, the lower clastic confining unit was input. Where the granitic intrusions were above this grid, the unit was truncated.

4. The remaining units (lower carbonate aquifer, upper clastic confining unit, upper carbonate aquifer, undifferentiated valley-fill unit, volcanic aquifers and confining units, basalt flows, and limestone aquifer) were entered in order by an onlap process onto the lower clastic confining unit and intrusions. Because the volcanic and sedimentary units fill in topographic lows, the onlap process of Stratamodel simulates this process. A special surface was placed at an appropriate location within the above general sequence to represent the thrust-faulted geometries.

5. The valley-fill aquifer and confining units were emplaced in the valleys.

6. The potentiometric surface (Figure 6-2) was then used as a truncation surface to clip the top of the HFM.

The HFM has volumetric units defined by the structure contour maps of individual hydrogeologic units. The hydrogeologic units are numbered consecutively in stratigraphic order from bottom to top (Table 6-2) beginning with sequence number 2. The SGM requires the specification of an arbitrary base unit, or sequence number 1, which is not used in the actual model. Only the hydrogeologic units and structures occurring above the bottom of the regional SZ flow model and below the potentiometric surface are included in the framework. Although the cells have uniform horizontal dimensions throughout the HFM, the number of cell layers may be controlled. In many locations hydrogeologic units have a large thickness. To improve the vertical resolution, the units can be subdivided into layers.

The SGM software allows each cell to reflect multiple attributes. The software automatically assigns some attributes to each cell, including row number, column number, sequence number, layer number, and elevation. The cells were further attributed to reflect the hydrogeologic units. For ground-water flow modeling, the HFM can be used to assign representative hydraulic property values.

The stratigraphy and structure represented in the HFM are shown in a fence diagram through the site model (Figure 6-1). The resulting HFM omits many small and even intermediate-scale features within the subsurface. It does, however, represent the large-scale features as accurately as possible given the grid resolution, and, therefore provides substantial constraints for model development.

6.3.6 Potentiometric Surface

Because the potentiometric data dictate a complex 3D flow system, a number of different conceptual models of the flow system are possible. In particular, the different conceptual models may result in different potentiometric surfaces. Although the boreholes are open at different depths below the water table and are open to different geologic zones, water levels in most of the boreholes seem to represent a laterally continuous aquifer system. The well-connected system may result from the presence of many faults and fractures (Tucci and Burkhardt, 1995, p. 7), and, at the scale of the site model, the ground-water flow system may behave as a porous medium. Flow in the volcanic rocks occurs primarily in fractures and secondarily in the matrix of the rock. Therefore, the uppermost aquifer may be unconfined or confined depending upon the areal location of the point being measured (Tucci and Burkhardt, 1995, p. 7).

Figure 6-21 shows the top of the HFM as represented by the computer-generated potentiometric surface over the model area in which data from all available boreholes in and around the model area were used. The borehole locations from which potentiometric data were used in contouring are shown on Figure 6-2. For the case of boreholes having multiple piezometers, only data from the uppermost completed borehole interval was used. The potentiometric surface and data used to construct it are discussed in the Water-Level AMR (USGS 2000b).

Most of the boreholes are partially penetrating. No attempt was made to segregate and analyze water-level measurements associated with specific hydrogeologic units or fracture zones. Some water levels represent composite heads from multiple hydrogeologic units and fractures. In general, this portrayal of the potentiometric surface at Yucca Mountain (Figure 6-2) is consistent with those referenced consequent to and including the early work by Robison (1984), which implies a hydraulically well-connected flow system within the SZ (that is, perched or semi-perched conditions are absent).

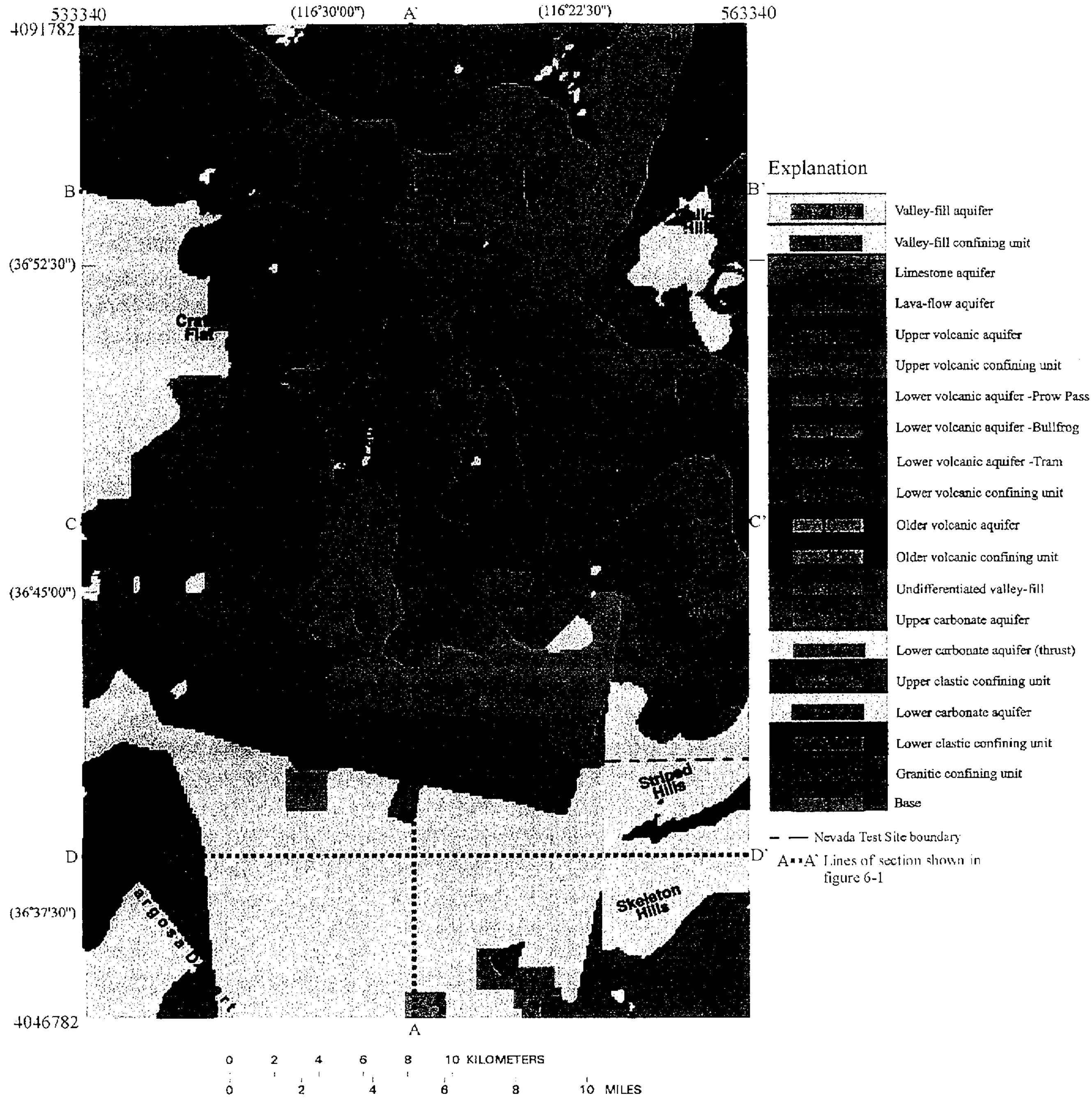

Figure 6-21. Map Showing Top of the Hydrogeologic Framework Model (DTN: GS000508312332.002)

The potentiometric-surface map presented does not strictly represent the water table, a concept reserved for the actual interface between the saturated and unsaturated zones. However, the potentiometric surface is probably a reasonable representation of the water table for the following reasons: (1) at Yucca Mountain, water levels at most boreholes were measured in Tertiary vocanic rocks in the uppermost part of the SZ (Graves and others, 1997, p. 1); (2) south of Yucca Mountain, boreholes penetrate the SZ to varying depths dependent upon the total depth of the borehole, but in this area most ground-water flow is believed to be horizontal and all available data indicate that the vertical-head gradients are negligible; and, (3) for the case of boreholes having multiple piezometers, only water levels from the uppermost saturated interval were used in the construction of the potentiometric-surface map.

The potentiometric surface was used to form the upper surface or top of the HFM. The potentiometric-surface was gridded and the grid values were resampled to 125-m spacing coincident with the HFM. The HFM was clipped by this surface to significantly reduce the number of nodes for the numerical flow model.

6.4 RESULTS AND DISCUSSION

The results of the HFM provide an interpretation of the spatial position and geometry of rock units and faults. Figure 6-1 shows a fence diagram of the HFM. Figure 6-21 shows the top of the HFM. The top of the HFM is equivalent to the hydrogeologic units at the potentiometric surface. Due to confined conditions and fracture flow, this figure may be misleading. The actual altitude of the ground water producing this potentiometric surface may be as much as several meters below the depicted potentiometric surface in some boreholes.

To fulfill the needs of users of the HFM without including a lengthy discussion of the modeled units, this section gives a brief summary of the model results. The geographic extents of the units can be seen in Figures 6-4 through 6-20. The thicknesses of these units can be determined by examining the HFM.

Examination of these figures and the actual HFM shows that in many areas the lack of hydrogeologic data or the presence of faulting causes a blocky or choppy appearance in the model. Future revisions of the HFM, using newly developed hydrogeologic data, could potentially reduce this effect.

Within the immediate site area, the site GFM was used as the principal source of subsurface data for the Upper Volcanic Confining Unit and the Prow Pass, Bullfrog, and Tram Tuffs within the Lower Volcanic Aquifer (Table 6-4). For these units, the GFM is effectively embedded within the HFM. However, because of differences between how data external to the GFM were used to construct the HFM and were used to establish the thicknesses of units along the lateral boundaries of the GFM, the process of embedding the GFM within the HFM introduced some apparently anomalous discontinuities in some unit thicknesses across the GFM model boundaries. These apparent discontinuities are artifacts of both differences between the HFM and GFM model grids and the data interpolation and extrapolation methods that were used in constructing the GFM and do not affect the applicability of the HFM in providing a hydrogeologic framework for the site-scale SZ flow model.

Some of the near surface units that cover most of the model land surface area (Figure 4-2) only account for a small amount of the total model volume. Most of the borehole information is above the top of the model. Both of these data sets do, however, help define the areal extent of the hydrogeologic units.

The configuration of the unconformity between Tertiary and Paleozoic rocks is uncertain. Only one borehole (UE-25 p#1) at Yucca Mountain penetrates the Paleozoic rocks, but Paleozoic rocks outcrop in several areas surrounding Yucca Mountain (Figure 4-2). There are alternative interpretations of the location of the carbonate aquifers and clastic confining units in the subsurface between these known points. No definitive data (such as another borehole or conclusive geophysical data) are available.

In the HFM interpretation, the dominant high-angle faults were simplified to be vertical. Some of the offsets on the faults are preserved through changes in altitude of a given geologic unit. Given the depth to which the model extends and the lack of information in most of the modeled volume, this seems to be a rational simplification.

6.5 MODEL VALIDATION

The HFM is a framework model that provides a static representation of the geometry internal to a unique fixed volume of the geosphere, specifically, that volume encompassed by the 3D model domain of the site-scale SZ flow and transport model for the Yucca Mountain site. The HFM, in particular, is not a numerical predictive model, such as the SZ flow and transport "process" model, that, in principle, can be "validated" by comparing model predictions against appropriately selected laboratory, field, or analog data. All appropriate data that were available by which to define the geometric relationships within the HFM model domain were used in constructing the HFM. As described previously, the geometry within the HFM consists of a 3D nexus of vertically sequenced and laterally discontinuous hydrogeologic units whose assigned hydrologic properties are considered to provide the dominant controls on ground-water flow within the flow and transport model domain. The hydrogeologic units consist of one or more contiguous, geologically defined stratigraphic units that are grouped into hydrogeologic units based on measured or inferred common hydrologic properties. The HFM was assembled from the hydrogeologic units defined in Table 6-1 by using standard techniques by which to interpolate and extrapolate the locations and extent of the hydrogeologic units based on data from boreholes, surface geologic maps, geologic cross sections, and geophysical surveys.

6.5.1 Methods for Conducting Preliminary Validation

The model construction process can be validated by comparing input data (geologic section unit tops, unit tops from borehole lithologic logs, and geologic map unit tops) with grids representing tops of hydrogeologic units in the HFM. Because all available input data were used, model results could not be compared with data acquired from field observations that were not used in the original development of the model.

6.5.2 Specific Tests Conducted

Specifically, a grid representing the top of a hydrogeologic unit was taken from the HFM. This grid was visually compared to the input data. Because of the inconsistent distribution of data, exact values of approximation varied over the model area. The unit tops of the HFM and input data were checked to see if:

1. Grid values approximated input data,
2. Extrapolation from data values seemed reasonable,
3. Grids were not clipped unreasonably where input data exists.

6.5.3 Results of Validation Tests Completed to Date

These initial validation tests showed that the HFM closely approximates the input data. Where more data exists (near the potential repository and near the land surface) the model appears to be more accurate. Further from data points more extrapolation occurs. The hydrogeologic unit tops have some truncations that the result of lack of data and where search distances are exceeded in the gridding algorithms. These truncations have not been removed. Furthermore, the extrapolation of unit extents may be too far, however, without additional data this cannot be determined. This should be taken into consideration by uncertainty analyses in flow modeling. Specifically, the contact between the volcanic rocks and the alluvium down gradient from the potential repository should be examined.

In areas where no geologic data were available, the gridded surfaces were taken at face value. To resolve some of the extrapolation problems, resulting from structural control and depositional heterogeneity, the model was examined for geologic inconsistencies. The maps showing the distribution of the hydrogeologic units (figs. 6-4 through 6-20) were visually inspected to determine whether the gridded surfaces were consistent with the input data and the site-scale geologic setting.

By inspecting the HFM, it appears that the grid increment is reasonable in the area of the potential repository. As the distance from the potential repository increases (both horizontally and vertically), this grid increment is much finer than the data resolution.

Through the definition and assemblage of the hydrogeologic units integral to its construction, the HFM provides an internally consistent, volume-filling representation of the spatial distribution of, effectively, block-averaged hydrologic properties within the 3D SZ flow and transport model domain. This representation, in turn, is founded on the underlying geologically defined stratigraphic and structural framework. Spatial resolution obtainable within the HFM is limited by the lack of well-distributed subsurface data over most of the model domain and, consequently, the HFM must be considered to be a coarse-scale approximation rather than an accurate depiction of reality. However, the significance of the HFM is that it enables the computational grid of the SZ flow and transport model to be populated with an initial set of hydrologic-property values that, subsequently, can be refined through calibration of the flow model. The calibrated property sets are those that are used subsequently to generate the ground-water flow fields on which transport calculations to support total system performance assessment are based. In this context of providing a set of initial approximations for the spatial distribution of hydrologic properties, the HFM is considered to be appropriate and adequate for its intended use.

6.6 EFFECT OF TO BE VERIFIED (TBV) INPUTS ON THE HFM

The effect of TBV inputs on the analysis and model varies with the type, location, and extent of the data. Some data could easily be removed without affecting the model. In general, in areas near the potential repository and in the upper parts of the section, there are enough data that removal of some data would not greatly affect the model. In areas without much data, removal of the data would definitely impact the model. In areas down gradient of the potential repository, changes to the HFM would be more likely to affect ground-water flow than changes (even those of larger magnitude) up gradient of the potential repository. Thus, the effect of removing TBV data is unknown. Some of the effects could and should be tested using sensitivity analyses conducted with the flow model.

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6.7 UNCERTAINTIES

For the HFM, uncertainty is an estimation of how closely the model matches the actual hydrogeologic setting of the site-scale SZ model area and the interpretations of the geologic setting it is built on. Where known, uncertainty in the input data is discussed in Section 6. The primary factor affecting uncertainty in the HFM is distance from the gridding cells to the nearest input data. Hydrogeologic units near the surface are constrained by the hydrogeologic map (Figure 4-2). The horizontal distance from a data point shows part of the distribution of uncertainty (Figures 6-4 through 6-20). Most of the borehole data are limited to very shallow depths, therefore uncertainty increases with depth (vertical distance) to an even greater extent. Hence, interpretations regarding deeper hydrogeologic units have more uncertainty associated with them than that associated with shallower hydrogeologic units.

Geostatistical techniques were not used to estimate uncertainty, because of the faulting and associated complexity of the model. Practical methods that examine the modeling process and uncertainty associated with gridding, contouring, interpreting, extrapolating, and interpolating could be included in future model validation techniques. As new data and additional geologic interpretations become available, the HFM should be updated. Each of the gridded surfaces should be examined and modified where the surfaces have been extrapolated away from available data.

7. SUMMARY AND CONCLUSIONS

The HFM provides a representation of the location and distribution of hydrogeologic units in the SZ of the Yucca Mountain area for use in ground-water flow modeling. The input data from the map, geologic sections, boreholes, models, and geophysical investigations provide controls within the domain. The lower boundary of the model is coincident with that of the regional flow model (DTN: GS960808312144.003). This boundary is generally consistent with no vertical flow in or out of the base of the site-scale model domain. A geologic map and cross sections developed for the model domain was the main input to the HFM (DTN: GS991208314221.001). Data from all available boreholes were incorporated in the construction of the HFM; however, borehole lithologic data from Nye County boreholes and boreholes USW SD-6 and USW WT-24 were not available at the time of model construction. These boreholes (and any other new boreholes) could be used at a later date for validation. The top of the HFM was set to an updated potentiometric surface map.

Most of the modeled volume is unsampled and many of the input files are interpretations. Therefore, the HFM is an interpretation, mostly a mathematical interpolation and extrapolation, rather than an absolute representation of reality. In general, the data distribution is very uneven and the character of the formations from which the unit tops are derived is highly variable. As a result, the expected error in the HFM varies significantly over the model area. Typically, uncertainty increases with depth and distance from the potential repository as data become sparse and the effects of faults deeper in the system become unknown. For example, the unit tops may be characterized within meters in the immediate potential repository area; however, there is much more uncertainty in the rest of the model area. In summary, most of the model is poorly constrained by data. As a result, the model contains an inherent level of uncertainty that is a function of data distribution and geologic complexity.

The representativeness and accuracy of the HFM depends on the quality and density of the data points used to define the hydrogeologic unit top surfaces. The HFM incorporates all the errors and limitations associated with the input data. Where applicable, these errors and limitations are identified in this report. Some of these surfaces, such as that of the upper volcanic aquifer in the area of the potential repository, were relatively well defined by more than one data set (derived from the surface hydrogeologic unit map, borehole lithologic logs, and geologic sections). Others, especially the units that crop out less commonly, are less well defined and were extrapolated from sparse data. In the area of the potential repository the unit locations are relatively well known. Even in this area, however, there is only one borehole that penetrates the Paleozoic rocks.

Given software and data constraints and the flow model resolution, faulting in the area is greatly simplified. The major simplification is that all high-angle faults are treated as vertical features. Where it was deemed of hydrologic significance, thrust faults were included. A subset of mapped faults (DTN: GS991208314221.001) was simplified for use in the HFM. As a result, many fault offsets will be smoothed in the HFM. In the area of the GFM, the appropriate offsets on units, based on dipping faults, will be retained.

Preliminary validations of techniques used to construct the model indicate that the HFM agrees with the input data within expected tolerances and is suitable for its intended use.

Although new boreholes drilled by Nye County were intended to help characterize the contact between the valley-fill and the volcanic rocks in the southern portion of the model ares, the location and character of this contact is still speculative. The Nye County boreholes were being drilled at the time of this report, but the stratigraphic data were not available in time for model construction. As a result, generalized units such as 'undifferentiated valley-fill', 'valley-fill', and 'volcanic units' are used to describe near surface units that are particularly variable in lithologic characteristics and hydaulic properties. In general, near surface units grade from north to south from primarily volcanic rocks to valley-fill. This should be taken into consideration with zonation arrays or another method during flow model calibration, and will not be specifically represented in the HFM.

In conclusion, the HFM is intended for and restricted to the development of the site-scale SZ ground-water flow and transport model. The HFM was examined and corrected for geologic inconsistencies; however, the model is not intended for precise geologic unit locations or identification. The HFM is a simplified and generalized geometric foundation for the ground-water flow model. It is not meant to be an absolute representation of the geologic setting of the site-scale model area. The model output, Hydrogeologic Framework Model for the Saturated-Zone Site-Scale Flow and Transport Model, is available from the Technical Data Management System, under DTN: GS000508312332.002.

8. INPUTS AND REFERENCES

8.1 DOCUMENTS CITED

CRWMS M&O 1998. *Yucca Mountain Site Description.* B00000000-01717-5700-00019 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19981202.0492.

CRWMS M&O 2000a. *Repository Safety Strategy: Plan to Prepare the Postclosure Safety Case to Support Yucca Mountain Site Recommendation and Licensing Considerations.* TDR-WIS-RL-000001 REV 03. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000119.0189.

CRWMS M&O 2000b, *Calibration of the Site-Scale Saturated Zone Flow Model.* MDL-NBS-HS-000011 REV00. Las Vegas, Nevada: CRWMS M&O URN-0191

D'Agnese, F.A.; Faunt, C.C.; Turner, A.K.; and Hill, M.C. 1997. *Hydrogeologic Evaluation and Numerical Simulation of the Death Valley Regional Ground-Water Flow System, Nevada and California.* Water-Resources Investigations Report 96-4300. Denver, Colorado: U.S. Geological Survey. ACC: MOL.19980306.0253.

Dyer, J.R. 1999. "Revised Interim Guidance Pending Issuance of New U.S. Nuclear Regulatory Commission (NRC) Regulations (Revision 01, July 22, 1999), for Yucca Mountain, Nevada." Letter from Dr. J.R. Dyer (DOE/YMSCO) to Dr. D.R. Wilkins (CRWMS M&O), September 3, 1999, OL&RC:SB-1714, with enclosure, "Interim Guidance Pending Issuance of New NRC Regulations for Yucca Mountain (Revision 01)." ACC: MOL.19990910.0079.

Graves, R.P.; Tucci, P.; and O'Brien, G.M. 1997. *Analysis of Water-Level Data in the Yucca Mountain Area, Nevada, 1985-95.* Water-Resources Investigations Report 96-4256. Denver, Colorado: U.S. Geological Survey. ACC: MOL.19980219.0851.

Laczniak, R.J.; Cole, J.C.; Sawyer, D.A.; and Trudeau, D.A. 1996. *Summary of Hydrogeologic Controls on Ground-Water Flow at the Nevada Test Site, Nye County, Nevada.* Water Resources Investigations 96-4109. Carson City, Nevada: U.S. Geological Survey. TIC: 226157.

Luckey, R.R.; Tucci, P.; Faunt, C.C.; Ervin, E.M.; Steinkampf, W.C.; D'Agnese, F.A.; and Patterson, G.L. 1996. *Status of Understanding of the Saturated-Zone Ground-Water Flow System at Yucca Mountain, Nevada, as of 1995.* Water-Resources Investigations Report 96-4077. Denver, Colorado: U.S. Geological Survey. ACC: MOL.19970513.0209.

Robison, J.H. 1984. *Ground-Water Level Data and Preliminary Potentiometric-Surface Maps, Yucca Mountain and Vicinity, Nye County Nevada.* Water-Resources Investigations Report 84-4197. Lakewood, Colorado: U.S. Geological Survey. ACC: NNA.19930629.0013.

Tucci, P. and Burkhardt, D.J. 1995. *Potentiometric-Surface Map, 1993, Yucca Mountain and Vicinity, Nevada.* Water-Resources Investigations Report 95-4149. Denver, Colorado: U.S. Geological Survey. ACC: MOL.19960924.0517.

USGS (U.S. Geological Survey) 1999. *Work Direction and Planning Document for B00000000-01717-0200-00202*, Hydrogeologic Framework Model AMR Package, Denver, Colorado: USGS. ACC: MOL.19990921.0091.

USGS 2000a. *Hydrogeologic Framework for the Site Saturated Zone Model.* SN-USGS-SCI-072-V2. ACC: Submit to RPC.

USGS 2000b. *Water-Level Date Analysis for the Saturated Zone Site-Scale Flow and Transport Model.* ANL-NBS-HS-000034. Denver, Colorado: U.S. Geological Survey. Submit to RPC DTN: GS000508312332.001

Winograd, I.J. and Thordarson, W. 1975. *Hydrogeologic and Hydrochemical Framework, South-Central Great Basin, Nevada-California, with Special Reference to the Nevada Test Site.* Professional Paper 712-C. Washington, D.C.: U.S. Geological Survey. TIC: 206787.

8.2 CODES, STANDARDS, REGULATIONS, AND PROCEDURES CITED

AP-2.13Q, Rev. 0, ICN 3. *Technical Product Development Planning*. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL.20000504.0305

AP-3.10Q, Rev.2, ICN 1. *Analysis and Models*. Washington, D. C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL.20000512.0066

AP-3.15Q, Rev. 1, ICN 1. *Managing Technical Product Inputs.* Washington, D.C.: U.S. Department of Energy. Office of Civilian Radioactive Waste Management. ACC: MOL.20000218.0069

AP-SI.1Q, Rev. 2, ICN 4. *Software Management*. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL.20000223.0508

AP-SIII.2Q, Rev. 0, ICN 2. *Qualification of Unqualified Data and the Documentation of Rationale for Accepted Data.* Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste management. ACC: MOL.19991214.0625

AP-SV.1Q, Rev. 0, ICN 1. *Control of Electronic Management of Data.* Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL.20000512.0068

QAP-2-0, Rev. 5, ICN 1 *Conduct of Activities.* Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19991109.0221.

CRWMS M&O 1999a. *M&O Site Investigations*. Activity Evaluation. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990317.0330

CRWMS M&O 1999b. *M&O Site Investigations*. Activity Evaluation. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990928.0224.

DOE (U.S. Department of Energy) 2000. *Quality Assurance Requirements and Description.* DOE/RW-0333P, Rev. 10. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL.20000427.0422.

Wemheuer, R.F. 1999. "First Issue of FY00 NEPO QAP-2-0 Activity Evaluations." Interoffice correspondence from R.F. Wemheuer (CRWMS M&O) to R.A. Morgan (CRWMS M&O), October 1, 1999, LV.NEPO.RTPS.TAG.10/99-155, with attachments, Activity Evaluations. ACC: MOL.19991028.0162.

8.3 SOFTWARE USED

U.S. Geological Survey 2000. *ERMA Site Geologist V6.0.1.* STN: 10210-6.0.1-00.

U.S. Geological Survey 2000. *Stratamodel V4.1.1.* STN: 10121-4.1.1-00.

U.S. Geological Survey 2000. *Software Code: ARCINFO V7.2.1.* STN: 10033-7.2.1-00.

U.S. Geological Survey 2000. *Software Code: Petrosys V7.60d.* STN: 10168-7.60d-00.

8.4 SOURCE DATA, LISTED BY DATA TRACKING NUMBER

GS000400002332.001. Digital Elevation Models Death Valley East Scale 1:250,000. Submittal date: 04/12/2000.

GS000400002332.002. Underground Test Area Subproject Phase I Data Analysis Task, 1996. Submittal date 04/18/2000.

GS000508312332.001. Water-Level Data Analysis for the Saturated Zone Site-Scale Flow and Transport Model. Submittal date: 05/19/2000.

GS900908314211.007. A Summary of Geologic Studies Through January 1, 1983, of a Potential High-Level Radioactive Waste Repository Site at Yucca Mountain, Southern Nye County, Nevada. Submittal date: 09/17/1990.

GS940908312132.004. Lithologic and Geophysical Logs of Drill Holes Felderhoff Federal 5-1 and 25-1, Amargosa Desert, Nye County, Nevada. Submittal date: 09/08/1994.

GS950108314212.001. Major Results of Regional Geophysical Investigations at Yucca Mountain and Vicinity, Nevada. Submittal date: 01/06/1995.

GS950508312333.001. Cross-Section Data for Hydrogeologic Framework Model Construction in Intergraph Design File Format. Submittal date: Submittal date: 05/19/1995.

GS950508312333.002. Borehole Data for Hydrogeologic Framework Model Construction. Submittal date: Submittal date: 05/19/1995.

GS960108314211.002. Hybrid-Source Seismic Reflection Profiling Across Yucca Mountain, Nevada: Regional Lines 2 and 3. Submittal date: 01/10/1996.

GS960808312144.003. Hydrogeologic Evaluation and Numerical Simulation of the Death Valley Regional Ground-Water Flow System, Nevada and California, Using Geoscientific Information Systems. Submittal date: 08/29/1996.

GS991208314221.001. Geologic Map of the Yucca Mountain Region. Submittal date: 12/01/1999. Submit to RPC

MO9901MWDGFM31.000. Geologic Framework Model. Submittal date: 01/06/1999.

8.5 AMR OUTPUT DATA, LISTED BY DATA TRACKING NUMBER

GS000508312332.002. Hydrogeologic Framework Model for the Saturated-Zone Site-Scale Flow and Transport Model