Three-Dimensional Hydrogeologic Framework Model

By Claudia C. Faunt, Donald S. Sweetkind, and Wayne R. Belcher

Chapter E of

Death Valley Regional Ground-Water Flow System, Nevada and California—Hydrogeologic Framework and Transient Ground-Water Flow Model

Edited by Wayne R. Belcher

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Introduction

The complex stratigraphic and structural framework of the Death Valley region, described in Chapter B of this volume, controls ground-water flow in the Death Valley regional ground-water flow system (DVRFS). A three-dimensional (3D) hydrogeologic framework model (HFM), described herein, was constructed to represent the hydrogeologic units (HGUs) and major structures in the DVRFS region for the development of the transient numerical ground-water flow model (Chapter F, this volume).

Construction of the Hydrogeologic Framework Model

The HFM consists of 196 rows, 162 columns, and 28 units (including the base). The north-south-oriented HFM grid has a horizontal resolution of 1,500 m (fig. E–1). Resolution in the vertical dimension ranges from 0 to the maximum thickness of each HGU. Software constraints require that the HFM grid be constructed for a bounding rectangle, but the gridded surfaces are truncated at the model boundary for input to the ground-water flow model. The depth of the HFM extends to 4,000 m below sea level to encompass nearly all of the aquifer units in the region (Chapter B, this volume). Some small areas in Tikaboo Valley and the northern Pahranagat Range in the northeastern part of the DVRFS model domain (fig. A–1, this volume), however, may have relatively thin stratigraphic sections of potential aquifer material that extend deeper than this. Those thin sections are assumed to have little, if any, effect on regional ground-water flow.

Conceptual Model of the Hydrogeologic Framework

The HFM was constructed to represent the complexity of the hydrogeology of the DVRFS region (Chapter B, this volume). The unconsolidated sediments and consolidated rocks were subdivided into 27 HGUs on the basis of lateral extent, physical characteristics, and structural features to construct the HFM (table E–1).

Modeling Approach

The HFM is constructed by combining and extracting information from a variety of data sets, such as elevation models, geologic maps, borehole lithologic logs, cross sections, and digital geologic models. Because the HFM is a regional model, data sources (such as maps and cross sections) contain geological details typically shown on regional 1:250,000- to 1:100,000-scale maps. Some data sources, such as lithologic logs, were simplified to represent a regional scale.

A number of different software packages were selected for various parts of the HFM construction process. Each software package was chosen for its proficiency in a particular task and(or) suitability for project needs, but other software packages could have been used.

Spatial data, such as digital elevation, outcrop, and borehole information, were manipulated using Environmental Science Research Institute (ESRI) ARC/INFO® geographic information system (GIS) software. Cross-sectional hydrogeologic data were manipulated using Intergraph Corporation Modular GIS Environment® (MGE). Gridded surfaces were constructed using Petrosys Pty. Ltd. Petrosys® and Golden Software SURFER® gridding software. The HFM itself was constructed using Landmark Graphics Stratigraphic Geocellular Modeler® (SGM® or Stratamodel®). SGM is designed to accurately represent stratigraphic and structural relations of sedimentary basins, including deposition (and onlap), erosion, and unconformities, as well as truncation of units and faulting. Arrays representing HGU geometries were developed from the HFM and visualized and processed using ARC/INFO®.

The geometries (horizons and thicknesses) of the HGUs were exported from the HFM and incorporated into the flow model MODFLOW-2000 (Harbaugh and others, 2000; Hill and others, 2000) by using the Hydrogeologic-Unit Flow (HUF) package (Anderman and Hill, 2000). The HUF package resamples the HGUs into the flow-model grid, calculating which HGUs are in each flow-model layer.

Data Inputs

The construction of the HFM involves the use of data from several sources to define the top surface and extent of each regional HGU. These surfaces are termed “horizons.”

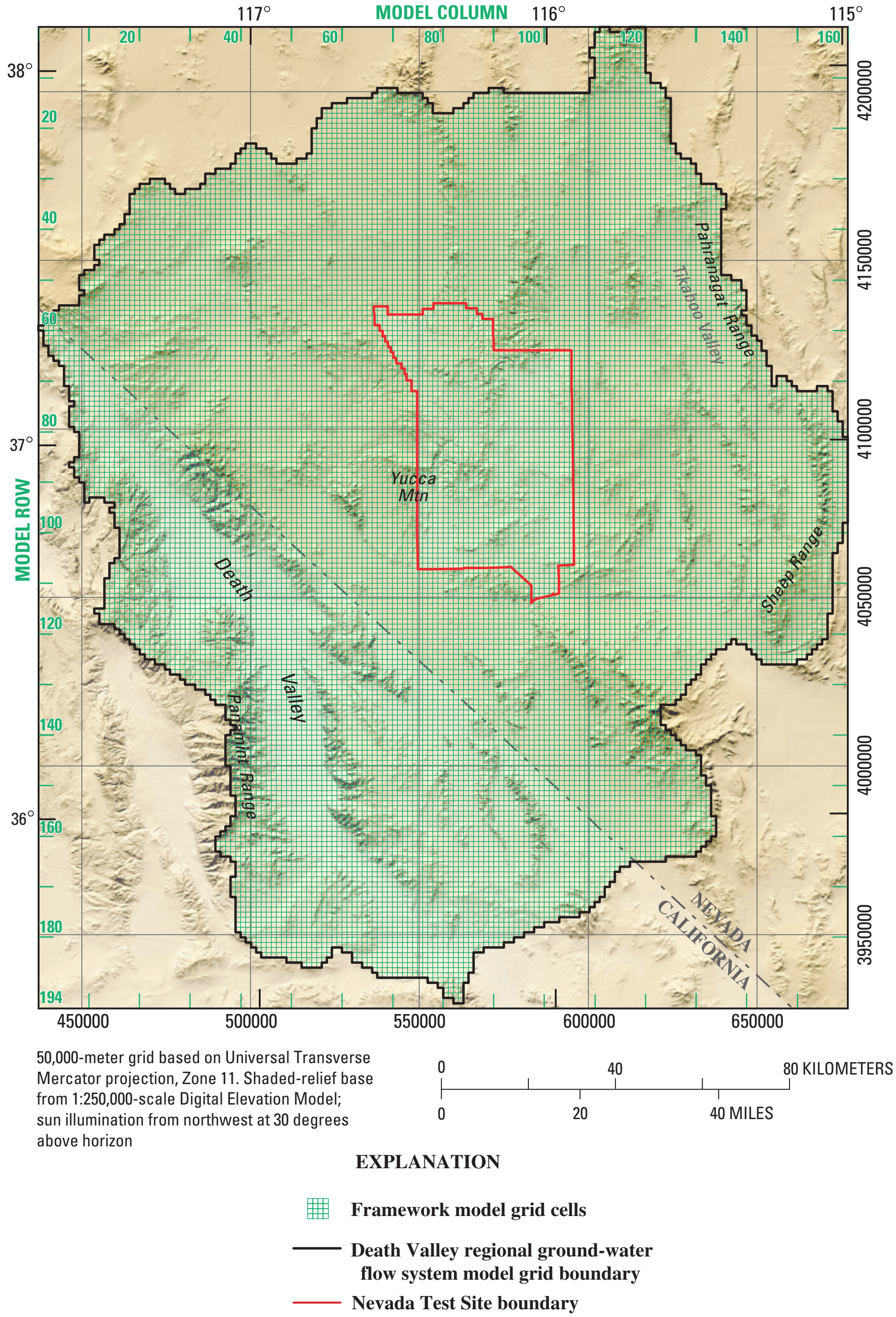


Figure E–1. Model grid for the Death Valley regional ground-water flow system hydrogeologic framework model.

Input data are the result of a comprehensive geologic interpretation (Chapter B, this volume) using digital elevation models, geologic and structural geologic maps, lithologic data from boreholes, cross sections, gridded data from previously constructed geologic framework models, and hydrologically important faults and structures (table E–2 and fig. E–2).

Topographic Data

Digital elevation data from the 1:250,000-scale and 7.5-minute National Elevation Data (NED) digital elevation models (DEMs) (U.S. Geological Survey, 2004) were merged into a single DEM for the DVRFS in Universal Transverse Mercator (UTM) projection Zone 11, North American Datum

Table E–1. Hydrogeologic units for the Death Valley regional ground-water flow system hydrogeologic framework model.

[Stacking order, the order that gridded surfaces were entered into the model during construction, with 1 being first and 27 being last; NTS, Nevada Test Site; SWNVF, southwestern Nevada volcanic field]

Hydro-geologic unit abbreviation	Hydrogeologic unit name	Description	Stacking order
YAA	Younger alluvial aquifer	Pliocene to Holocene coarse-grained basin-fill deposits	27
YACU	Younger alluvial confining unit	Pliocene to Holocene playa and fine-grained basin-fill deposits	26
OAA	Older alluvial aquifer	Pliocene to Holocene coarse-grained basin-fill deposits	25
OACU	Older alluvial confining unit	Pliocene to Holocene playa and fine-grained basin-fill deposits	24
LA	Limestone aquifer	Cenozoic limestone, undivided	23
LFU	Lava-flow unit	Cenozoic basalt cones and flows and surface outcrops of rhyolite-lava flows	22
YVU	Younger volcanic-rock unit	Cenozoic volcanic rocks that overlie the Thirsty Canyon Group	21
Upper VSU	Volcanic- and sedimentary-rock unit	Cenozoic volcanic and sedimentary rocks, undivided, that overlie volcanic rocks of SWNVF	20
TMVA	Thirsty Canyon–Timber Mountain volcanic-rock aquifer	Miocene Thirsty Canyon and Timber Mountain Groups, plus Stonewall Mountain tuff, undivided	19
PVA	Paintbrush volcanic-rock aquifer	Miocene Paintbrush Group	18
CHVU	Calico Hills volcanic-rock unit	Miocene Calico Hills Formation	17
WVU	Wahmonie volcanic-rock unit	Miocene Wahmonie and Salyer Formations	16
CFPPA	Crater Flat–Prow Pass aquifer	Miocene Crater Flat Group, Prow Pass Tuff	15
CFBCU	Crater Flat–Bullfrog confining unit	Miocene Crater Flat Group, Bullfrog Tuff	14
CFTA	Crater Flat–Tram aquifer	Miocene Crater Flat Group, Tram Tuff	13
BRU	Belted Range unit	Miocene Belted Range Group	12
OVU	Older volcanic-rock unit	Oligocene to Miocene; near the NTS consists of all volcanic rocks older than the Belted Range Group. Elsewhere, consists of all tuffs that originated outside of the SWNVF	11
Lower VSU	Volcanic- and sedimentary-rock unit	Cenozoic volcanic and sedimentary rocks, undivided; where named Cenozoic volcanic rocks exist, lower VSU underlies them	10
SCU	Sedimentary-rock confining unit	Paleozoic and Mesozoic sedimentary and volcanic rocks	9
UCA	Upper carbonate-rock aquifer	Paleozoic carbonate rocks (UCA only used where UCCU exists, otherwise UCA is lumped with LCA)	8
UCCU	Upper clastic-rock confining unit	Upper Devonian to Mississippian Eleana Formation and Chainman Shale	7
LCA_T1	Lower carbonate-rock aquifer (thrusted)	Cambrian through Devonian predominantly carbonate rocks – thrusted	6
LCCU_T1	Lower clastic-rock confining unit (thrusted)	Late Proterozoic through Lower Cambrian primarily siliciclastic rocks (including the Pahrump Group and Noonday dolomite) – thrusted	5
LCA	Lower carbonate-rock aquifer	Cambrian through Devonian predominantly carbonate rocks	4
LCCU	Lower clastic-rock confining unit	Late Proterozoic through Lower Cambrian primarily siliciclastic rocks (including the Pahrump Group and Noonday dolomite)	3
XCU	Crystalline-rock confining unit	Middle Proterozoic metamorphic and igneous rocks	2
ICU	Intrusive-rock confining unit	All intrusive rocks, regardless of age	1

1927 (NAD27) with a grid spacing of approximately 90 m. To ensure that topographic data were consistent with other data, the land-surface altitudes from the DEMs were replaced by reported land-surface altitudes at borehole locations.

Geologic Maps

Data from three geologic maps were used as input to the HFM. The primary source of data was the 1:250,000-scale geologic compilation of the DVRFS region (Workman, Menges, Page, Taylor, and others, 2002). Because the DVRFS HFM will be used for site-scale models at Yucca Mountain and the Nevada Test Site (NTS), additional stratigraphic detail was required in that area for specific Cenozoic volcanic-rock units. The locations of outcrops of the Calico Hills Formation, intrusive rocks at the Wahmonie volcanic center, and the Prow Pass, Bullfrog, and Tram Tuffs of the Crater Flat Group were extracted from the 1:120,000-scale map of the NTS (Slate and others, 2000). In the vicinity of Yucca Mountain, data from the 1:50,000-scale map of Potter, Dickerson, and others (2002) were used to define the locations of the Tram, Bullfrog, and Prow Pass Tuffs of the Crater Flat Group.

Table E–2. Data sources for hydrogeologic units in the hydrogeologic framework model for the Death Valley regional ground-water flow system.

[YMP, Yucca Mountain Project; GFM, geologic framework model; SCCC, Silent Canyon caldera complex; PMOV, Pahute Mesa–Oasis Valley]

Hydro-geologic unit abbreviation	Hydrogeologic unit name	Map[1]	Bore-hole[2]	Cross sections[3]	Unit extent map[4]	Hydro-structural map[5]	YMP GFM[6]	SCCC GFM[7]	PMOV GFM[8]
YAA	Younger alluvial aquifer	X							
YACU	Younger alluvial confining unit	X							
OAA	Older alluvial aquifer	X							
OACU	Older alluvial confining unit	X							
LA	Limestone aquifer		X						
LFU	Lava-flow unit	X	X	X		1, 2			
YVU	Younger volcanic-rock units	X		X		1, 2			X
Upper VSU	Volcanic- and sedimentary-rock unit	X	X	X		1, 2, 3			
TMVA	Thirsty Canyon–Timber Mountain volcanic aquifer	X	X	X	X	1, 2, 3, 4			X
PVA	Paintbrush volcanic-rock aquifer	X	X	X	X	1, 2, 3, 4	X	X	X
CHVU	Calico Hills volcanic-rock unit	X	X	X	X	1, 2, 4	X	X	X
WVU	Wahmonie volcanic-rock unit	X	X	X	X	1, 2, 4			
CFPPA	Crater Flat–Prow Pass aquifer	X	X	X		1, 2, 3, 4	X	X	X
CFBCU	Crater Flat–Bullfrog confining unit	X	X	X		1, 2, 3, 4	X	X	X
CFTA	Crater Flat–Tram aquifer	X	X	X		1, 2, 3, 4	X		
BRU	Belted Range unit	X	X	X		1, 2, 4		X	X
OVU	Older volcanic-rock unit	X	X	X		1, 2, 4		X	X
Lower VSU	Volcanic- and sedimentary-rock unit	X	X	X		1, 2, 3			
SCU	Sedimentary-rock confining unit	X	X	X		1, 2			
LCA_T1	Lower carbonate-rock aquifer - thrust	X	X	X	X	Thrust extent			
LCCU_T1	Lower clastic-rock confining unit - thrust	X		X	X	Thrust extent			
UCA	Upper carbonate-rock aquifer	X	X	X		1, 2, 3, 4, 5, 6, 7			
UCCU	Upper clastic-rock confining unit	X	X	X		1, 2, 3, 4, 5, 6, 7			
LCA	Lower carbonate-rock aquifer	X	X	X		1, 2, 3, 4, 5, 6, 7			
LCCU	Lower clastic-rock confining unit	X	X	X		1, 2, 3, 4, 5, 6, 7			
XCU	Crystalline-rock confining unit	X	X	X		1, 2, 3, 4, 5, 6, 7			
ICU	Intrusive-rock confining unit	X	X	X		1, 2, 3, 4, 5, 6, 7			X

[1]Workman, Menges, Page, Taylor, and others, 2002.

[2]U.S. Geological Survey National Water Information System (NWIS).

[3]Sweetkind and others, 2001; Potter, Dickerson, and others, 2002; R.W. Spengler, U.S. Geological Survey, written commun., 2001.

[4]Workman, Menges, Page, Ekren and others, 2002; Potter, Sweetkind, and others, 2002; Sweetkind and others, 2001.

[5]1 (normal), 2 (strike slip), 3 (detachment), 4 (caldera boundary), 5 (thrust), 6 (inferred thrust), 7 (transverse); Potter, Sweetkind, and others, 2002.

[6]Bechtel SAIC Company, 2002.

[7]McKee and others, 2001.

[8]Bechtel Nevada, 2002.

A surface hydrogeology map was constructed by merging the mapped lithostratigraphic units from the sources into HGUs using the computer-based GIS methods described in Faunt and others (1997). The geometry of HGU outcrops was defined by integrating the hydrogeologic map and the array of DEM and topographic information. Topographic data with x,y,z coordinate locations within each outcrop area were assigned to the appropriate HGU and exported as a series of files. Table E–3 shows the correlation of lithostratigraphic units used in the sources with the HGUs used in the HFM. Figure E–3 shows a simplified version of the resulting surface hydrogeology map in which the 27 HGUs are grouped into the 10 HGUs displayed in the figure.

Borehole Lithologic Data

Lithologic log data from 1,533 boreholes in the DVRFS region were compiled and manipulated as input for the HFM (fig. E–4), resulting in approximately 7,000 lithologic contacts between HGUs. Borehole lithologic data came from the

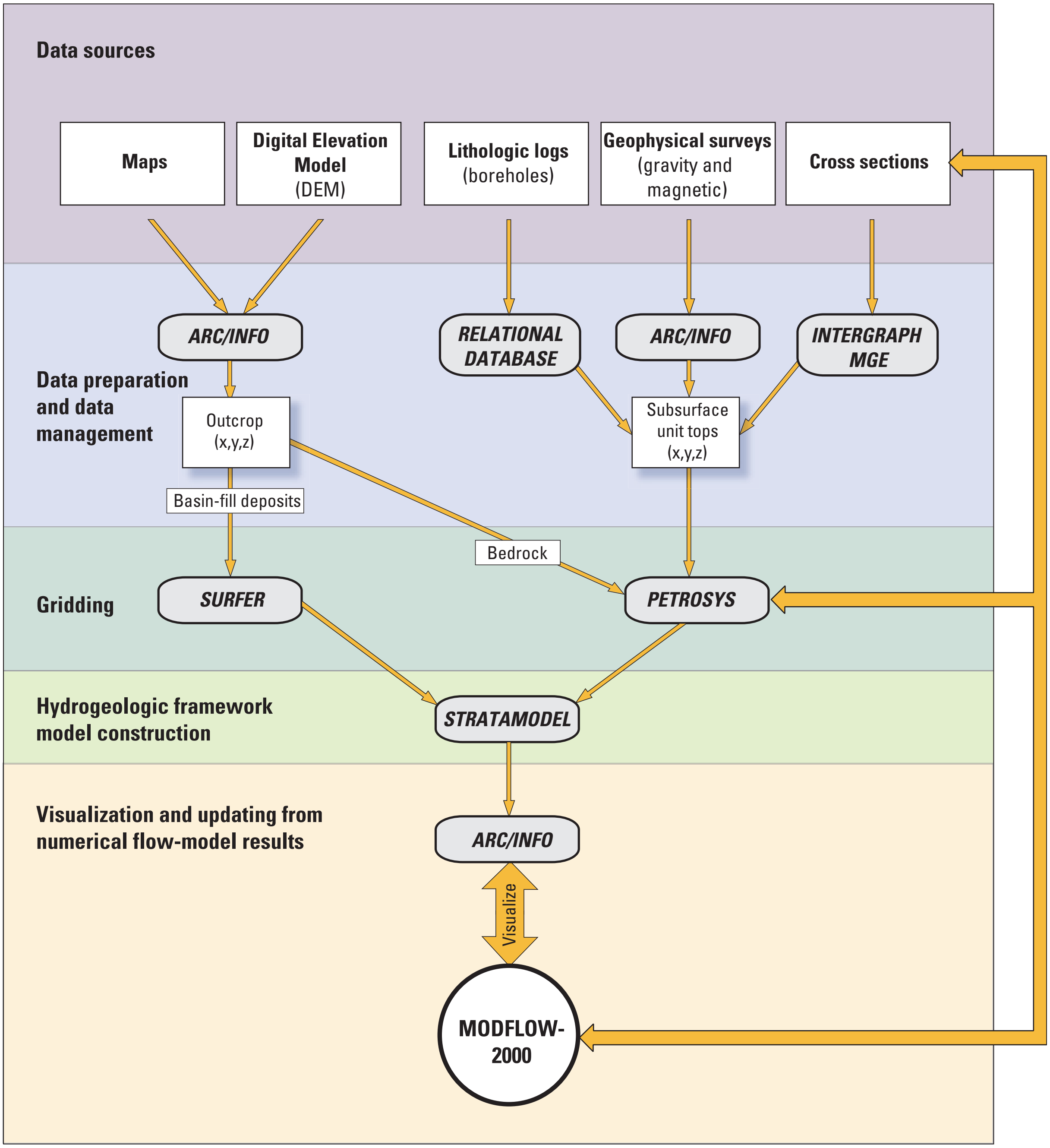


Figure E–2. Process of integration of data into Death Valley regional ground-water flow system hydrogeologic framework model.

following sources: (1) the USGS National Water Information System (NWIS), (2) well drillers' reports obtained through the Nevada Division of Water Resources, (3) previously compiled data from 235 boreholes from the SWNVF (Warren and others, 1998); (4) unpublished data collected by the USGS for the YMP as part of site characterization, (5) borehole data from the Nye County Early Warning Drilling Program (EWDP) (Nye County, 2004), (6) borehole data compiled for the DOE/NV-UGTA model (IT Corporation, 1996a), and (7) borehole reports by Federal and State agencies.

The lithostratigraphic units in the borehole records were correlated with HGUs and the locations defining the HGU horizons were extracted. The x,y,z coordinates are defined by the location and depth from the land surface (the altitude of the top of the HGU horizon was calculated by subtracting the depth from the land-surface altitude). If the land-surface altitude was not reported in the borehole records, DEMs were used to interpolate the land-surface altitude at the borehole. Boreholes outside the model domain were retained for control along the model boundary.

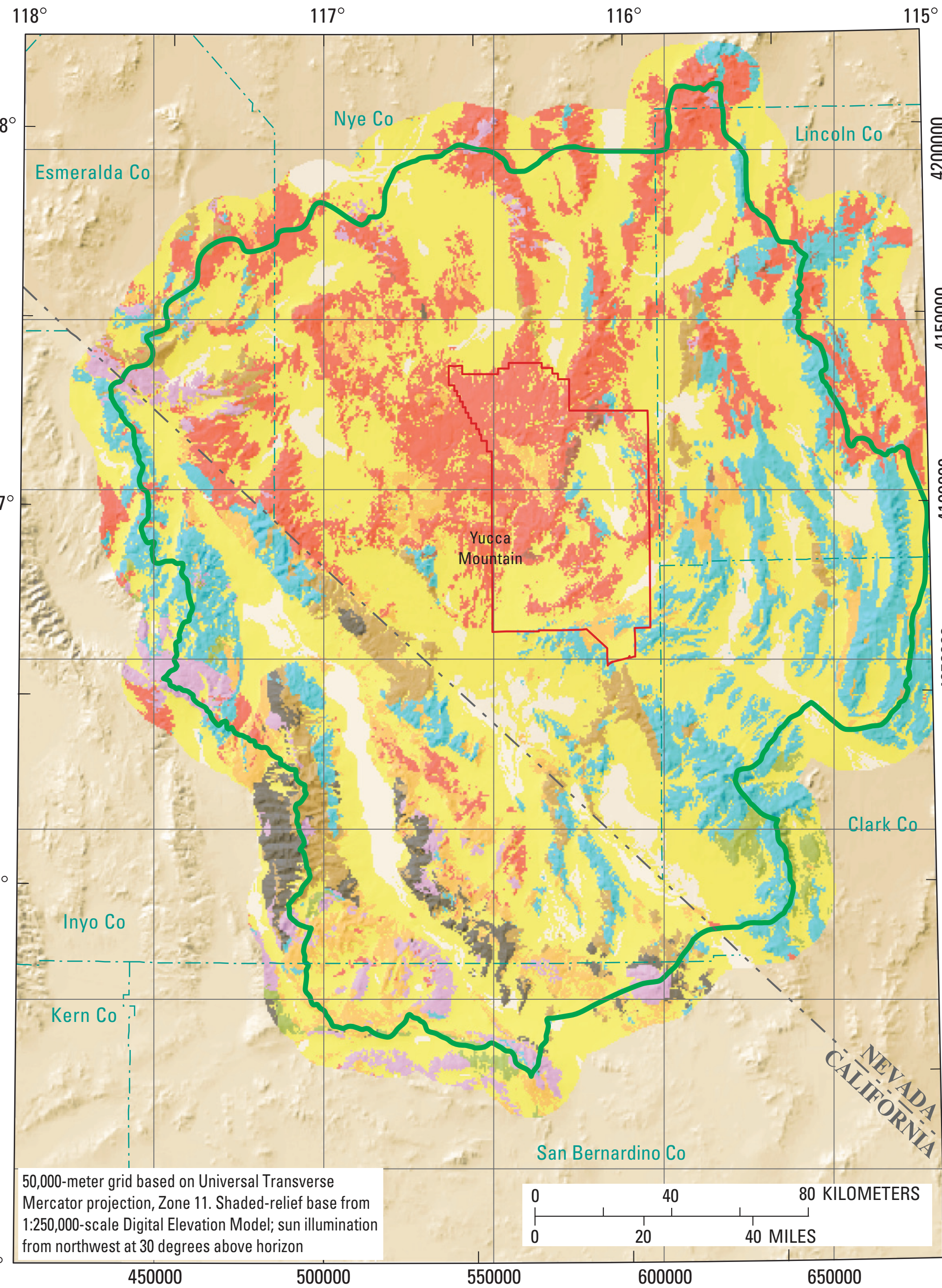
Table E–3. Correlation of hydrogeologic units with lithostratigraphic units from geologic map and cross sections.

Hydro-geologic unit abbreviation	Hydrogeologic unit name	Regional cross sections (Sweetkind and others, 2001)	Geologic map (Workman, Menges, Page, Taylor, and others, 2002)	Nye County cross sections (R.W. Spengler, U.S. Geological Survey, written commun., 2001)
YAA	Younger alluvial aquifer	Qu	Qc, Qay, Qayo, Qau, Qe, QTau, QTls	Qal, Qa
YACU	Younger alluvial confining unit	Qu	Qp, Qayf, QTd, Qayfe	Not depicted
OAA	Older alluvial aquifer	QTu	Qao, QTa, Qlc	QTa, QTu, Tal, Trx
OACU	Older alluvial confining unit	QTu	QTsf	Not depicted
LA	Limestone aquifer	Not depicted	Not depicted	not depicted
LFU	Lava-flow unit	QTb	Qa, Qb, QTb, Tb, Tr, Tar, Tas, Tgy, Tvg	Tby, Tvy
YVU	Younger volcanic-rock unit	Not depicted	Tt4, Tv	Not depicted
Upper and lower VSU	Volcanic- and sedimentary-rock unit	Tvu (Tgv, Tvu, Tvuy), Tsu (Tsu, Tso, Ts3, Ts4)	Ta4, Tls, Ts, Ts1, Ts3, Ts4, Tso	Tge, Tget, Tab
TMVA	Timber Mountain volcanic-rock aquifer	Tt, Tm	Tmt, Tst	Tmr, Tma
PVA	Paintbrush volcanic-rock aquifer	Tp, Tvx	Tpt	Tpc, Tpcbt, Tpt, Tptbt
CHVU	Calico Hills volcanic-rock unit	Ta	Not depicted	Tac
WVU	Wahmonie volcanic-rock unit	Tw	Tw	Tw
CFPPA	Crater Flat–Prow Pass aquifer	Not depicted	Tct (Tcp)	Tcp, Tcpbt
CFBCU	Crater Flat–Bullfrog confining unit	Not depicted	Tct (Tcb)	Tcb, Tcbbt, Tcbss
CFTA	Crater Flat–Tram aquifer	Not depicted	Tct (Tct)	Tct, Tcts
BRU	Belted Range unit	Tb	Tbt	
OVU	Older volcanic-rock unit	Tov, Tvuo	Ta2, Ta3, Tkv, Tlt, Tqv, Tt2, Tt3, Tuv	Trl, Trlbt, Trls, Trr
SCU	Sedimentary-rock confining unit	Pkt, Ŧcm, Ja	Ŧc, Ŧm, Ja, Klw, Mzsv, PIPkc, Pkt, Pov, Pr, Pzu	Not depicted
UCA	Upper carbonate-rock aquifer	PIPu where Me or Mc is present	PIPMb, PIPt	Not depicted
UCCU	Upper clastic-rock confining unit	Me, Mc	IPMsc, MDe	Not depicted
LCA and LCA_T1	Lower carbonate-rock aquifer and thrusts	Cnbc, Ou, Sdu, Mu	Ꞓb, Ꞓc, Ꞓe, Ꞓms, Ꞓn, Ꞓnb, Ꞓnbc, Ꞓu, DꞒd, DꞒm, DꞒu, Dlb, Ds, Dsf, DShv, DSlm, DSsl, DSu, MDu, Mu, Mm, Oep, Oepn, Oeu, Oe, Oee, Oes, Opa, PSu, Sr	Dn, Du, Su, Ou, Cn, Cb, Cc
LCCU and LCCU_T1	Lower clastic-rock confining unit and thrusts	LCCU, ZYp, Zu, Zj, CZw, Pzx, Zs	Ꞓcam, Ꞓh, Ꞓpo, Ꞓz, ꞒZcaa, ꞒZw, ꞒZws, Zd, Zj, Zs	Cz, CZw
XCU	Crystalline-rock confining unit	ZYXm, ZYm, Xmi	Tws, Xmi, ZYp	ZYm, Xm
ICU	Intrusive-rock confining unit	Ti, TKi	JŦqm, Tai, TKd, TKi, Ŧg, Tgo	Not depicted

Geologic and Hydrogeologic Cross Sections

Cross sections from five sources were used as input to the HFM (fig. E–4): (1) DVRFS region (Sweetkind and others, 2001), (2) southern Nevada and eastern California (Grose, 1983; Grose and Smith, 1989), (3) DOE/NV-UGTA model (IT Corporation, 1996a), (4) Yucca Mountain area (Potter, Dickerson, and others, 2002), and (5) the southern part of Yucca Mountain and the northern part of Amargosa Desert (R.W. Spengler, U.S. Geological Survey, written commun., 2001).

Many of the cross sections in Grose (1983), Grose and Smith (1989), and IT Corporation (1996a) are inconsistent with or superseded by cross sections developed using new data and structural interpretations. Of the 32 1:250,000-scale cross sections in Grose (1983) and Grose and Smith (1989),



EXPLANATION

Hydrogeologic units (some combined; modified from Workman, Menges, Page, Taylor, and others, 2002)
The 27 hydrogeologic units used in the hydrogeologic framework model are simplified by grouping into 10 hydrogeologic units in this figure.

- Younger alluvial aquifer/Older alluvial aquifer (YAA/OAA)
- Younger alluvial confining unit/Older alluvial confining unit (YACU/OACU)
- Cenozoic volcanics (11 combined units)
- Volcanic- and sedimentary-rock units (VSU)
- Sedimentary-rock confining unit (SCU)
- Upper clastic-rock confining unit (UCCU)
- Upper/lower carbonate-rock aquifer (UCA/LCA)
- Lower clastic-rock confining unit (LCCU)
- Crystalline-rock confining unit (XCU)
- Intrusive-rock confining unit (ICU)
- **Nevada Test Site**
- **Death Valley regional ground-water flow system model boundary**

Figure E–3. Outcrop of hydrogeologic units at the land surface for the Death Valley regional ground-water flow system region.

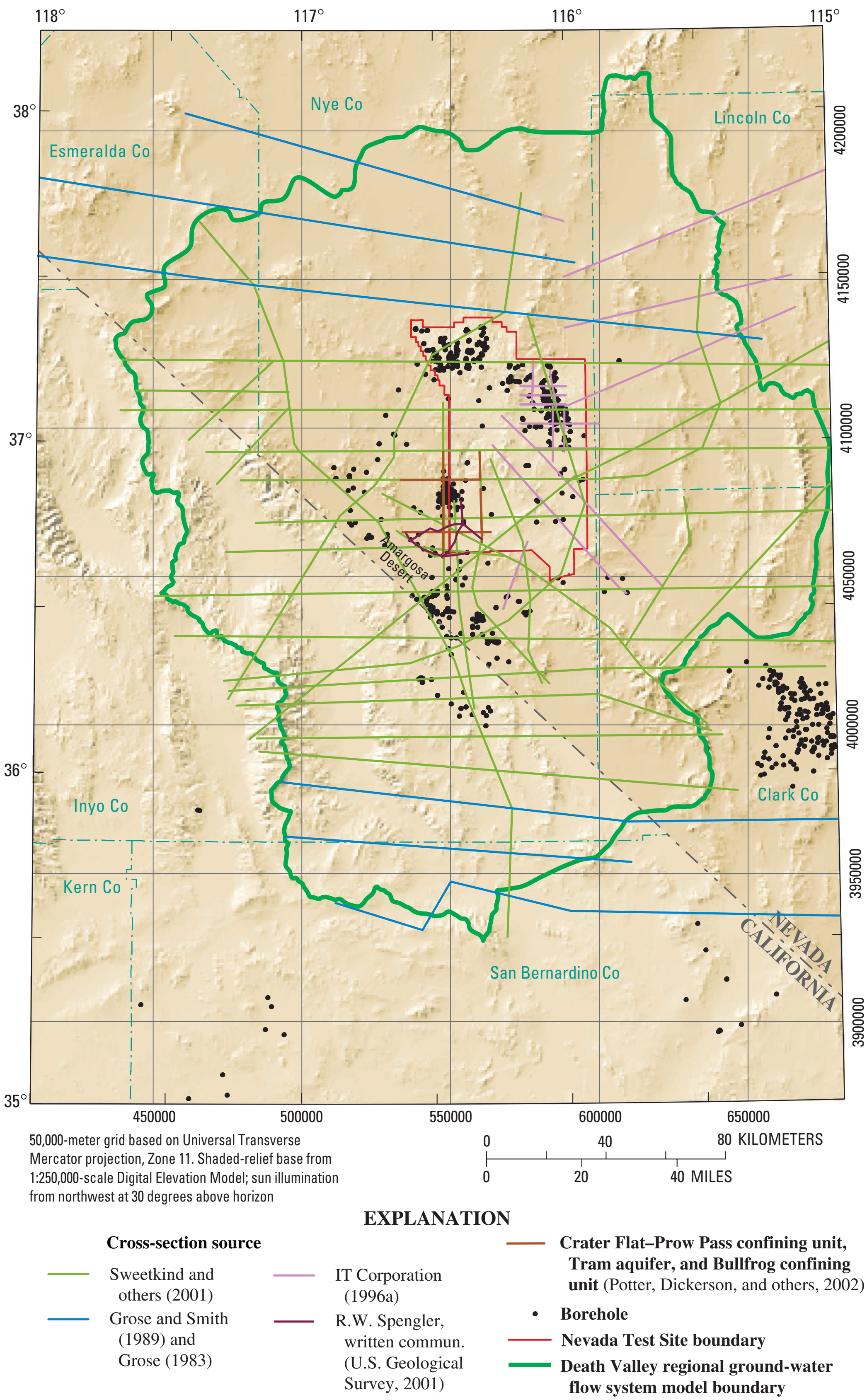


Figure E–4. Locations of boreholes and cross sections used to construct the hydrogeologic framework model.

6 were used as data input to the HFM (NCT1, NCT9, NCT10, NT7, NT8, and CT1). These cross sections portray the geology north of the NTS and the southern part of Death Valley and the Mojave Desert (see fig. A–1, this volume).

Of the 52 cross sections from the DOE/NV-UGTA model (IT Corporation, 1996a), 22 were used as data input to the HFM. These cross sections portray the hydrogeology of specific areas of the NTS at scales ranging from 1:12,000 to 1:100,000. These cross sections provide greater detail with regard to Cenozoic unit thickness and the location of faults in the Cenozoic stratigraphic sequence.

As a part of this study, 28 regional geologic cross sections of the DVRFS region were developed (Sweetkind and others, 2001); all were used as input to the HFM (fig. E–4). These cross sections, constructed at 1:250,000 scale, form a network across the central part of the model domain (fig. E–4). The cross sections were constructed on the basis of interpretive maps of geology (Workman, Menges, Page, Taylor, and others, 2002), tectonics (Workman, Menges, Page, Ekren, and others, 2002), aeromagnetics (Ponce and Blakely, 2001), isostatic gravity (Ponce and others, 2001), and the depth-to-basement (Blakely and Ponce, 2001).

To provide additional detail for the geologic formations that constitute the Crater Flat Group (Prow Pass, Bullfrog, and Tram Tuffs) in the vicinity of Yucca Mountain and Crater Flat, data on four cross sections that were developed from 1:50,000-scale mapping at Yucca Mountain (Potter, Dickerson, and others, 2002) were used as input for the HFM. These cross sections are similar to those constructed by Sweetkind and others (2001) but provide greater stratigraphic detail, especially within the Cenozoic volcanic-rock stratigraphy.

Three unpublished cross sections of southern Yucca Mountain and the northern Amargosa Desert that were developed by the USGS for the Yucca Mountain Project (YMP) (R.W. Spengler, written commun., 2001) were used as input data for the HFM. These cross sections incorporate detailed stratigraphic data for the Cenozoic rocks south and southeast of Yucca Mountain from the Nye County EWDP boreholes that were not available during construction of the other cross sections used in this study.

The lithostratigraphic units on the cross sections were correlated with the HGUs (table E–3) and used to extract horizontal (x,y) and altitude (z) coordinates for the HGU horizon along a given trace. The MGE software allowed the x,y,z coordinates of the HGU horizon on the cross sections to be extracted by merging and scaling the digital file of each cross section to fit its surface trace digitized from a map. Each cross section was queried to determine the altitudes of points spaced every 250 m horizontally along an HGU horizon and a series of files that contained x,y,z coordinates for each HGU horizon was exported.

Existing Geologic Framework Models

Several 3D geologic framework models have been constructed for various studies of areas in the region, primarily for the YMP and the Underground Test Area (UGTA) program. Data from three existing framework models were used in the HFM (fig. E–5): (1) Yucca Mountain Project geologic framework model (YMP-GFM) (Bechtel SAIC Company, 2002), (2) Pahute Mesa–Oasis Valley (PMOV) model (Bechtel Nevada, 2002), and (3) Silent Canyon caldera complex (SCCC) model (McKee and others, 2001). Data from these models provided greater detail of the geometry of Cenozoic volcanic-rock HGUs in areas critical to ground-water flow and provided more consistency between the regional HFM these local-scale models. Because of the scale of these models, they contain more detailed HGUs grouped into many of the regional HGUs. The gridded horizons from the group of local HGUs were merged into a single gridded horizon representing the regional HGU by comparing the individual local HGU grids with each other and selecting the highest altitude that occurs in each grid cell.

The YMP-GFM (Bechtel SAIC Company, 2002) is an interpretation of the geology at the proposed underground geologic repository for high-level radioactive waste at Yucca Mountain. The model represents an area of 168 km^2. The boundary of the YMP-GFM (fig. E–5) was chosen to provide a geologic framework over the area of interest for ground-water flow and radionuclide transport through the unsaturated zone.

The PMOV hydrostratigraphic model was constructed to portray subsurface geologic units at Pahute Mesa, a nuclear testing area at the NTS, and Oasis Valley, a ground-water discharge area downgradient from Pahute Mesa (fig. E–5). The model area covers more than 2,700 km^2 and is geologically complex (Bechtel Nevada, 2002). To build the PMOV model, a hydrostratigraphic interpretation was formulated using a structural model of the PMOV that subdivides the area into a series of structural blocks that may not be detectable from surface mapping (Warren and others, 2000). The model depicts the thickness, extent, and geometric relations of more than 40 HGUs, as well as all the major structural features that control them, including calderas and faults. Data from the PMOV were not used to modify the units for the UCA, UCCU, LCA, LCCU, and XCU (table E–4).

Examination of the regional ICU horizon revealed great differences between the cross-section data (Sweetkind and others, 2001) and the intrusive rock horizons from the PMOV model. The ICU surfaces of the PMOV model were strictly interpreted from gravity data (Bechtel Nevada, 2002), whereas the cross sections (Sweetkind and others, 2001) tended to be more conceptual. Because of this, ICU cross-section data from within the limits of the PMOV model were deleted to avoid conflicting data sets.

A 3D caldera model of the Silent Canyon caldera complex (SCCC) in the central part of Pahute Mesa based on gravity inversion, drill-hole data, and geologic mapping was constructed using a more traditional interpretation of the caldera structure as an alternative to the PMOV model (McKee and others, 2001). The traditional interpretation, which assumes a circular collapse feature to explain the caldera shape, is analogous to the structure and shape of other calderas worldwide (Lipman, 1984; Lipman 1997) and is consistent with gravity-model interpretations from Pahute Mesa (Hildenbrand and others, 1999). For the SCCC model, 47 Cenozoic stratigraphic

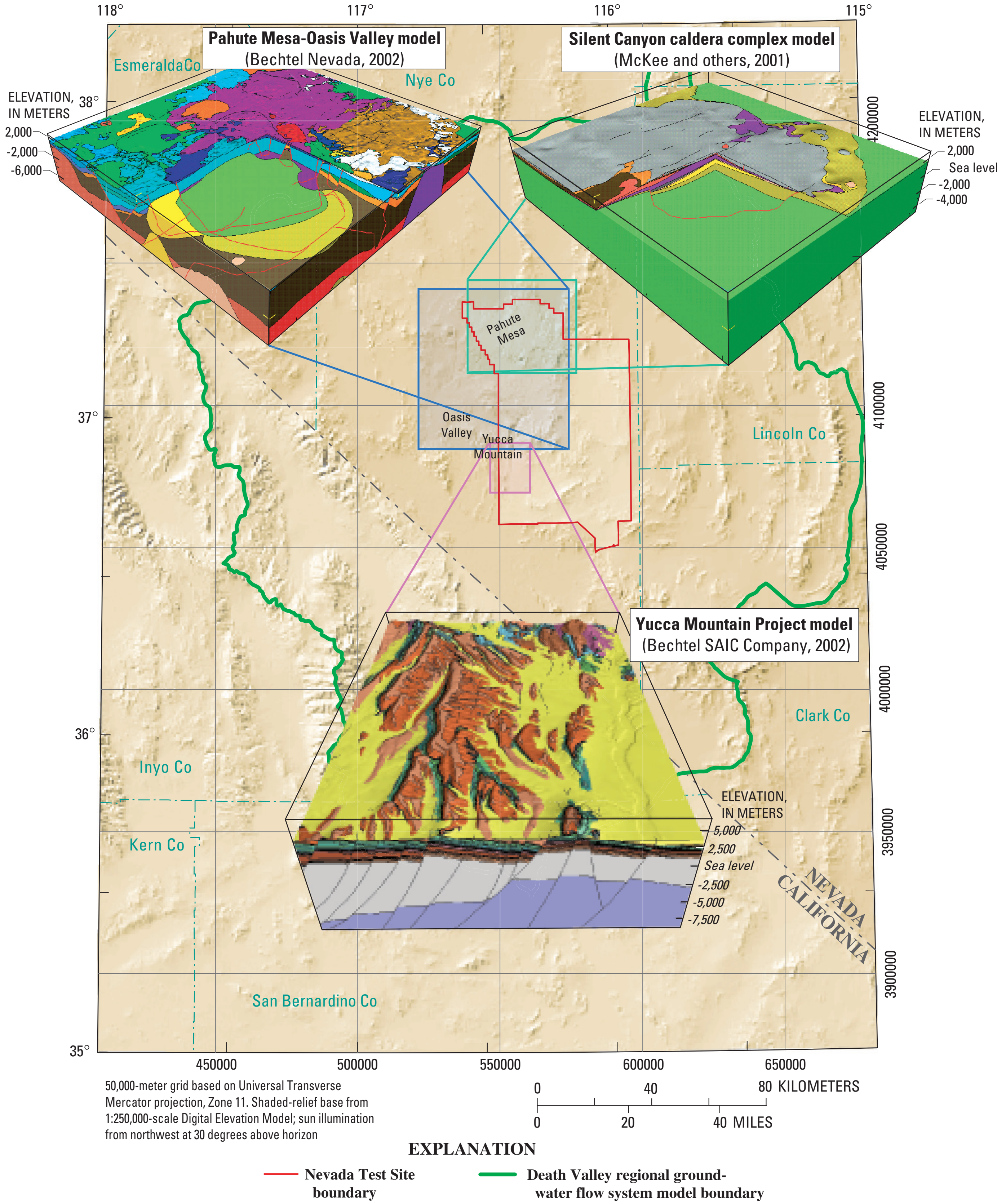


Figure E–5. Location and isometric views of local-scale geologic framework models used to construct the regional hydrogeologic framework model.

Table E–4. Correlation of units in the geologic framework models for Yucca Mountain, Pahute Mesa–Oasis Valley, Silent Canyon caldera complex, and the Death Valley regional ground-water flow system.

[DVRFS, Death Valley regional ground-water flow system; YMP-GFM, Yucca Mountain Project geologic framework model; PMOV, Pahute Mesa–Oasis Valley; SCCC, Silent Canyon caldera complex]

DVRFS hydrogeologic unit	YMP-GFM units (Bechtel SAIC Company, 2002)	PMOV hydrostratigraphic model units (Bechtel Nevada, 2002)	SCCC units (McKee and others, 2001)
Younger volcanic-rock unit (YVU)		YVCM	
Thirsty Canyon–Timber Mountain volcanic-rock aquifer (TMVA)		WWA, FCCU, TMA, THCM, THLFA, TMCM, FCA, FCCM, DVA, DVCM, TCVA	
Paintbrush volcanic-rock aquifer (PVA)	Tpbt2, Tpbt3, Tpbt4, Tpbt1, TpcLD, Tpcp, Tpcpv1, Tpcpv2, Tpcpv3, Tptf, Tptpll, Tptpln, Tptpmn, Tptpul, Tptpv1, Tptpv2, Tptpv3, Tptrl, Tptrn, Tptrv1, Tptrv2, Tptrv3, Pah, PostTivaNorth, RHH, Tiva_Rainier	PCM, PVTA, BA, UPCU, TCA, PLFA, LPCU, TSA	ba, lp, tca, tsa
Calico Hills volcanic-rock unit (CHVU)	Tac, Tacbt	CHCU, CHZCM, CHVCM, CHVTA	ch
Crater Flat–Prow Pass aquifer (CFPPA)	Tcplv, Tcplc, Tcpmd, Tcpuc, Tcpuv, Tcpbt	IA, CFCM, CFCU, KA	cf, ia
Crater Flat–Bullfrog confining unit (CFBCU)	Tcblv, Tcblc, Tcbmd, Tcbuc, Tcbuv, Tcbbt	BCU	bf
Crater Flat–Tram aquifer (CFTA)	Tctlv, Tctlc, Tctmd, Tctuc, Tctuv, Tctbt	Not used	
Belted Range unit (BRU)	Not used	BRA	br
Older volcanic-rock unit (OVU)	Not used	PBRCM	pbr
Intrusive-rock confining unit (ICU)	Not used	MGCU, SCICU, CHICU, CCICU, RMICU, ATICU, BMICU, SCVCU	

units shown on the geologic map of Wahl and others (1997), or encountered in drill holes on Pahute Mesa and classified by Warren and others (1998), were defined as aquifers, confining units, and composite units according to their hydrologic properties (table E–4).

Although the PMOV and the SCCC models used the same data, differences in modeled horizons reflect the different approaches in modeling geologic structures. The SCCC model better reflects the traditional interpretation of a caldera system, as opposed to the structural block model used in the PMOV model. As a result, the SCCC model horizons were used for the HGUs common to both models (BRU, CFBCU, CHVU, OVU, and PVA) within the boundary of the SCCC model.

Structures

Regionally important faults that influence ground-water flow were used in the construction of the DVRFS HFM (fig. E–6). Maps showing the surface expression of faults and other structures and cross sections showing faults were used to incorporate offsets in HGUs during the gridding process. For the purposes of the HFM, the structures were classified as: normal, strike-slip, detachment, caldera boundary, thrust, inferred thrust, or transverse zone (Potter, Sweetkind, and others, 2002). On the basis of these classifications, structures were incorporated into the HGUs that they affected (table E–2). Faults and other structures in the model area can dip at almost any angle, but most are high-angle faults (greater than 60 degrees). These high-angle faults are simplified in the HFM as vertical features.

Thrust faults can create a stratigraphic repetition of HGUs, which were incorporated in the HFM where they are thought to be hydrologically important. Because horizons must be represented as grids in the HFM, they cannot have multiple altitudes at a single location. Therefore, the repeated stratigraphy in thrusted areas was modeled by constructing a separate gridded surface of the overlying hanging wall part of the thrusted unit. In map view, the spatial extent of the perimeter of the thrust sheet was defined by combining the surface trace of the fault from Workman, Menges, Page, Ekren, and others (2002) and Potter, Sweetkind, and others (2002) (see fig. B–31, this volume) with the interpreted downdip extent of the thrust sheets from the cross sections (Sweetkind and others, 2001). For the purposes of the HFM, the trailing edge of the thrust was defined as the point at which the HGU is no longer stratigraphically repeated. Within this thrust boundary, the horizons were treated as defining unique additional HGU horizons for the LCA and LCCU (fig. E–7). The interpreted subsurface extents of nine thrust plates (see fig. B–31, this volume) were defined. The thrust plates were selected for their size, offset, and potential hydrologic importance in juxtaposing the regional aquifer and confining units. Although a number of other thrusts are known within the model boundaries (see Snow and Wernicke, 2000, and references cited therein), these were not treated explicitly in the HFM.

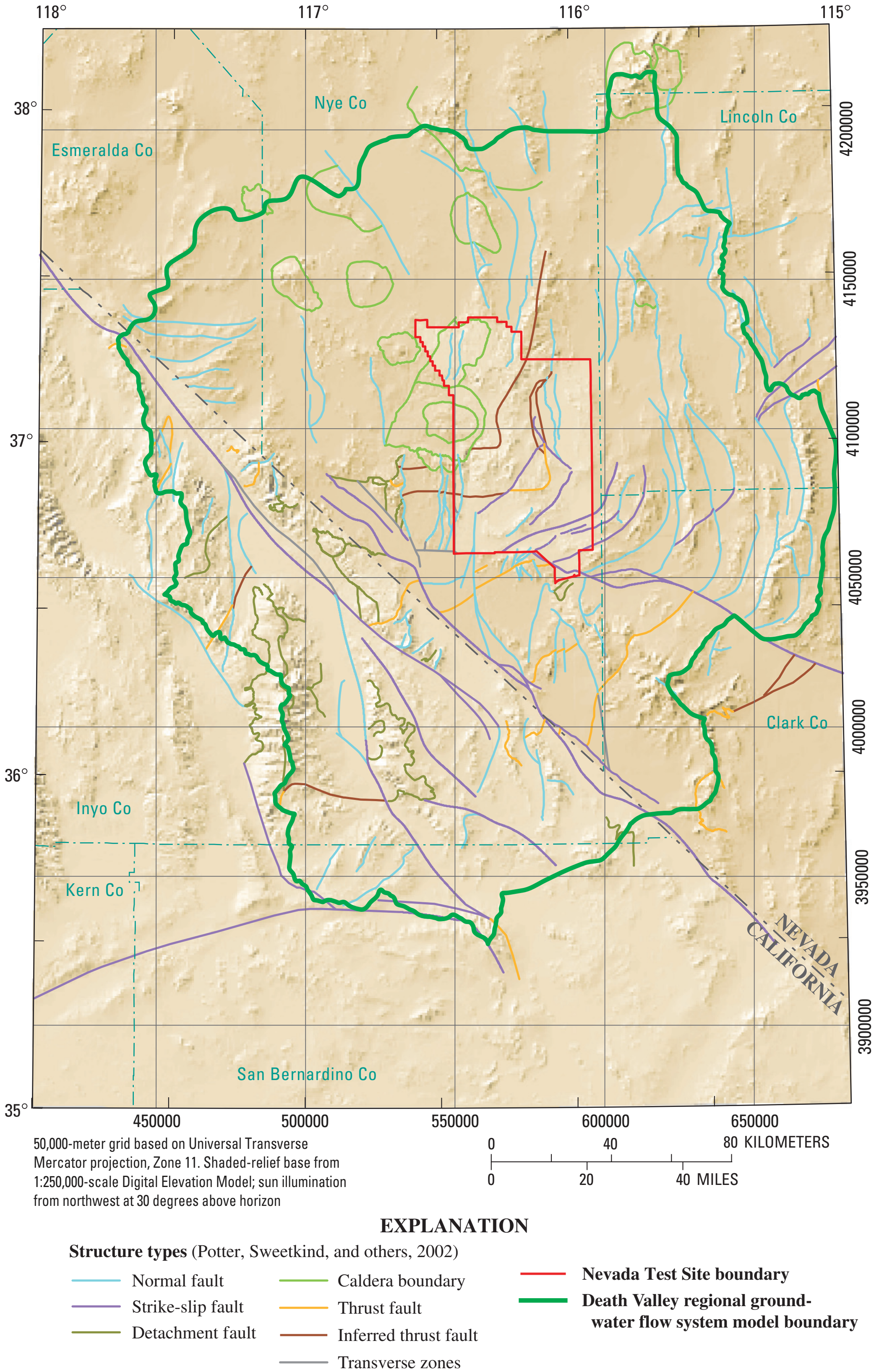
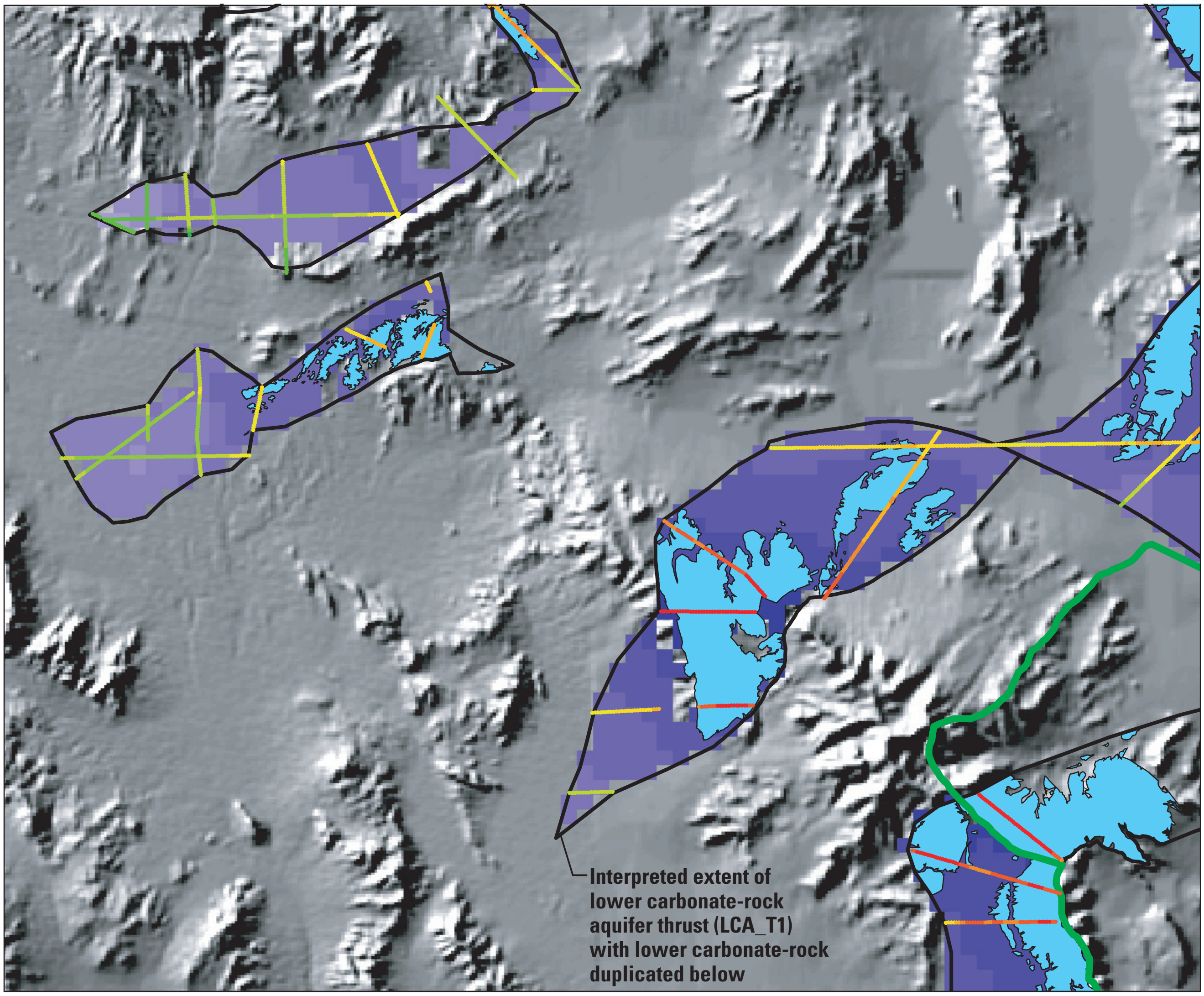
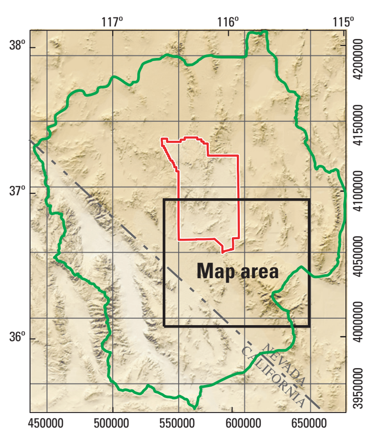


Figure E–6. Traces of structures represented in the hydrogeologic framework model.





EXPLANATION

Extent of LCA_T1 on geologic map (modified from Workman, Menges, Page, Ekren, Taylor, and others, 2002; Sweetkind and others, 2001). Altitude data from digital elevation model (DEM).

Lower altitude — Higher altitude
Cross-section data, coded by depth (Sweetkind and others, 2001)

Lower altitude — Higher altitude
Altitude of gridded surface shown in purple

Thrust plate extent (Chapter B, this volume)

Death Valley regional ground-water flow system model boundary

Figure E–7. Example of the lower carbonate-rock aquifer thrust (LCA_T1), showing data sources and interpreted extents.

Gridding of Hydrogeologic Unit Horizons

The gridded surfaces defining the HGU horizons were interpolated and extrapolated from the available data and information. For all of the HGUs except for the YAA, YACU, OAA, and OACU, a hybrid gridding algorithm (Petrosys Pty. Ltd., 2003) was used to calculate the grid from the top surface of each HGU defined by the text files containing spatial coordinates from surface exposures, borehole lithologic logs, cross sections, and geologic models and by taking into account structural discontinuities from faulting (table E–2). The hybrid gridding algorithm is a combination of minimum curvature and first-order least-squares algorithms (Petrosys Pty. Ltd., 2003). It uses the first-order least squares algorithm within one grid cell of a fault and the minimum curvature algorithm to calculate all other grid cells. The minimum curvature algorithm involves several iterations to converge on an optimal grid definition by fitting a minimum curvature spline through the data points on either side of the point being calculated, thus preserving the rate of change of slope. The first-order least-squares algorithm fits a plane through the data points on either side of the model cell being calculated. The hybrid gridding process generates a coarse grid that is progressively refined with further iterations. During each iteration, the goodness-of-fit between the grid and the data was calculated to determine if more iterations were necessary. The effect of this iterative process caused a trendlike solution in areas of sparse data, though the grid accurately represented existing data points. Because the algorithms can extrapolate or interpolate grid cells that may be higher than land surface, each grid was limited by the topographic surface.

A clipping distance was applied to each gridded surface to limit the extent of extrapolation. These clipping distances varied for each interpreted gridded surface with assumed extents of the units and data density. The gridded surfaces were manually edited to clip areas where the gridding algorithms were judged to have over-extrapolated the HGU extents. As an example, figure E–8 presents an oblique view of the gridded surface of the LCA.

The accuracy of individual gridded surfaces depends on the available defining data and the complexity of the geologic unit being modeled. For example, because of their relatively simple geometry, planar bedded tuffs can be represented accurately with only a few data points, whereas faulted and folded rocks with more complex geometries are much more difficult to represent even with a large number of data points. Some gridded HGU surfaces were relatively well defined by numerous well-distributed data. Other gridded surfaces, such as those HGUs that crop out less, were less defined. In general, the lower an HGU is stratigraphically, the less defined it is, and the more structurally complex (Sweetkind and others, 2001).

In areas with more data, the computer-generated gridded surfaces generally are thought to be acceptable. In areas with sparse data, computer-generated gridding is more suspect. In these suspect areas, the gridded surfaces of all of the pre-Cenozoic HGUs were examined and compared with the altitude of the top of the pre-Cenozoic surface based on the gravity inversion model (Blakely and Ponce, 2001) and revised as necessary. All gridded surfaces were edited manually to ensure that they followed structural trends and honored faults, surface data, and subsurface data.

Gridded surfaces for the basin-fill units (YAA, YACU, OAA, and OACU) were defined on the basis of geologic map data and stratigraphic depositional rules. Owing to lack of lithologic information, these units are not defined in boreholes. The nearest-neighbor algorithm (Golden Software, Inc., 1997) was used to populate the grid. Each grid cell that had at least one basin-fill data point was attributed with the altitude of the point nearest the grid cell center. Because these basin-fill HGUs have an identifiable stratigraphic succession, a set of rules based on surficial stratigraphy in the area (table E–5) was developed to define the stratigraphic order and maximum thickness of each basin-fill HGU (E.M. Taylor, U.S. Geological Survey, written commun., 2002). In this scheme, the top of each basin-fill HGU is defined by outcrop, by stratigraphic order, and(or) defined thickness. Because the thickness of the actual basin-fill HGUs is unknown, the VSU was defined to fill in the remaining depth of the basin. Where the LA exists, the YACU was allowed to extend to a greater thickness.

Building the Model

The HFM was constructed in SGM by importing gridded surfaces to define the horizons of the HGUs that were stacked in stratigraphic sequence to form a 3D digital solid. The geometries of the ICU and the thrust plate units affected the stratigraphic order in which the HGUs were imported into the HFM. Because SGM is not designed to handle time-stratigraphic emplacement of intrusions (unit 6 in fig. E–9*A*), these features were inserted into the HFM out of their correct time sequence (unit 1 in fig. E–9*B*). Therefore, the youngest intrusion represented the lowest (“oldest”) deposition surface. In the thrust fault areas, the overlying thrust horizons unit 5b in fig. E–9*B* were emplaced as a second step for the same HGU (unit 5a in fig. E–9*B*). Although neither of these accommodations for the geometries of the intrusions and the thrusted units affected the resulting model, it did affect the order in which they were put into the model. Table E–1 presents the order in which the HGUs were inserted (stacking order) to produce the HFM. Visualizations of the HFM as a fence diagram (fig. E–10) and a block diagram (fig. E–11) show the internal and external shape of the HGUs.

Evaluation of the Hydrogeologic Framework Model

The HFM was evaluated for accuracy by visual inspection and by mathematical manipulations of the gridded surfaces for extent and thickness of the HGUs. The HFM was compared to the known extent of HGUs, input cross sections, and other 3D framework models.

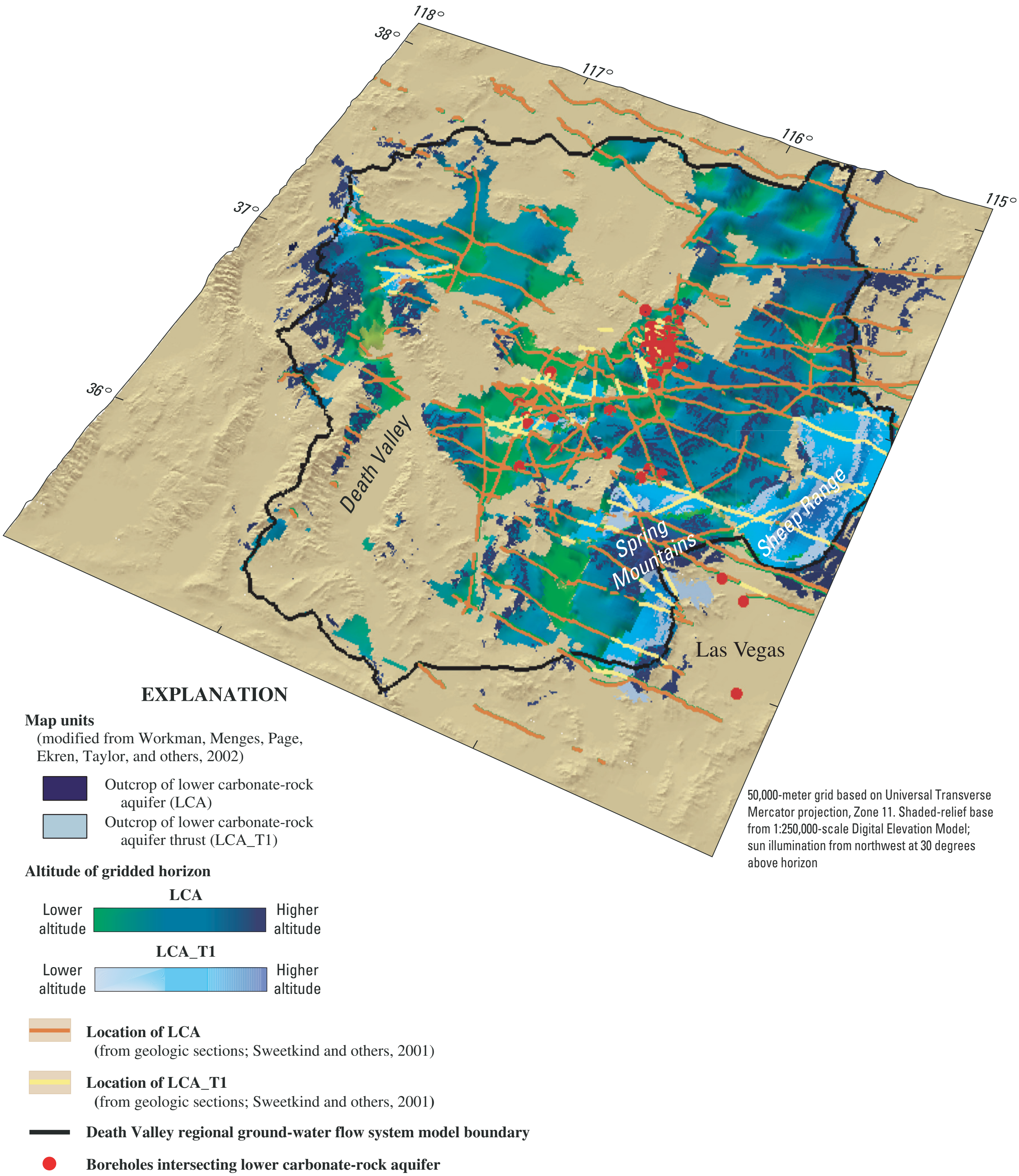


Figure E–8. Oblique view of gridded surface of the regional carbonate-rock aquifer with associated data sources.

Table E–5. Basin-fill hydrogeologic unit stratigraphic succession.

[Abbreviations: LA, limestone aquifer; OAA, older alluvial aquifer; OACU, older alluvial confining unit; VSU, volcanic- and sedimentary-rock units; YAA, younger alluvial aquifer; YACU, younger alluvial confining unit; >, greater than]

Surface hydro-geologic unit	Maximum thickness (meters)	Underlying hydrogeologic unit(s)
YAA	25	OAA, LA, VSU, or bedrock
YACU	25 (>25 where LA exists)	LA, VSU, or bedrock
OAA	45	LA, VSU, or bedrock
OACU	100	VSU or bedrock
LA	10	VSU or bedrock

Comparison of Gridded Surfaces with Known Extents of Hydrogeologic Units

Gridded surfaces of the HGU horizons were compared to the input data used to construct the surfaces to assess the accuracy of the gridding processes. Grids of unit thickness were constructed to examine areas of potential anomalous thickness. Comparing the gridded surfaces and thickness with the input data provided a suitable method of evaluating the representation of the HGUs in the HFM. Where necessary, a gridded surface was recalculated using different gridding algorithm settings (such as search radius and distance weighting) or manually edited to produce a more accurate match to known geologic conditions.

Comparison of Model Sections to Input Cross Sections

Visually comparing the vertical slices of the model along traces of the cross sections of Sweetkind and others (2001) (fig. E–5) with the input cross sections provided an acceptable method of evaluating the model representation (fig. E–12). On the basis of gross morphology, no discrepancies deemed geologically or hydrologically significant were recognized. The model sections retain the basic geometric characteristics from the input cross sections but typically did not include minor features. Discrepancies occurred mainly where HGUs are thin and undulating.

Comparison with Other 3D Framework Models

Comparing the surfaces from the input 3D models (YMP-GFM, PMOV, and SCCC) to the gridded surfaces from the HFM provided an acceptable method of evaluating the HFM representation. On the basis of gross morphology, reasonably good agreement between the input surfaces from other 3D models and the HFM surfaces was found and no discrepancies deemed geologically or hydrologically significant were identified. Although they were not directly input, the YMP/HRMP HFM (D'Agnese and others, 1997) and the DOE/NV-UGTA geologic model (IT Corporation, 1996a) were compared to the HFM. On the basis of gross morphology, reasonably good agreement between the HFM and these two previous HFMs was found.

Major differences between this HFM and previous HFMs are:

1. In the Emigrant Valley area (fig. A–1, this volume), the LCA most likely eroded prior to volcanic rock deposition (IT Corporation, 1996a, fig. G1–1). Potentiometric data show a steep hydraulic gradient between Emigrant Valley and Yucca Flat (fig. C–2, this volume). Calibration of both the DOE/NV-UGTA (IT Corporation, 1996b) and previous USGS flow models (D'Agnese and others, 1997; D'Agnese and others, 2002) was difficult with a carbonate-rock corridor present in this area. As a result, an alternative interpretation was used in this regional HFM that provides a partial barrier to southward flow by involving structurally higher LCCU instead of the thick carbonate-rock corridor.

2. In Penoyer Valley (fig. A–1, this volume), the DOE/NV-UGTA model has basin-fill sediments in overlying volcanic rocks which in turn overlie LCA (IT Corporation, 1996a). This configuration does not provide enough low-permeability rocks to support ground-water levels near the ground surface and produce the steep hydraulic gradient between Penoyer and Desert Valleys (fig. C–2, this volume). In order to simulate the steep hydraulic gradient, the DOE/NV-UGTA geologic model (IT Corporation, 1996a) was updated at Penoyer Valley with an underlying LCCU. This interpretation was included in this regional HFM.

3. Geologic information was incorporated in the regional HFM at Yucca Mountain by using the more recent YMP-GFM (Bechtel SAIC Company, 2002), mainly to help define the location of the volcanic-rock HGUs in greater detail than the previous models.

4. New information from the Nye County EWDP boreholes was incorporated along with new interpretations based on these data (R.W. Spengler, U.S. Geological Survey, written commun., 2002). A more abrupt termination of the volcanic rocks in the basin fill and more detailed definition of the basin fill south and east of Yucca Mountain are indicated.

5. The definition of the basement rocks (LCA and LCCU) at the Striped Hills southeast of Yucca Mountain (fig. A–1, this volume) in the regional HFM is based on the more recent interpretation of Potter, Dickerson, and others (2002). This interpretation portrays the LCCU as part of a series of imbricated thrusts, which may form a significant barrier to ground-water flow in the area.

6. The PMOV model further defines the geologic units in this area (Bechtel Nevada, 2002). The classic interpretation of a caldera system (McKee and others, 2001) is used in the regional HFM as opposed to the structural block model

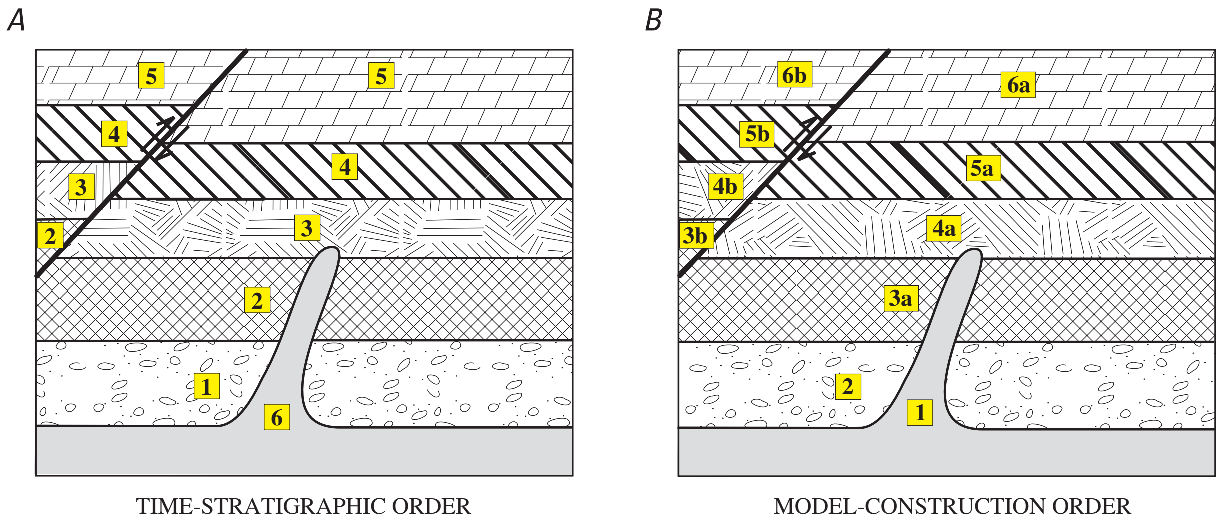


Figure E–9. Diagrams showing (*A*) time-stratigraphic and (*B*) model-construction order of geologic events.

(Warren and others, 2000) used by the DOE/NV-UGTA geologic model (IT Corporation, 1996a) and the PMOV model (Bechtel Nevada, 2002).

7. Recent drilling near Rainier Mesa (fig. A–1, this volume) has revealed the presence of the UCCU (Warren and others, 1998). Vertical hydraulic gradients in the boreholes in this area are an indication that the UCA is separated from the LCA. This regional HFM attempts to replicate this local stratigraphy.

8. The basin-fill HGUs have not been segregated much in previous models. The regional HFM splits the basin fill into seven units: YAA, YACU, OAA, OACU, LA, upper VSU, and lower VSU. This allows ground-water flow in the local and intermediate flow systems, where most of the ground-water development has occurred, to be defined in greater detail.

Revisions During Flow-Model Calibration

The flow modeling process also provided a mechanism to evaluate the HFM. These analyses were used in conjunction with independent hydrogeologic data to modify and improve the existing conceptual model, observation data sets, and weighting of the observations of the flow model (Chapter F, this volume). Modifications to the HFM were made only when supporting independent hydrogeologic criteria were identified, not simply to improve flow-model calibration.

Description of the Hydrogeologic Framework Model

The following describes the manner in which the HGUs were simulated in the HFM. This description includes the extent and thickness of the hydrogeologic units and key areas within the HFM.

Representation of Hydrogeologic Units in the Model

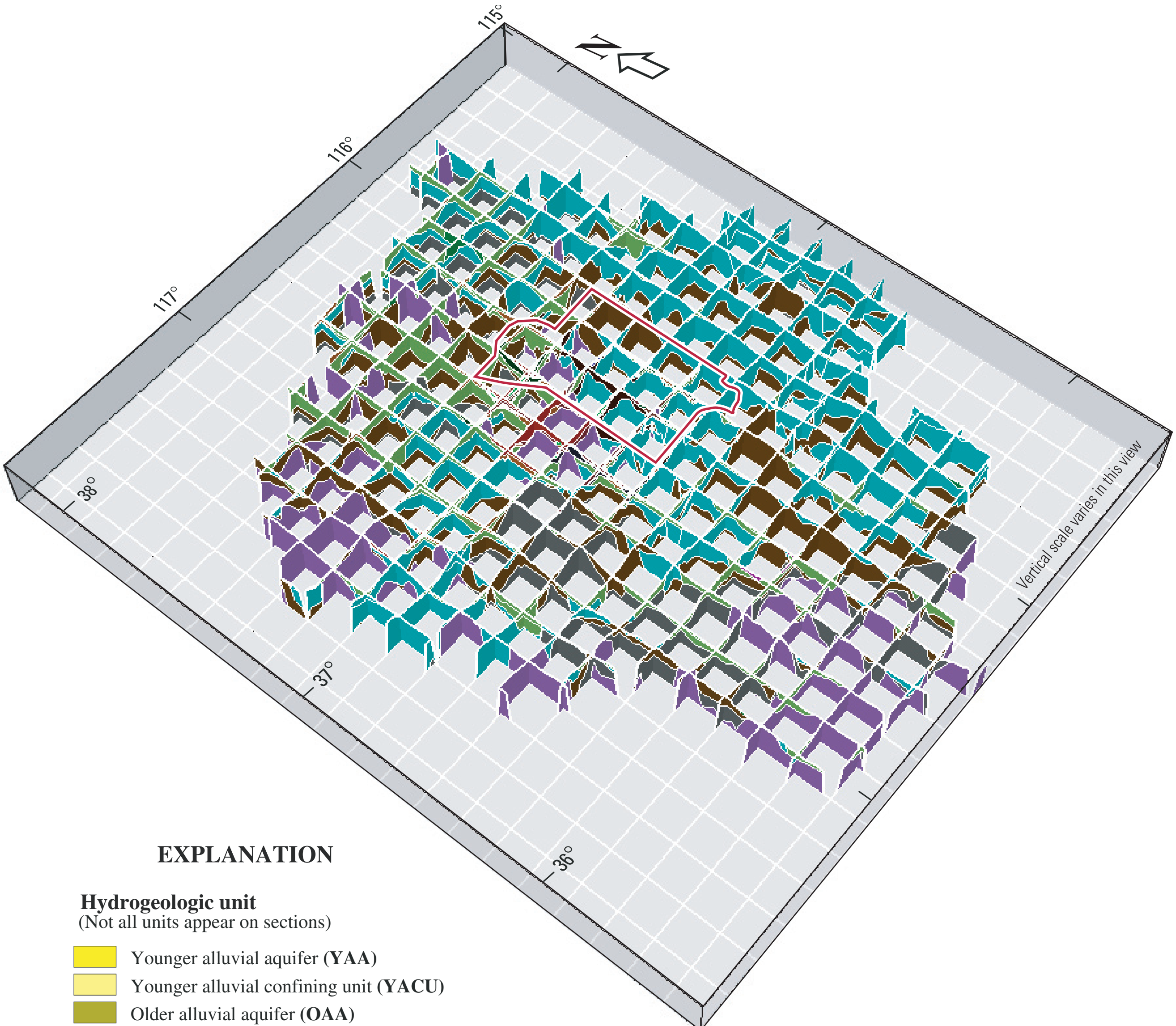
The HGUs as they are depicted in the HFM are described below. The extent and thickness of each HGU are those from the HFM and may differ somewhat from those described in Chapter B (this volume). The distribution of the data sources is shown in the “*A*” figures and the thickness of the HGU as simulated in the HFM is shown in the “*B*” figures.

Younger and Older Alluvial Aquifers (YAA and OAA)

The distribution of the younger alluvial aquifers (YAA) (fig. E–13*A*) and, to a lesser extent, the older alluvial aquifers (OAA) (fig. E–14*A*) is less in the HFM than shown in the surface exposures. The coarse grid resolution and stacking of HGUs from older to younger favors the older HGU in a grid cell when more than one unit is present. As a result, the YAA is often represented as a much smaller area where it does not cover an entire cell. The maximum thicknesses of the YAA and OAA in the HFM are 25 m and 45 m, respectively (figs. E–13*B* and E–14*B*).

Younger and Older Alluvial Confining Units (YACU and OACU)

The younger and older alluvial confining units (YACU and OACU, respectively) tend to be confining units and are restricted to the topographically lowest areas of structural basins in the DVRFS region. In particular, Death Valley, Pahrump Valley, and the Amargosa Desert have extensive deposits of YACU (fig. E–15*A*). Like the basin-fill aquifers, the distribution

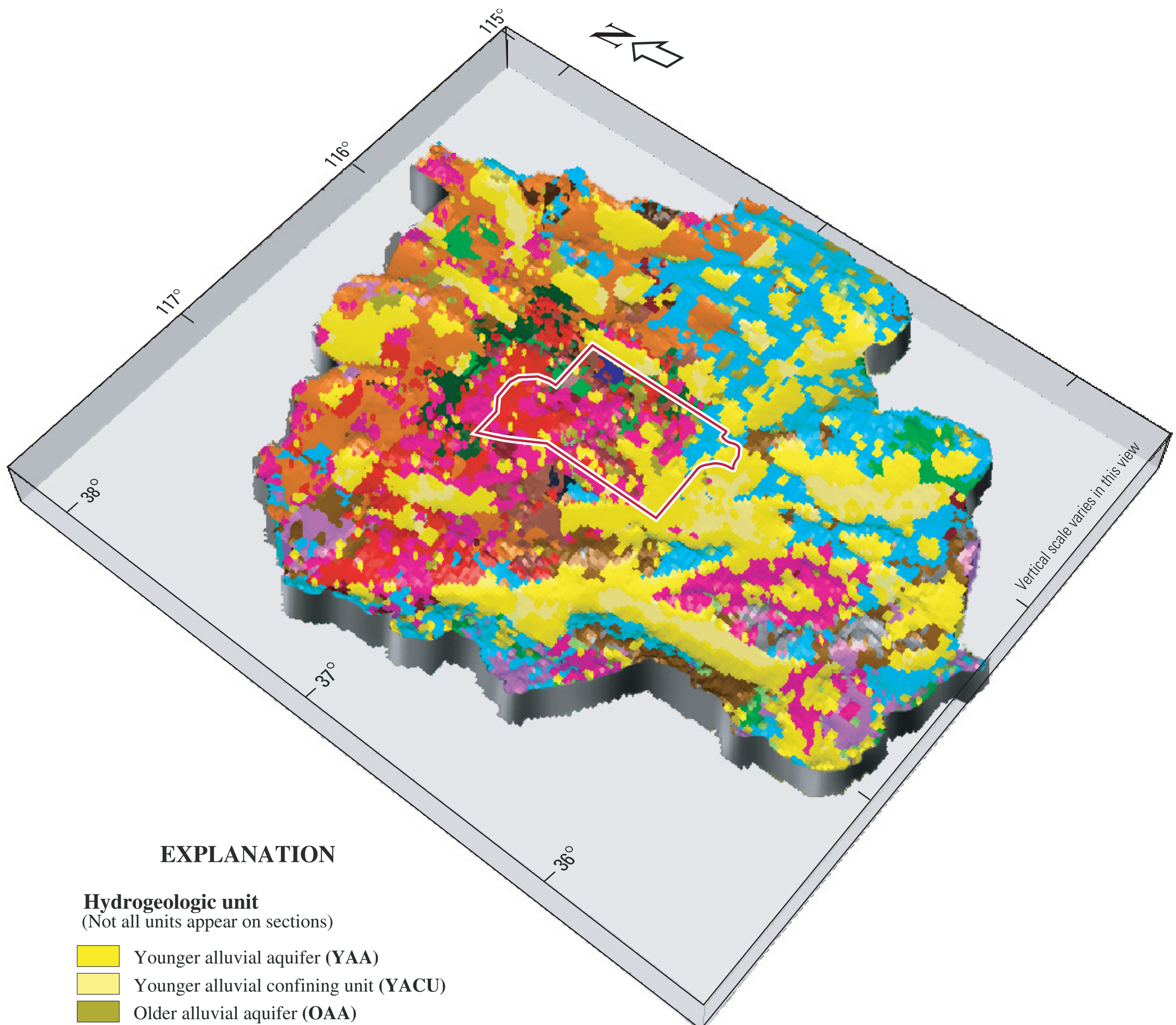


EXPLANATION

Hydrogeologic unit
(Not all units appear on sections)

- Younger alluvial aquifer **(YAA)**
- Younger alluvial confining unit **(YACU)**
- Older alluvial aquifer **(OAA)**
- Older alluvial confining unit **(OACU)**
- Limestone aquifer **(LA)**
- Lava-flow unit **(LFU)**
- Younger volcanic-rock unit **(YVU)**
- Upper volcanic- and sedimentary-rock unit **(upper VSU)**
- Timber Mountain–Thirsty Canyon volcanic-rock aquifer **(TMVA)**
- Paintbrush volcanic-rock aquifer **(PVA)**
- Calico Hills volcanic-rock unit **(CHVH)**
- Wahmonie volcanic-rock unit **(WVU)**
- Crater Flat–Prow Pass aquifer **(CFPPA)**
- Crater Flat–Bullfrog confining unit **(CFBCU)**
- Crater Flat–Tram aquifer **(CFTA)**
- Belted Range unit **(BRU)**
- Older volcanic-rock unit **(OVU)**
- Lower volcanic- and sedimentary-rock unit **(lower VSU)**
- Sedimentary-rock confining unit **(SCU)**
- Lower carbonate-rock aquifer-thrust **(LCA_T1)**
- Lower clastic-rock confining unit-thrust **(LCCU_T1)**
- Upper carbonate-rock aquifer **(UCA)**
- Upper clastic-rock confining unit **(UCCU)**
- Lower carbonate-rock aquifer **(LCA)**
- Lower clastic-rock confining unit **(LCCU)**
- Crystalline-rock confining unit **(XCU)**
- Intrusive-rock confining unit **(ICU)**
- **Nevada Test Site boundary**

Figure E–10. Oblique view of three-dimensional hydrogeologic framework model in which a fence diagram shows the distribution of the hydrogeologic units.



EXPLANATION

Hydrogeologic unit
(Not all units appear on sections)

- Younger alluvial aquifer **(YAA)**
- Younger alluvial confining unit **(YACU)**
- Older alluvial aquifer **(OAA)**
- Older alluvial confining unit **(OACU)**
- Limestone aquifer **(LA)**
- Lava-flow unit **(LFU)**
- Younger volcanic-rock unit **(YVU)**
- Upper volcanic- and sedimentary-rock unit **(upper VSU)**
- Timber Mountain–Thirsty Canyon volcanic-rock aquifer **(TMVA)**
- Paintbrush volcanic-rock aquifer **(PVA)**
- Calico Hills volcanic-rock unit **(CHVU)**
- Wahmonie volcanic-rock unit **(WVU)**
- Crater Flat–Prow Pass aquifer **(CFPPA)**
- Crater Flat–Bullfrog confining unit **(CFBCU)**
- Crater Flat–Tram aquifer **(CFTA)**
- Belted Range unit **(BRU)**
- Older volcanic-rock unit **(OVU)**
- Lower volcanic- and sedimentary-rock unit **(lower VSU)**
- Sedimentary-rock confining unit **(SCU)**
- Lower carbonate-rock aquifer-thrust **(LCA_T1)**
- Lower clastic-rock confining unit-thrust **(LCCU_T1)**
- Upper carbonate-rock aquifer **(UCA)**
- Upper clastic-rock confining unit **(UCCU)**
- Lower carbonate-rock aquifer **(LCA)**
- Lower clastic-rock confining unit **(LCCU)**
- Crystalline-rock confining unit **(XCU)**
- Intrusive-rock confining unit **(ICU)**
- **Nevada Test Site boundary**

Figure E–11. Oblique view of three-dimensional hydrogeologic framework model in which a solid block shows the distribution of the hydrogeologic units.

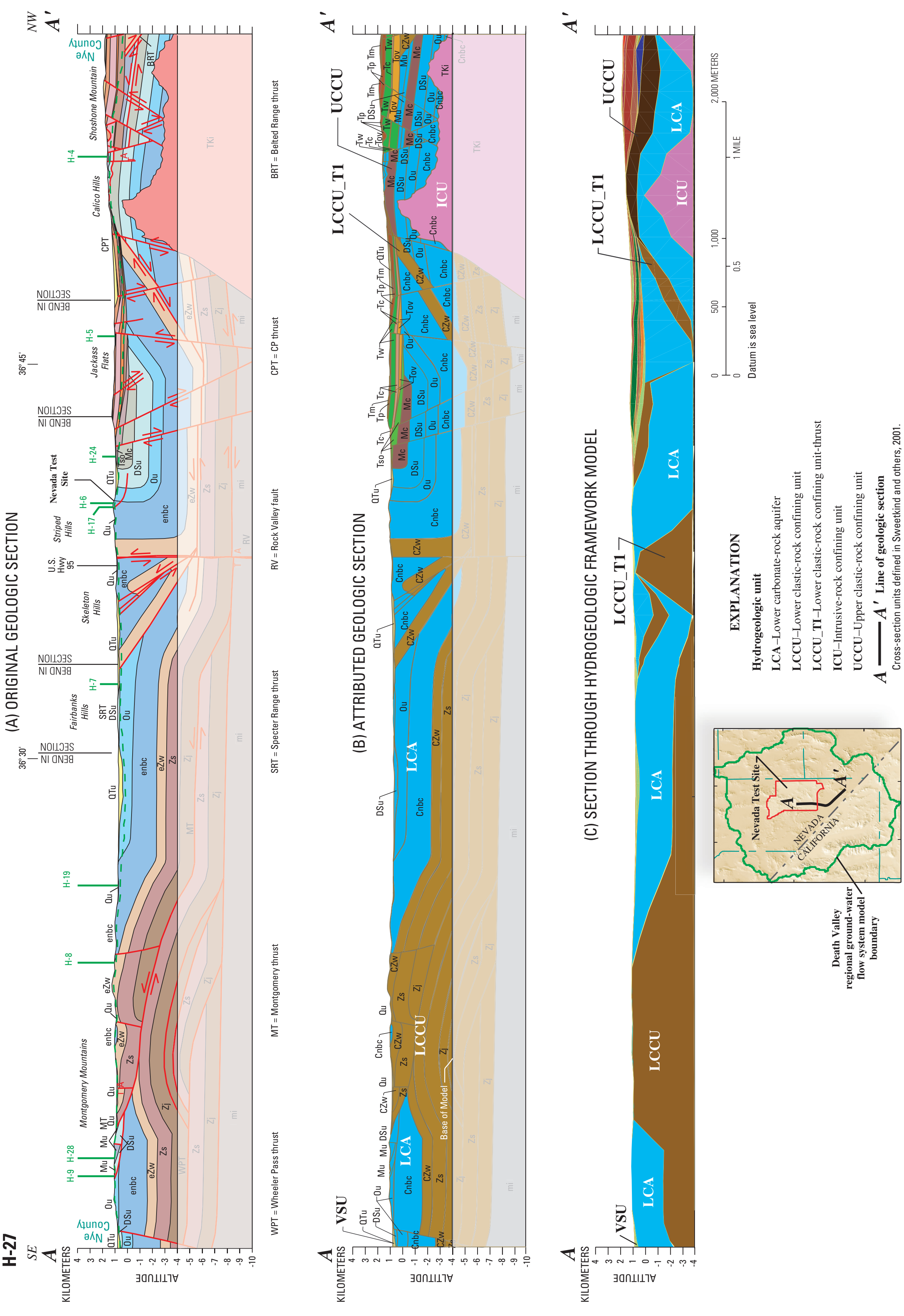


Figure E–12. Examples of (*A*) original input geologic section, (*B*) attributed geologic section, and (*C*) section through hydrogeologic framework model.

of the YACU (fig. E–15*A*) and, to a lesser extent, the OACU (fig. E–16*A*) is less in the HFM than shown in the surface exposure maps because an older HGU in a grid cell is favored when more than one unit is present. As a result, the younger HGUs are often represented as much smaller areas where they do not cover an entire cell. The YACU is defined with a maximum thickness of 25 m (table E–5 and fig. E–15*B*), except in the Amargosa Desert where the limestone aquifer (LA) exists and the YACU is defined to have thicknesses greater than 25 m. In this area, the maximum thickness of the YACU is about 160 m. Generally, the unit thickens along the axes of the deeper structural basins. The OACU is assumed to have a maximum thickness of 100 m (table E–5 and fig. E–16*B*) and only occurs in the northern part of Death Valley and in the area of Shoshone, Calif., and Tecopa, Calif.

Limestone Aquifer (LA)

The limestone aquifer (LA) is limited in areal extent to the Amargosa Desert and is known primarily through drilling records (fig. E–17*A*). The LA is assumed to have a maximum thickness of 10 m (fig. E–17*B* and table E–5), but may be thicker locally. Below the LA is either bedrock or the upper VSU. The LA was modeled as a relatively continuous unit in the Amargosa Desert but actually may be more discontinuous owing to its original lacustrine depositional environment and resulting overrepresentation in the HFM.

Lava-Flow Unit (LFU)

The individual lava flows that make up the lava-flow unit (LFU) are not laterally extensive (fig. E–18*A*) and reach a maximum thickness of about 900 m in the Greenwater Range (fig. E–18*B*). Most of the LFU is above the water table and has a limited influence on ground-water flow in the region. Where they are below the water table, fractures in the LFU can create locally productive aquifers.

Younger Volcanic-Rock Unit (YVU)

Most of the volcanic rocks making up the younger volcanic-rock unit (YVU) are localized within the SWNVF. The YVU is not laterally extensive and is most expansive northeast of Timber Mountain and at Black Mountain (fig. E–19*A*). The thickness of the YVU approaches 300 m (fig. E–19*B*). Most of the unit occurs above the water table and is thought to have limited influence on ground-water flow in the DVRFS model domain. Like the basin-fill aquifers and confining units, the extent of the YVU is less in the HFM than is indicated by the unit outcrop (fig. E–19*A*) because an older HGU in a grid cell is favored when more than one unit is present.

Volcanic- and Sedimentary-Rock Units (VSU)

The volcanic- and sedimentary-rock units (VSU) have been divided into upper and lower parts. In general, these two divisions are lithologically similar but are of different ages. The upper VSU and lower VSU encase the Cenozoic volcanic-rock units of the SWNVF.

The upper VSU is defined to lie above the Cenozoic volcanic rocks (fig. E–20*A*). Below it is either bedrock or lower VSU. Because the units are lithologically similar, in areas where the lower VSU lies directly beneath the upper VSU the contact between the units is arbitrary. The upper VSU has a maximum thickness of about 2,700 m and reaches thicknesses greater than 1,000 m at the northern and southern parts of Death Valley and Cactus Flat (fig. E–20*B*).

The lower VSU lies below the basin-fill HGUs or the upper VSU, and the Cenozoic volcanic rock HGUs (fig. E–21*A*). Below the basin-fill units and upper VSU, the top of the lower VSU is arbitrary. Where the lower VSU is present below the volcanic-rock unit HGUs, it is defined as being 50 m below the top surface of the stratigraphically lowest volcanic-rock HGU defined in the area and fills the space below the volcanic rocks and above the Paleozoic bedrock. In most of the SWNVF and the northern part of the model domain, the lower VSU represents the deeply buried older volcanic-rock units. As a result of this arbitrary definition, this HGU is as thick as about 5,500 m in many areas of the model domain (fig. E–21*B*).

Thirsty Canyon–Timber Mountain Volcanic-Rock Aquifer (TMVA)

The Thirsty Canyon–Timber Mountain volcanic-rock aquifer (TMVA) is extensive and covers most of the SWNVF, reaching into the northern end of the Amargosa Desert (fig. E–22*A*). Thicknesses exceeding 500 m occur at Pahute Mesa and in the vicinity of Timber Mountain (fig. E–22*B*). The TMVA reaches a maximum thickness of about 2,600 m within its source caldera at Timber Mountain.

Paintbrush Volcanic-Rock Aquifer (PVA)

Like the basin-fill units, the distribution of the Paintbrush volcanic-rock aquifer (PVA) in the HFM (fig. E–23*A*) is less than is shown by the borehole data in western Yucca Flat because the older units dominate where the PVA does not cover an entire cell. Thick accumulations of intracaldera PVA are present to the north of Yucca Mountain, where it reaches thicknesses of nearly 2,400 m (fig. E–23*B*); however, the PVA at Yucca Mountain and eastern and central Pahute Mesa is generally above the water table. Conversely, the PVA is below the water table in western Pahute Mesa, east and south of Yucca Mountain, and in Crater Flat.

A

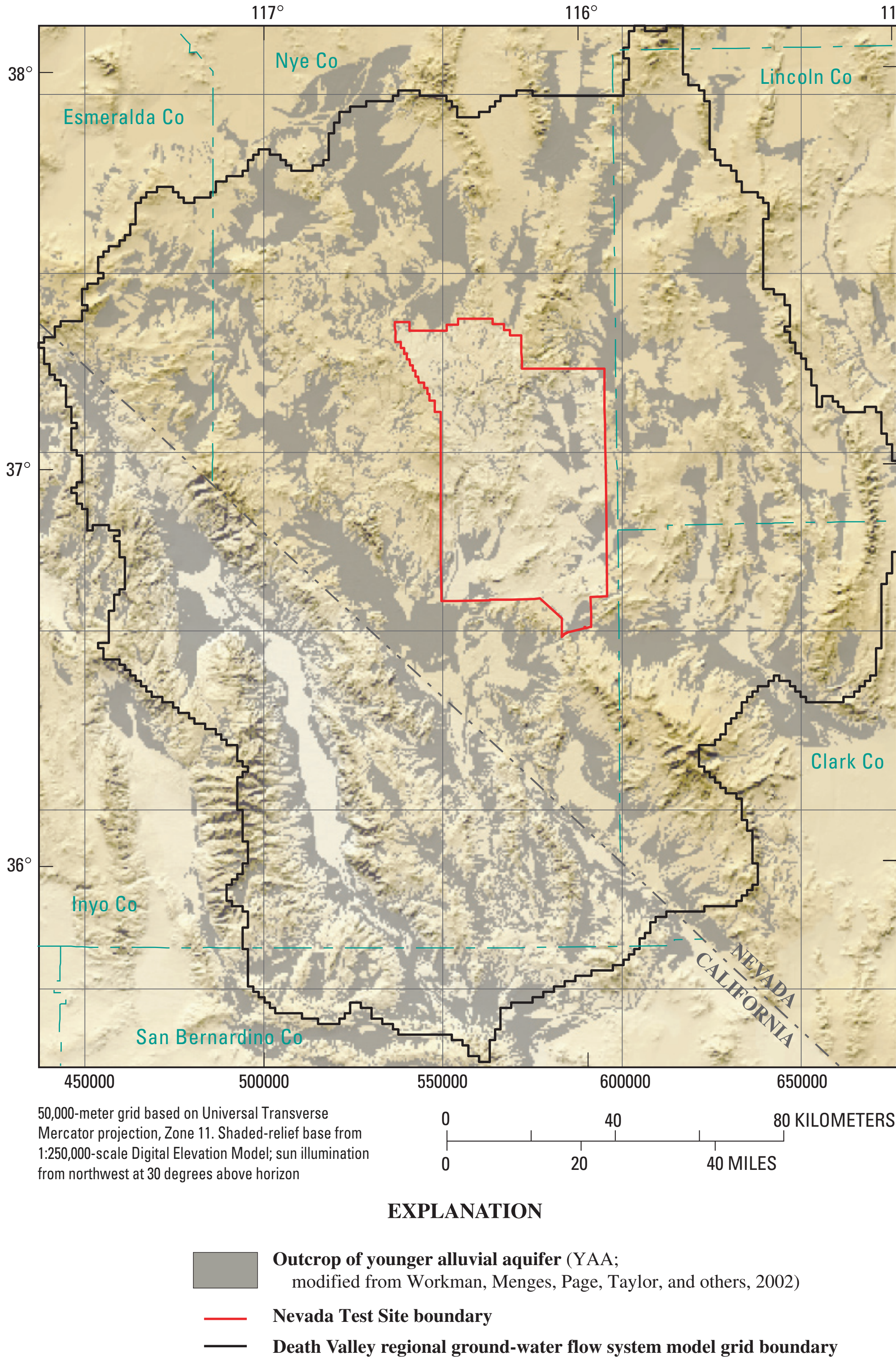


Figure E–13. (*A*) Data sources and (*B*) thickness of younger alluvial aquifer.

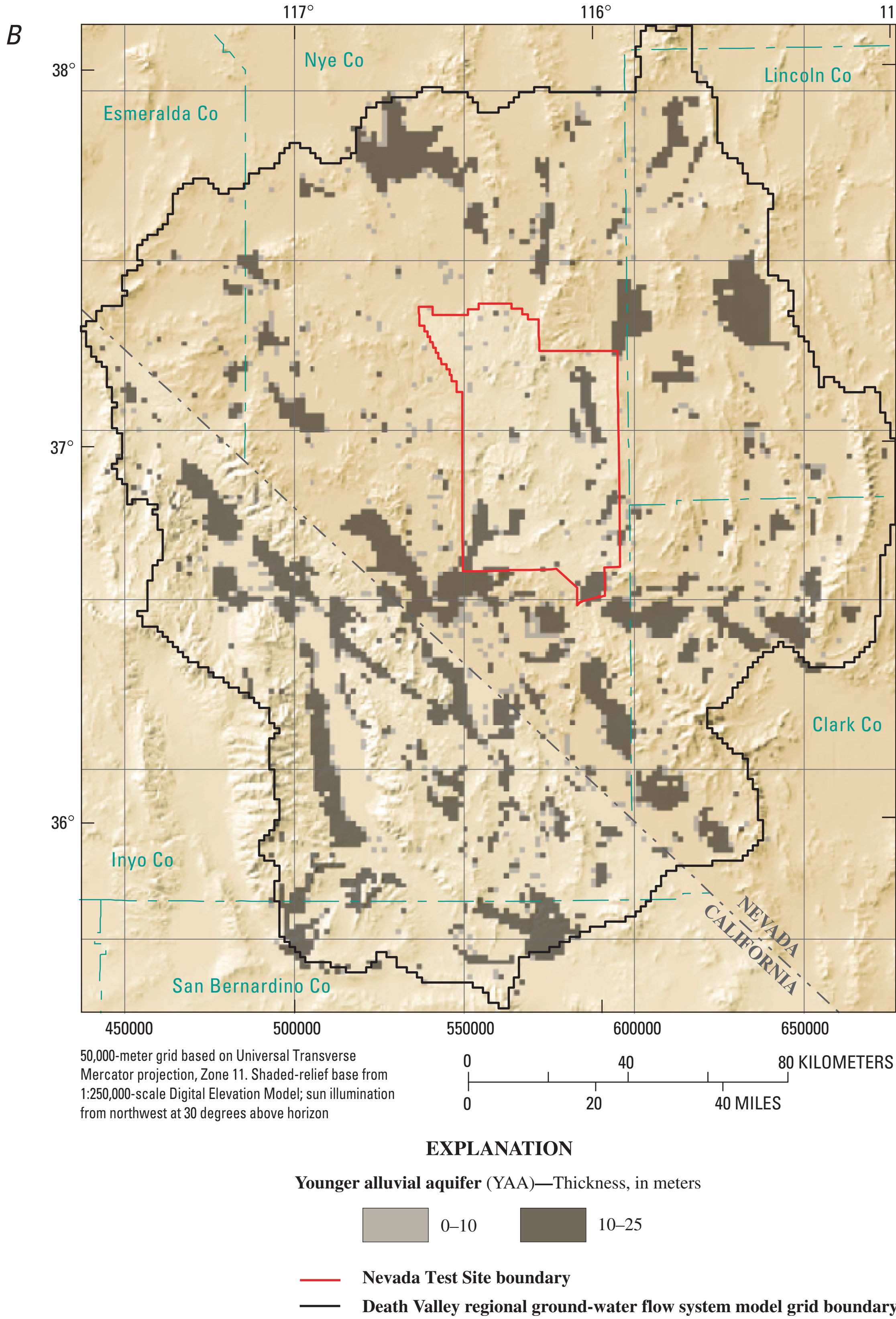


Figure E–13. (*A*) Data sources and (*B*) thickness of younger alluvial aquifer.—Continued

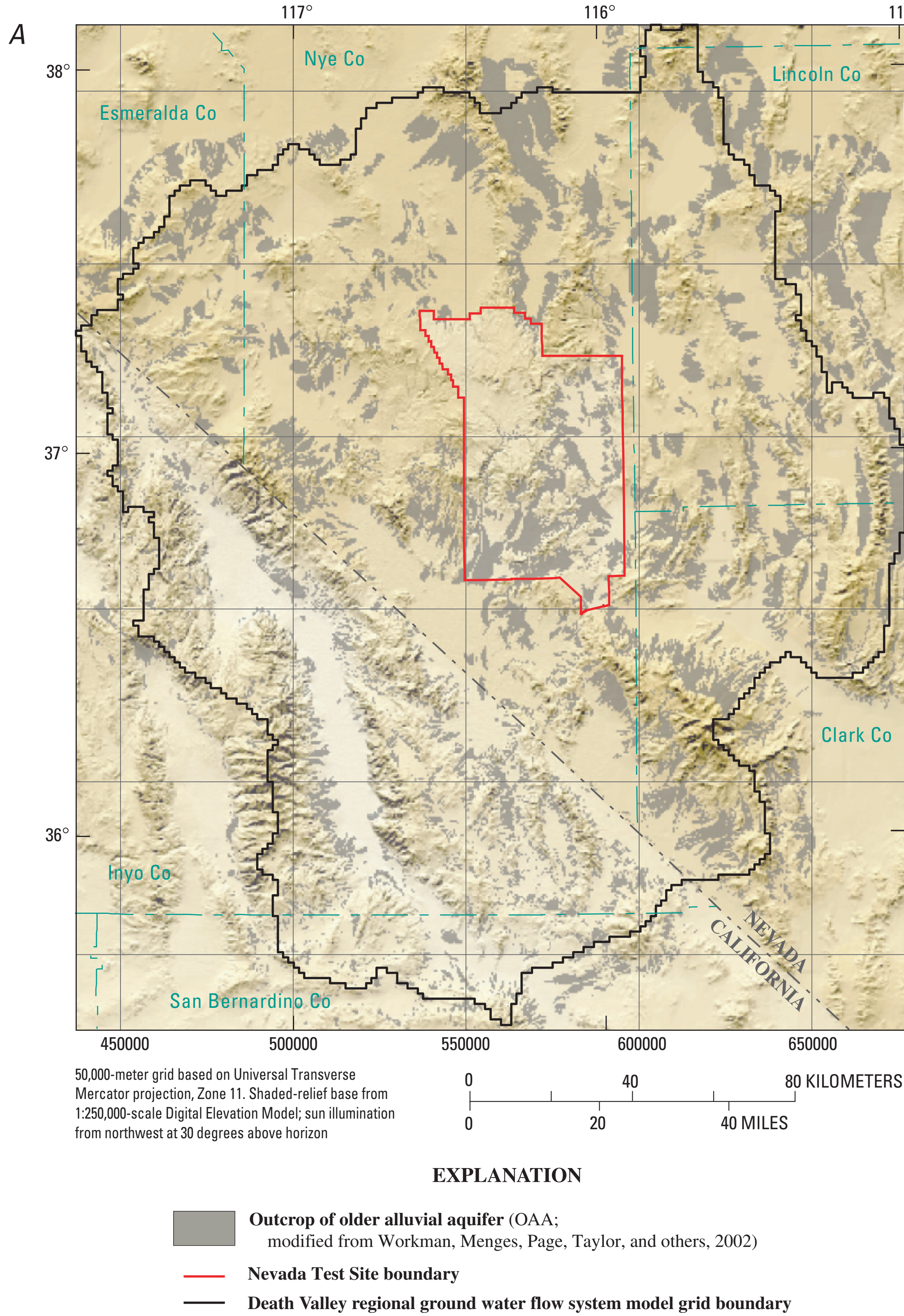


Figure E–14. (*A*) Data sources and (*B*) thickness of older alluvial aquifer.

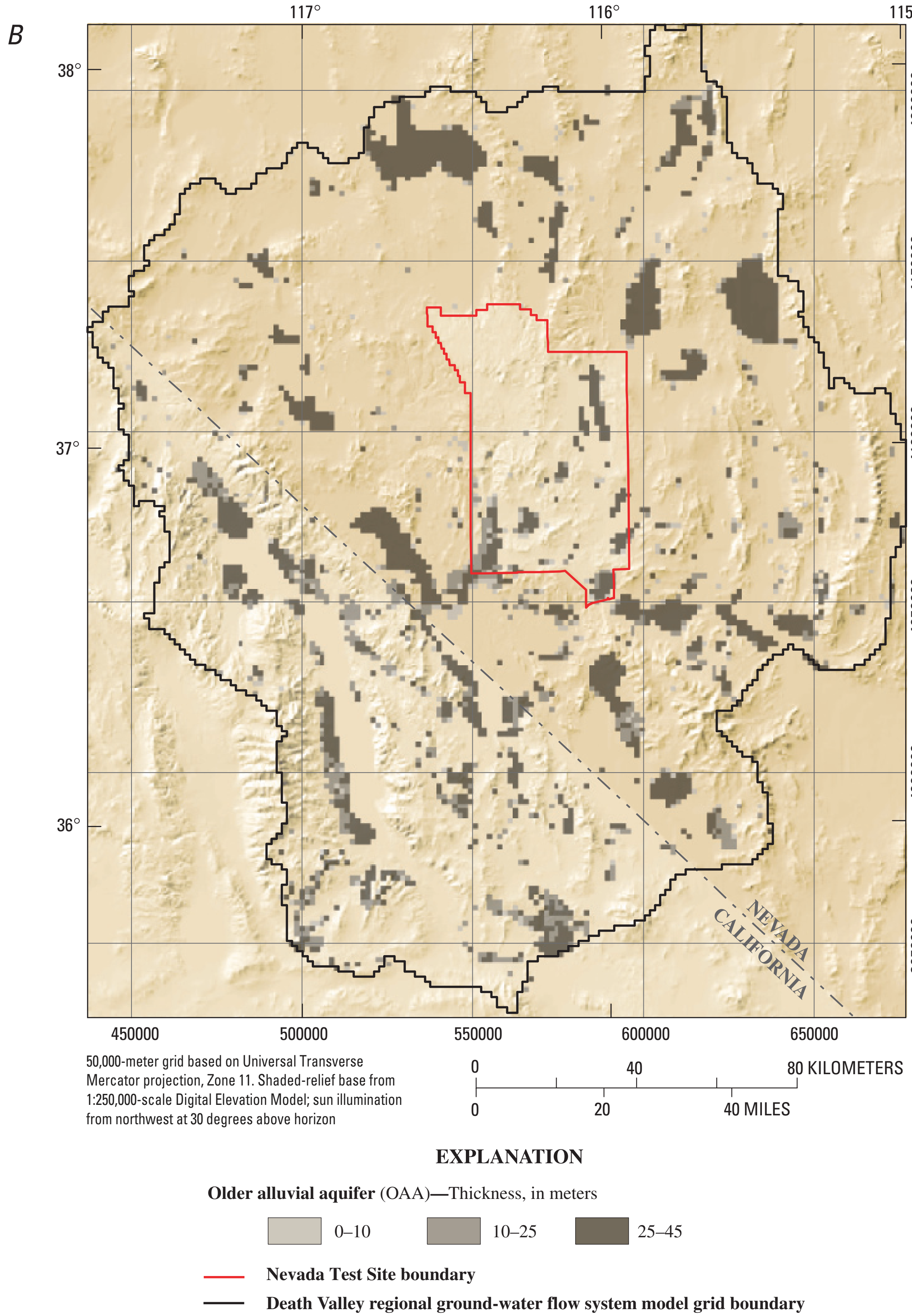


Figure E–14. (*A*) Data sources and (*B*) thickness of older alluvial aquifer.—Continued

Figure E–15. (*A*) Data sources and (*B*) thickness of younger alluvial confining unit.

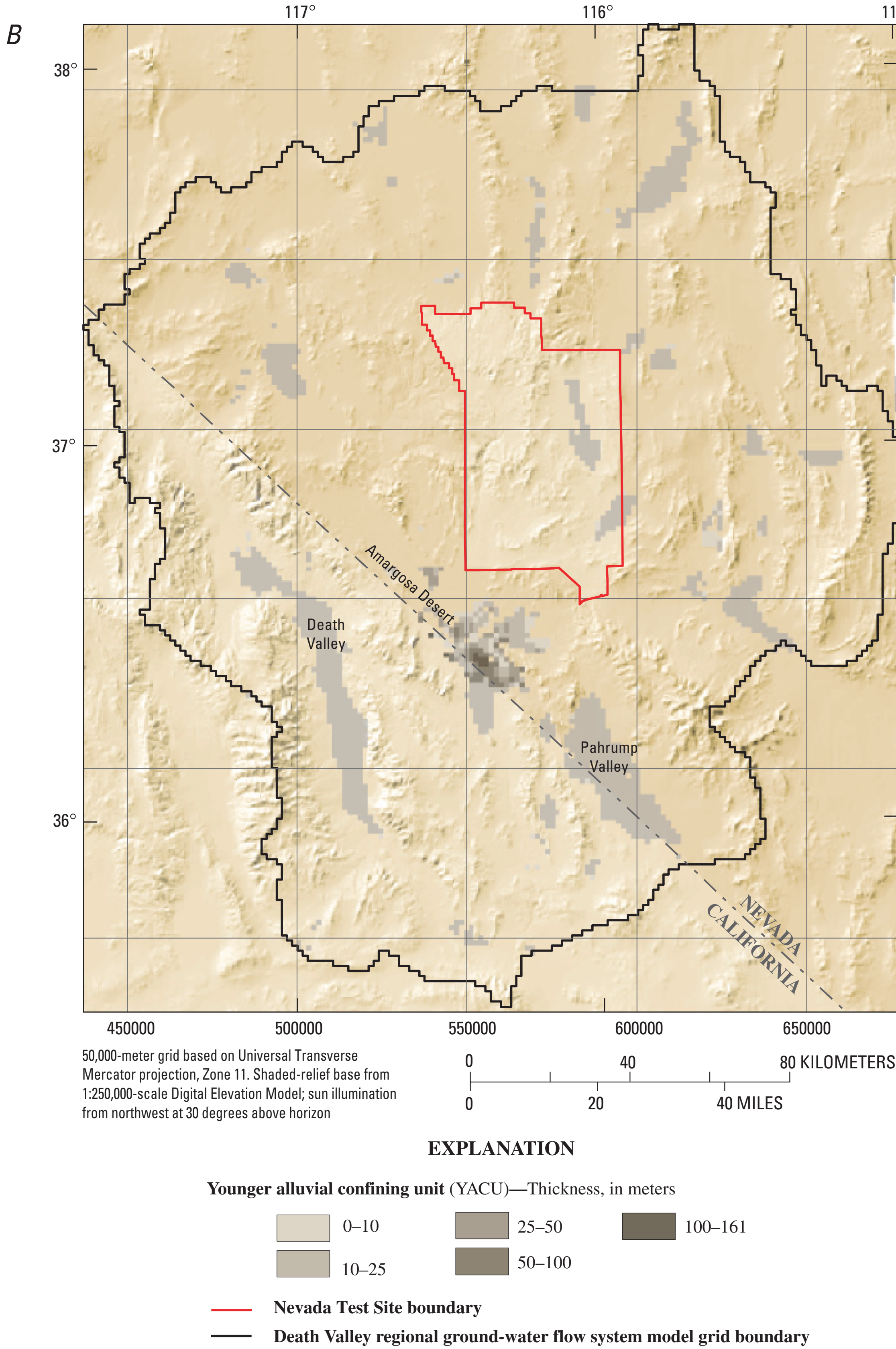


Figure E–15. (*A*) Data sources and (*B*) thickness of younger alluvial confining unit.—Continued

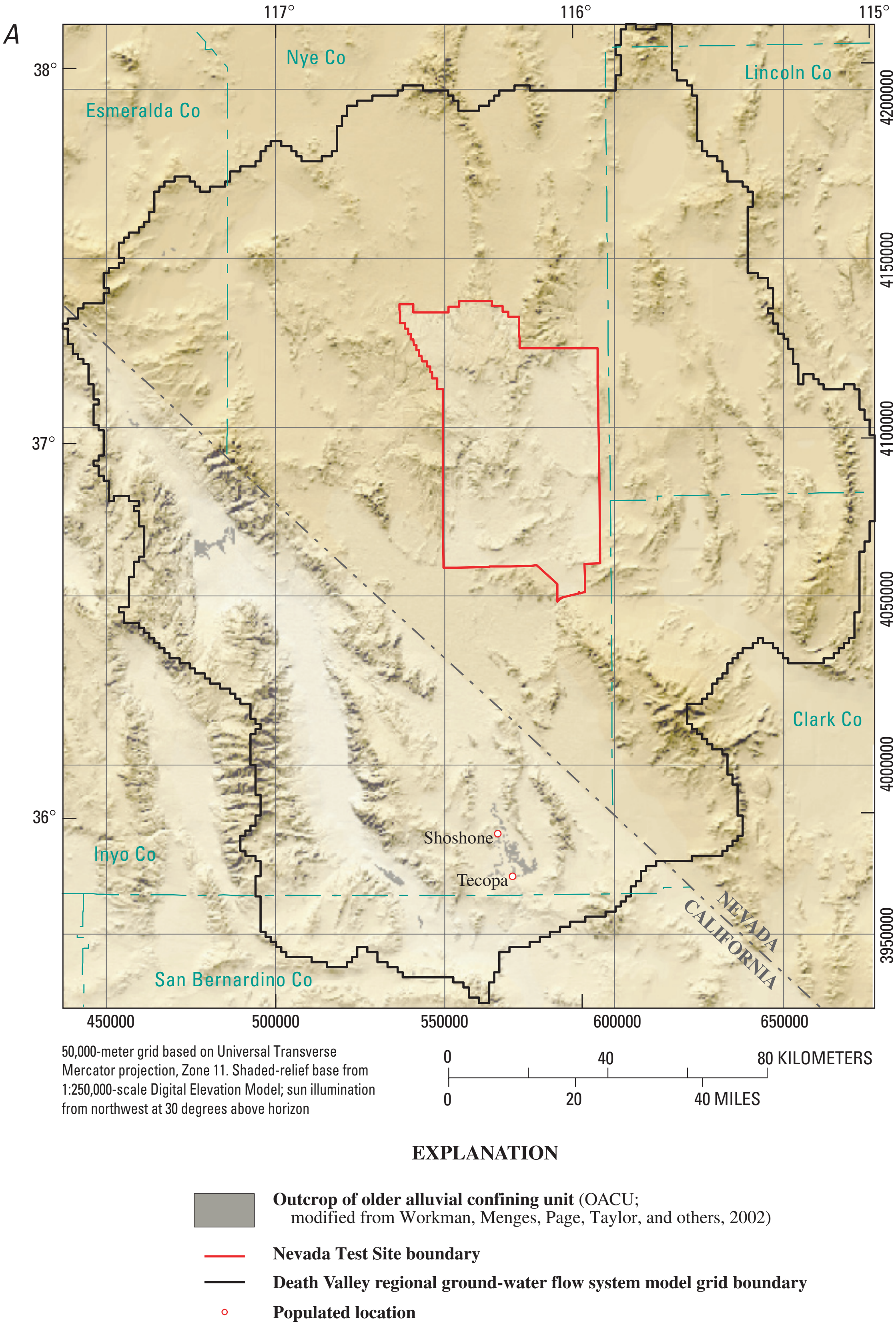


Figure E–16. (*A*) Data sources and (*B*) thickness of older alluvial confining unit.

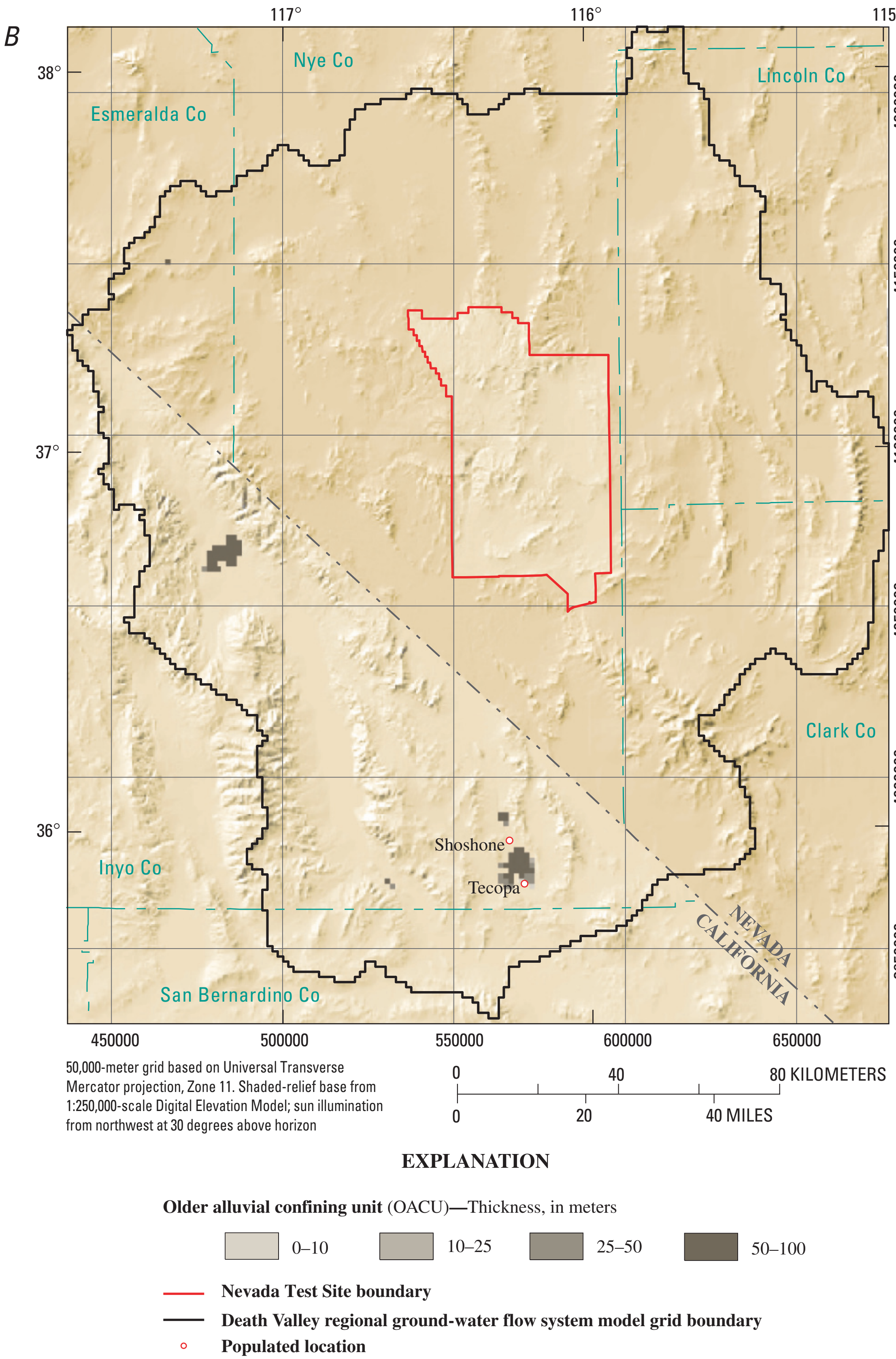


Figure E–16. (*A*) Data sources and (*B*) thickness of older alluvial confining unit.—Continued

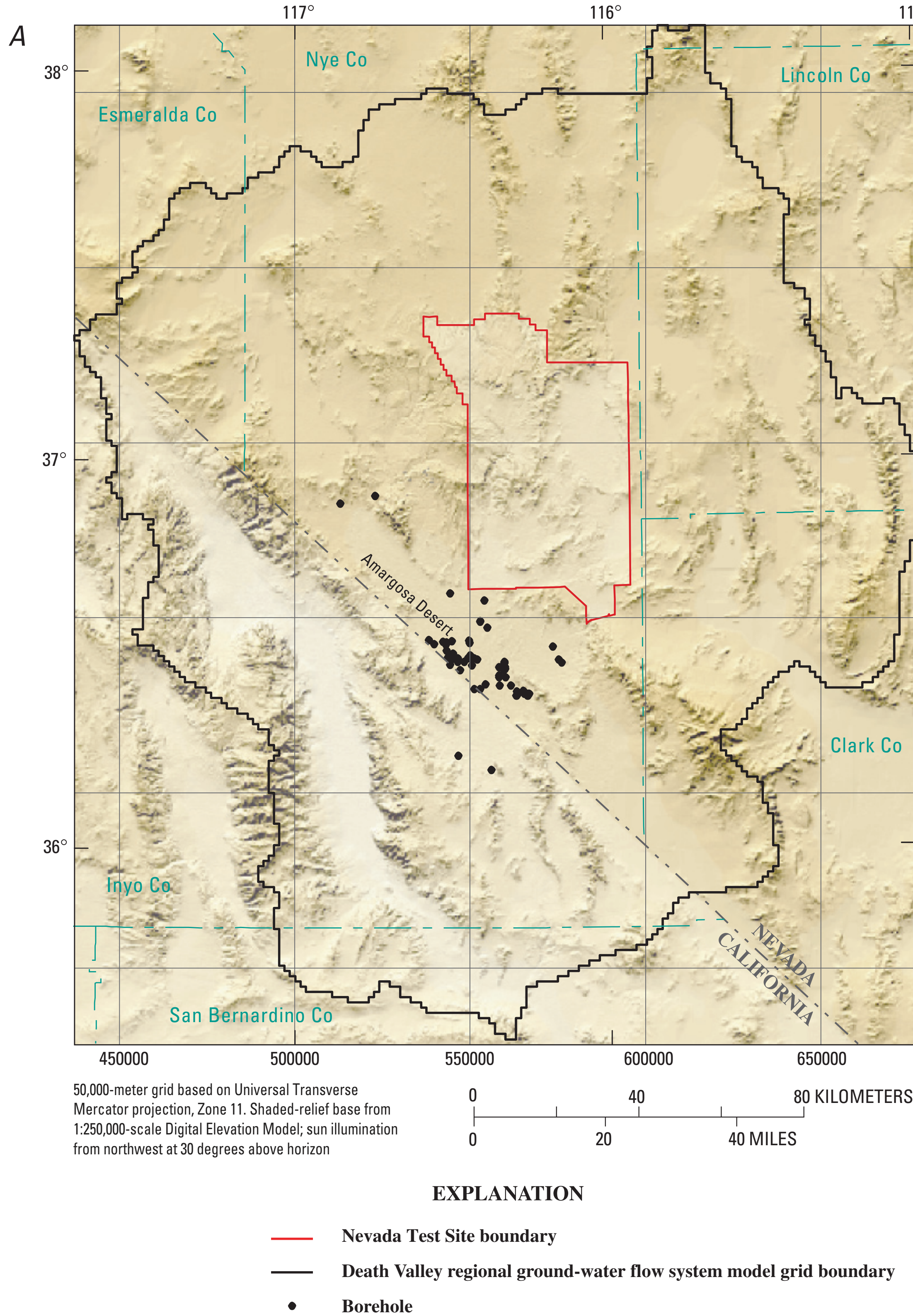
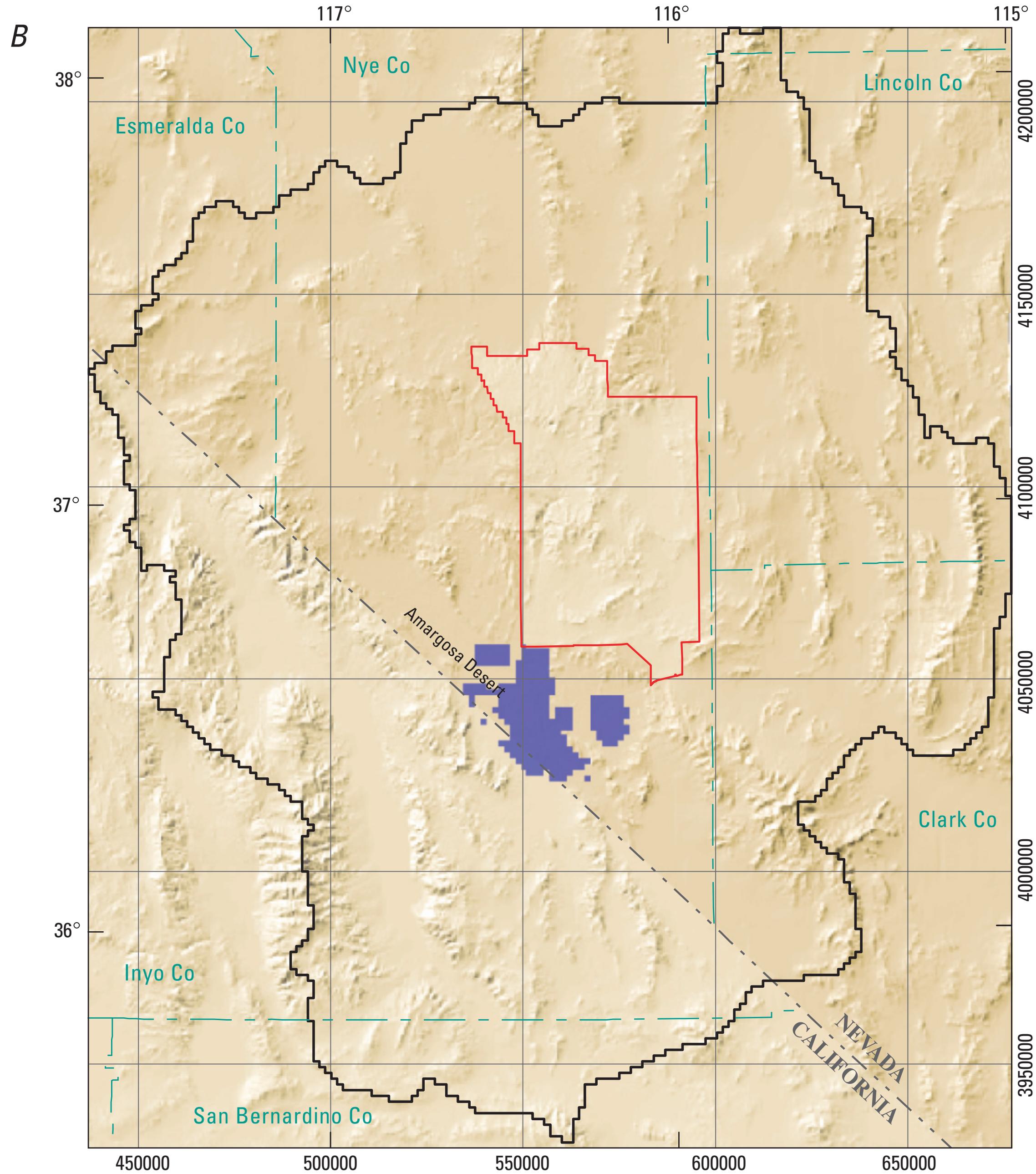


Figure E–17. (*A*) Data sources and (*B*) thickness of limestone aquifer.

B



50,000-meter grid based on Universal Transverse Mercator projection, Zone 11. Shaded-relief base from 1:250,000-scale Digital Elevation Model; sun illumination from northwest at 30 degrees above horizon

0 40 80 KILOMETERS
0 20 40 MILES

EXPLANATION

Limestone aquifer (LA)—Thickness, in meters

0–10

Nevada Test Site boundary

Death Valley regional ground-water flow system model grid boundary

Figure E–17. (*A*) Data sources and (*B*) thickness of limestone aquifer.—Continued

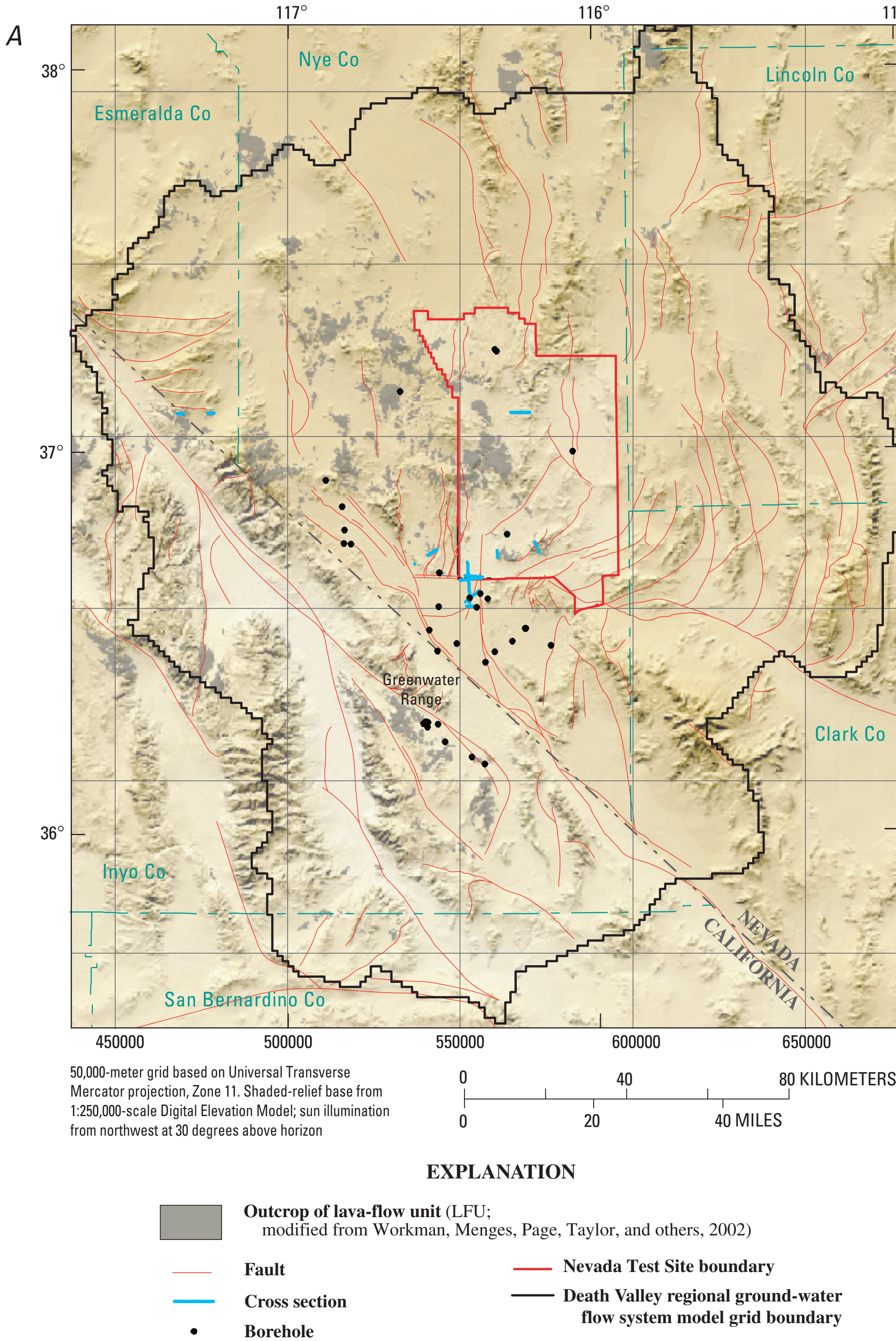
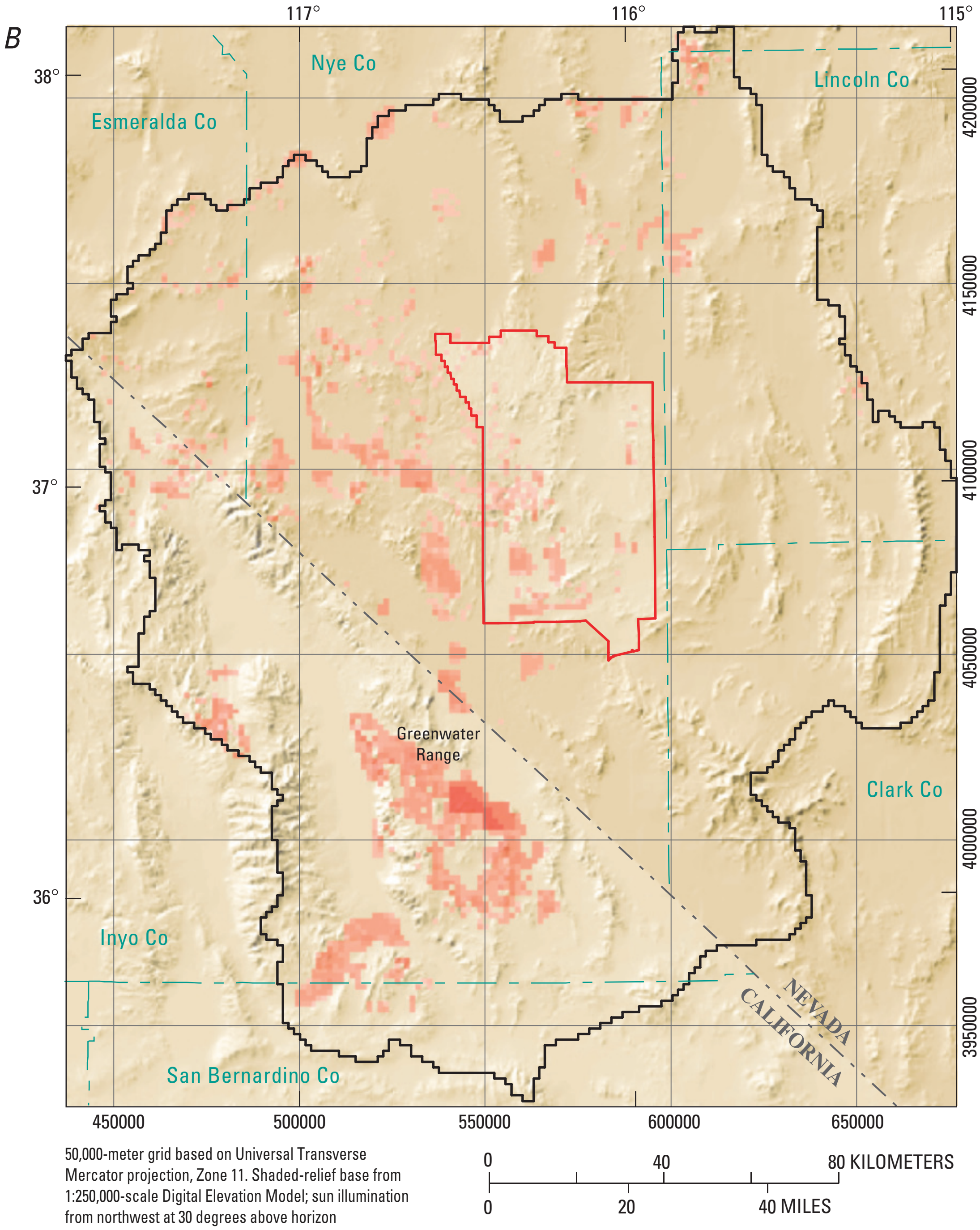


Figure E–18. (*A*) Data sources and (*B*) thickness of lava-flow unit.



EXPLANATION

Lava-flow unit (LFU)—Thickness, in meters

- 0–10
- 10–25
- 25–50
- 50–100
- 100–250
- 250–500
- 500–923

Nevada Test Site boundary

Death Valley regional ground-water flow system model grid boundary

Figure E–18. (*A*) Data sources and (*B*) thickness of lava-flow unit.—Continued

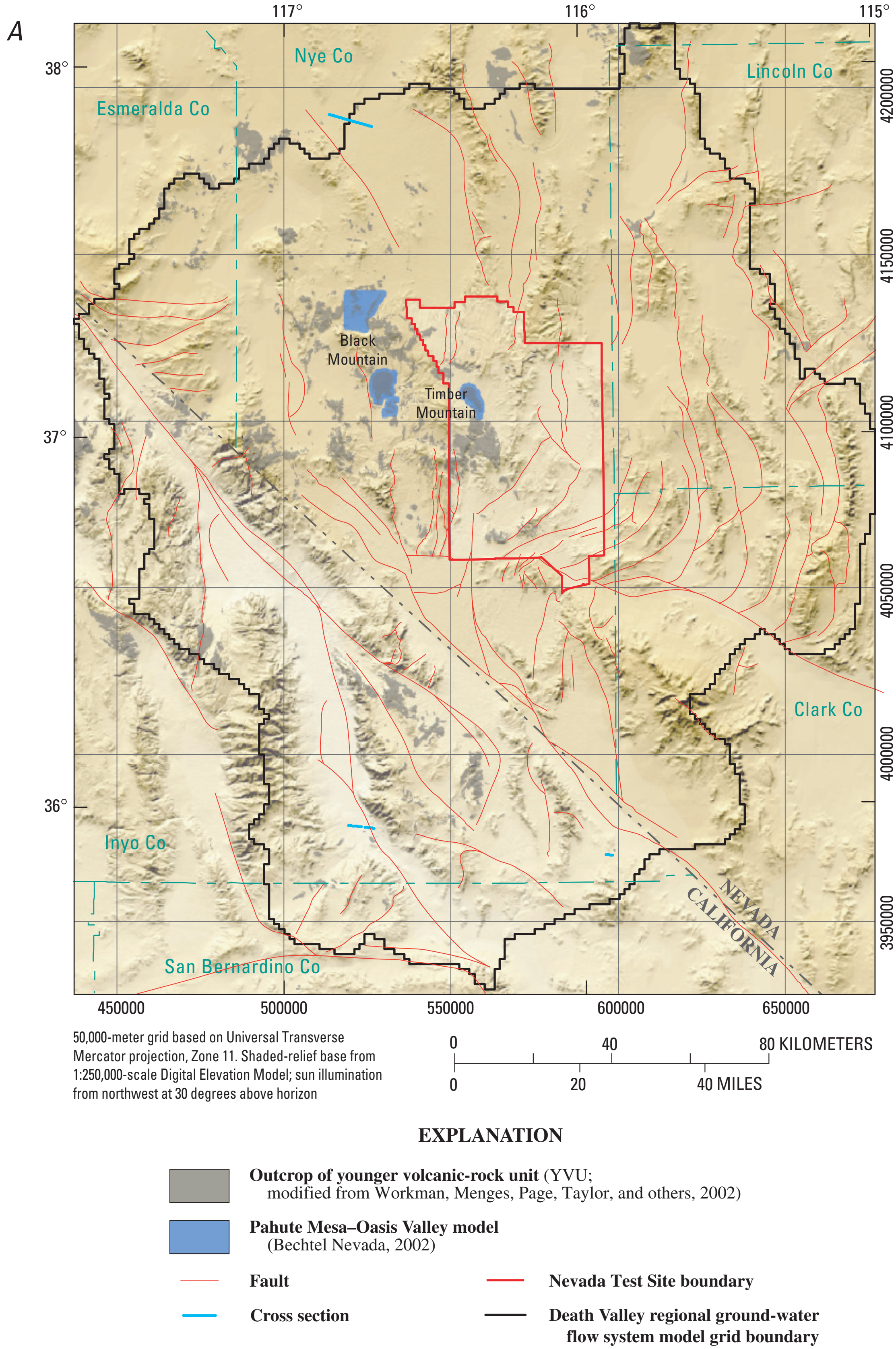


Figure E–19. (*A*) Data sources and (*B*) thickness of younger volcanic-rock unit.

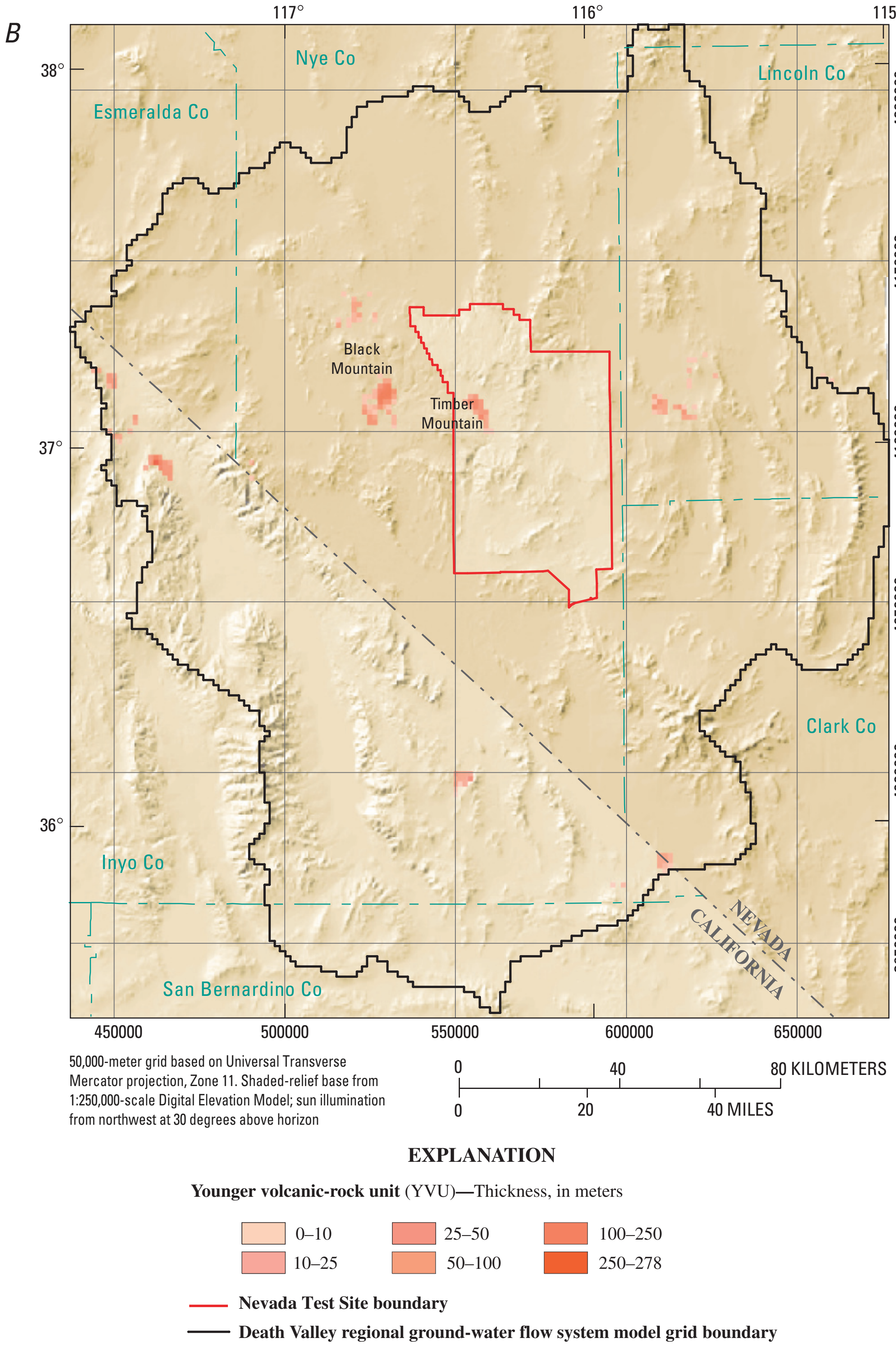


Figure E–19. (*A*) Data sources and (*B*) thickness of younger volcanic-rock unit.—Continued

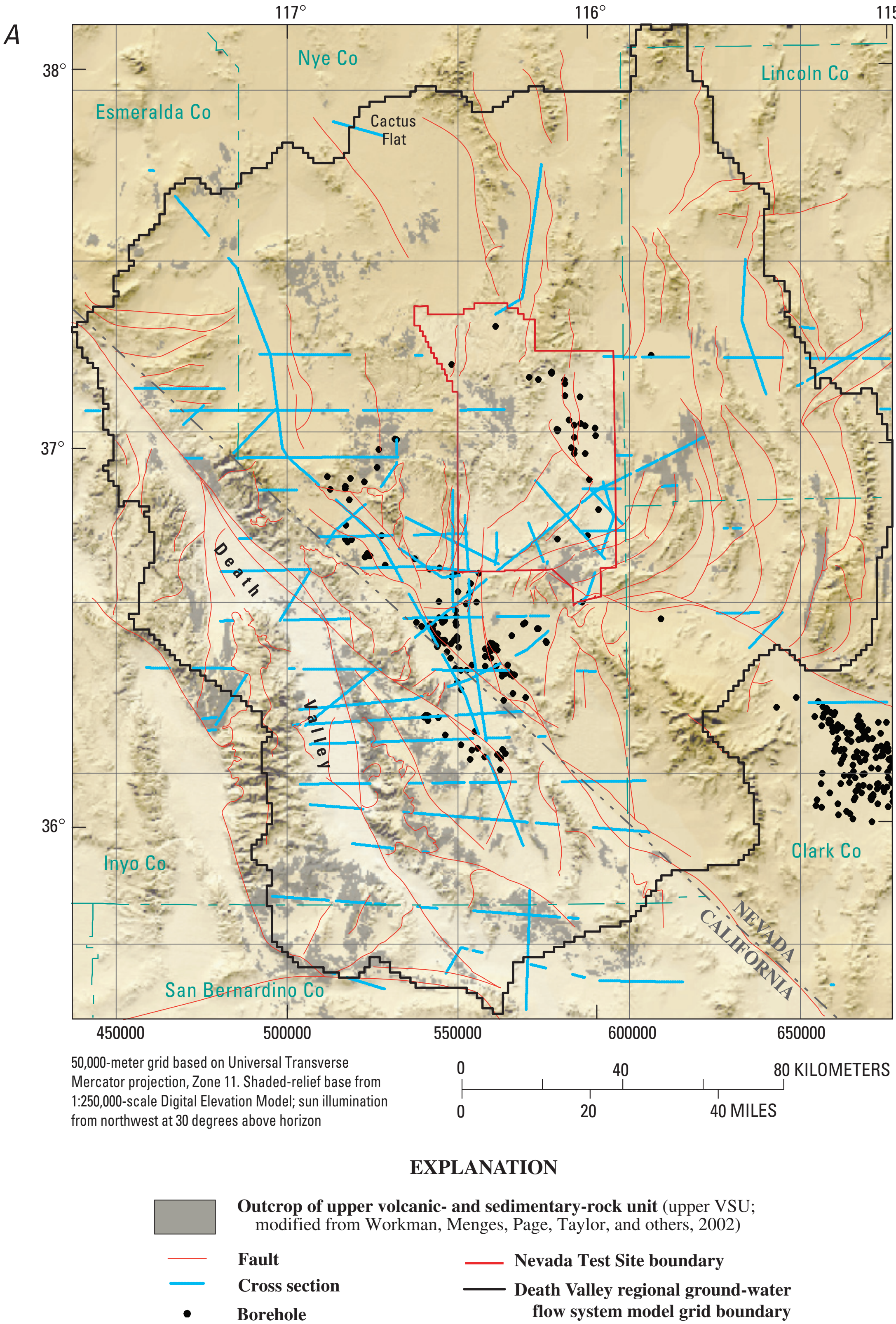


Figure E–20. (*A*) Data sources and (*B*) thickness of upper volcanic- and sedimentary-rock unit.

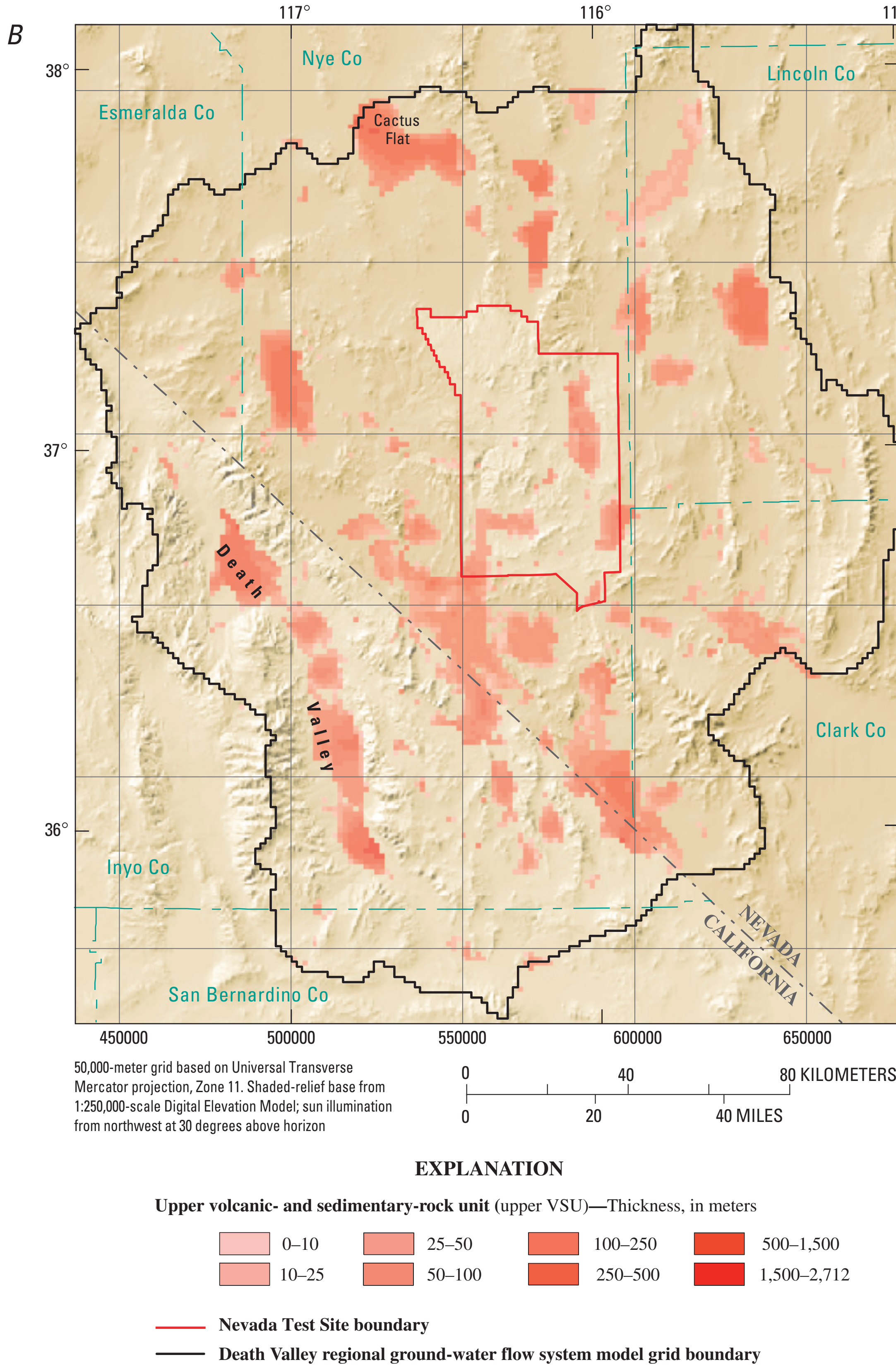
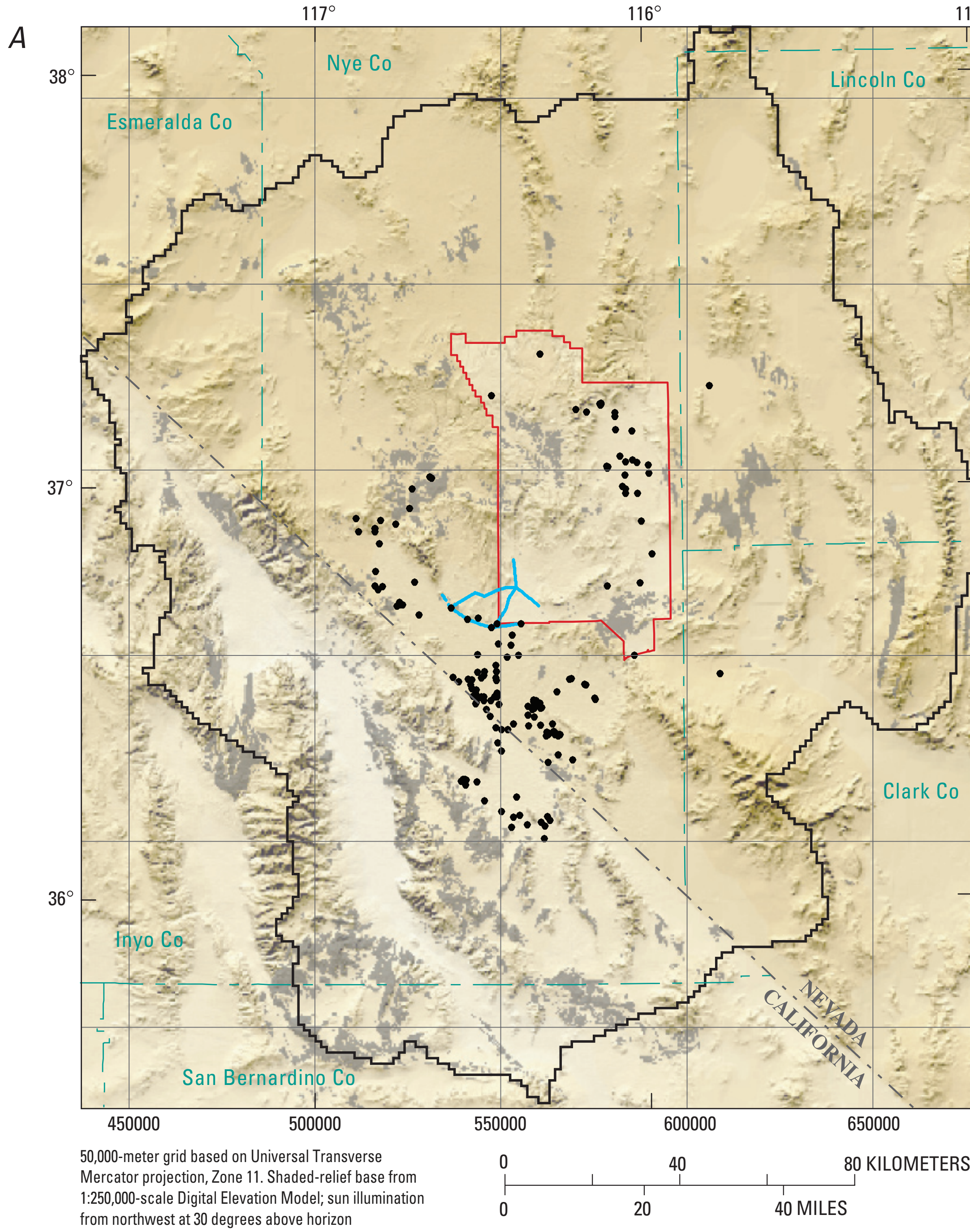


Figure E–20. (*A*) Data sources and (*B*) thickness of upper volcanic- and sedimentary-rock unit.—Continued



EXPLANATION

Outcrop of lower volcanic- and sedimentary-rock unit (lower VSU; Workman, Menges, Page, Taylor, and others, 2002)

Cross section

Borehole

Nevada Test Site boundary

Death Valley regional ground-water flow system model grid boundary

Figure E–21. (*A*) Data sources and (*B*) thickness of lower volcanic- and sedimentary-rock unit.

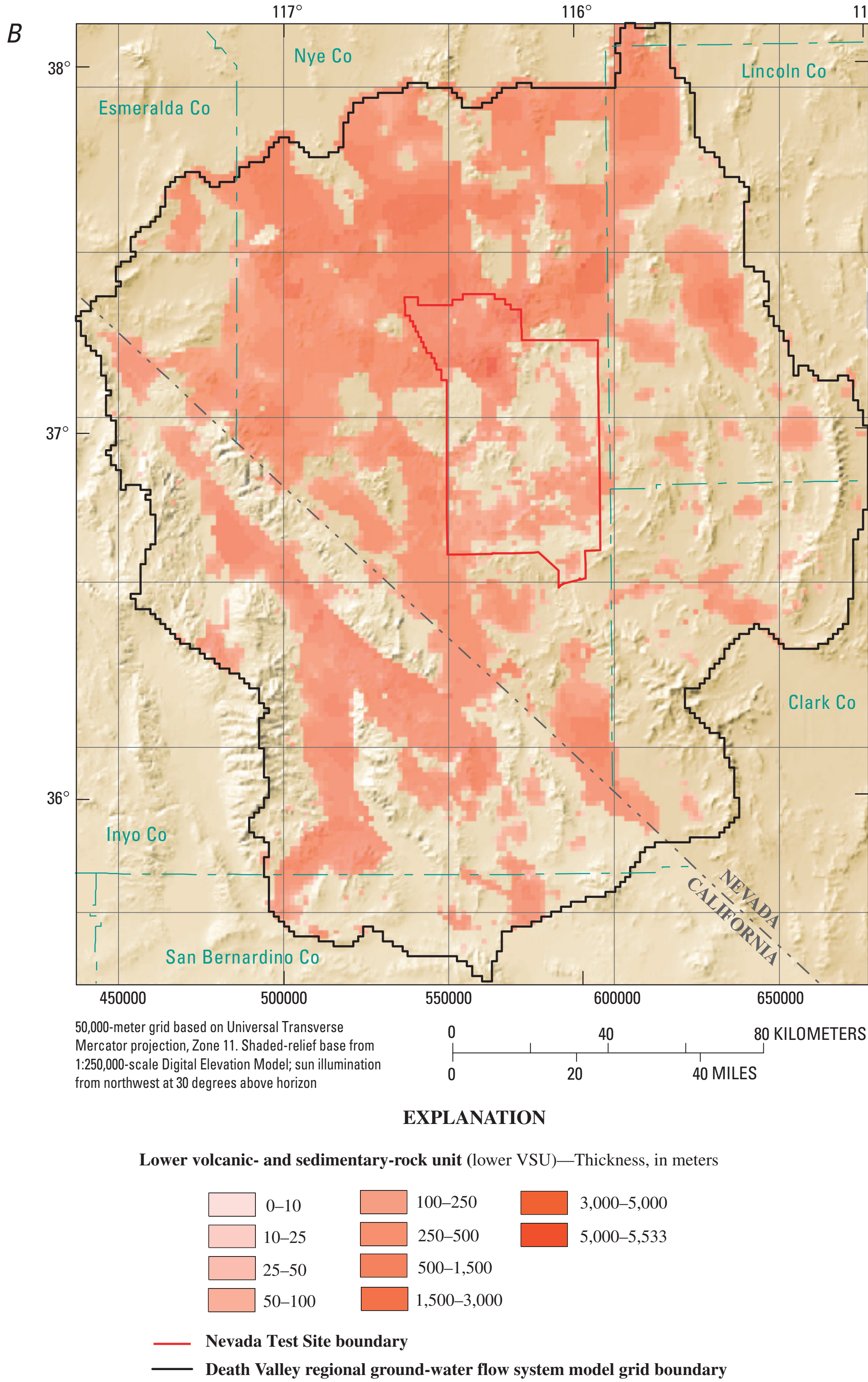
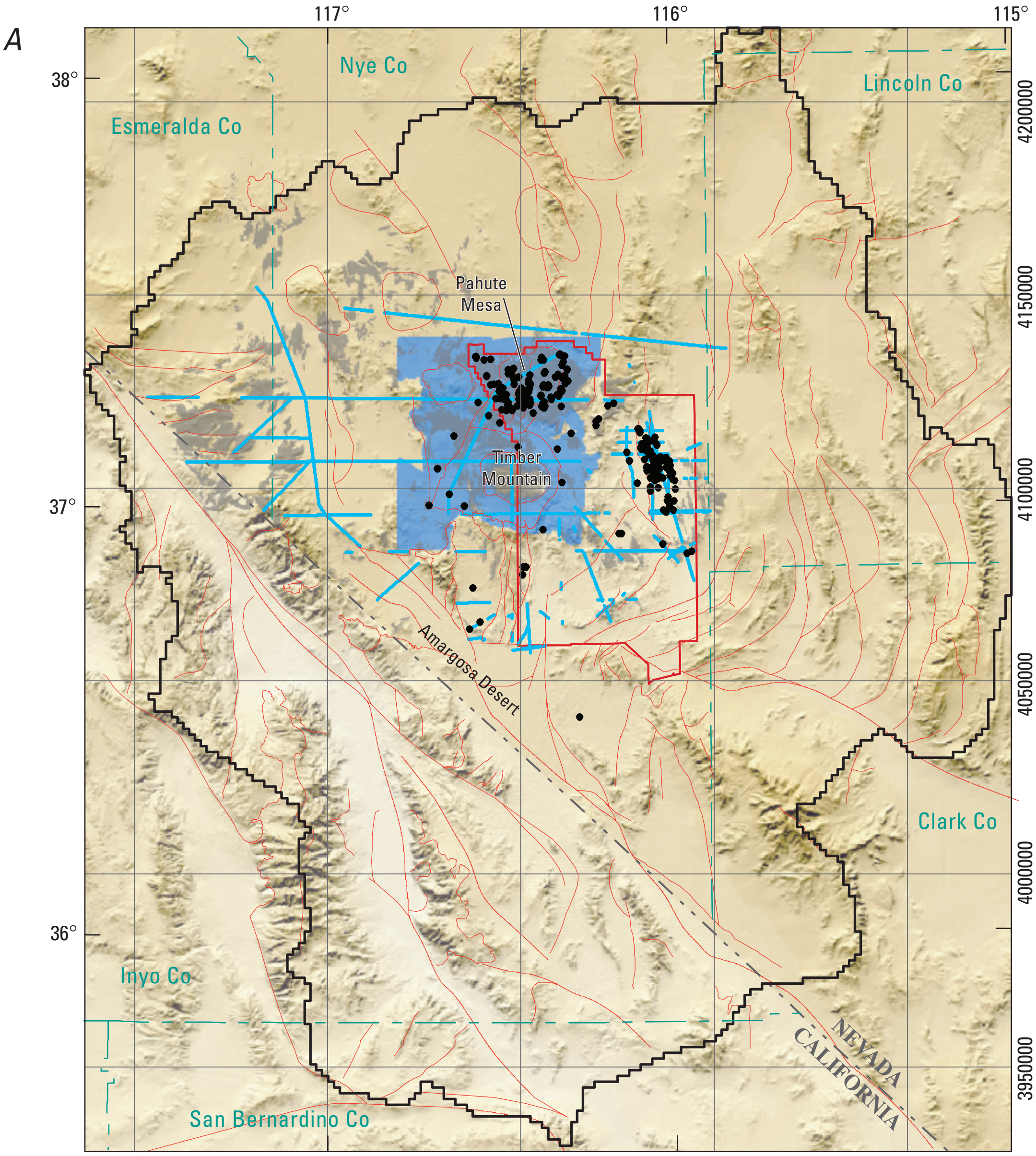


Figure E–21. (*A*) Data sources and (*B*) thickness of lower volcanic- and sedimentary-rock unit.
—Continued



50,000-meter grid based on Universal Transverse Mercator projection, Zone 11. Shaded-relief base from 1:250,000-scale Digital Elevation Model; sun illumination from northwest at 30 degrees above horizon

EXPLANATION

Outcrop of Timber Mountain–Thirsty Canyon volcanic-rock aquifer (TMVA; modified from Workman, Menges, Page, Taylor, and others, 2002)

Pahute Mesa–Oasis Valley model (Bechtel Nevada, 2002)

Fault

Cross section

Borehole

Nevada Test Site boundary

Death Valley regional ground-water flow system model grid boundary

Figure E–22. (*A*) Data sources and (*B*) thickness of Thirsty Canyon–Timber Mountain volcanic-rock aquifer.

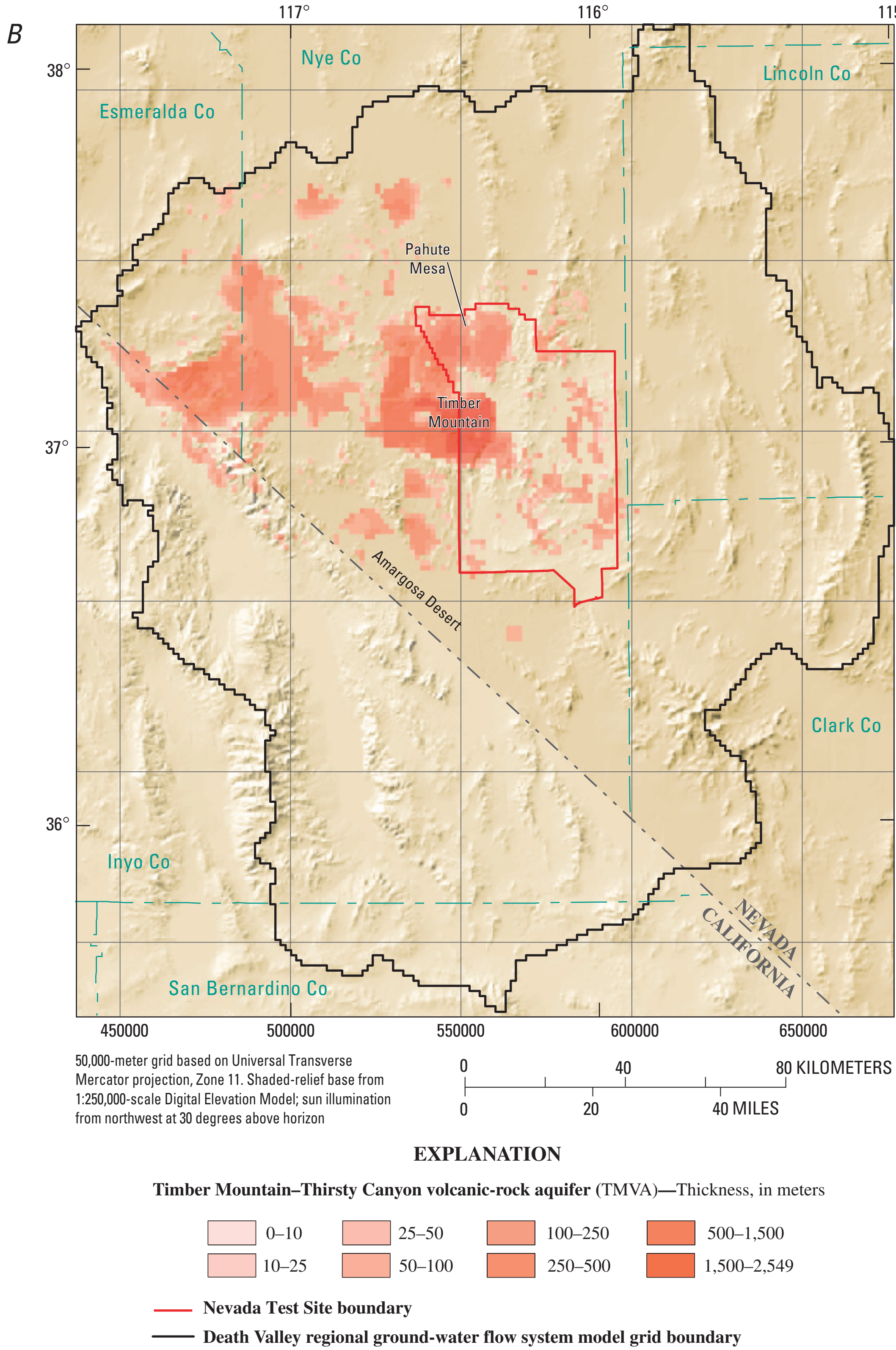
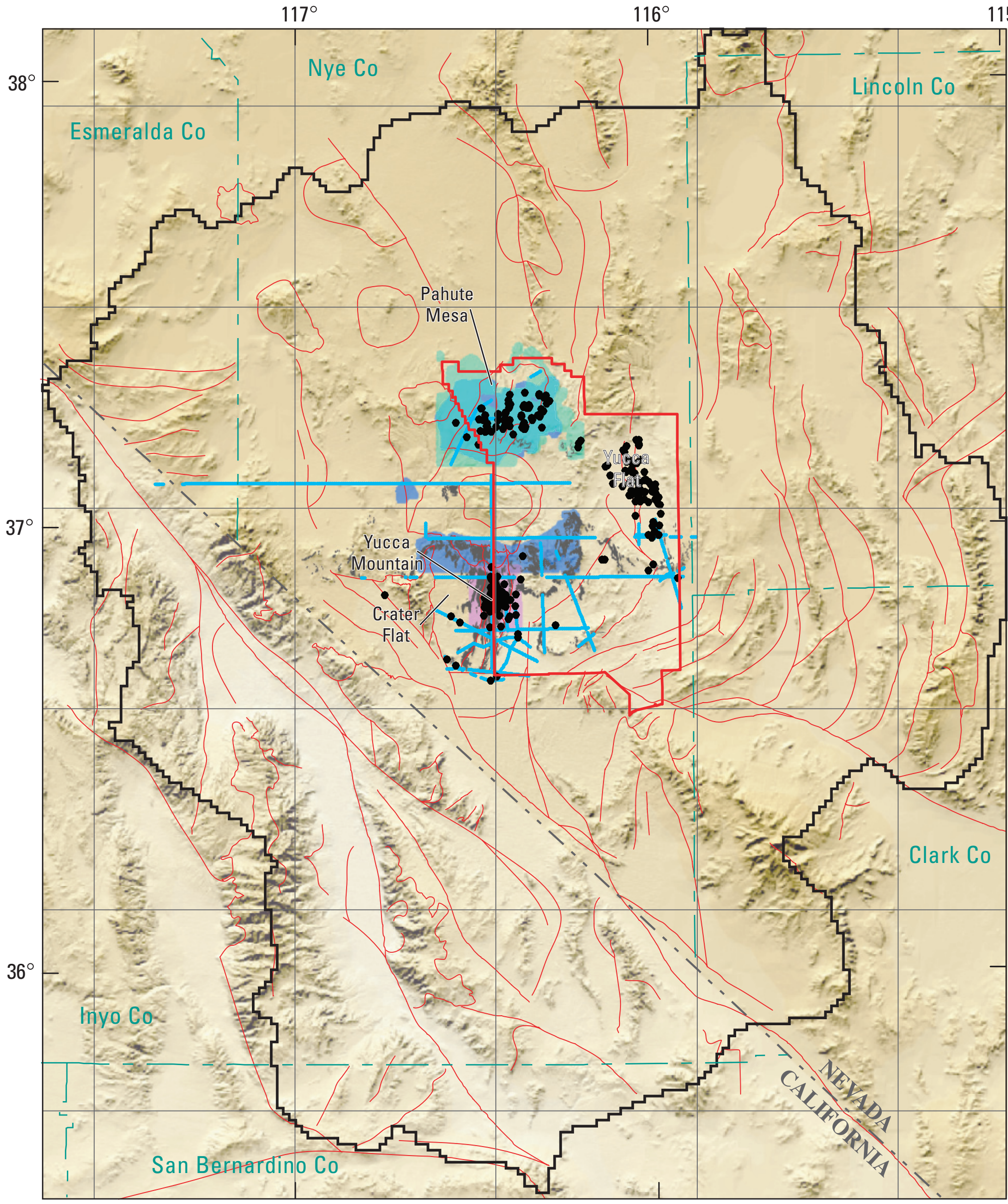


Figure E–22. (*A*) Data sources and (*B*) thickness of Thirsty Canyon–Timber Mountain volcanic-rock aquifer.—Continued

A



50,000-meter grid based on Universal Transverse Mercator projection, Zone 11. Shaded-relief base from 1:250,000-scale Digital Elevation Model; sun illumination from northwest at 30 degrees above horizon

0 40 80 KILOMETERS
0 20 40 MILES

EXPLANATION

Outcrop of Paintbrush volcanic-rock aquifer (PVA; modified from Workman, Menges, Page, Taylor, and others, 2002)

Pahute Mesa–Oasis Valley model (Bechtel Nevada, 2002)

Yucca Mountain Project model (Bechtel SAIC Company, 2002)

Silent Canyon Caldera complex model (McKee and others, 2001)

Fault

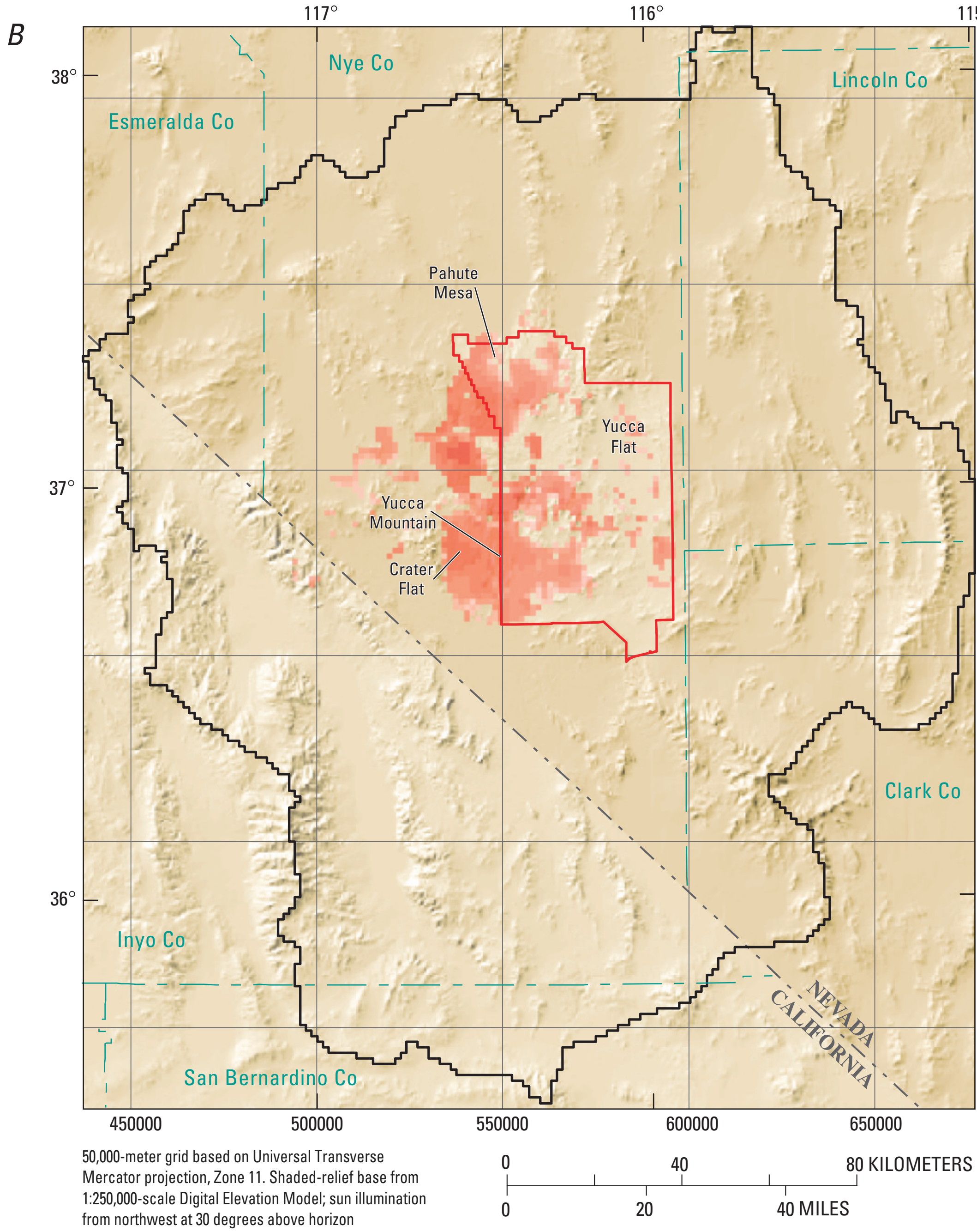
Cross section

Borehole

Nevada Test Site boundary

Death Valley regional ground-water flow system model grid boundary

Figure E–23. (*A*) Data sources and (*B*) thickness of Paintbrush volcanic-rock aquifer.



EXPLANATION

Paintbrush volcanic-rock aquifer (PVA)—Thickness, in meters

- 0–10
- 10–25
- 25–50
- 50–100
- 100–250
- 250–500
- 500–1,500
- 1,500–2,386

Nevada Test Site boundary

Death Valley regional ground-water flow system model grid boundary

Figure E–23. (*A*) Data sources and (*B*) thickness of Paintbrush volcanic-rock aquifer.—Continued

Calico Hills Volcanic-Rock Unit (CHVU)

The Calico Hills volcanic-rock unit (CHVU) is exposed at the surface in the Calico Hills, Fortymile Canyon, and Paintbrush Canyon (fig. E–24*A*), where thicknesses exceed 500 m (fig. E–24*B*). Thicknesses of the unit reach about 1,500 m in the caldera moat just west of Timber Mountain.

Wahmonie Volcanic-Rock Unit (WVU)

Regionally, the Wahmonie volcanic-rock unit (WVU) extends east to Yucca Flat, north to Rainier Mesa, and southwest to Little Skull Mountain, Busted Butte, and southern Yucca Mountain (fig. E–25*A*). In general, the unit lies south and east of the CHVU. The WVU reaches a maximum thickness of about 1,100 m southeast of the Calico Hills (fig. E–25*B*).

Crater Flat–Prow Pass Aquifer (CFPPA)

The Crater Flat–Prow Pass aquifer (CFPPA) thins westward into Crater Flat but extends southward to its southernmost exposures at the southern end of Yucca Mountain (fig. E–26*A*), where it has a thickness approaching 340 m in the HFM (fig. E–26*B*). The aquifer is thickest beneath Pahute Mesa, where it reaches almost 1,400 m.

Crater Flat–Bullfrog Confining Unit (CFBCU)

The Crater Flat–Bullfrog confining unit (CFBCU) is widely distributed south, southwest, southeast, and north of the Timber Mountain caldera complex (TMCC) (fig. E–27*A*) (Carr and others, 1986). The CFBCU has a maximum simulated thickness of about 1,000 m (fig. E–27*B*). Although the CFBCU is present directly south of Little Skull Mountain, it is not represented there in the HFM because of the relatively coarse discretization of the HFM.

Crater Flat–Tram Aquifer (CFTA)

The Crater Flat–Tram aquifer (CFTA) is present in the area of Yucca Mountain (fig. E–28*A*). Although the CFTA is present along the south side of Little Skull Mountain and along the flank of Shoshone Mountain (Carr and others, 1986), it is not represented there in the HFM because of the relatively coarse discretization of the HFM. The CFTA reaches its greatest modeled thickness of more than 1,600 m to the north of Yucca Mountain (fig. E–28*B*).

Belted Range Unit (BRU)

The Belted Range unit (BRU) is present beneath and extends outward from Pahute Mesa (fig. E–29*A*). The BRU thickens toward the eastern margin of the SCCC, where it reaches a maximum thickness of about 1,700 m (fig. E–29*B*). The BRU is not present in the southern parts of the SWNVF or beneath Yucca Mountain.

Older Volcanic-Rock Unit (OVU)

The older volcanic-rock unit (OVU) is present in much of the northern half of the model domain (fig. E–30*A*). In the HFM, the OVU has a maximum thickness of more than 2,800 m near Timber Mountain (fig. E–30*B*) and elsewhere, the OVU has extensive areas of thicknesses exceeding 500 m.

Sedimentary-Rock Confining Unit (SCU)

The sedimentary-rock confining unit (SCU) outcrops in the Spring Mountains and to the east outside the DVRFS model domain, in the lower plate of the Keystone thrust fault (fig. E–31*A*). The SCU also is present in the northern part of the model domain. The SCU has a maximum thickness of about 2,400 m in the HFM (fig. E–31*B*).

Upper Carbonate-Rock Aquifer (UCA)

The upper carbonate-rock aquifer (UCA) is present primarily in the area of Yucca Flat, the northern part of Jackass Flats, and the Eleana Range where these carbonate rocks are preserved in a syncline at Syncline Ridge and several isolated remnants above the UCCU (fig. E–32*A*). The UCA has a maximum thickness of about 1,200 m in the HFM (fig. E–32*B*).

Upper Clastic-Rock Confining Unit (UCCU)

The upper clastic-rock confining unit (UCCU) is present primarily in the area of Yucca Flat, the northern part of Jackass Flats, and the Eleana Range (fig. E–33*A*). The thickest parts of the UCCU are in the Eleana Range and western part of Yucca Flat, where it is about 3,100 m thick (fig. E–33*B*).

Lower Carbonate-Rock Aquifer (LCA) and Thrusts (LCA_T1)

The lower carbonate-rock aquifer (LCA) covers an extensive part of the DVRFS model domain, especially in the eastern and southern parts (fig. E–34*A*). The LCA is missing in the northwestern and central part of the model domain because of volcanic activity and associated igneous intrusions and thick accumulations of volcanic rocks (Chapter B, this volume). The area between the southern Funeral Mountains and the Spring Mountains contains separately defined thrust-fault areas where the thrusted LCA_T1 is repeated in the stratigraphic sequence above the LCA (fig. E–35*A*).

The LCA is particularly thick and continuous beneath the Pintwater and Spotted Ranges area (fig. E–34*B*) where it is in a regional syncline. One of the thickest parts of the LCA is in the structural trough west of the Spring Mountains. Because the base of the HFM is higher than the base of the LCA in some areas, the maximum thickness of the LCA in the HFM is only 6,500 m. The maximum thickness of the LCA_T1 is about 5,500 m (fig. E–35*B*).

Lower Clastic-Rock Confining Unit (LCCU) and Thrusts (LCCU_T1)

The lower clastic-confining unit (LCCU) is exposed through a broad area including the Spring Mountains, the NTS, and some of the mountains surrounding Death Valley (fig. E–36*A*). The area between the southern Funeral Mountains and the Spring Mountains contains separately defined thrust-fault areas where the thrusted LCCU_T1 is repeated in the stratigraphic sequence above the LCCU (fig. E–37*A*). The LCCU reaches a maximum thickness of about 6,300 m (fig. E–36*B*) where it outcrops in the mountains and extends to the base of the model. The LCCU_T1 reaches a maximum thickness of about 4,400 m (fig. E–37*B*).

Crystalline-Rock Confining Unit (XCU)

The crystalline-rock confining unit (XCU) consists of cratonic rocks that likely lie beneath the entire model domain, except directly beneath the calderas. The extent of the XCU outcrops in the HFM is shown in figure E–38*A*. In many areas the HFM truncates this unit at the base of the model 4,000 m below sea level. The XCU reaches a maximum thickness of about 6,500 m in the model (fig. E–38*B*).

Intrusive-Rock Confining Unit (ICU)

In most of the DVRFS region, the ICU occurs as small stocks, such as the Climax Stock in Yucca Flat and the Gold Meadows Stock on Rainier Mesa (Houser and others, 1961) (fig. E–39*A*). In the mountain ranges on the west and east sides of Death Valley, intrusive bodies are greater in size, more irregular in shape, and more common than elsewhere in the DVRFS region (Grose and Smith, 1989). Thicknesses vary but are about 6,700 m in parts of the HFM (fig. E–39*B*). The HFM truncates this unit at the base of the model 4,000 m below sea level. The intrusive bodies in the HFM are treated as vertical-sided blocks intruding through one or all other HGUs.

Representation of Key Areas in the Model

Key areas in the HFM that represent significant hydrogeologic features in the DVRFS model domain were compared to features in those areas of the hydrogeologic framework. Geometric relations of the HGUs in the HFM were visualized by producing a series of subparallel sections through four key areas of the HFM (fig. E–40): (1) the Sheep Range and adjacent areas, (2) the Eleana Range and Calico Hills, (3) the SWNVF, and (4) the Funeral Mountains and Amargosa Desert. Visual inspection of sections from the HFM is complicated by several confusing factors that need to be considered, such as graphic artifacts from grid spacing, the abrupt truncation of HGUs, and representation of faults as steep offsets in onlapping relations in the HFM.

Sheep Range and Adjacent Areas

The Sheep Range is hydrologically important because it is a center of recharge and is near the boundary between the DVRFS and the Colorado River ground-water flow system. Sections from the HFM in the vicinity of the Sheep Range show two structural highs of LCCU (fig. E–41) that represent the north-trending Pintwater anticline to the west (Longwell and others, 1965) and the LCCU_T1 in the upper plate of the Gass Peak thrust to the east. North of the LVVSZ, Cenozoic extensional faults have overprinted the Mesozoic thrust belt (Guth, 1981, 1990; Wernicke and others, 1984). The HFM portrays the effect of these faults as variable thicknesses of LCCU_T1 in the upper plate of the Gass Peak thrust.

Eleana Range and Calico Hills

In the vicinity of the Eleana Range and Calico Hills thrusted LCCU is present in the upper plate of the Belted Range thrust and is almost completely buried beneath volcanic-rock HGUs, as portrayed in the HFM (fig. E–42). The Belted Range thrust is intruded by the Gold Meadows Stock (ICU) beneath Rainier Mesa and by a pluton beneath the Calico Hills, both represented in the HFM. Few faults appear to interrupt the continuity of the thrust system in the subsurface, although the thrusts are disrupted by the TMCC and the Claim Canyon caldera, as portrayed in the HFM. Below the Belted Range thrust is a series of footwall imbricate thrusts that carry UCCU in their upper plate (Cole and Cashman, 1999) and generally serve as the westward truncation of the LCA. Although not visible at the scale of figure E–42, this imbricate thrust is represented in the HFM by the UCCU in the lower plate of the Belted Range thrust.

Southwestern Nevada Volcanic Field

Sections from the HFM in the vicinity of the SWNVF (fig. E–43) portray the thickness and extent of the various volcanic-rock HGUs in the SCCC and the TMCC. Within the calderas of the SWNVF, the HFM portrays the Paleozoic and older bedrock (LCA, LCCU, and XCU) as missing or present only at very deep levels.

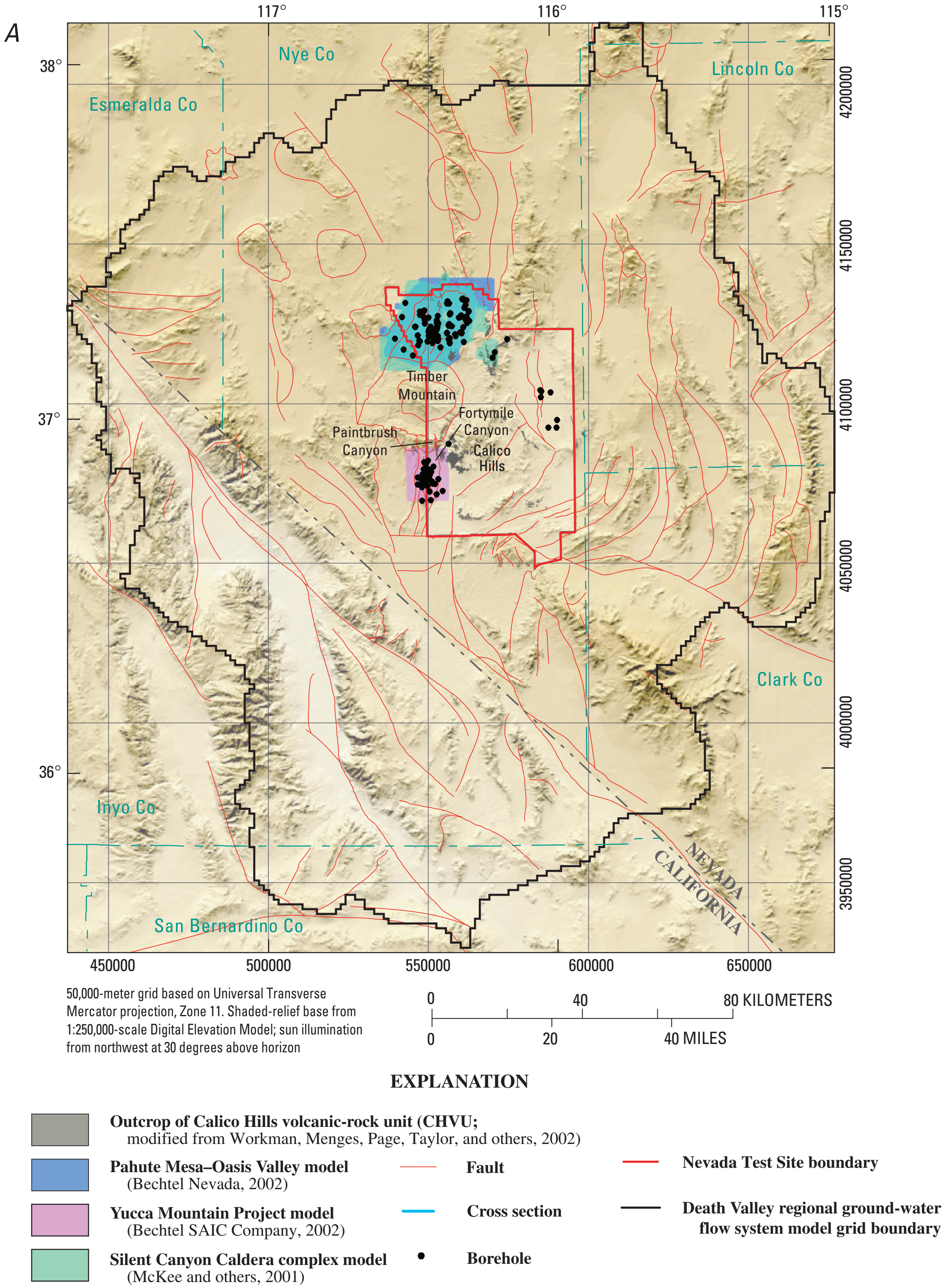


Figure E–24. (*A*) Data sources and (*B*) thickness of Calico Hills volcanic-rock unit.

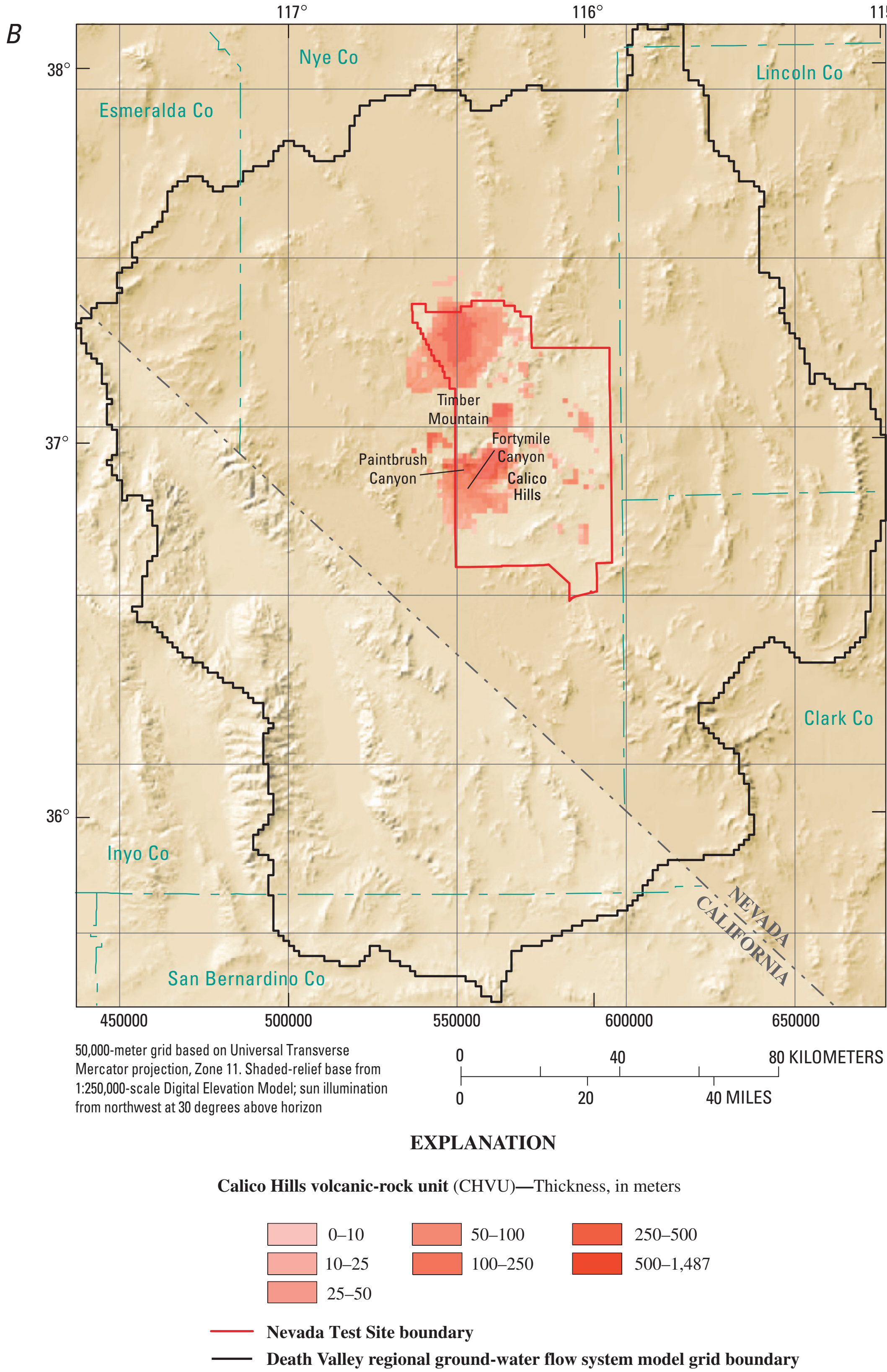


Figure E–24. (*A*) Data sources and (*B*) thickness of Calico Hills volcanic-rock unit.—Continued

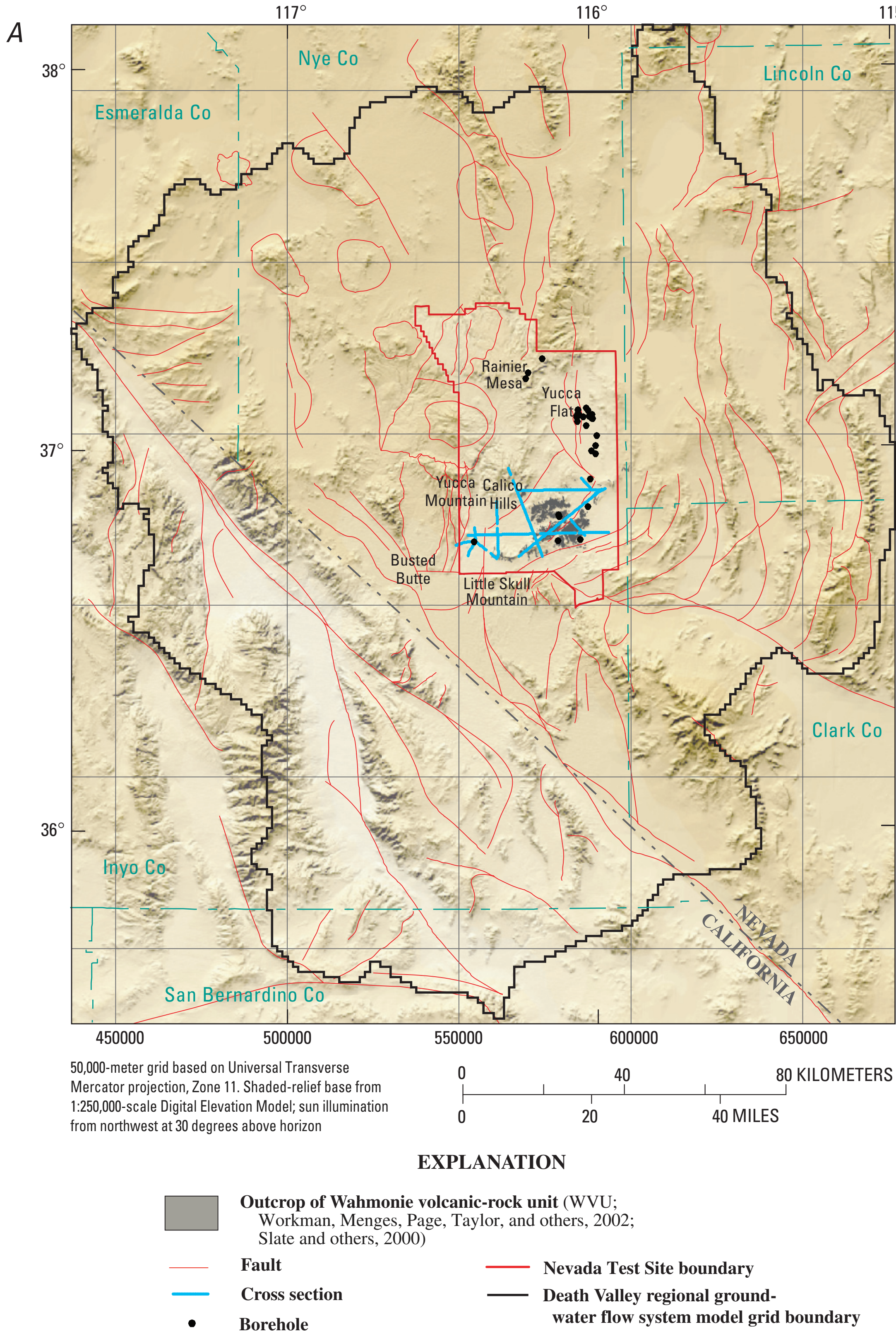


Figure E–25. (*A*) Data sources and (*B*) thickness of Wahmonie volcanic-rock unit.

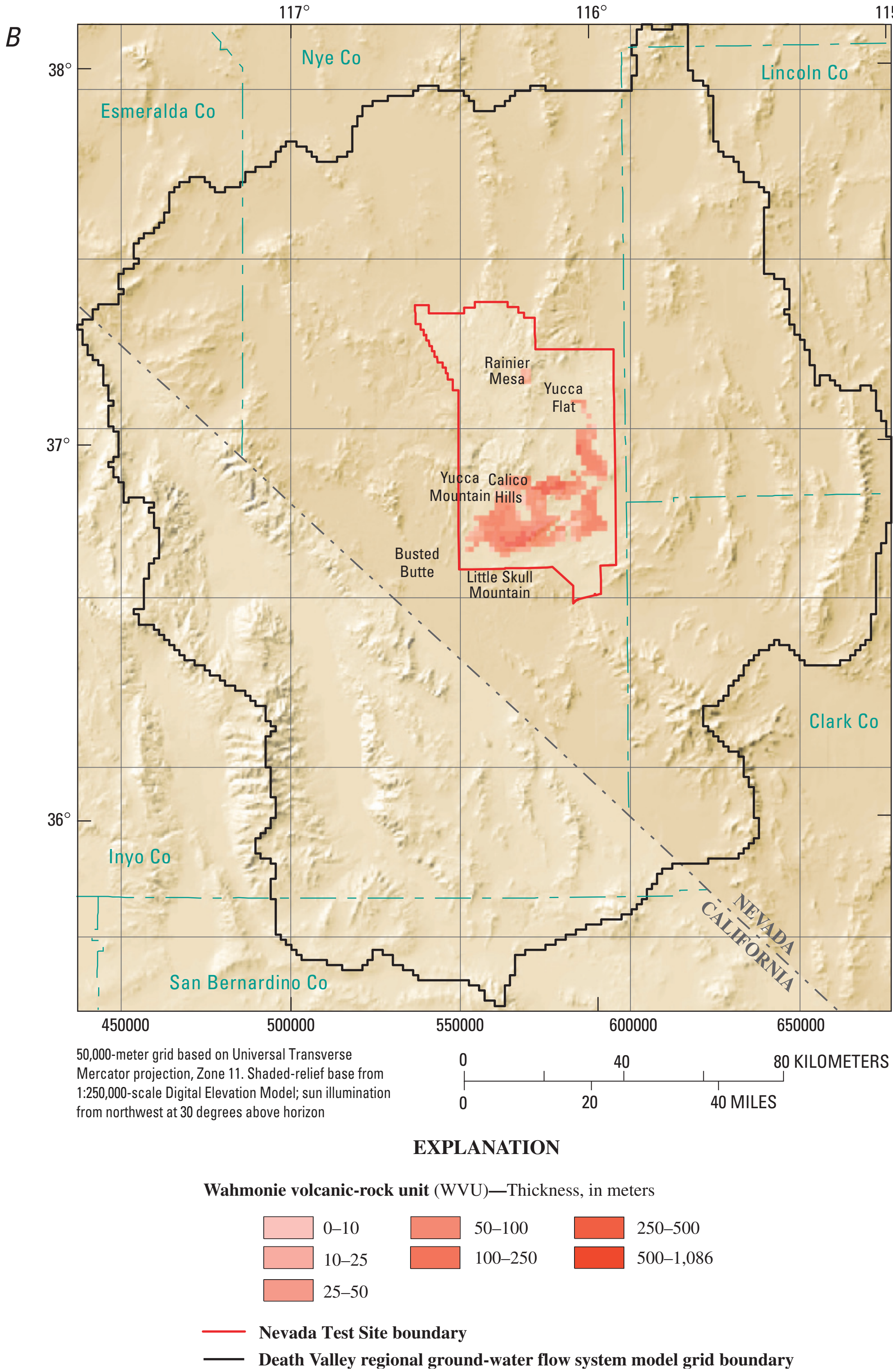
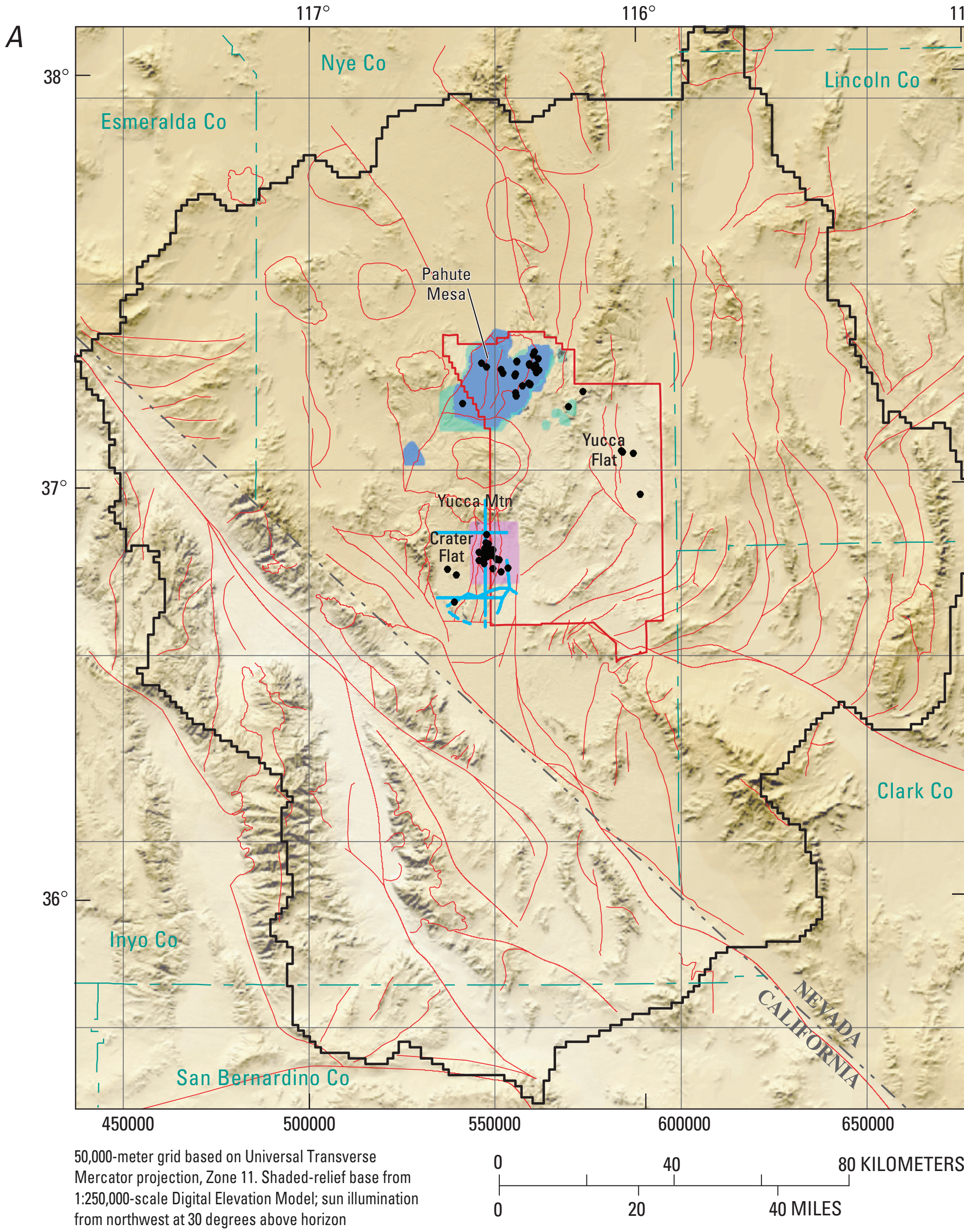


Figure E–25. (*A*) Data sources and (*B*) thickness of Wahmonie volcanic-rock unit.—Continued



50,000-meter grid based on Universal Transverse Mercator projection, Zone 11. Shaded-relief base from 1:250,000-scale Digital Elevation Model; sun illumination from northwest at 30 degrees above horizon

EXPLANATION

Outcrop of Crater Flat–Prow Pass aquifer (CFPPA; modified from Workman, Menges, Page, Taylor, and others, 2002; Slate and others, 2000; Potter, Dickerson, and others, 2002)

Pahute Mesa–Oasis Valley model (Bechtel Nevada, 2002)

Yucca Mountain Project model (Bechtel SAIC Company, 2002)

Silent Canyon Caldera complex model (McKee and others, 2001)

Fault

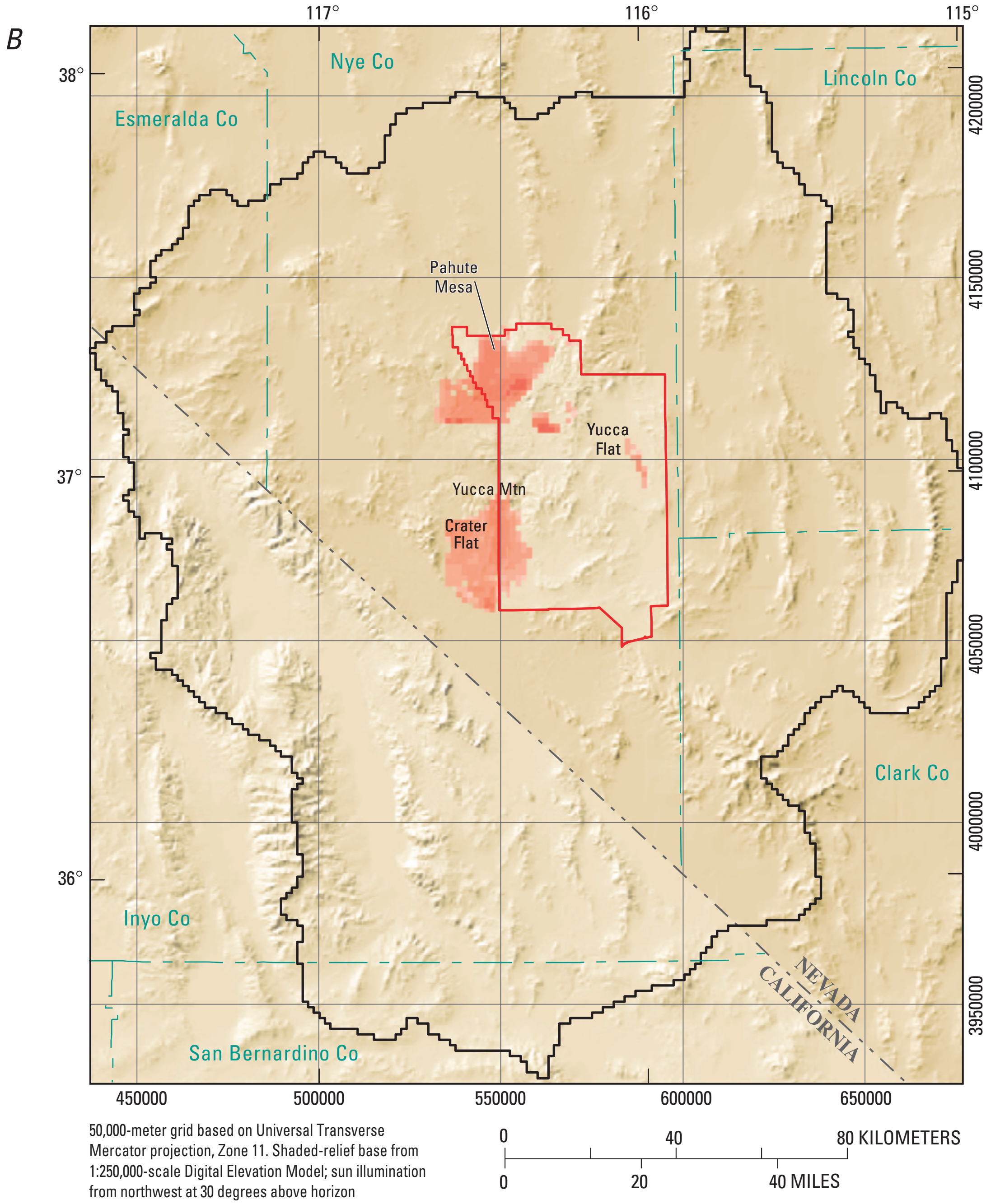
Cross section

Borehole

Nevada Test Site boundary

Death Valley regional ground-water flow system model grid boundary

Figure E–26. (*A*) Data sources and (*B*) thickness of Crater Flat–Prow Pass aquifer.



50,000-meter grid based on Universal Transverse Mercator projection, Zone 11. Shaded-relief base from 1:250,000-scale Digital Elevation Model; sun illumination from northwest at 30 degrees above horizon

EXPLANATION

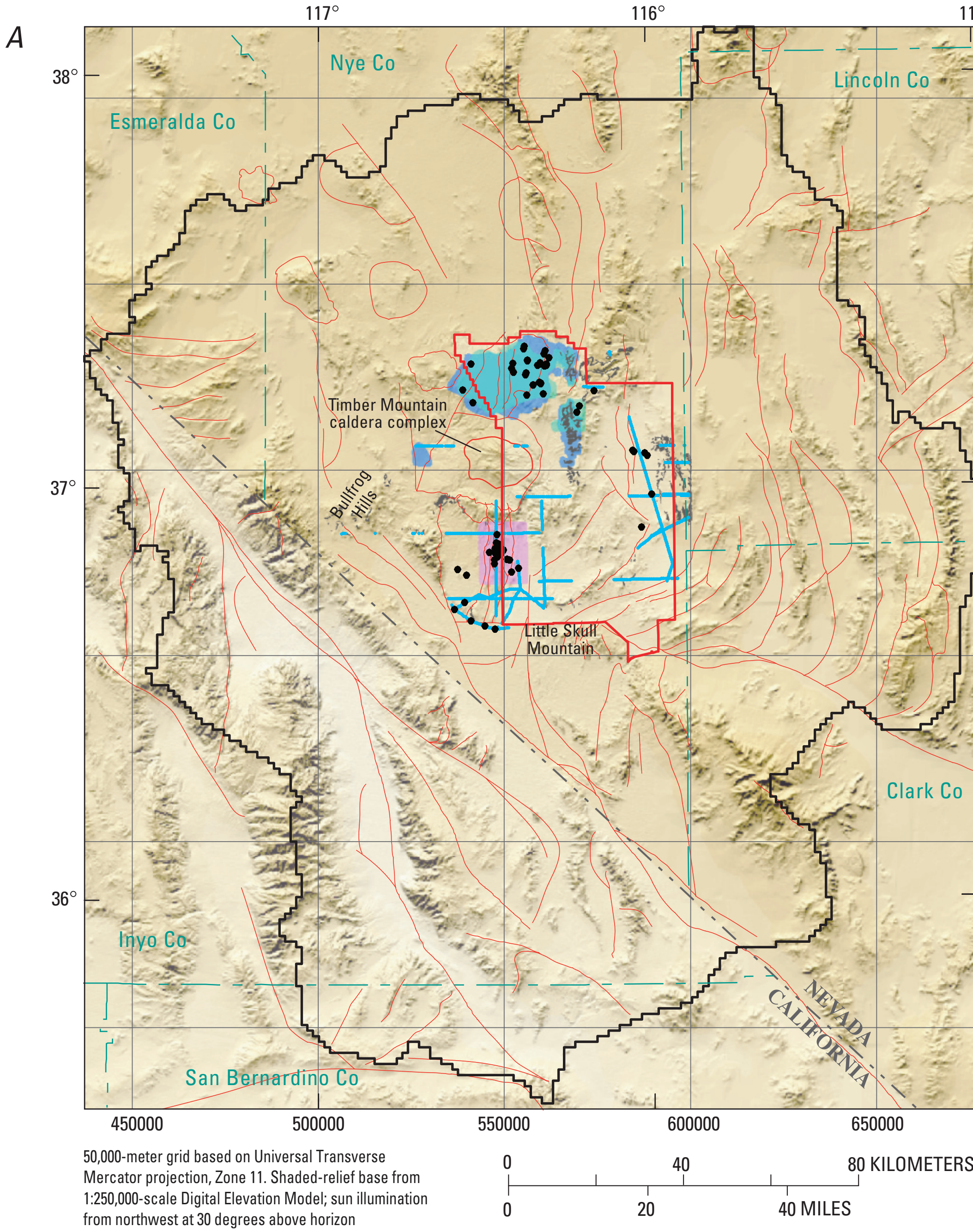
Crater Flat–Prow Pass aquifer (CFPPA)—Thickness, in meters

- 0–10
- 10–25
- 25–50
- 50–100
- 100–250
- 250–500
- 500–1,372

Nevada Test Site boundary

Death Valley regional ground-water flow system model grid boundary

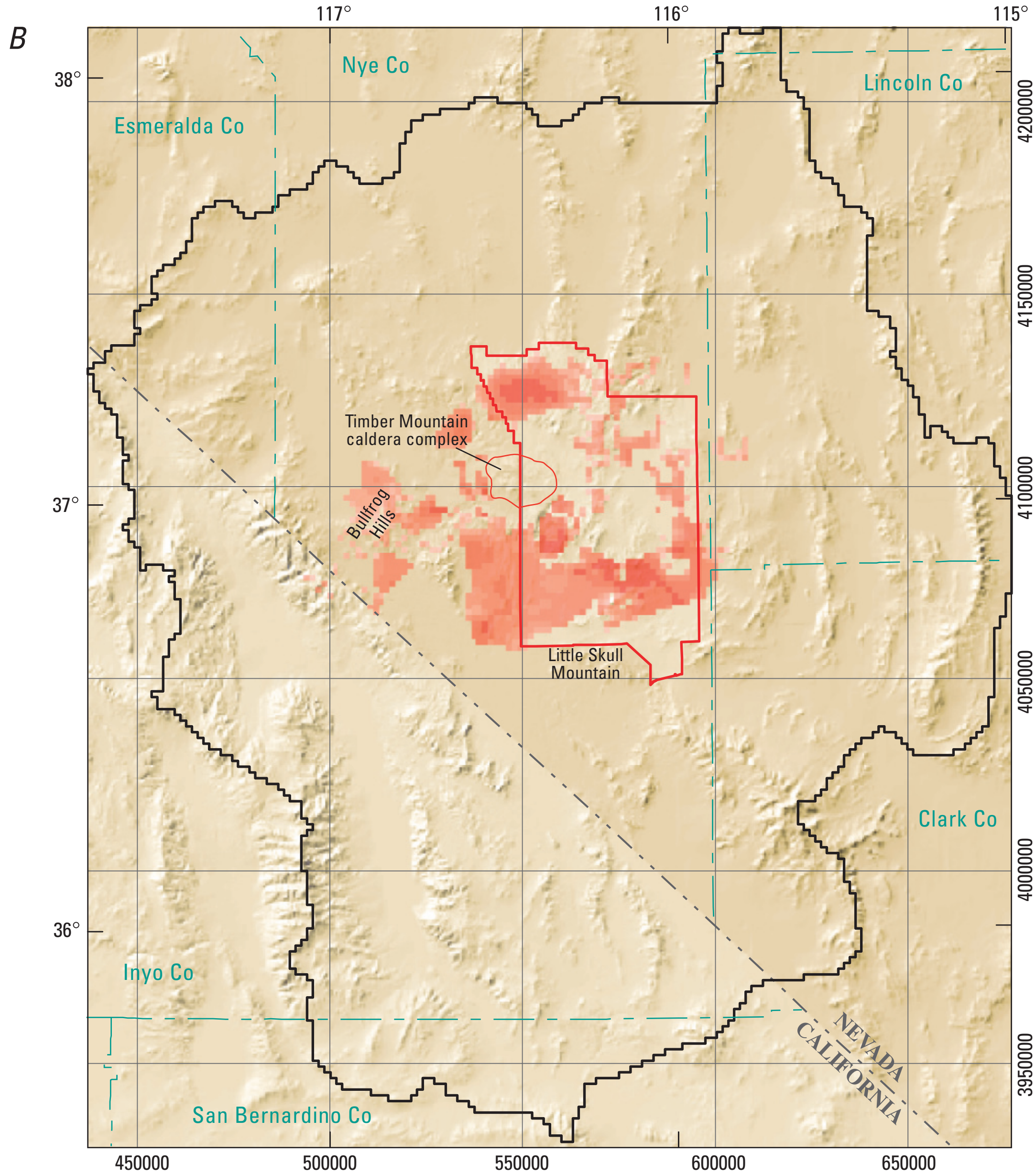
Figure E–26. (*A*) Data sources and (*B*) thickness of Crater Flat–Prow Pass aquifer.—Continued



EXPLANATION

- **Outcrop of Crater Flat–Bullfrog confining unit** (CFBCU**;** modified from Workman, Menges, Page, Taylor, and others, 2002; Slate and others, 2000; Potter, Dickerson, and others, 2002)
- **Pahute Mesa–Oasis Valley model** (Bechtel Nevada, 2002)
- **Yucca Mountain Project model** (Bechtel SAIC Company, 2002)
- **Silent Canyon Caldera complex model** (McKee and others, 2001)
- **Fault**
- **Cross section**
- **Borehole**
- **Nevada Test Site boundary**
- **Death Valley regional ground-water flow system model grid boundary**

Figure E–27. (*A*) Data sources and (*B*) thickness of Crater Flat–Bullfrog confining unit.



50,000-meter grid based on Universal Transverse Mercator projection, Zone 11. Shaded-relief base from 1:250,000-scale Digital Elevation Model; sun illumination from northwest at 30 degrees above horizon

0 40 80 KILOMETERS

0 20 40 MILES

EXPLANATION

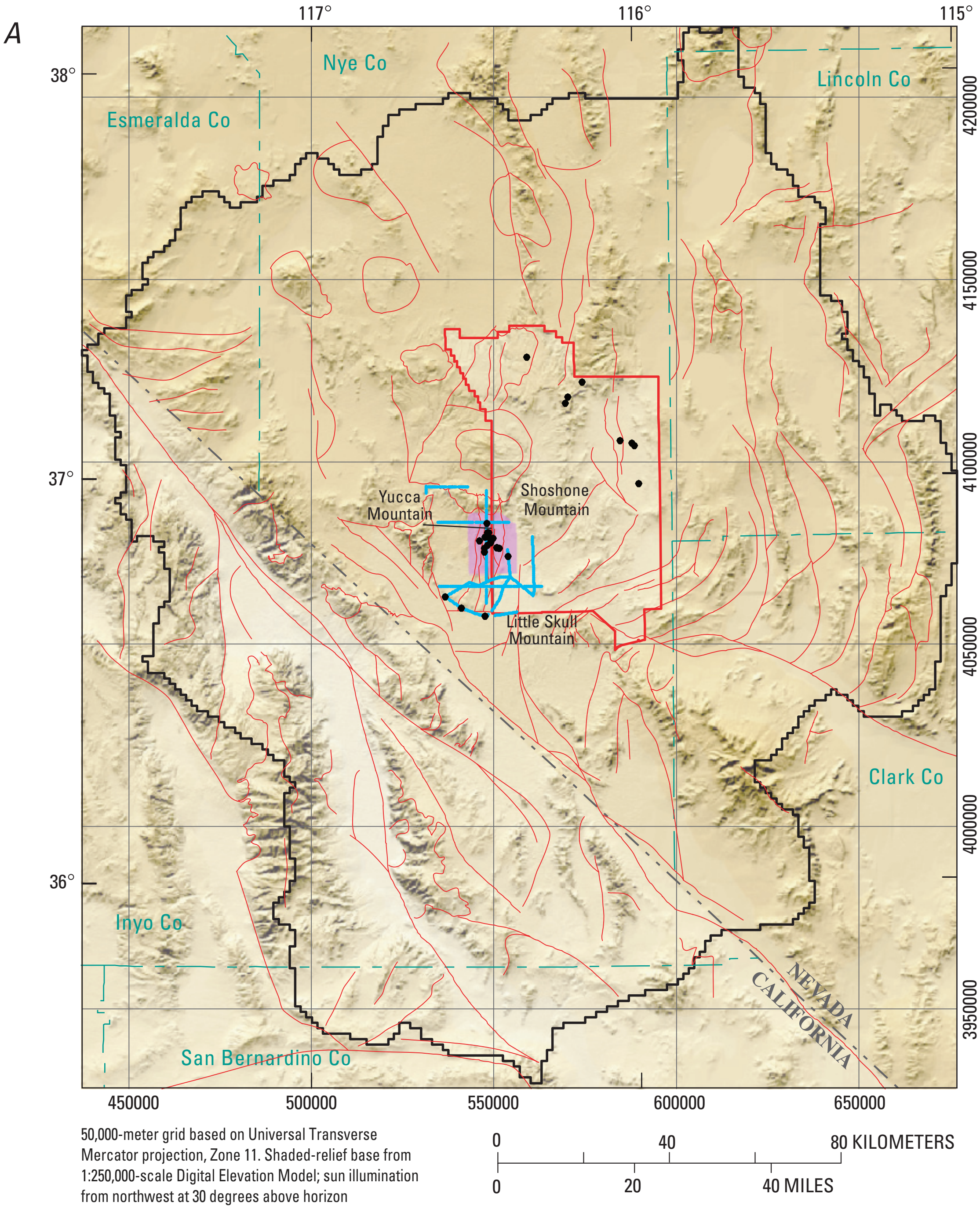
Crater Flat–Bullfrog confining unit (CFBCU)—Thickness, in meters

0–10
10–25
25–50
50–100
100–250
250–500
500–960

Nevada Test Site boundary

Death Valley regional ground-water flow system model grid boundary

Figure E–27. (*A*) Data sources and (*B*) thickness of Crater Flat–Bullfrog confining unit.—Continued



EXPLANATION

Outcrop of Crater Flat-Tram aquifer (CFTA; modified from Workman, Menges, Page, Taylor, and others, 2002; Slate and others, 2000; Potter, Dickerson, and others, 2002)

Yucca Mountain project model (Bechtel SAIC Company, 2002)

Fault

Cross section

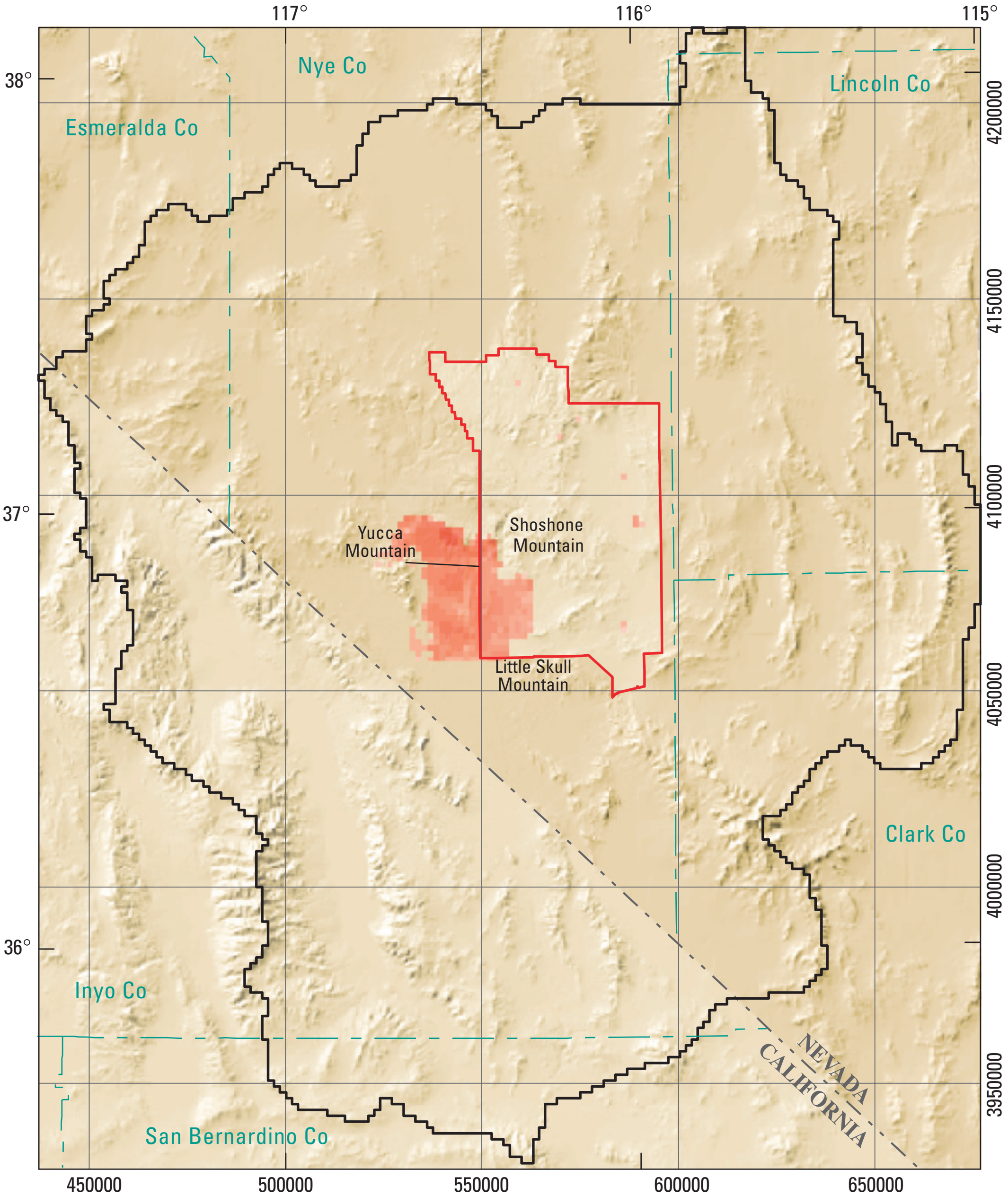
Borehole

Nevada Test Site boundary

Death Valley regional ground-water flow system model grid boundary

Figure E–28. (*A*) Data sources and (*B*) thickness of Crater Flat–Tram aquifer.

B



50,000-meter grid based on Universal Transverse Mercator projection, Zone 11. Shaded-relief base from 1:250,000-scale Digital Elevation Model; sun illumination from northwest at 30 degrees above horizon

0 40 80 KILOMETERS
0 20 40 MILES

EXPLANATION

Crater Flat–Tram aquifer (CFTA)—Thickness, in meters

0–10
10–25
25–50
50–100
100–250
250–500
500–1,500
1,500–1,634

Nevada Test Site boundary

Death Valley regional ground-water flow system model grid boundary

Figure E–28. (*A*) Data sources and (*B*) thickness of Crater Flat–Tram aquifer.—Continued

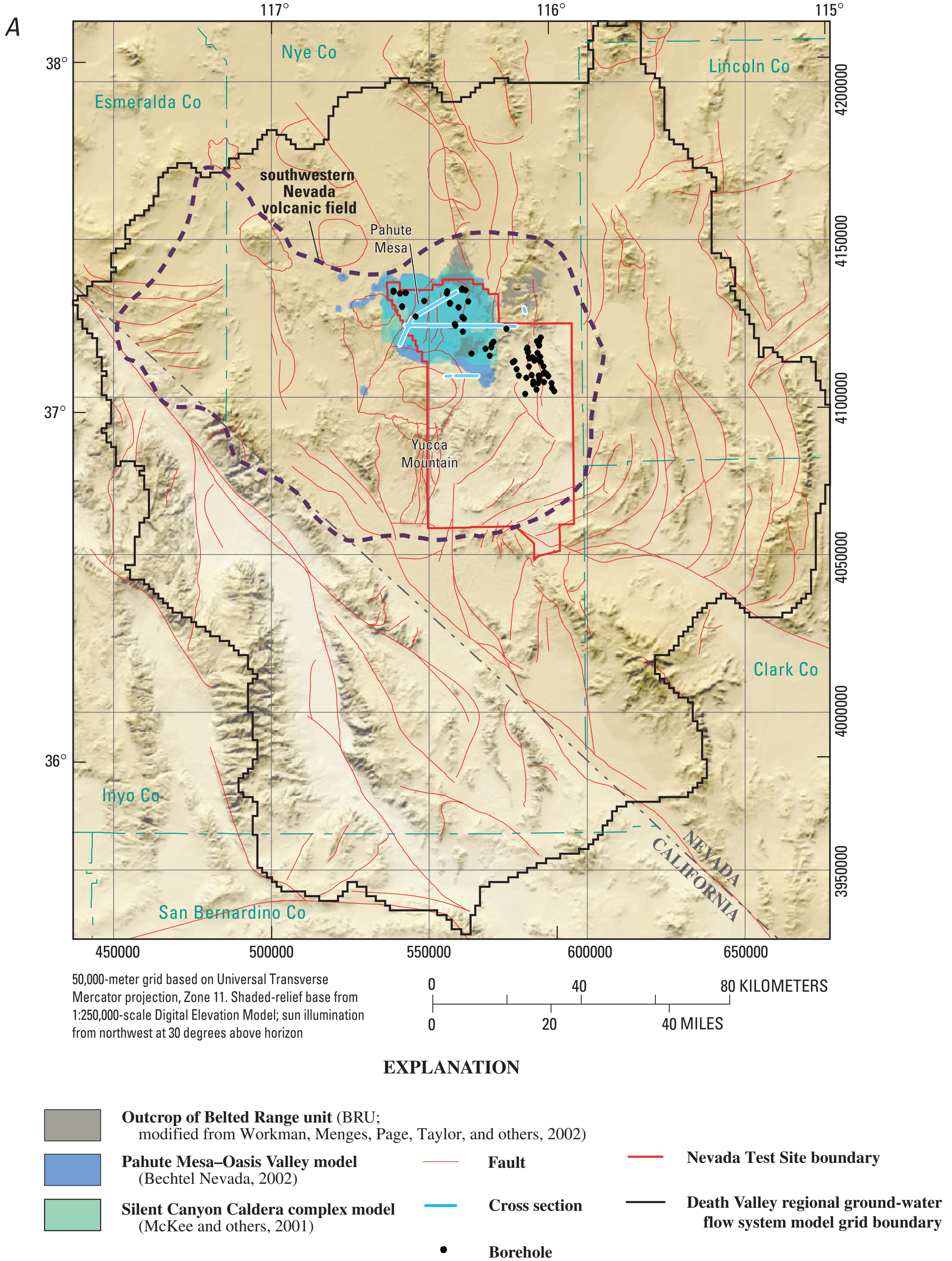


Figure E–29. (*A*) Data sources and (*B*) thickness of Belted Range unit.

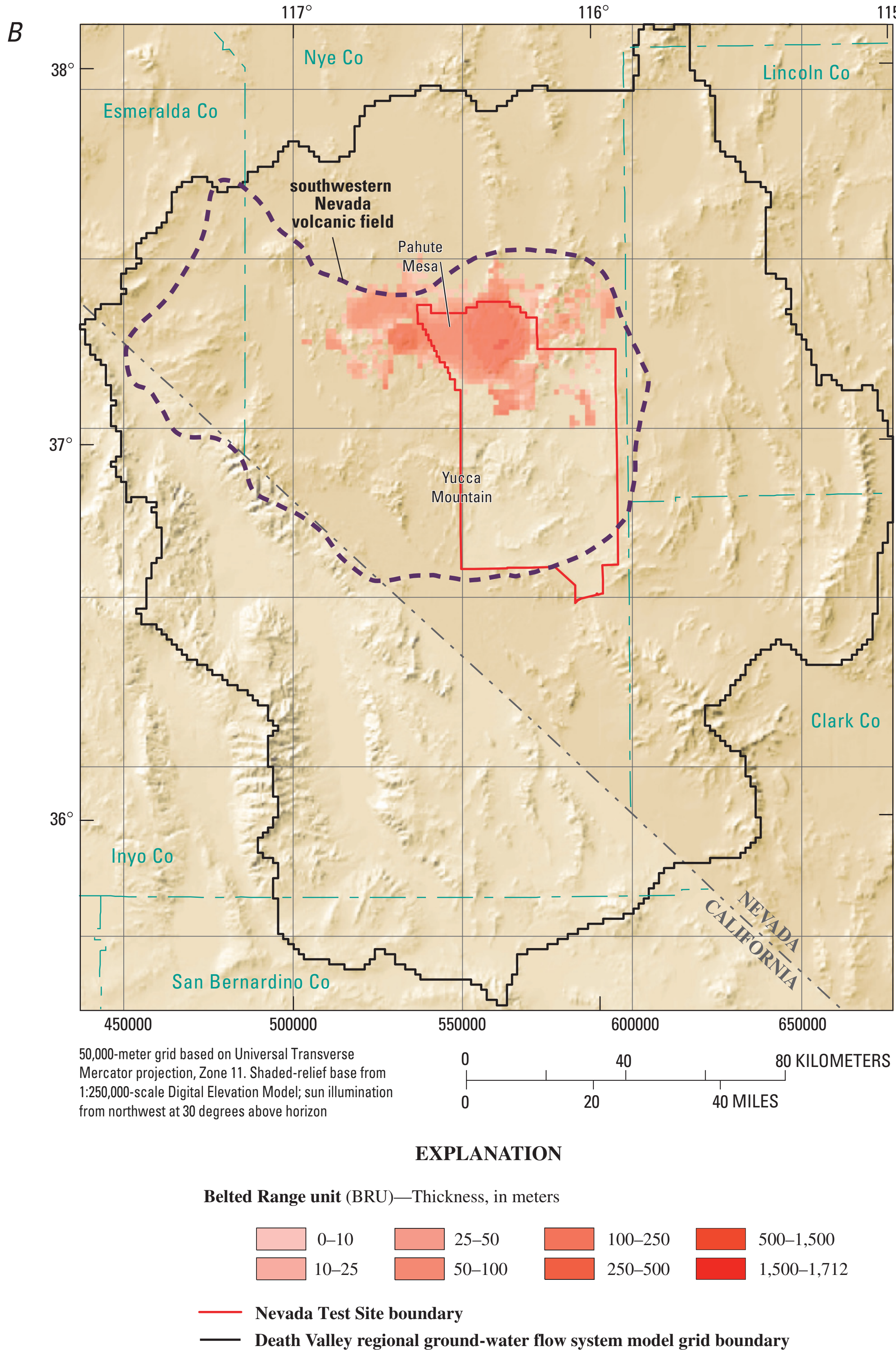
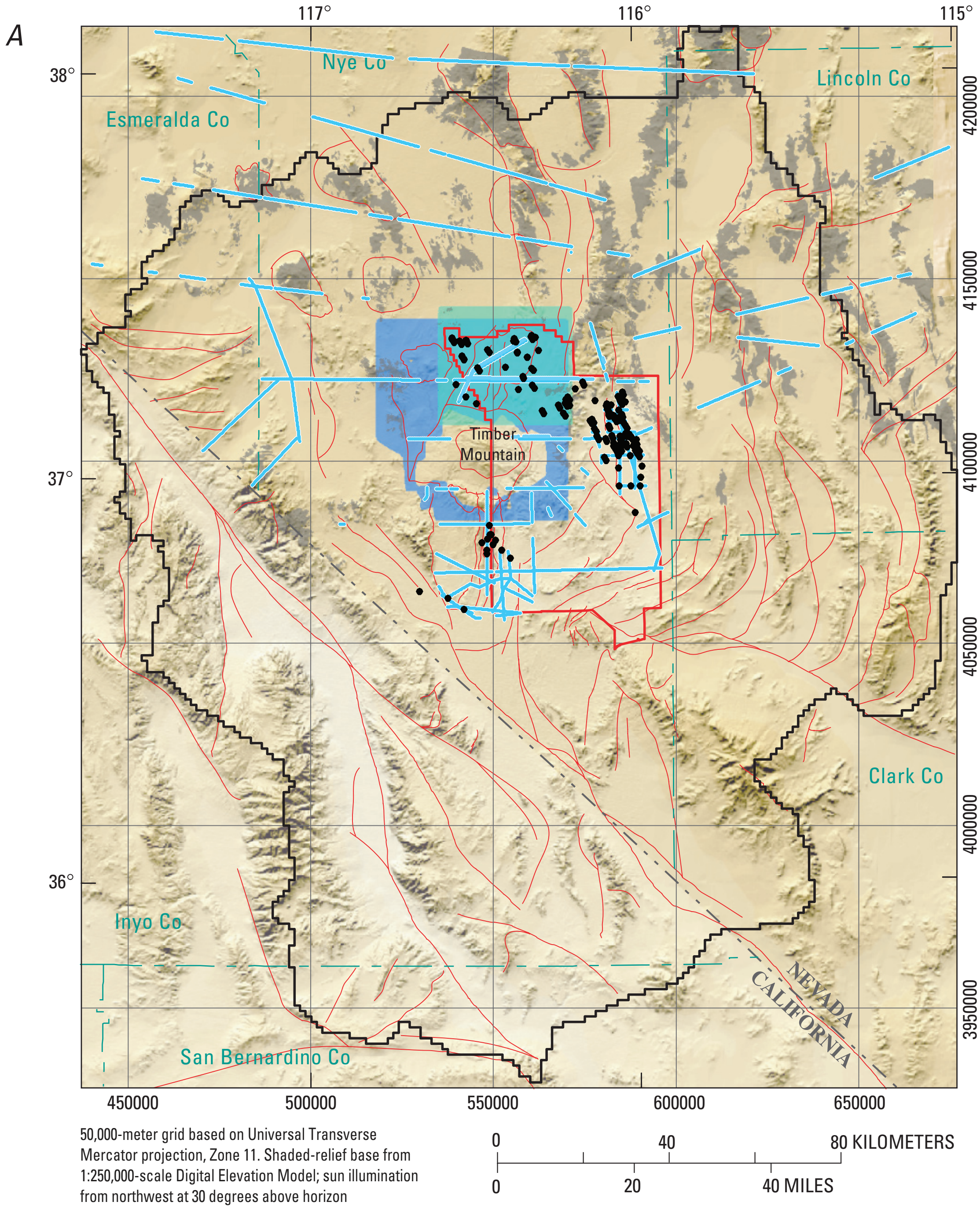


Figure E–29. (*A*) Data sources and (*B*) thickness of Belted Range unit.—Continued



EXPLANATION

Outcrop of older volcanic-rock unit (OVU; modified from Workman, Menges, Page, Taylor, and others, 2002)

Pahute Mesa–Oasis Valley model (Bechtel Nevada, 2002)

Silent Canyon Caldera complex model (McKee and others, 2001)

Fault

Cross section

Borehole

Nevada Test Site boundary

Death Valley regional ground-water flow system model grid boundary

Figure E–30. (*A*) Data sources and (*B*) thickness of older volcanic-rock unit.

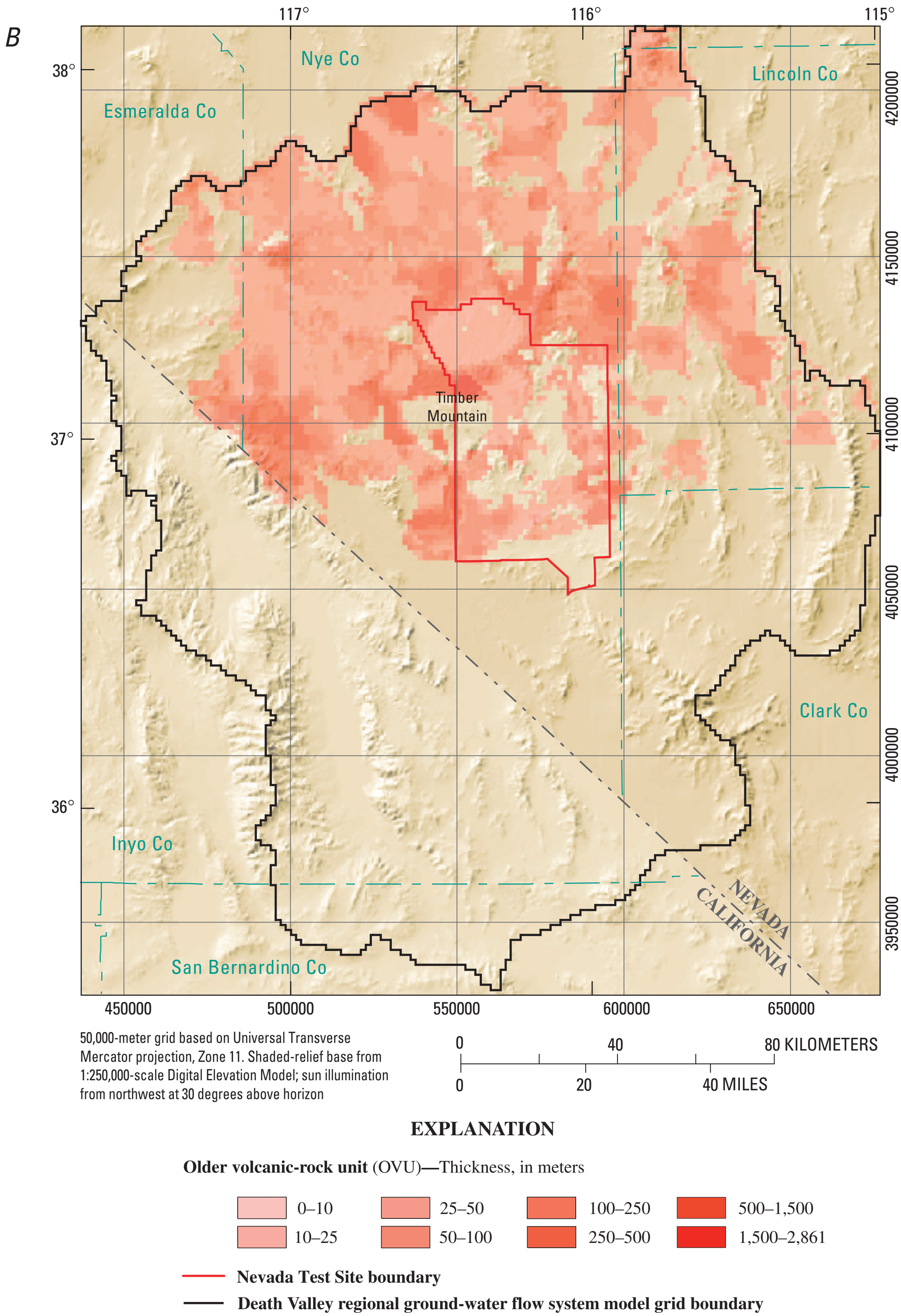


Figure E–30. (*A*) Data sources and (*B*) thickness of older volcanic-rock unit.—Continued

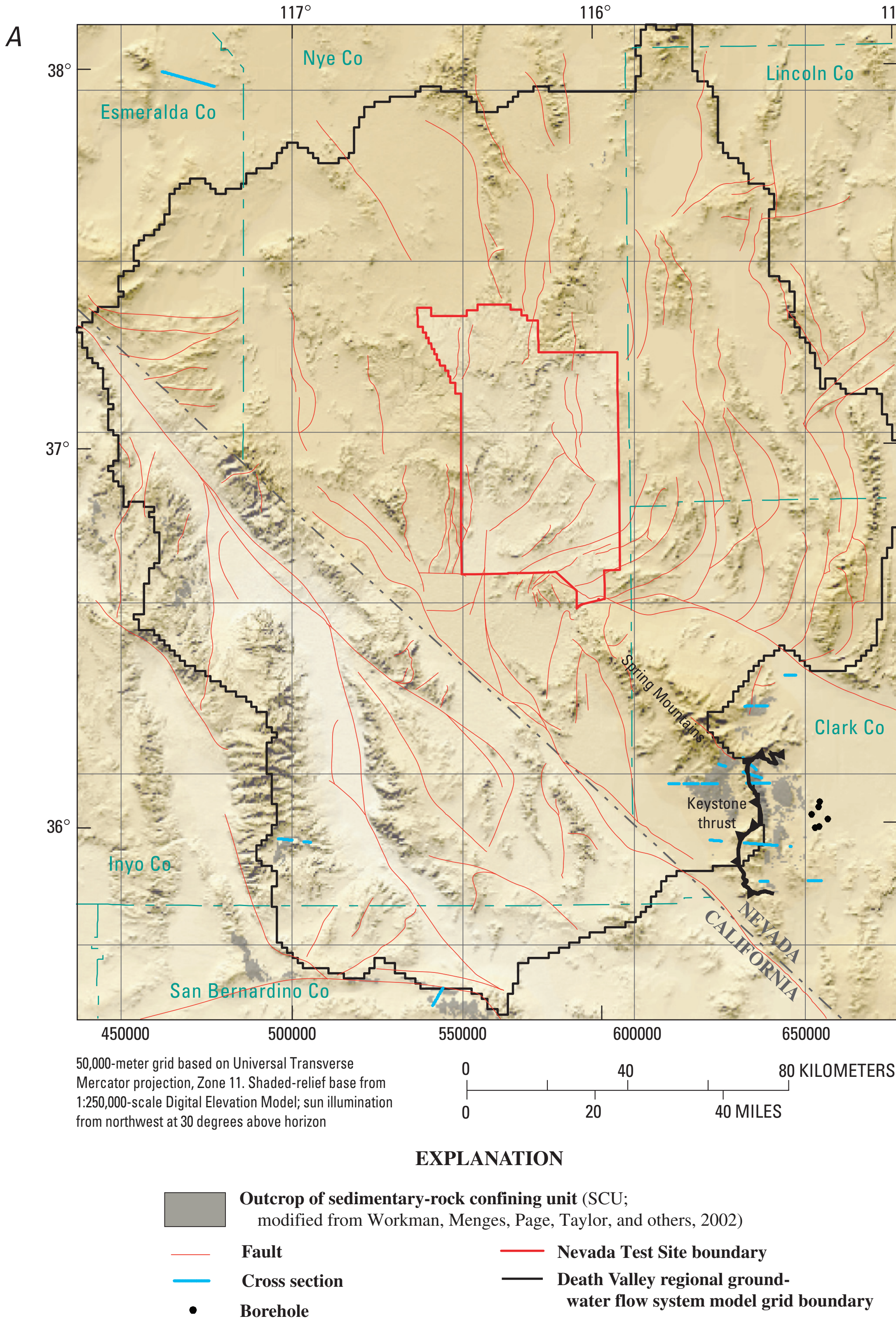
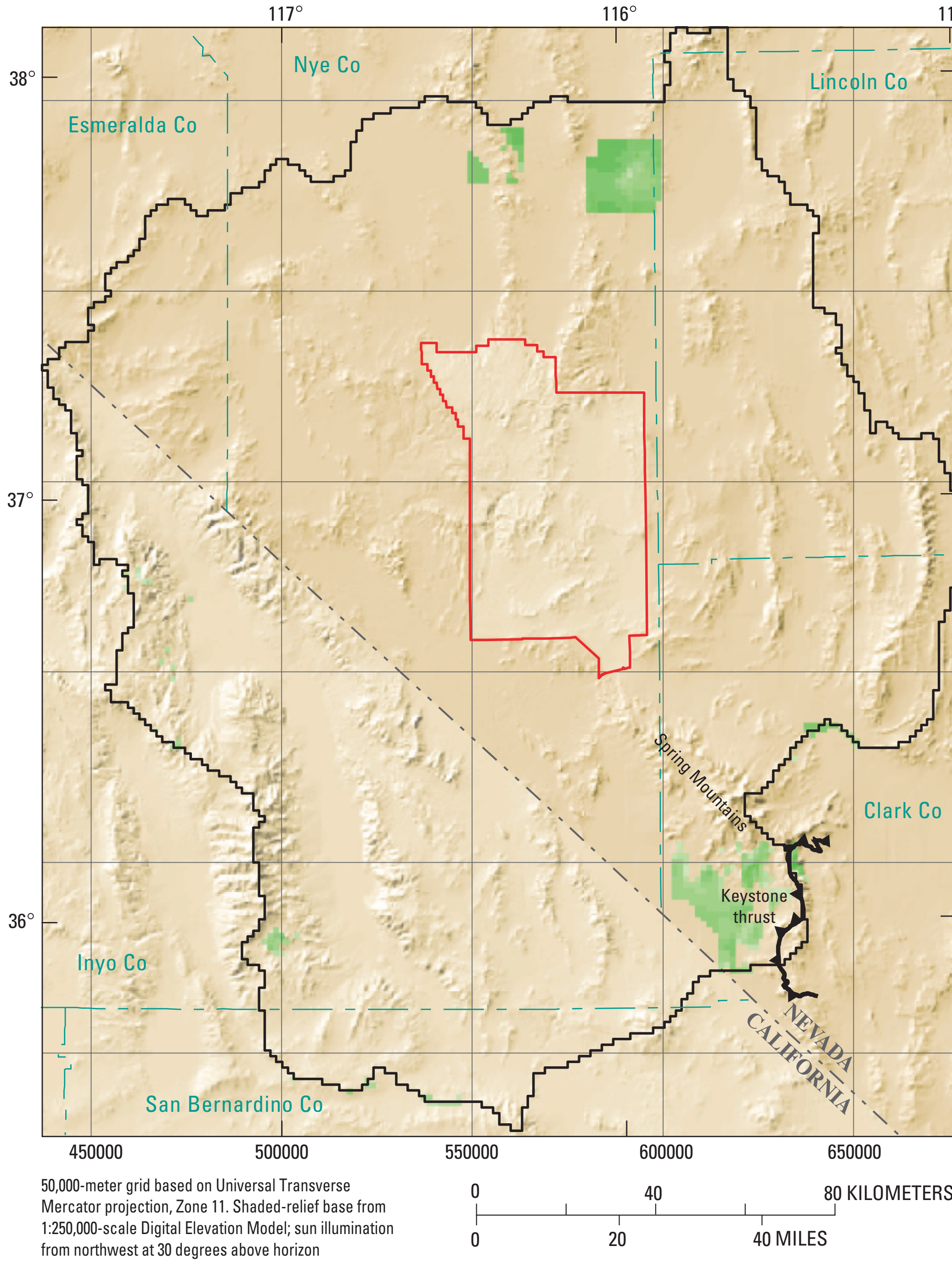


Figure E–31. (*A*) Data sources and (*B*) thickness of sedimentary-rock confining unit.

B



50,000-meter grid based on Universal Transverse Mercator projection, Zone 11. Shaded-relief base from 1:250,000-scale Digital Elevation Model; sun illumination from northwest at 30 degrees above horizon

EXPLANATION

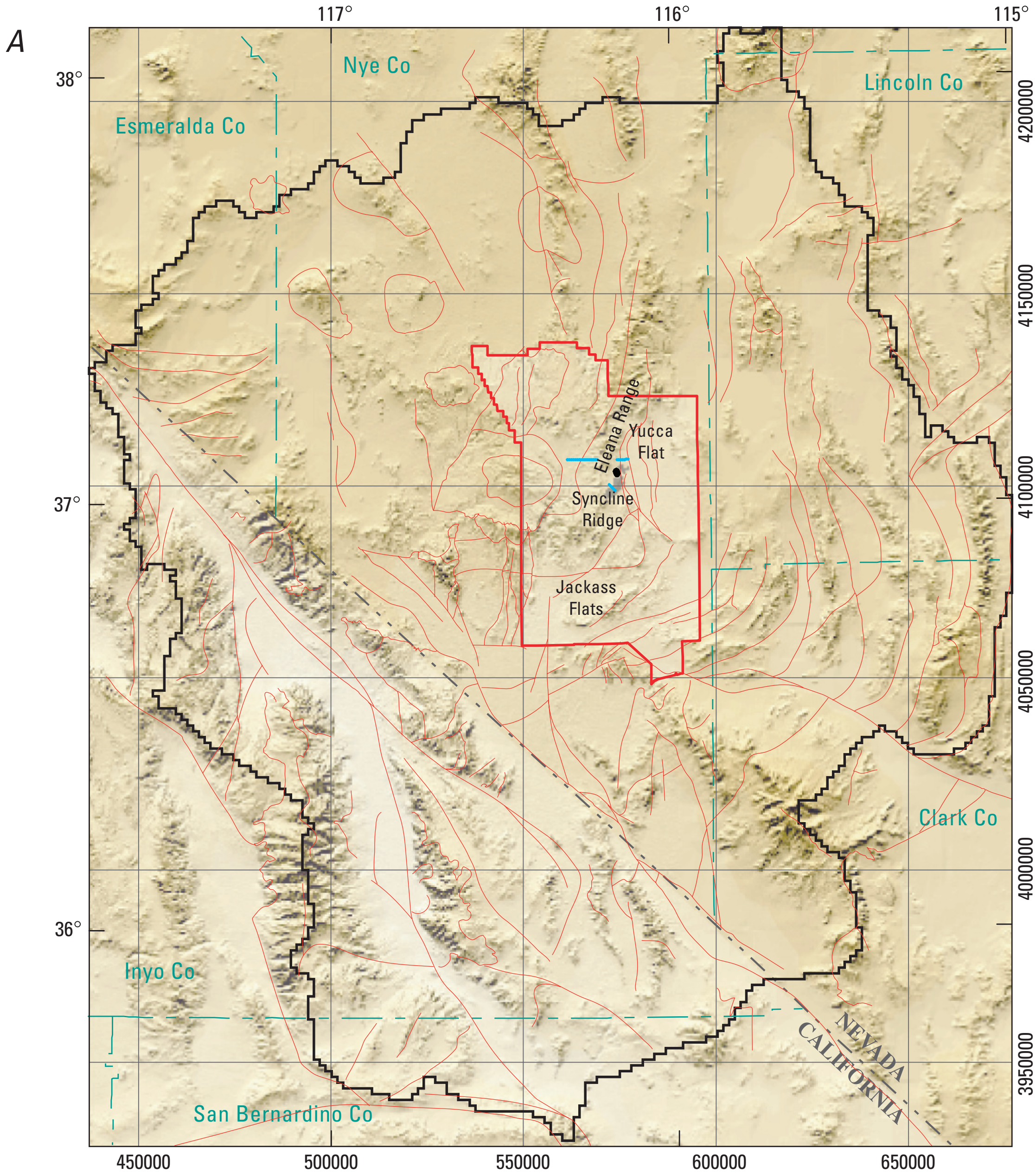
Sedimentary-rock confining unit (SCU)—Thickness in meters,

0–10
10–25
25–50
50–100
100–250
250–500
500–1,500
1,500–2,390

Nevada Test Site boundary

Death Valley regional ground-water flow system model grid boundary

Figure E–31. (*A*) Data sources and (*B*) thickness of sedimentary-rock confining unit.—Continued



50,000-meter grid based on Universal Transverse Mercator projection, Zone 11. Shaded-relief base from 1:250,000-scale Digital Elevation Model; sun illumination from northwest at 30 degrees above horizon

0 40 80 KILOMETERS
0 20 40 MILES

EXPLANATION

Outcrop of upper carbonate-rock aquifer (UCA; modified from Workman, Menges, Page, Taylor, and others, 2002)

Fault

Cross section

Borehole

Nevada Test Site boundary

Death Valley regional ground-water flow system model grid boundary

Figure E–32. (*A*) Data sources and (*B*) thickness of upper carbonate-rock aquifer.

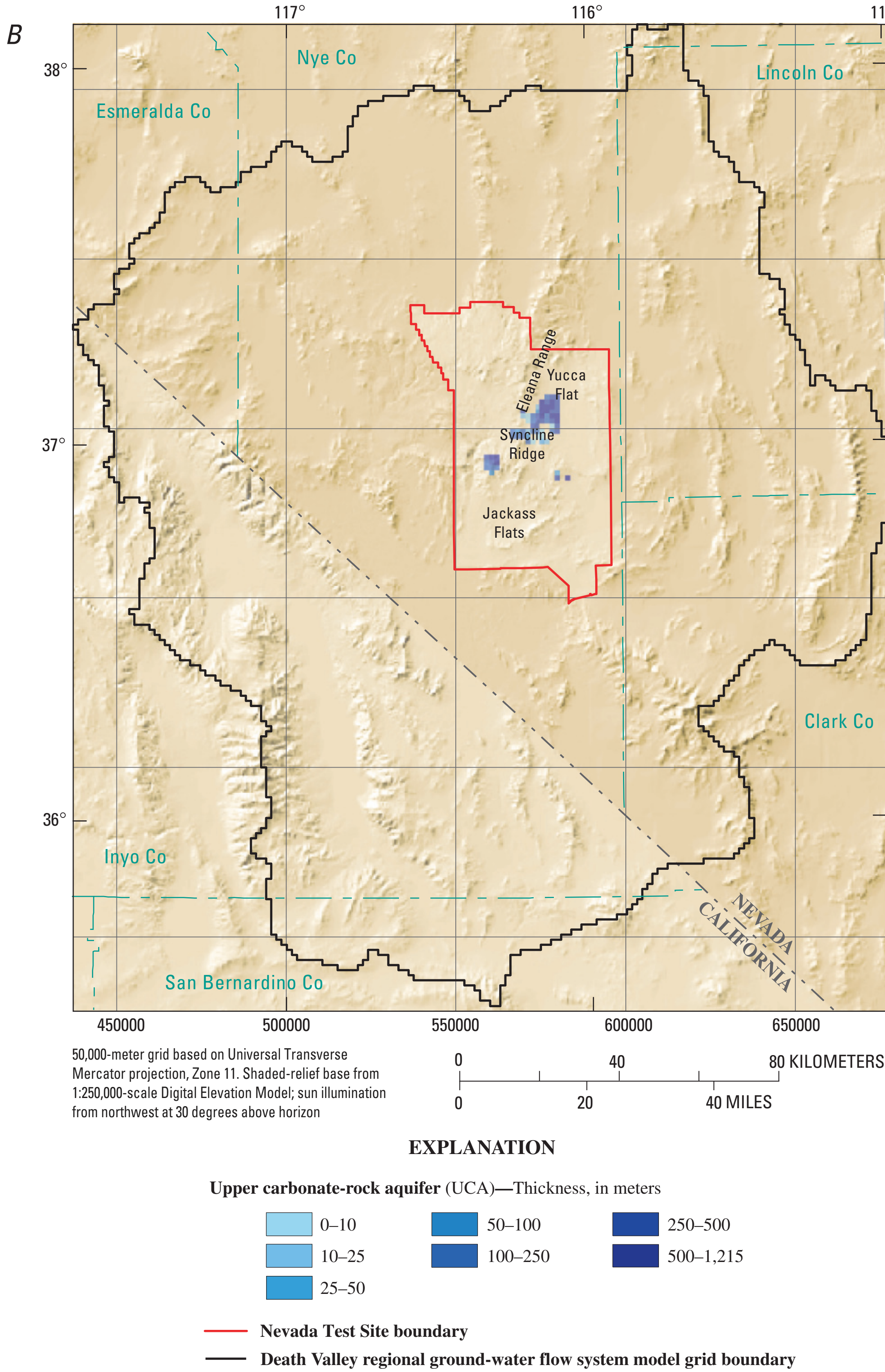


Figure E–32. (*A*) Data sources and (*B*) thickness of upper carbonate-rock aquifer.—Continued

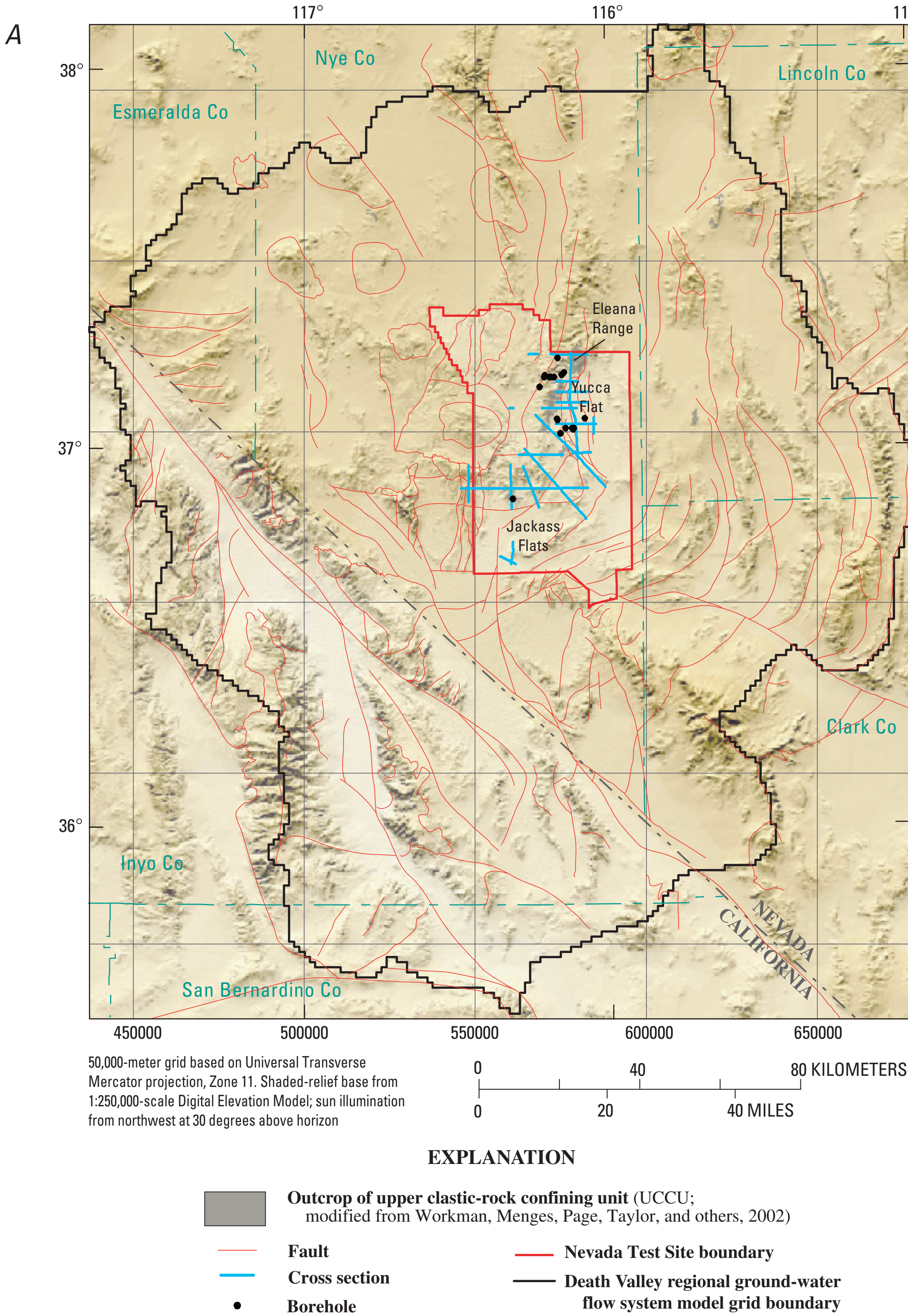
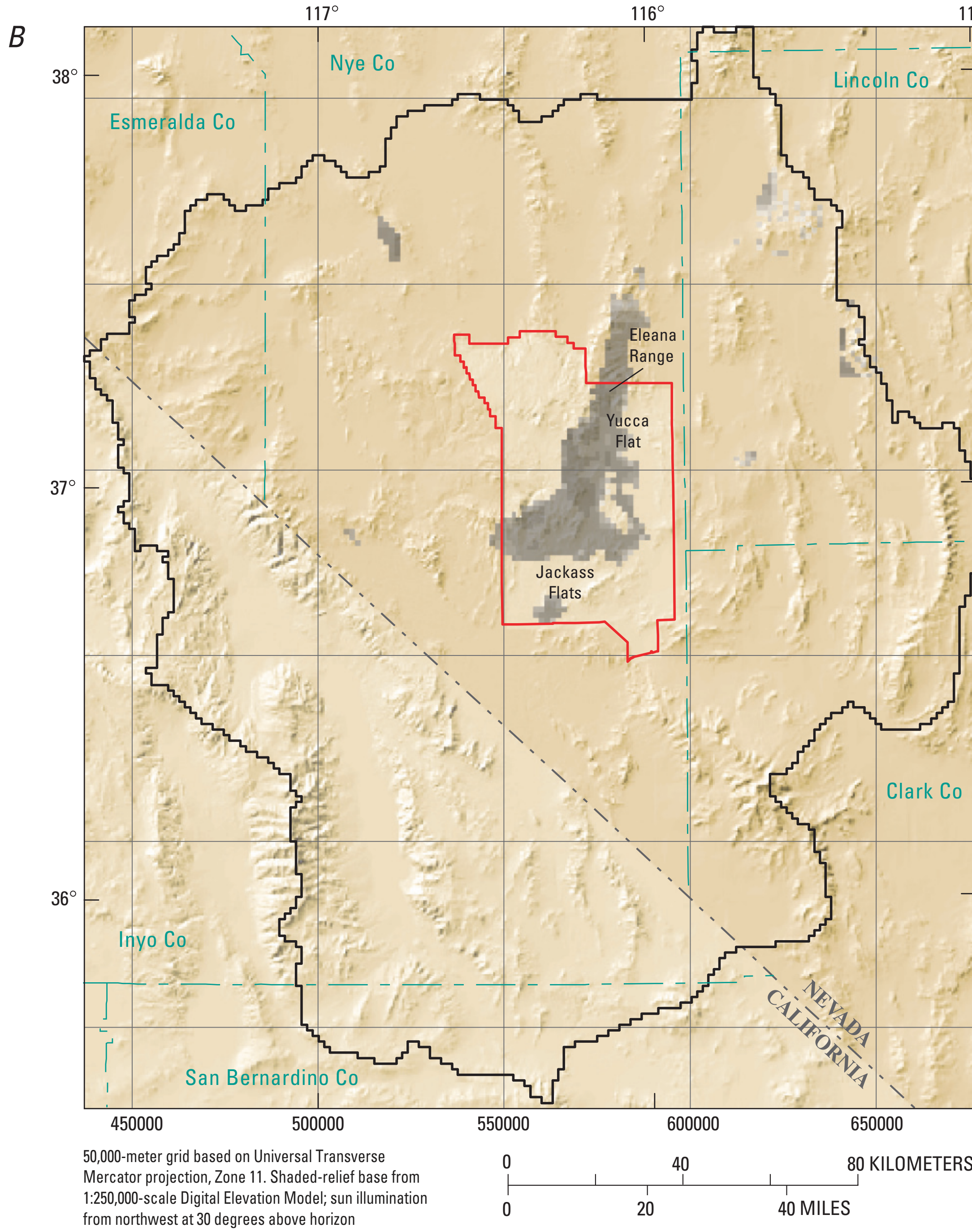


Figure E–33. (*A*) Data sources and (*B*) thickness of upper clastic-rock confining unit.



EXPLANATION

Upper clastic-rock confining unit (UCCU)—Thickness, in meters

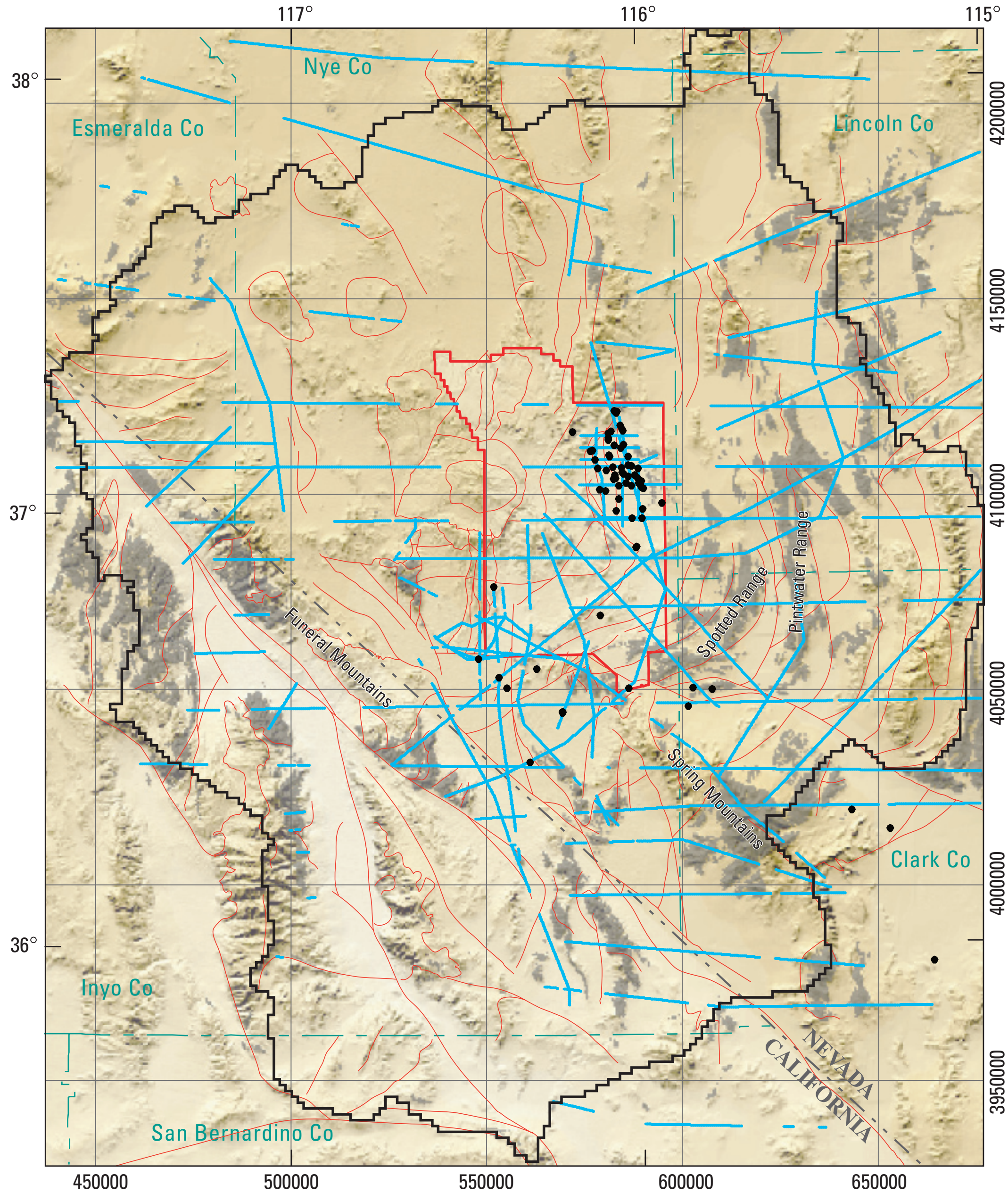
- 0-10
- 10-25
- 25-50
- 50-100
- 100-250
- 250-500
- 500-1,500
- 1,500-3,000
- 3,000-3,107

Nevada Test Site boundary

Death Valley regional ground-water flow system model grid boundary

Figure E–33. (*A*) Data sources and (*B*) thickness of upper clastic-rock confining unit.—Continued

A



50,000-meter grid based on Universal Transverse Mercator projection, Zone 11. Shaded-relief base from 1:250,000-scale Digital Elevation Model; sun illumination from northwest at 30 degrees above horizon

0 40 80 KILOMETERS
0 20 40 MILES

EXPLANATION

Outcrop of lower carbonate-rock aquifer (LCA; modified from Workman, Menges, Page, Taylor, and others, 2002)

Fault

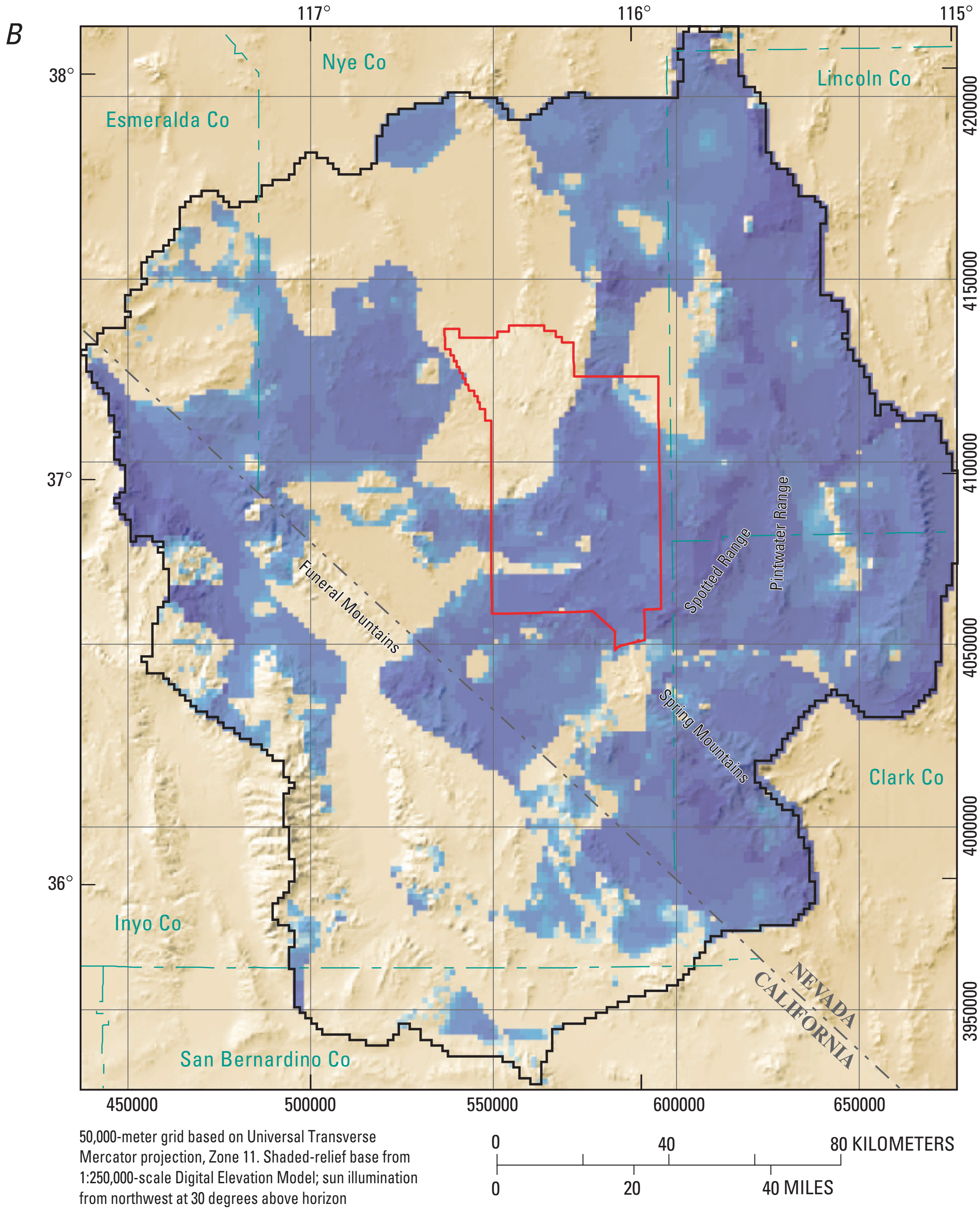
Cross section

Borehole

Nevada Test Site boundary

Death Valley regional ground-water flow system model grid boundary

Figure E–34. (*A*) Data sources and (*B*) thickness of lower carbonate-rock aquifer.



50,000-meter grid based on Universal Transverse Mercator projection, Zone 11. Shaded-relief base from 1:250,000-scale Digital Elevation Model; sun illumination from northwest at 30 degrees above horizon

EXPLANATION

Lower carbonate-rock aquifer (LCA)—Thickness, in meters

- 0–10
- 10–25
- 25–50
- 50–100
- 100–250
- 250–500
- 500–1,500
- 1,500–3,000
- 3,000–5,000
- 5,000–6,497

Nevada Test Site boundary

Death Valley regional ground-water flow system model grid boundary

Figure E–34. (*A*) Data sources and (*B*) thickness of lower carbonate-rock aquifer.—Continued

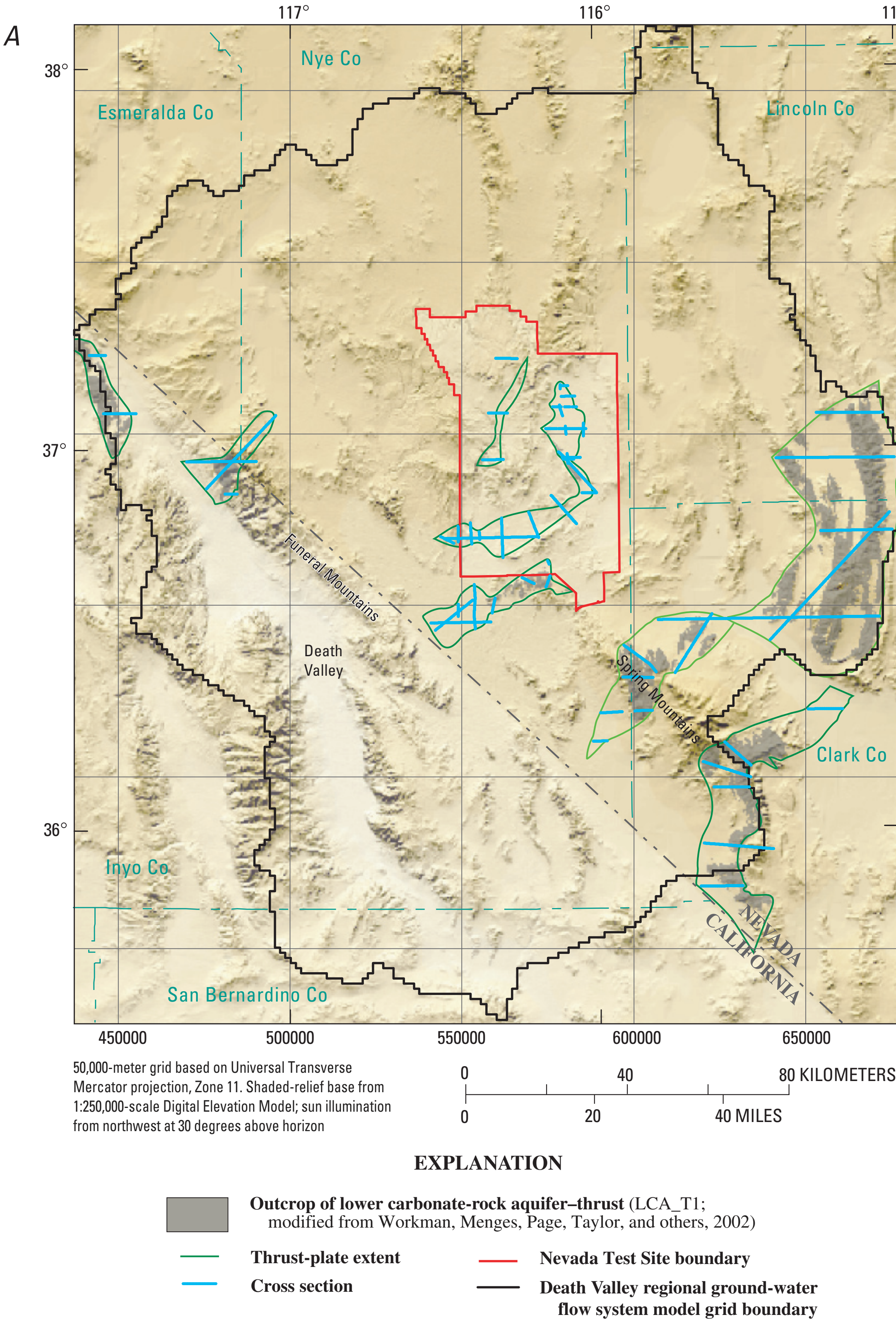
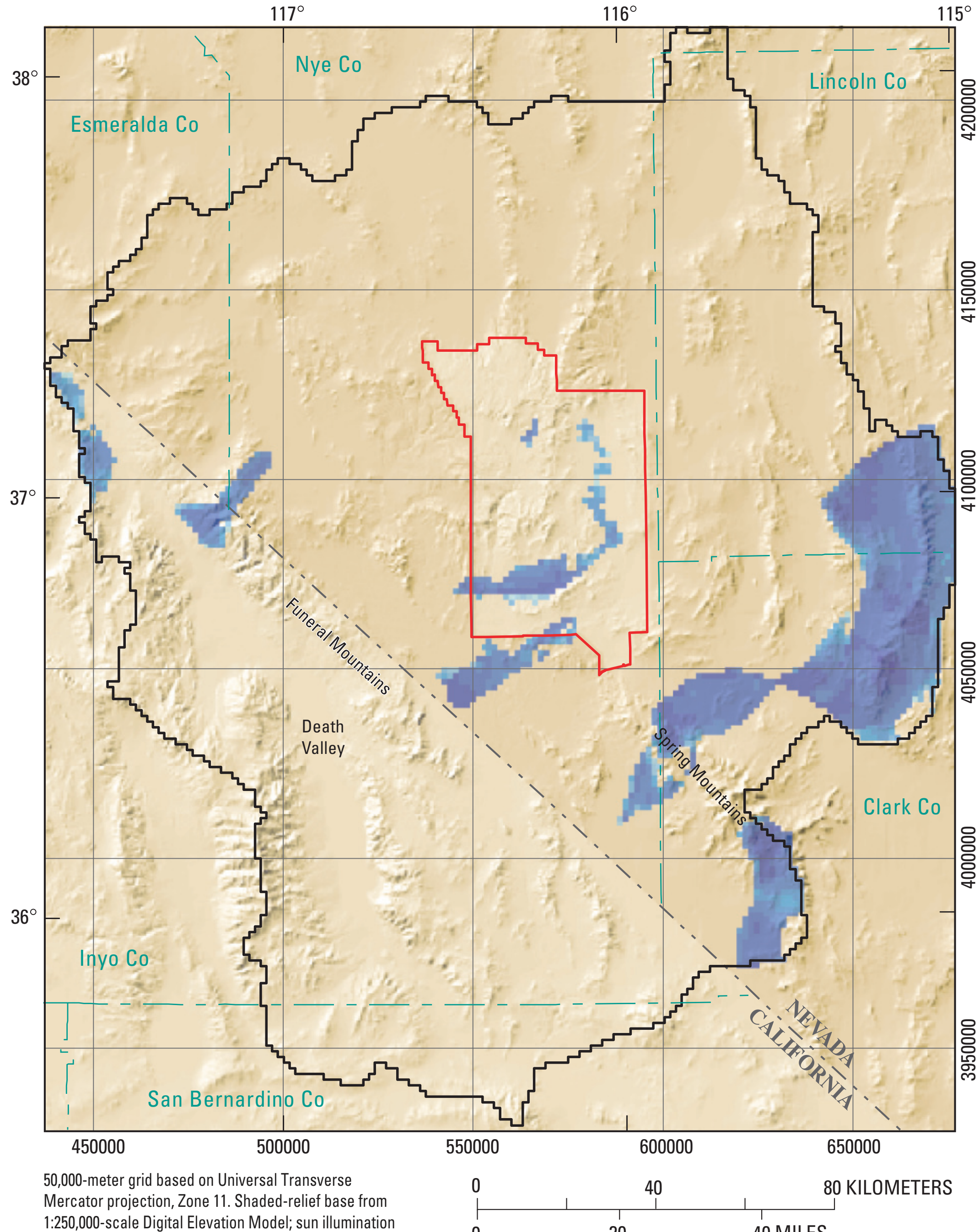


Figure E–35. (*A*) Data sources and (*B*) thickness of thrusted lower carbonate-rock aquifer.

B



50,000-meter grid based on Universal Transverse Mercator projection, Zone 11. Shaded-relief base from 1:250,000-scale Digital Elevation Model; sun illumination from northwest at 30 degrees above horizon

EXPLANATION

Lower carbonate-rock aquifer–thrust (LCA_T1)—Thickness, in meters

0–10
10–25
25–50
50–100
100–250
250–500
500–1,500
1,500–3,000
3,000–5,000
5,000–5,517

Nevada Test Site boundary

Death Valley regional ground-water flow system model grid boundary

Figure E–35. (*A*) Data sources and (*B*) thickness of thrusted lower carbonate-rock aquifer.—Continued

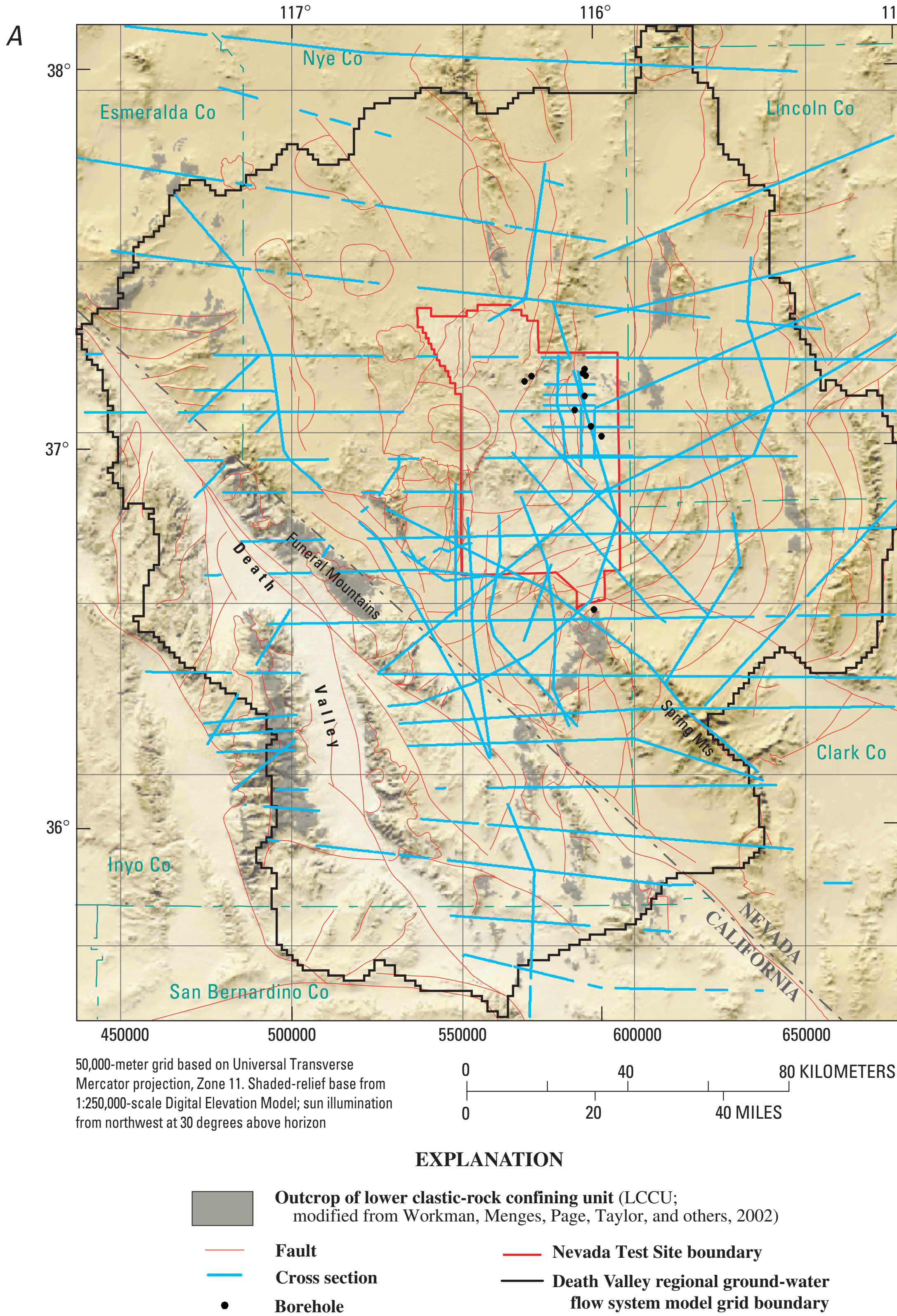
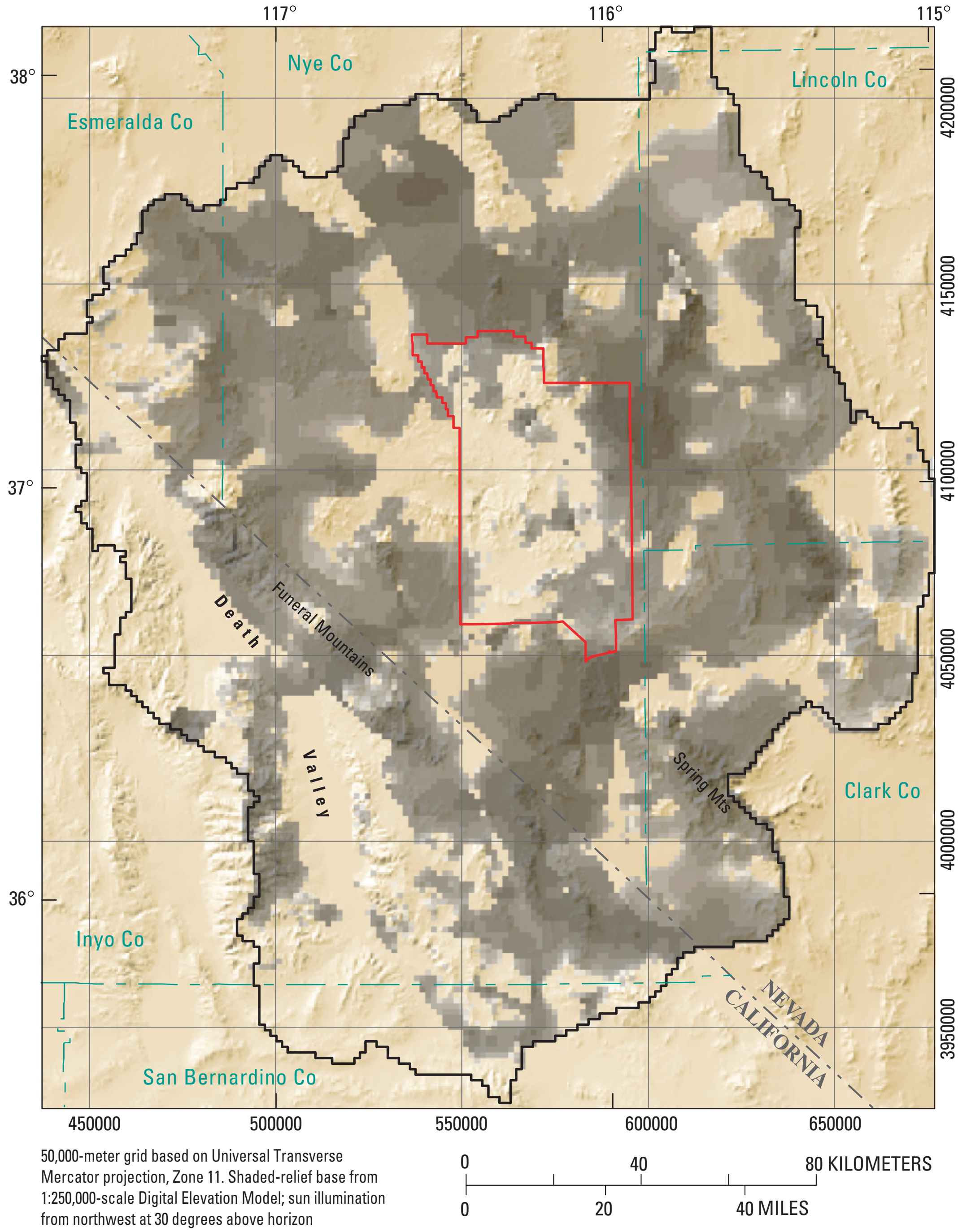


Figure E–36. (*A*) Data sources and (*B*) thickness of lower clastic-rock confining unit.

B



50,000-meter grid based on Universal Transverse Mercator projection, Zone 11. Shaded-relief base from 1:250,000-scale Digital Elevation Model; sun illumination from northwest at 30 degrees above horizon

EXPLANATION

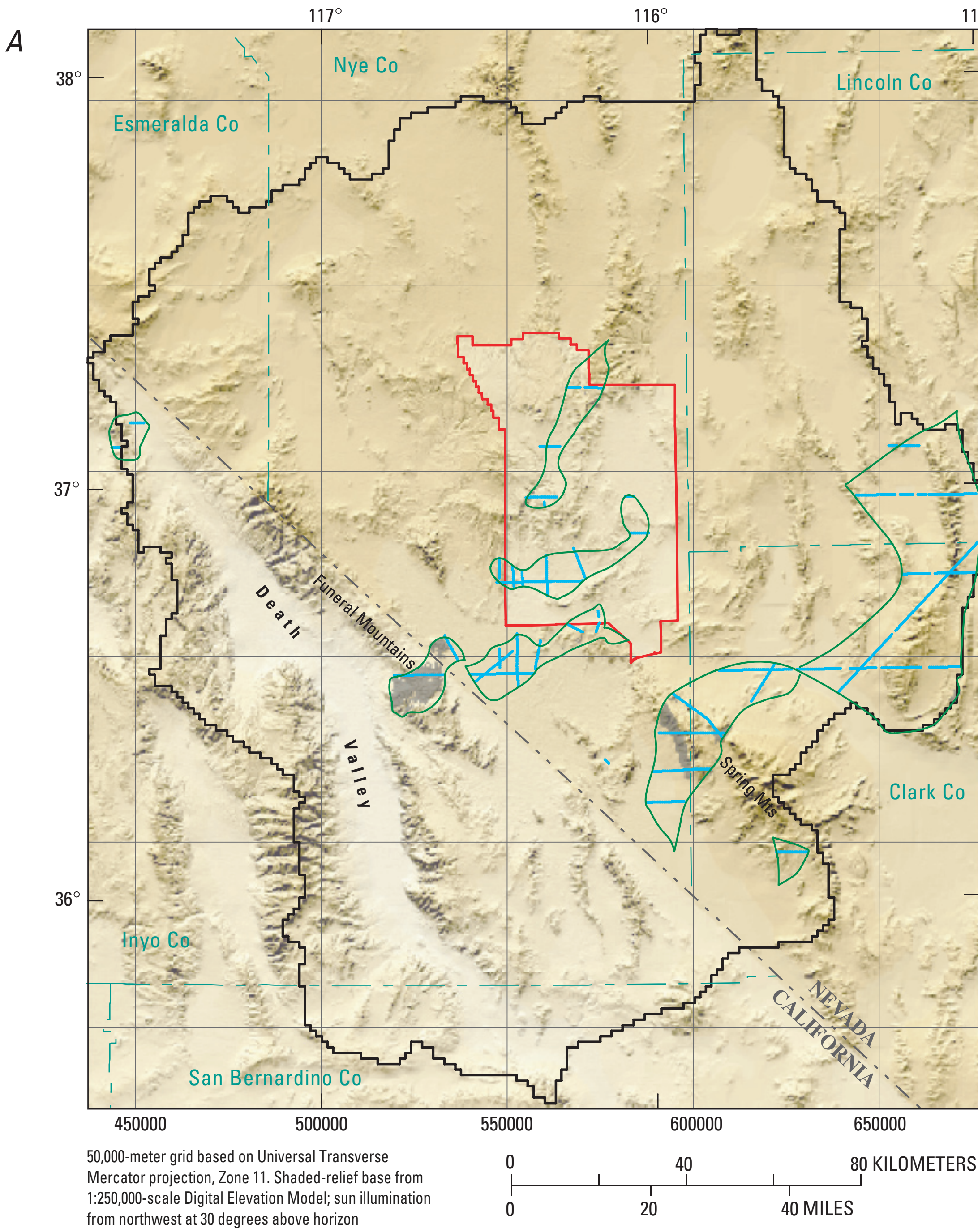
Lower clastic-rock confining unit (LCCU)—Thickness, in meters

- 0–10
- 10–25
- 25–50
- 50–100
- 100–250
- 250–500
- 500–1,500
- 1,500–3,000
- 3,000–5,000
- 5,000–6,250

Nevada Test Site boundary

Death Valley regional ground-water flow system model grid boundary

Figure E–36. (*A*) Data sources and (*B*) thickness of lower clastic-rock confining unit.—Continued



EXPLANATION

Outcrop of lower clastic-rock confining unit–thrust (LCCU_T1; modified from Workman, Menges, Page, Taylor, and others, 2002)

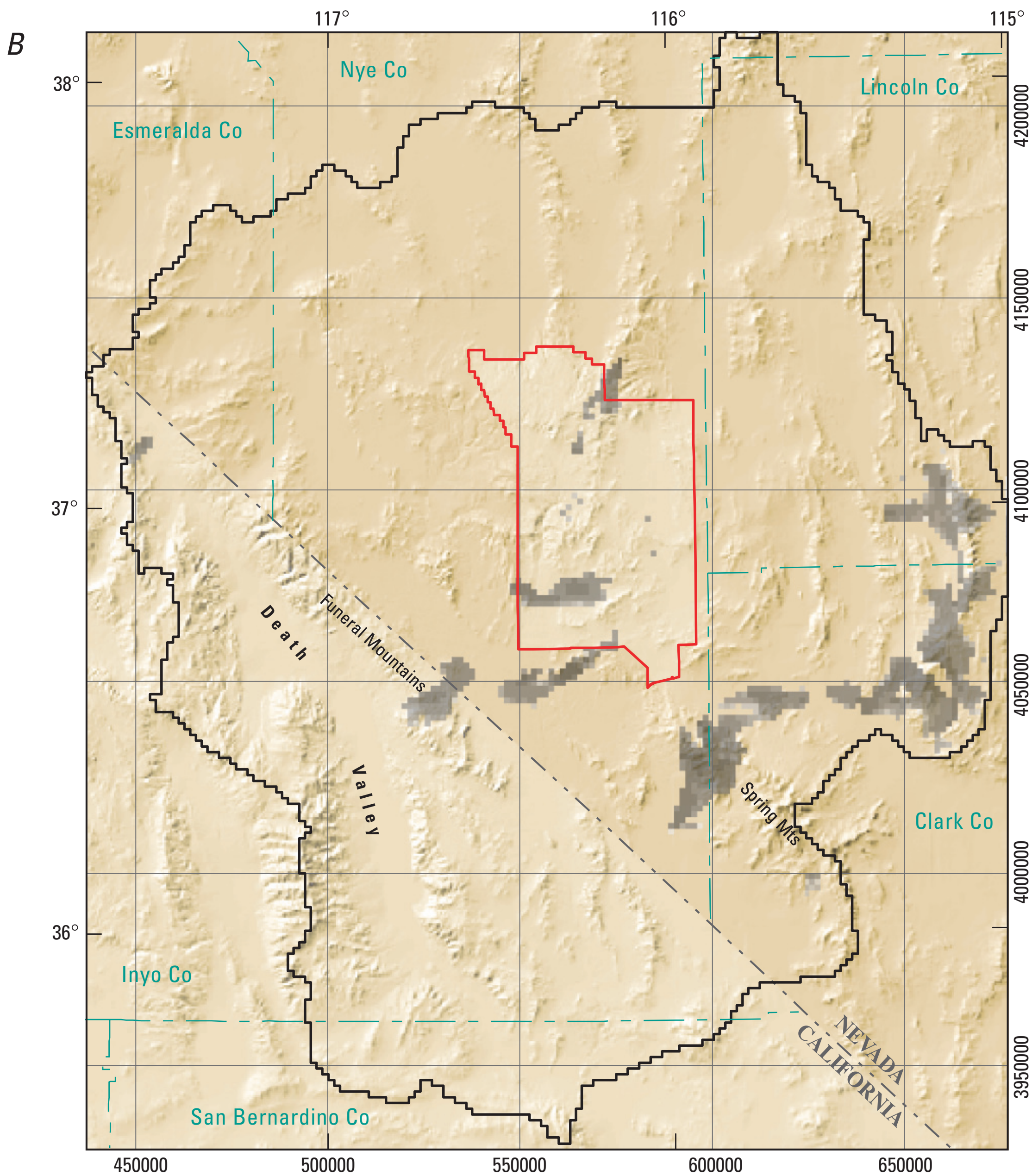
Thrust-plate extent

Cross section

Nevada Test Site boundary

Death Valley regional ground-water flow system model grid boundary

Figure E–37. (*A*) Data sources and (*B*) thickness of thrusted lower clastic-rock confining unit.



50,000-meter grid based on Universal Transverse Mercator projection, Zone 11. Shaded-relief base from 1:250,000-scale Digital Elevation Model; sun illumination from northwest at 30 degrees above horizon

0 40 80 KILOMETERS
0 20 40 MILES

EXPLANATION

Lower clastic-rock confining unit–thrust (LCCU_T1)—Thickness, in meters

0–10
10–25
25–50
50–100
100–250
250–500
500–1,500
1,500–3,000
3,000–4,412

Nevada Test Site boundary

Death Valley regional ground-water flow system model grid boundary

Figure E–37. (*A*) Data sources and (*B*) thickness of thrusted lower clastic-rock confining unit.—Continued

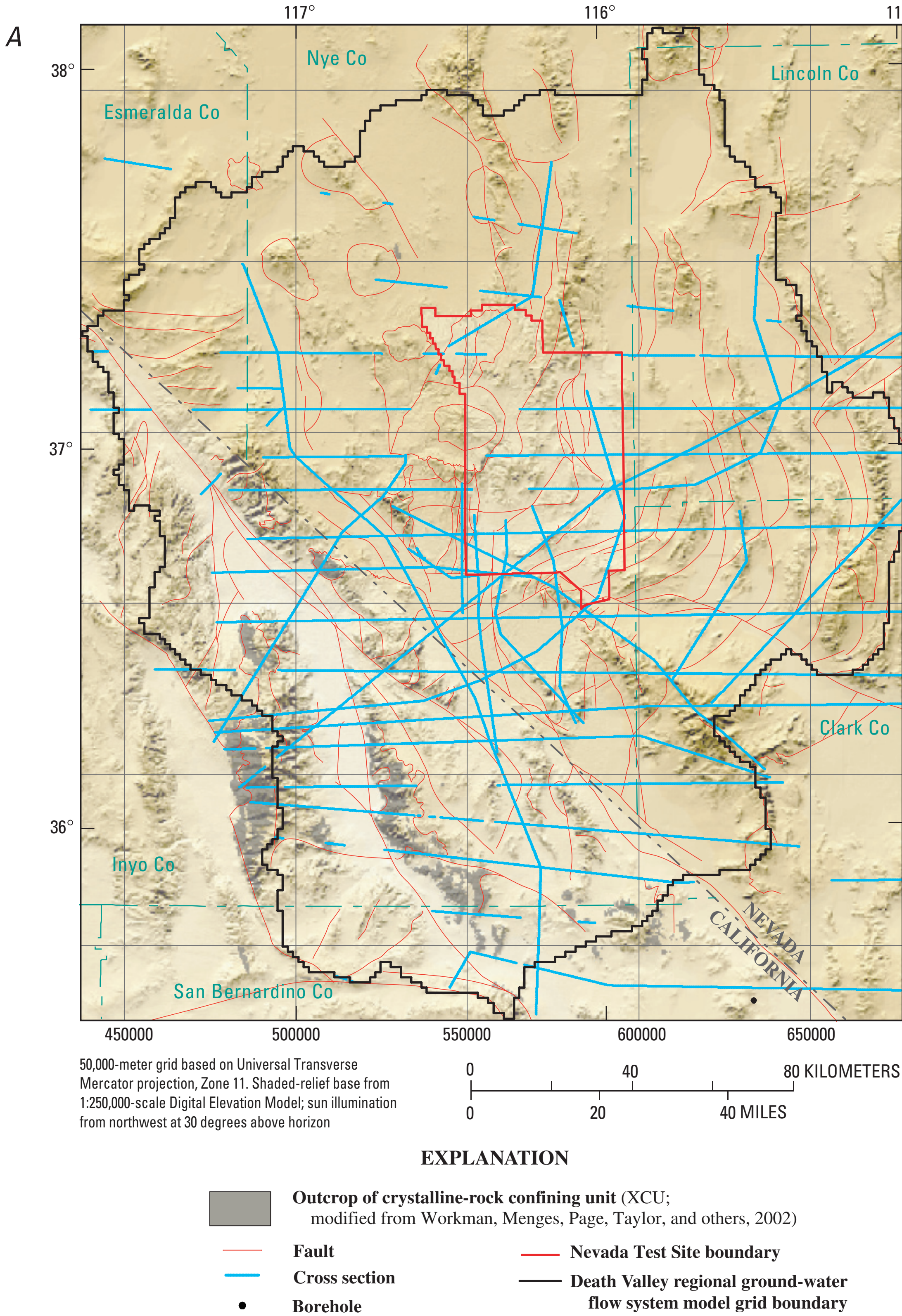


Figure E–38. (*A*) Data sources and (*B*) thickness of crystalline-rock confining unit.

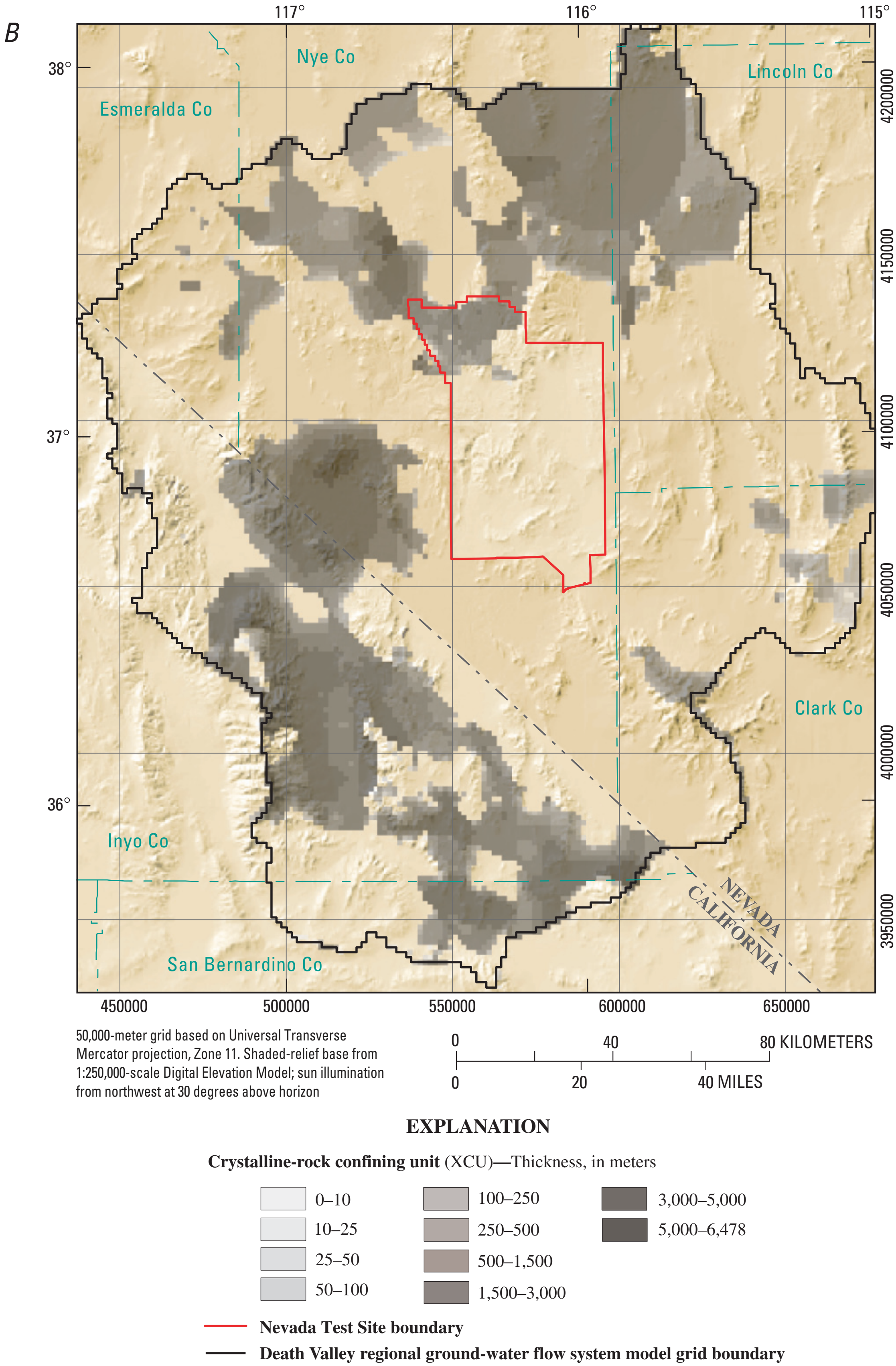
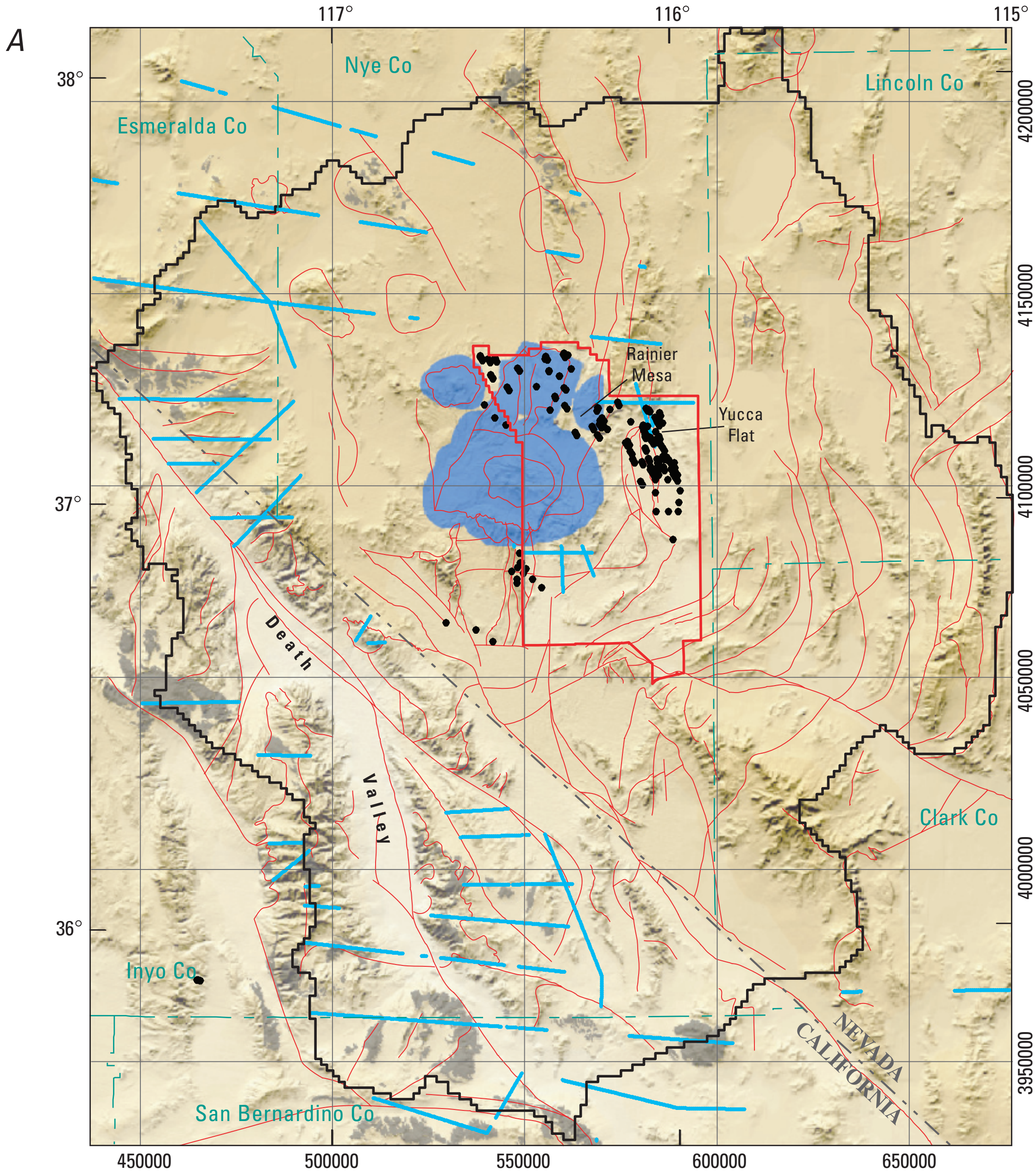


Figure E–38. (*A*) Data sources and (*B*) thickness of crystalline-rock confining unit.—Continued



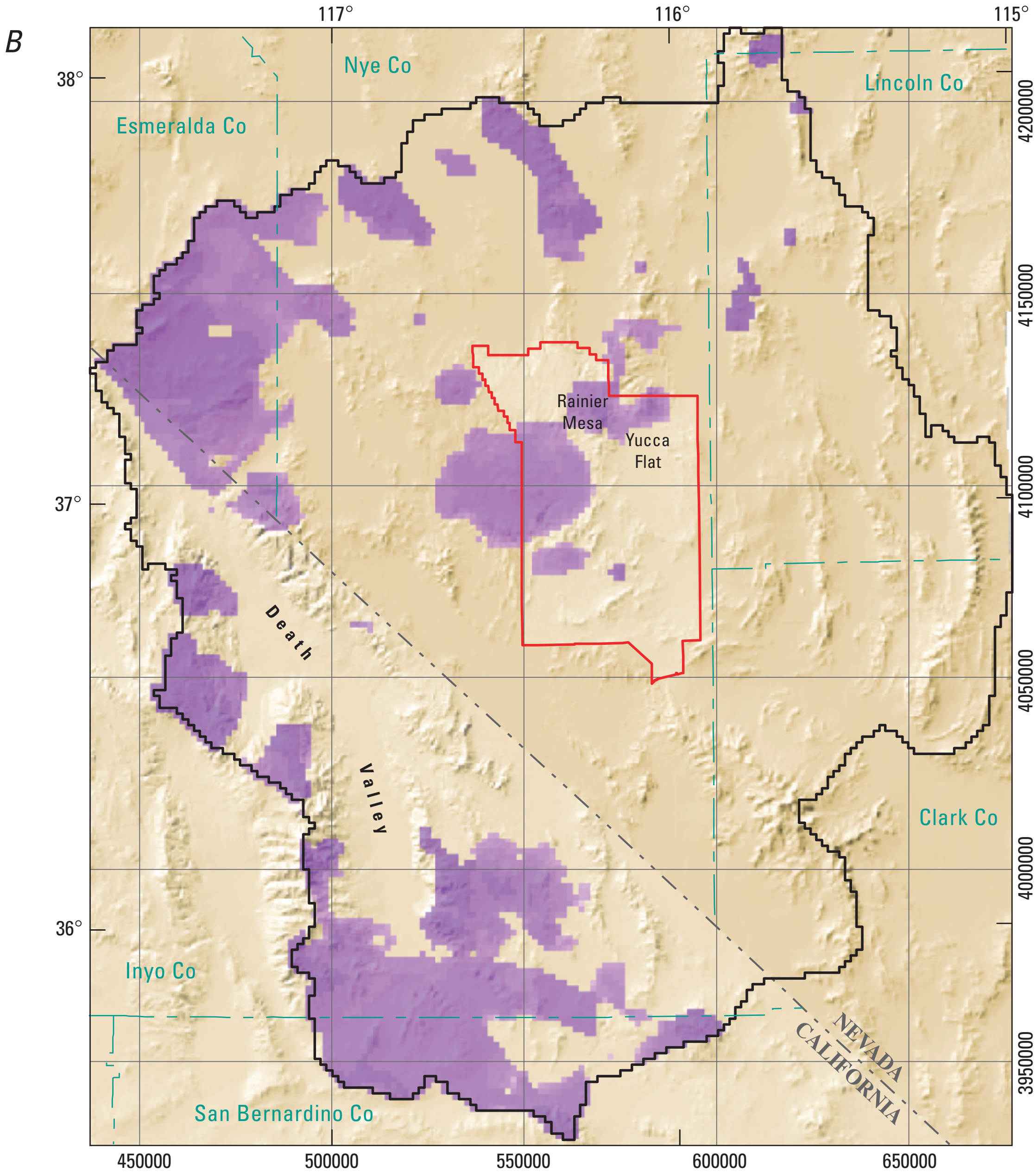
50,000-meter grid based on Universal Transverse Mercator projection, Zone 11. Shaded-relief base from 1:250,000-scale Digital Elevation Model; sun illumination from northwest at 30 degrees above horizon

0 40 80 KILOMETERS
0 20 40 MILES

EXPLANATION

- **Outcrop of intrusive-rock confining unit** (ICU; modified from Workman, Menges, Page, Taylor, and others, 2002)
- **Pahute Mesa–Oasis Valley model** (Bechtel Nevada, 2002)
- **Fault**
- **Cross section**
- **Borehole**
- **Nevada Test Site boundary**
- **Death Valley regional ground-water flow system model grid boundary**

Figure E–39. (*A*) Data sources and (*B*) thickness of intrusive-rock confining unit.



50,000-meter grid based on Universal Transverse Mercator projection, Zone 11. Shaded-relief base from 1:250,000-scale Digital Elevation Model; sun illumination from northwest at 30 degrees above horizon

0 40 80 KILOMETERS
0 20 40 MILES

EXPLANATION

Intrusive-rock confining unit (ICU)—Thickness, in meters

- 0–10
- 10–25
- 25–50
- 50–100
- 100–250
- 250–500
- 500–1,500
- 1,500–3,000
- 3,000–6,672

Nevada Test Site boundary

Death Valley regional ground-water flow system model grid boundary

Figure E–39. (*A*) Data sources and (*B*) thickness of intrusive-rock confining unit.—Continued

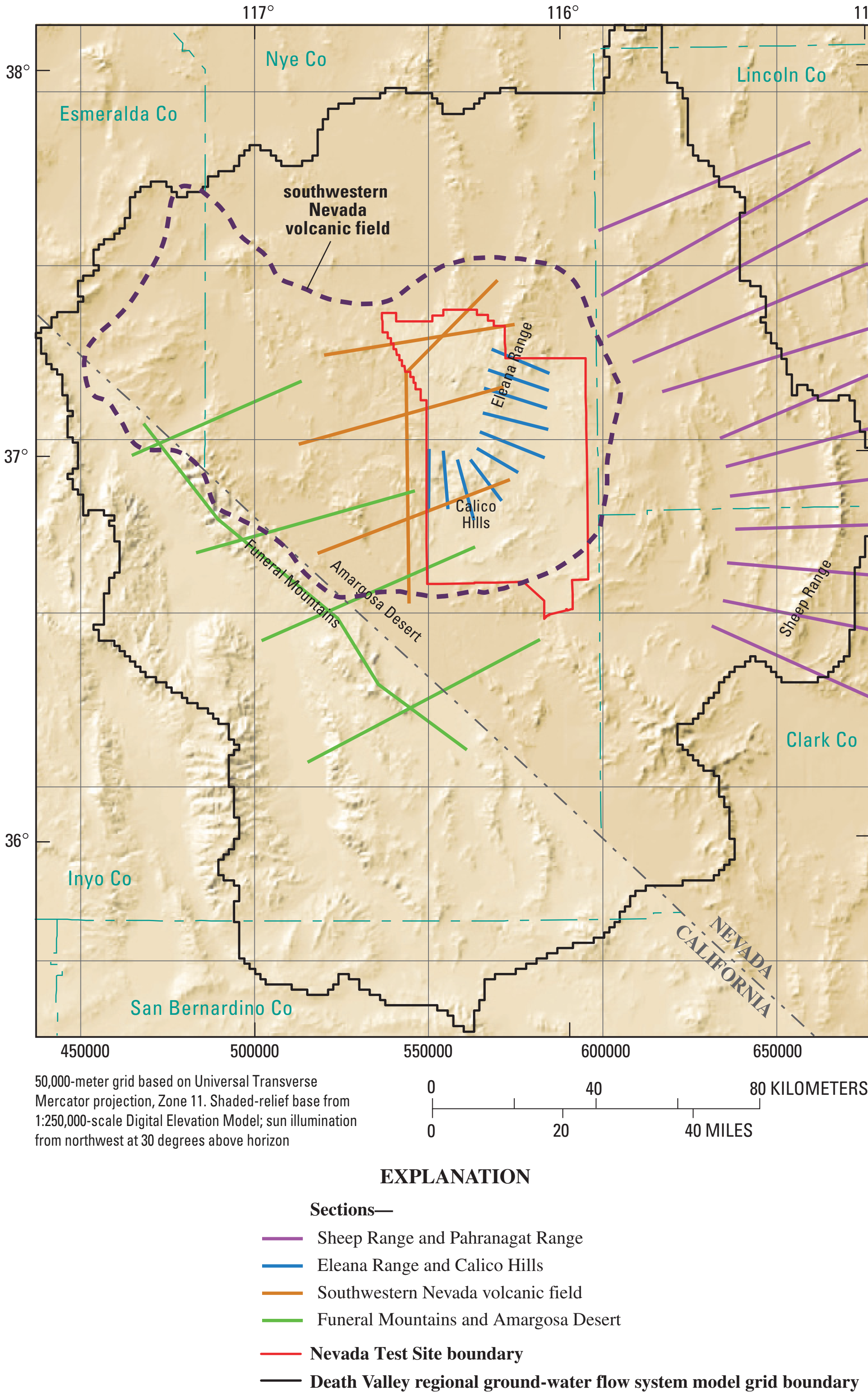
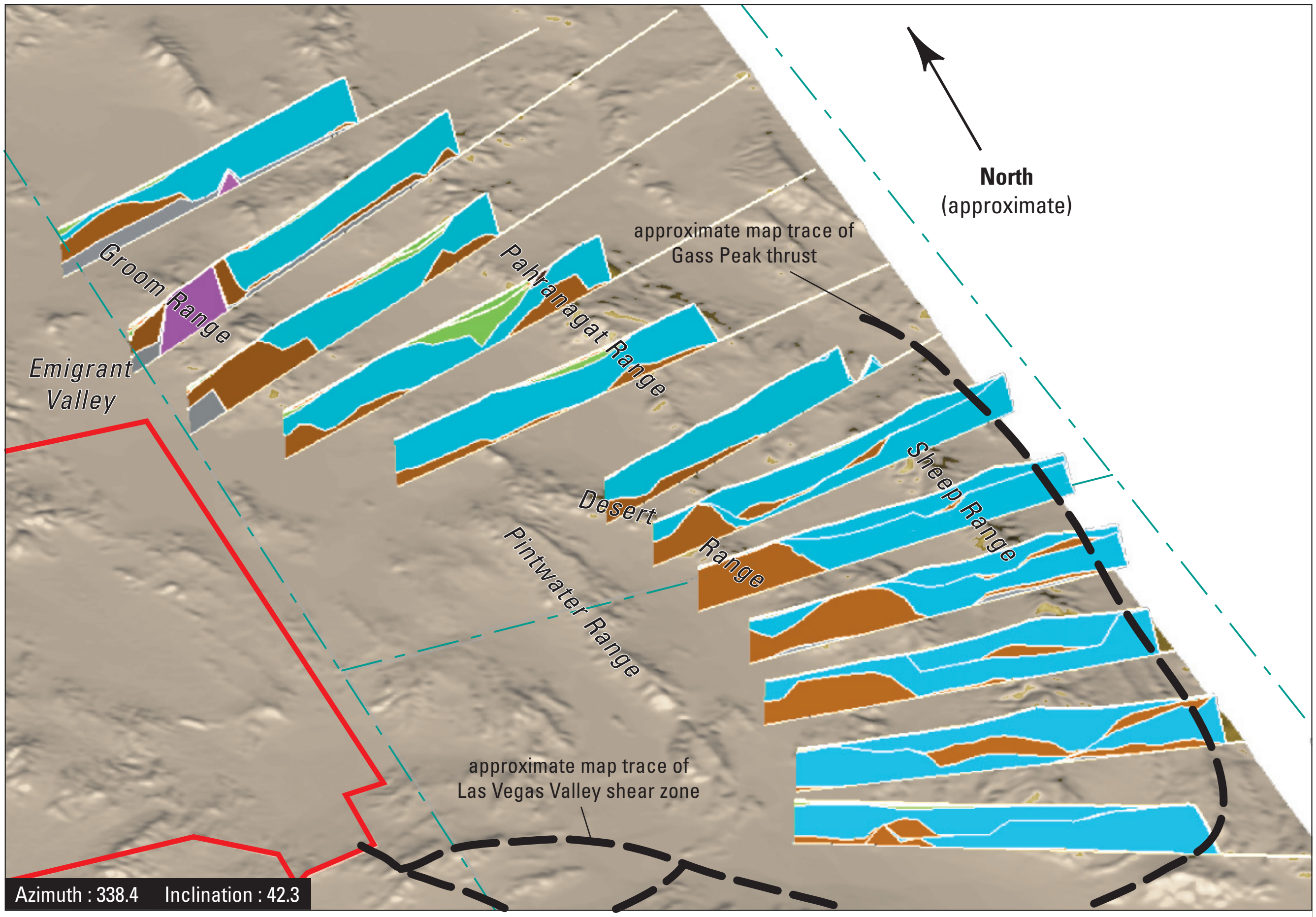


Figure E–40. Locations of sections from the hydrogeologic framework model in key areas.



Shaded-relief base from 1:250,000-scale Digital Elevation Model;
sun illumination from northwest at 30 degrees above horizon

EXPLANATION

Hydrogeologic unit
(Not all units appear on sections)

- Younger alluvial aquifer **(YAA)**
- Younger alluvial confining unit **(YACU)**
- Older alluvial aquifer **(OAA)**
- Older alluvial confining unit **(OACU)**
- Limestone aquifer **(LA)**
- Lava-flow unit **(LFU)**
- Younger volcanic-rock unit **(YVU)**
- Upper volcanic- and sedimentary-rock unit **(upper VSU)**
- Timber Mountain–Thirsty Canyon volcanic-rock aquifer **(TMVA)**
- Paintbrush volcanic-rock aquifer **(PVA)**
- Calico Hills volcanic-rock unit **(CHVU)**
- Wahmonie volcanic-rock unit **(WVU)**
- Crater Flat–Prow Pass aquifer **(CFPPA)**
- Crater Flat–Bullfrog confining unit **(CFBCU)**
- Crater Flat–Tram aquifer **(CFTA)**
- Belted Range unit **(BRU)**
- Older volcanic-rock unit **(OVU)**
- Lower volcanic- and sedimentary-rock unit **(lower VSU)**
- Sedimentary-rock confining unit **(SCU)**
- Lower carbonate-rock aquifer-thrust **(LCA_T1)**
- Lower clastic-rock confining unit-thrust **(LCCU_T1)**
- Upper carbonate-rock aquifer **(UCA)**
- Upper clastic-rock confining unit **(UCCU)**
- Lower carbonate-rock aquifer **(LCA)**
- Lower clastic-rock confining unit **(LCCU)**
- Crystalline-rock confining unit **(XCU)**
- Intrusive-rock confining unit **(ICU)**

Base of each cross section corresponds to the base of the regional hydrogeologic framework model (4,000 meters below sea level)

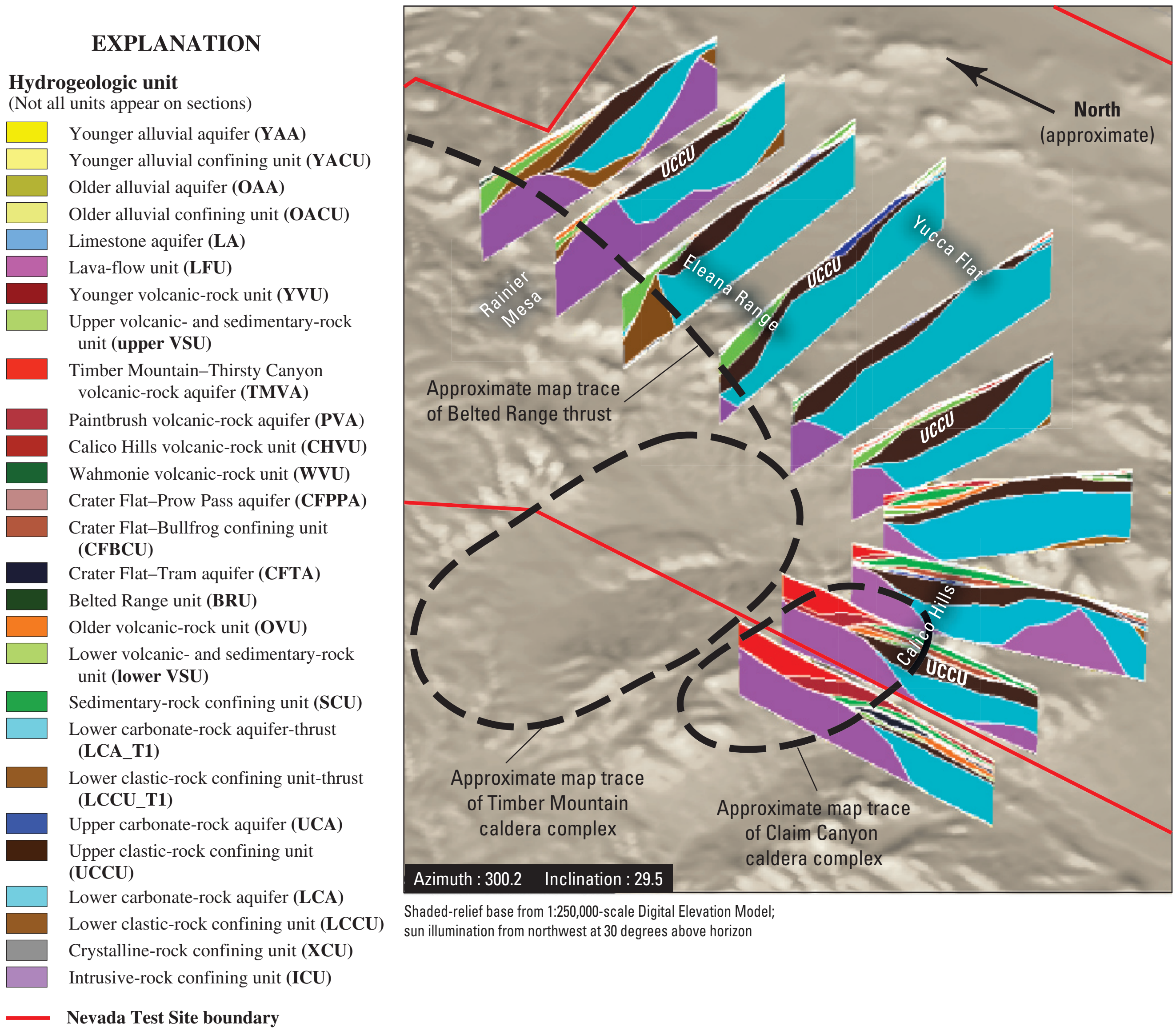
Azimuth—Specifies horizontal angle that north end of model has been rotated from north

Inclination—Specifies vertical angle that the model has been rotated from horizontal

County line

Nevada Test Site boundary

Figure E–41. Sections from the hydrogeologic framework model across the Sheep Range and adjacent areas.



Base of each cross section corresponds to the base of the regional hydrogeologic framework model (4,000 meters below sea level)

Azimuth—Specifies horizontal angle that north end of model has been rotated from north

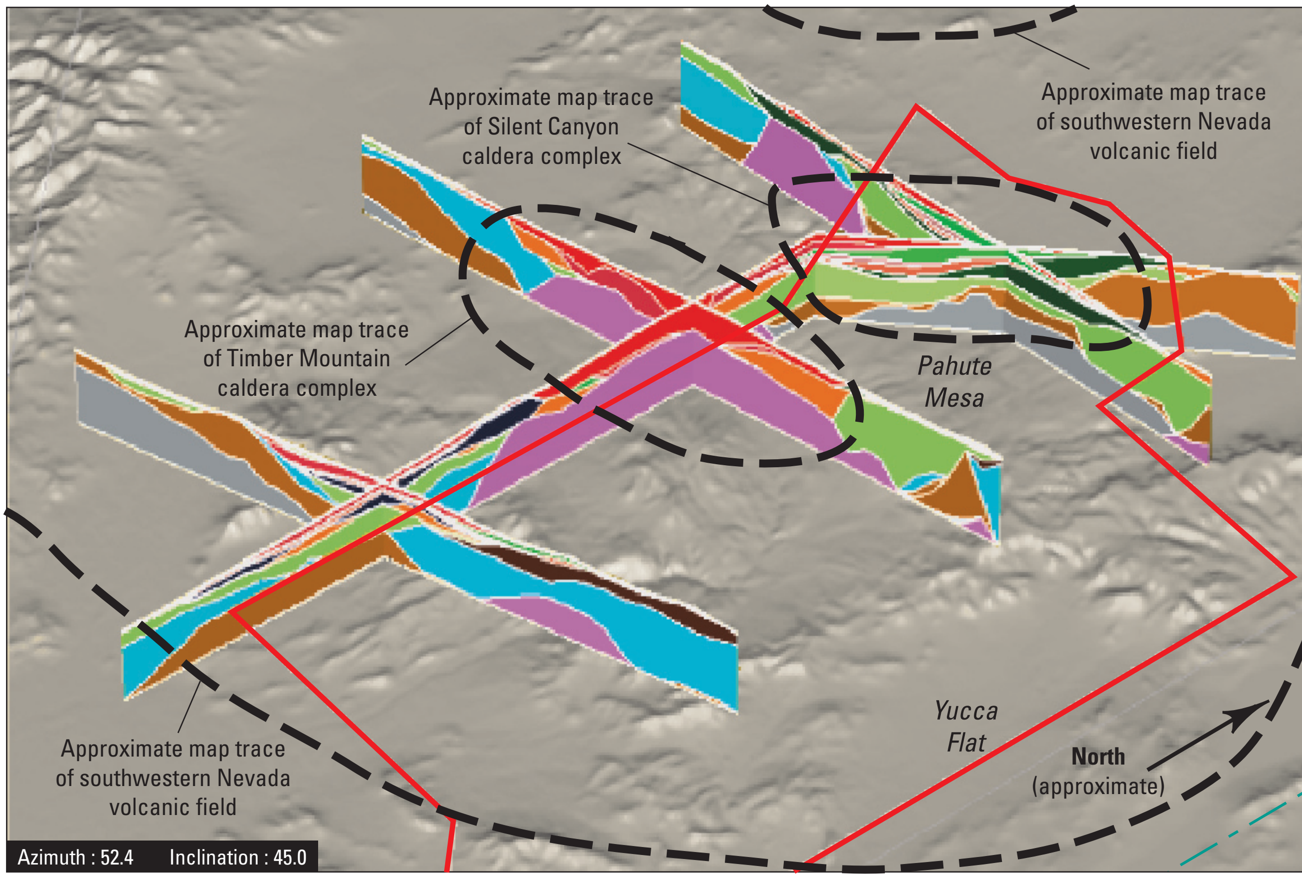
Inclination—Specifies vertical angle that the model has been rotated from horizontal

Figure E–42. Sections from the hydrogeologic framework model across the Eleana Range and Calico Hills.

Funeral Mountains and Amargosa Desert

The Boundary Canyon detachment in the central Funeral Mountains is a gently dipping fault that juxtaposes LCCU and XCU in the lower plate, and the unmetamorphosed rocks of the upper plate (Wright and Troxel, 1993; Hamilton, 1988). Sections from the HFM in the vicinity of the Funeral Mountains (fig. E–44) portray the archlike Boundary Canyon detachment in the Grapevine and Funeral Mountains. In the vicinity of the Grapevine Mountains, the upper plate of the detachment fault as portrayed in the HFM contains LCCU and LCA, which are onlapped by volcanic rocks in the vicinity of Sarcobatus Flat and Grapevine Canyon (northernmost section in fig. E–44). In the vicinity of Furnace Creek, the HFM is dominated by LCCU above the Boundary Canyon detachment fault and both LCCU and XCU exist beneath this fault. The southeastern end of the Funeral Mountains is dominated by LCA, with LCCU being carried in the upper plates of the thrusts.

The southernmost section from the HFM (fig. E–44) extends from the vicinity of Badwater Basin in Death Valley through Furnace Creek Wash, the southern Funeral Mountains, and the Amargosa Desert. The eastern end of the section includes the vicinity of Devils Hole and Amargosa Flat. This section portrays the juxtaposition of the basin fill and the LCA in the Amargosa Desert. The Furnace Creek fault zone



Shaded-relief base from 1:250,000-scale Digital Elevation Model; sun illumination from northwest at 30 degrees above horizon

EXPLANATION

Hydrogeologic unit
(Not all units appear on sections)

- Younger alluvial aquifer **(YAA)**
- Younger alluvial confining unit **(YACU)**
- Older alluvial aquifer **(OAA)**
- Older alluvial confining unit **(OACU)**
- Limestone aquifer **(LA)**
- Lava-flow unit **(LFU)**
- Younger volcanic-rock unit **(YVU)**
- Upper volcanic- and sedimentary-rock unit **(upper VSU)**
- Timber Mountain–Thirsty Canyon volcanic-rock aquifer **(TMVA)**
- Paintbrush volcanic-rock aquifer **(PVA)**
- Calico Hills volcanic-rock unit **(CHVU**
- Wahmonie volcanic-rock unit **(WVU)**
- Crater Flat–Prow Pass aquifer **(CFPPA)**
- Crater Flat–Bullfrog confining unit **(CFBCU)**
- Crater Flat–Tram aquifer **(CFTA)**
- Belted Range unit **(BRU)**
- Older volcanic-rock unit **(OVU)**
- Lower volcanic- and sedimentary-rock unit **(lower VSU)**
- Sedimentary-rock confining unit **(SCU)**
- Lower carbonate-rock aquifer-thrust **(LCA_T1)**
- Lower clastic-rock confining unit-thrust **(LCCU_T1)**
- Upper carbonate-rock aquifer **(UCA)**
- Upper clastic-rock confining unit **(UCCU)**
- Lower carbonate-rock aquifer **(LCA)**
- Lower clastic-rock confining unit **(LCCU)**
- Crystalline-rock confining unit **(XCU)**
- Intrusive-rock confining unit **(ICU)**

Base of each cross section corresponds to the base of the regional hydrogeologic framework model (4,000 meters below sea level)

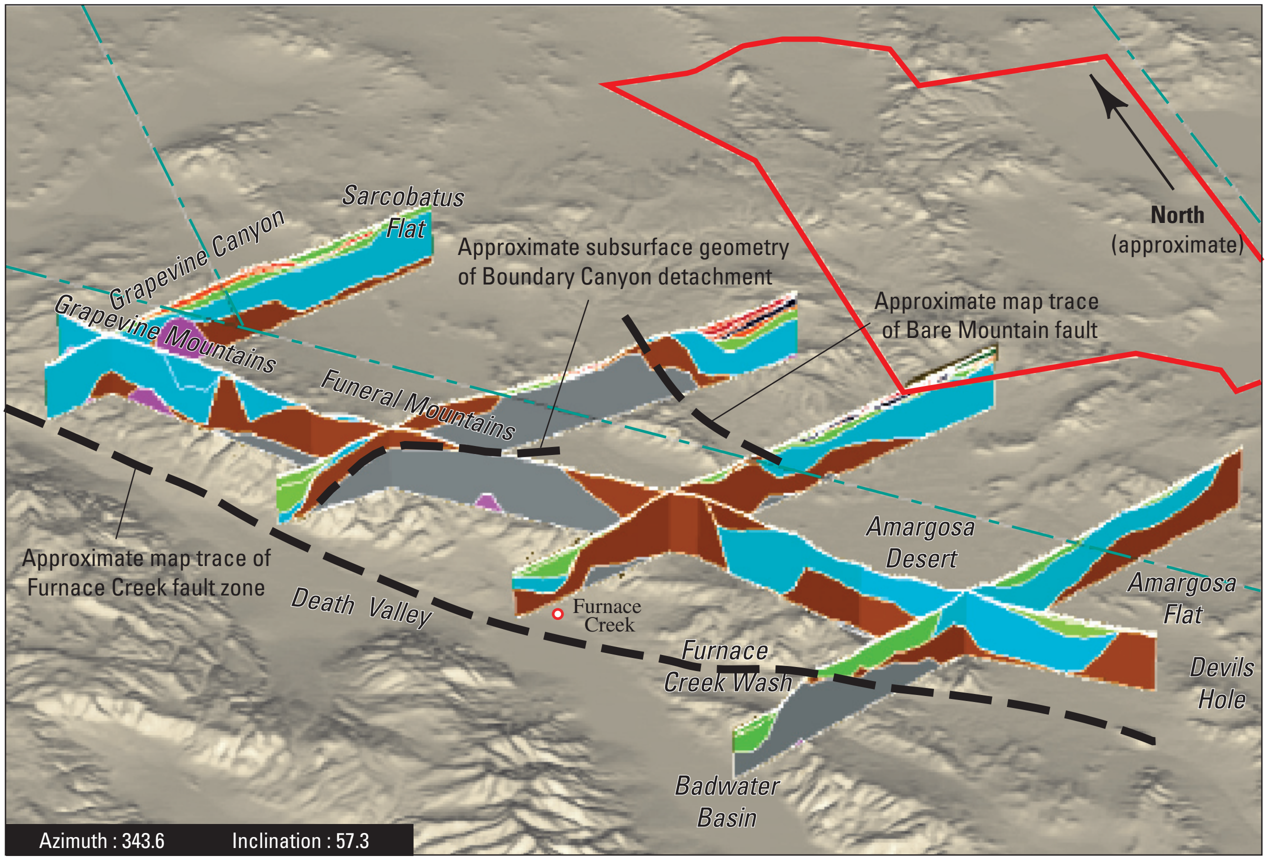
Azimuth—Specifies horizontal angle that north end of model has been rotated from north

Inclination—Specifies vertical angle that the model has been rotated from horizontal

County line

Nevada Test Site boundary

Figure E–43. Sections from the hydrogeologic framework model across the southwestern Nevada volcanic field.



Shaded-relief base from 1:250,000-scale Digital Elevation Model;
sun illumination from northwest at 30 degrees above horizon

EXPLANATION

Hydrogeologic unit
(Not all units appear on sections)

- Younger alluvial aquifer **(YAA)**
- Younger alluvial confining unit **(YACU)**
- Older alluvial aquifer **(OAA)**
- Older alluvial confining unit **(OACU)**
- Limestone aquifer **(LA)**
- Lava-flow unit **(LFU)**
- Younger volcanic-rock unit **(YVU)**
- Upper volcanic- and sedimentary-rock unit **(upper VSU)**
- Timber Mountain–Thirsty Canyon volcanic-rock aquifer **(TMVA)**
- Paintbrush volcanic-rock aquifer **(PVA)**
- Calico Hills volcanic-rock unit **(CHVU)**
- Wahmonie volcanic-rock unit **(WVU)**
- Crater Flat–Prow Pass aquifer **(CFPPA)**
- Crater Flat–Bullfrog confining unit **(CFBCU)**
- Crater Flat–Tram aquifer **(CFTA)**
- Belted Range unit **(BRU)**
- Older volcanic-rock unit **(OVU)**
- Lower volcanic- and sedimentary-rock unit **(lower VSU)**
- Sedimentary-rock confining unit **(SCU)**
- Lower carbonate-rock aquifer-thrust **(LCA_T1)**
- Lower clastic-rock confining unit-thrust **(LCCU_T1)**
- Upper carbonate-rock aquifer **(UCA)**
- Upper clastic-rock confining unit **(UCCU)**
- Lower carbonate-rock aquifer **(LCA)**
- Lower clastic-rock confining unit **(LCCU)**
- Crystalline-rock confining unit **(XCU)**
- Intrusive-rock confining unit **(ICU)**

Base of each cross section corresponds to the base of the regional hydrogeologic framework model (4,000 meters below sea level)

Azimuth—Specifies horizontal angle that north end of model has been rotated from north

Inclination—Specifies vertical angle that the model has been rotated from horizontal

- **County line**
- **Nevada Test Site boundary**
- **Populated location**

Figure E–44. Sections from the hydrogeologic framework model across the Funeral Mountains and Amargosa Desert.

abruptly terminates the LCA on the southwestern side of the Funeral Mountains. To the southwest, the Cenozoic sedimentary and volcanic rocks of the Furnace Creek Basin are portrayed by the lower VSU, deposited on LCCU/XCU/ICU, with the LCA having been tectonically removed through extreme extension (Chapter B, this volume).

Sections from the HFM in the vicinity of the western part of the Amargosa Desert (fig. E–44) portray a structurally high LCCU/XCU underlying a relatively thin (1,000 m or less) veneer of Cenozoic volcanic rocks and basin-fill deposits. Depth to pre-Cenozoic rocks increases east of the southern projection of the Bare Mountain fault, where basin fill reaches thicknesses of as much as 2,000 m on the basis of models of gravity data (Blakely and Ponce, 2001). The HFM portrays relatively continuous LCA deep beneath the Amargosa Desert. The basin-fill sedimentary rocks and unconsolidated deposits of the Amargosa Desert are largely portrayed by the lower VSU.

Summary

A three-dimensional (3D) digital hydrologic framework model (HFM) was constructed to develop an interpretation of the regional hydrogeology of the Death Valley regional ground-water flow system (DVRFS). The HFM integrates existing and new geologic information developed in the DVRFS region and describes the geometry and extent of the hydrogeologic units (HGUs) that control ground-water flow. It is an important information source for the DVRFS numerical ground-water flow model. The primary data sources used to develop the HFM are: digital elevation models, geologic maps, borehole lithologic logs, geologic and hydrogeologic cross sections, local 3D hydrogeologic framework models, and hydrostructural information. Approximately 70 regional geologic cross sections, reflecting a consistent interpretation of regional structural style, and approximately 7,000 lithologic contacts between HGUs from borehole information provided the subsurface control for the HFM. The geologic data from geologic maps, cross sections, and borehole lithologic logs were correlated into 27 HGUs. Gridded surfaces from other 3D hydrogeologic framework models constructed for the Nevada Test Site (NTS) and Yucca Mountain also were used.

The HFM defines regional-scale hydrogeology and structures to a depth of 4,000 m below sea level. The model has 1,500-m horizontal resolution and variable vertical thickness for the HGUs. The faults thought to be hydrologically significant were used for offsetting HGUs in the 3D model.

Evaluations of the HFM show that it generally portrays the regional hydrogeology. During flow-model calibration, in some locations the HFM did not allow accurate simulations. In such locations, the HFM was examined and the uncertainty in the existing interpretations considered; where alternative interpretations were appropriate and deemed necessary, the HFM was modified.

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