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A STRUCTURAL BLOCK MODEL FOR THE THREE-DIMENSIONAL GEOLOGY OF THE SOUTHWESTERN NEVADA VOLCANIC FIELD

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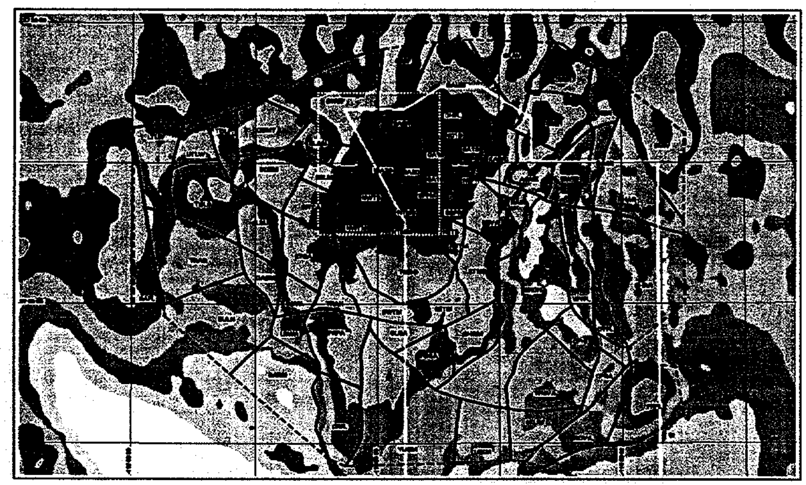


Purpose and Scope

To model the regional flow of groundwater within the southwestern Nevada volcanic field (SWNVF) of the Nevada Test Site (NTS), the subsurface geology must be described completely, even within regions where confidence in geologic interpretation is low. This report provides a two-dimensional representation of geologic structures that we consider the most significant within the SWNVF. Included are obvious, well known structures related to Basin-Range faulting or caldera formation, as well as buried, conjectural structures that explain discontinuities in mapped geologic units and/or distinctive features in regional geophysical datasets. The intersection of these structures forms a veritable jigsaw puzzle of structural blocks. Within each block, stratigraphic units are relatively uniform in character, and each block has a unique structural history that differs from that of its neighbors. The three-dimensional geology can be accurately constructed when subsurface and geophysical data are both available, or crudely conceptualized from geologic maps and geophysical data alone if drill holes have not been sited within the block. We provide a three-dimensional representation for an area centered on the Western Area 20 structural block. For all other blocks, we provide a summary of important structural data to guide construction of a three dimensional representation. Finally, to apply our three-dimensional geologic model for hydrologic modeling, stratigraphic units must be assembled, subdivided, or modeled as hydrogeologic units. We provide tables that allow conversion of this geologic model into a hydrogeologic model.

A two-dimensional structural model for the SWNVF based on linear structural elements

The most obvious geologic features of the SWNVF are calderas formed by the voluminous eruptions of zoned ignimbrites between 16 and 7.5 Ma ago. Most regional descriptions of the SWNVF assume that these calderas have approximately circular boundaries (Sawyer et al., 1994; Noble et al., 1991; Christiansen et al., 1977; Byers et al., 1976a and b), although structural boundaries of all calderas are obscured by burial or later resurgence. The location of even the largest and youngest calderas is only generally known, so the geometry of their structural boundaries can only be reckoned. In contrast, locations are well known for contemporaneous Basin-Range faults, which were clearly coupled with caldera formation (Warren et al., 1985; Christiansen et al., 1977; Cummings, 1968). Seismic refraction surveys found an exact correspondence between two Basin-Range faults and deeply buried boundaries for the Area 20 and Grouse Canyon calderas (Ferguson et al., 1994). Considering this finding and the highly extensional nature of the Basin-Range province, Ferguson et al. (1994) consider the creation of circular calderas unlikely within the SWNVF. In the words of Kane et al. (1981): "...gravity and aeromagnetic surveys of the Timber Mountain region ... have revealed new details of subsurface structure and lithology. The data strongly suggest that deformation caused by volcanic events has been accommodated along straight-line faults combining in such a fashion as to give a curvilinear appearance to the regional structure. Some of the curvilinear aspect may be caused by erosion and perhaps surface slumping following formation of the caldera."

Drilling for nuclear testing has provided extensive geologic data for subsurface of Pahute Mesa that demonstrates a unique episodic history of activity for each of the Basin-Range faults within this region of the SWNVF (Warren et al., 1985). These data demonstrate that the West Greeley fault has the greatest displacement of units that filled or buried the 13.1 Ma Area 20 and 13.6 Ma Grouse Canyon calderas formed there. The maximum cumulative displacement across this structure for the top of the 12.9 Ma Calico Hills formation is approximately 500 m (see data in Warren et al., 2000), compared with about 250 m displacement for the top of 11.6 Ma Rainier Mesa Tuff (Prothro and Warren, 2000). Clearly,

Table 1. Descriptions for structural blocks of the SWNVF

Symbols for stratigraphic units are defined in Table 2, and in parentheses for hydrogeologic unit type in Table 6. Structural descriptions refer to general elevations above Mean Sea Level for the top of the unit being described: structurally very high = >1500 m; structurally high = 1000 to 1500 m; structurally intermediate = 0 to 1000 m; structurally low = <0 m. *TD* is elevation at bottom of hole.

Block	Code	Description	Location (km UTM) E	Location (km UTM) N	Strat, hydrogeol, top elev (m) at location
Saucer Mesa	SAUM	The block is structurally very high, north of the Grouse Canyon caldera (Ferguson et al., 1994), with Tbd and Tbg both wedging out at the northern edge of the block (Orkild et al., 1969;.Wahl et al., 1997). Tbd thickens to about 400 m near the caldera rim at the southern end of the block. Tbg thins toward the caldera from a medial maximum thickness in the block, like Tm relative to the Timber Mountain caldera complex (Warren et al., 1985). Older rocks probably thicken towards the Grouse Canyon caldera, considering the gravity (Figure 1), which indicates a southward dip for the pre-Tertiary surface.	557.1 557.8	4137.3 4146.7	Tbd (LF) >2200, Tbg (EW) 1900, Tu (LF?) 1750? Tbg (EW) 1920, Tq (EN) 1770, Tk (LF) 1600?, pre-T 1400??
Southern Kawich Valley	SKAV	Structurally low. Thickness of alluvium and volcanics unknown.	569.1	4137.8	Tm (EW) 1500??, Tbd (LF), Tbg (EW), Tu (LF), Tot? (EW), Tk (LF)
Central Belted Range	CBER	Tk is structurally very high.	579.8	4142	Tub (EW) 2400, Tk (TC) 2350, Te (EW) <1500
Southern Belted Range	SBER	Post-Tub lavas, Tub structurally much lower than block to N. Possibly intracaldera Tub. Tbt map unit of Sargent and Orkild (1973) is not Tub, but Tbq.	577.3	4134.9	Tbq (LF) >2200, Tbg (EW) 2040, Tuo (LF) 1920, Tub (EW?) 1700??
Southeastern Belted Range	SEBR	Structurally high Tm through Tu.	584.7	4132.4	Tm (EW) 1770, Th/Tc (EN) 1650, Tbg (EW) 1550, Tu (LF) 1450
Emigrant Valley	EMIV	A deep gravity low (Figure 1) indicates a structurally low basin. Elevations for the pre-Tertiary surface (Barnes et al., 1965) indicate that this block is north-plunging. Relatively thick volcanics are probably ponded within this basin, as Grouse Canyon Tuff and older units are thickly accumulated within erosional or structural topographic depressions within adjacent blocks to the west.	599.6	4128.8	
Northern Halfpint Range	NHAR	Structurally very high pC and lower Paleozoic draped with thin volcanics, with the pre-Tertiary surface slightly lower than in the Oak Spring Butte block to the west. Elevations for the pre-Tertiary surface are provided by Barnes et al. (1965 and 1963).	593.6	4112.6	Tub (EW) 1730, To (EN) 1700, Te (EW) 1600, pre-T 1550

Table 1 (continued). Descriptions for structural blocks of the SWNVF

Block	Code	Description	Location (km UTM) E	Location (km UTM) N	Strat, hydrogeol, top elev (m) at location
Oak Spring Butte	OASB	Structurally very high, with outcrops primarily lower Paleozoic, intruded by Cretaceous plutonics (Sargent and Orkild, 1973). Tb and older units thicken to the east in a narrow band near the central part of the block, certainly above a deep paleovalley.	583.9	4122.4	
Quartzite Ridge	QUAR	Structurally very high, with pre-Tertiary outcrops primarily upper Paleozoic, with a thin mantle of Tb and older units (Sargent and Orkild, 1973), certainly deposited within a deep paleovalley.	577.2	4119.6	Tm (EW) 2070, Th/Tc (EN) 1980, Tbg (EW) 1920, To (EN) 1900, pre-T 1700
Aqueduct Mesa	AQME	Strongly tilted block, structurally high to SE, where pre-Tertiary crops out, and intermediate to NE. Stratigraphic data from UE12P2 (Miller, 1970) and from UE12P4 (Warren et al., 2000) in this table, combined with data from outcrop (Sargent and Orkild, 1973; Sargent et al., 1966), require that the volcanic sequence steepen markedly to the northeast above a NE-plunging pre-Tertiary surface that is exposed in the southern part of the block. A relatively narrow gravity high along the western side of the block indicates that the pre-Tertiary is structurally high there. The prevalent SE dips in the volcanics probably flatten and slightly reverse direction in the eastern part of the block, following attitudes and fold axes in Tmr, exposed at the surface there.	574.2	4121	Tm (EW) 1950, Th (EN) 1745, Tw (EN) 1712, Tc (EN) 1704, Tbg (EW) 1580, Tbgb/Tn (EN) 1530, pre-T 1410
Kawich Canyon	KAWC	Extracaldera block east of Grouse Canyon caldera with intermediate Tbd thickness and thin Tbg. Tbd and Tbg crop out successively to the north in this block (Sargent and Orkild, 1973; Wahl et al., 1997), indicating Tb at relatively high structural levels within this block, and that the pre-Tertiary surface dips southward. Isostatic gravity signature (Figure 1) is similar to that of the Big Burn Valley block adjacent to the south, which has an elevation of 1.0 km for its pre-Tertiary surface (Figure 10 in Ferguson et al., 1994).	566.7	4125.6	Tm (EW) 2250, Th/Tc (EN) 2220, Tbd (LF) 2130, Tbg (EW) 1650?
Eastern Area 19	EA19	This block, outside Area 20 caldera, lies within outer (late) collapse zone of the Grouse Canyon caldera. Thin extracaldera Tbg has dropped to low structural levels during late (post-Tbg) collapse of the Grouse Canyon caldera, and filling of this outer collapse zone with very thick Tbd (Ferguson et al., 1994). Structural levels, represented in this table by UE19C	560.3	4124.7	Tm (EW) 2150, Tp (EW) 1679, Th/Tc (TC) 1632, Tbd (LF) 1419, Tbg (LF) -106,

Table 1 (continued). Descriptions for structural blocks of the SWNVF

Block	Code	Description	Location (km UTM)		Strat, hydrogeol, top elev (m) at location
			E	N	
Southeastern Gold Flat [illegible]	SEGF	A deep gravity low (Figure 1) indicates a structurally low basin. Elevation layers for the 3-D *geologic model* of this report show thin deposits for all units of the Tc Group and younger. [illegible]	549.9	4143.9	

[illegible]

Table 1 (continued). Descriptions for structural blocks of the SWNVF

Block	Code	Description	Location (km UTM) E	Location (km UTM) N	Strat, hydrogeol, top elev (m) at location
Black Mtn	BLAM	The location of this block, which defines intracaldera Black Mtn caldera, must lie within the topographic boundary of the Post-Spearhead caldera shown by Noble and Christiansen (1968); the Spearhead Member has been renamed to the Pahute Mesa Tuff (Noble et al., 1984). Because this young caldera is known only from outcrop (Wahl et al., 1997; Noble and Christiansen, 1968) and has nowhere been exhumed by erosion, thicknesses and attitudes for all subsurface units within this block are conjectural.	531.3	4126.1	Tth (LF) 2200, Ttt (IW) <1740
South of Black Mountain	SBLM	This block has an isostatic gravity signature similar to that of the Northwestern Timber Mtn Bench, but is the locus for the Ribbon Cliff trough (Prothro and Warren, 2000), probably formed by eastward rotation of units against the Purse fault, the signature structural style of Pahute Mesa (Warren et al., 1985).	535.2	4119.3	
Ribbon Cliff	RBCF	This block is characterized by a single drill hole, PM3 (Warren et al., 2000), which shows structurally high to intermediate Tm through Tbg. Thicknesses and elevations down through the top of Th/Tc are similar to those in the Western Area 20 block adjacent to the east (Warren et al., 2000). These units are probably rotated eastward along the Purse fault. However, Th/Tc is very thin and clearly outside both the Area 20 caldera and Area 20 half graben of the adjacent Western Area 20 block. The pre-Tertiary surface is at about 1.0 km below sea level in the structurally similar Southwestern Gold Flat block, adjacent to the north (Figure 10 in Ferguson et al., 1994); because Tbg is lower in the Ribbon Cliff block, the pre-Tertiary surface is probably less than 1.0 km below sea level.	539	4121.3	Tt (EW) 1775, Tm (EW) 1621, Tp (EN) 1223, Th/Tcbs (EN) 952, Tbg (EW) 876, Tq (EN) 860, TD 855
Western Area 20	WA20	Structurally intermediate, Area 20 caldera-burying units of Tp and Th within this block dip northeast (Warren et al., 1985). Older units within this block are best characterized by UE20F (Noto et al., 1999), which penetrates thick, intracaldera Tcbl of the Area 20 caldera and thick overlying Th/Tc, which thins rapidly westward from the West Greeley fault within the Area 20 half graben (Ferguson et al., 1994; Warren et al., 1985). Tb below the floor of the Area 20 caldera includes thin extracaldera Tbg and intermediate Tbq, but the great thickness for To in UE20F suggests that an even older caldera might be located within the block. The pre-Tertiary surface is at about 2 km below sea level (Figure 10 in Ferguson et al., 1994).	545.4	4124.9	Tt (EW) 1864, Tm (EW) 1764, Tp (EW) 1111, Th/Tc (TC) 965, Tcbl (IN) 5, Tbd (LF) -657, Tbg(EN) -1110, Tbq (EW) -1147, To (EN) -1514, TD -2307
Eastern	EA20	Thick Th fills the Area 20 half graben, which deeply drops intracaldera Tcbl within the Area 20	550.2	4125	Tt (EW) 1999, Tm

Table 1 (continued). Descriptions for structural blocks of the SWNVF

Block	Code	Description	Location (km UTM)		Strat, hydrogeol, top elev (m) at location
			E	N	
Northwestern Timber Mtn Bench	NWTB	ER/EC1 (IT Corporation, 2000b) and ER/EC6 (Bechtel Nevada, 2000), with stratigraphic assignments in this table for ER/EC6 modified from more recent unpublished work by R. G. Warren, demonstrate that this block lies outside the Ammonia Tanks and Rainier Mesa calderas, outside any calderas of Tp, and probably outside the Area 20 caldera. Mankinen et al. (1999) model relatively high isostatic gravity values to calculate a relatively thin section of volcanic rocks above a "basement ridge" within the eastern part of this block. This feature is contiguous into the adjacent Northern Timber Mtn Bench. Elevation layers for the 3-D geologic model of this report show that these two blocks have highly different structural character, so that similar thicknesses of volcanic rock are unlikely. Extreme alteration within ER/EC6 suggests that the gravity feature instead reflects relatively high densities localized by [redacted]	544.7	4115.7	Tmat (TC) 1708, Tmrf (EN) 1297, Tp (TC) 1248, Tpc (EW) 974, Tp (EN) 865, Tpt (EW) 795, Th (EN) 624, Tcps (TC) 501, TD 184

Table 1 (continued). Descriptions for structural blocks of the SWNVF

Block	Code	Description	Location (km UTM)		Strat, hydrogeol, top elev (m) at location
			E	N	
Quartz Mountain	QZMT	Structurally high, highly faulted block with units progressively markedly older towards the southeast. TP/AFB1, near center of block, penetrated intervening gravel between Tma, Tmr, as well as bounding these units, and indicates that Tq is structurally intermediate (structural data in this table from Noto et al., 1999, slightly modified with more recent unpublished work by R. G. Warren). Extracaldera Tq, probably near Tolicha Peak caldera, dominates exposed units in southern part of block, and typically dips 30-50^{o} away from Quartz Mountain (Wahl et al., 1997; Hausback and Frizzell, unpublished geologic map of Tolicha Peak 7.5' quadrangle; Noble and Christiansen, 1968). The extreme faulting and steep dips may result mostly from doming with concurrent westward detachment of these volcanics from structurally very high pre-Tertiary in northeastern corner of block, where a tiny outcrop of paleozoic carbonate is exposed (Wahl et al., 1997; Noble and Christiansen, 1968). This pre-Tertiary is the structurally highest northwest of Timber Mtn and is associated with the highest Bouger gravity (which trends westward across Tolicha Peak) within an extensive region (Healey et al., 1978); these data are consistent with a breakaway zone for detachment faulting. Such a breakaway zone would occur where tilts change from SE on the hanging wall to NW on the footwall. Although Carr (1990) does not address this region of the SWNVF, extrapolation northward of	519.4	4128.9	QTa 1734, Tt (EW) 1722, Tg 1709, Tfs (EN) 1699, Tg 1693, Tma (EW) 1475, Tg 1419, Tmr (EW) 1347, Tg 1228, TD 1125

Table 1 (continued). Descriptions for structural blocks of the SWNVF

Block	Code	Description	Location (km UTM)		Strat, hydrogeol, top elev (m) at location
			E	N	
Sleeping Butte	SLBU	Upper Tq is structurally very high, but no pre-Tq is exposed within block, and units young to north. Tq is probably domed, detached, and near caldera, or within Tolicha Peak and/or Sleeping Butte calderas.	523.2	4112.1	Tqs (IW) 1725
Southern Thirsty Canyon	STCA	Structurally intermediate to low Tm best characterized in ER/EC8 (IT Corporation, 2000c, with stratigraphic assignments modified from more recent unpublished work by R. G. Warren). The isostatic gravity (Figure 1) is similar to that of Northern Thirsty Canyon block, although Tt generally dips W. Like the Eastern Oasis Valley block, this block lies outboard of the Transvaal Hills block from the Ammonia Tanks caldera and so must lie outside that caldera. Even so, Tm is structurally intermediate to low and only the tops of caldera-filling Tf are exposed, as in the adjacent Northwestern Timber Mtn Moat and Eastern Oasis Valley blocks. Considering the similarity of structural data between ER/EC8 and ER/EC4 within the Northern Thirsty Canyon block, this block too lies outside the Rainier Mesa caldera.	533	4106	Tt (EN) 1294, Tfm (TC) 1252, Tf (EN) 873, Tma (EW) 845, TD 684
Eastern Oasis Valley	EOVA	Structurally intermediate to low Tm. Similar to Northern Thirsty Canyon block. Tt generally dips W. This block is characterized by a single drill hole, MYJOC1, which penetrated thick Tf and bottomed in hydrothermally altered Tma (Warren et al., 2000). The block lies outboard of the Transvaal Hills block and so is clearly outside the Ammonia Tanks caldera. Considering its similarity to the Northern Thirsty Canyon block, this block lies outside the Rainier Mesa caldera. Tilts in Transvaal Hills block adjacent to east, and for Tf in eastern part of Eastern Oasis Valley block are westward (Lipman et al., 1966).	531.5	4097.5	QTa 1306, Tt? (EN) 1065, Tf (TC) 1049, Tma (EW) 451, TD 124
Transvaal Hills	TRAH	Structurally high, W-dipping Tm. Thin extracaldera Tma overlies Tmr. Byers et al. (1976a), Noble et al. (1991), and Sawyer et al. (1994) all consider westward-tilted Tmr (Lipman et al.,	537.4	4095.8	Tma (EW) 1470, Tmr (IW) 1400

Table 1 (continued). Descriptions for structural blocks of the SWNVF

Table 1 (continued). Descriptions for structural blocks of the SWNVF

Block	Code	Description	Location (km UTM) E	Location (km UTM) N	Strat, hydrogeol, top elev (m) at location
Crater Flat	CRFL	Deep extracaldera basin as represented by USWVH2 (Carr, 1982), possibly intracaldera for Tc and older units.	537.7	4073.2	QTa 974, Tf (LF) 615, Tm (EW) 585, Tp (EW) 379, Tc (EW) -164, TD -245
Prospectors Pass	PRPA	Structurally high, S-dipping block. Possibly intracaldera for Tct and older units.	536.2	4091.5	Tp (EW) 1650, Th (EN) 1460, Tc (E?W) 1440
Lower Beatty Wash	LBWA	Isostatic gravity (Figure 1) indicates that this block is structurally intermediate. This block exposes only thin, extracaldera Tmr and underlying Tmrf. Tilts on Tmr are more gentle in this block than in the Bare Mtn block adjacent to the south, where the volcanic section is detached (Carr and Monsen, 1988), but both Tmr and Tmrf are only slightly structurally lower in the Lower Beatty Wash block. Due to the structural similarity of the two blocks, it is very likely that the volcanic section is also detached in the Lower Beatty Wash block, as shown in cross section B of Fridrich et al. (1999b).	528.7	4089.9	Tmrf (TC) 1260
Bare Mtn	BARM	This block exposes structurally very high pre-Tertiary (Wahl et al., 1997; Streitz and Stinson, 1977), and detached volcanics on the northeast end (Monsen et al., 1992; Maldonado, 1990; Maldonado and Hausback, 1990; Carr and Monsen, 1988). Line A-A' of Healey and Miller (1965), parallel to and about 3.5 km SE from the cross sectional line of this document, estimates a maximum alluvium thickness between 670 and 1100 m for the unnamed basin west of the Bare Mtn block.	530.1	4081.7	Pre-T 2100
Bullfrog Hills	BULH	This block is structurally high. Tf through To is detached from pre-Tertiary in thin, generally steeply E-dipping fault blocks (Maldonado, 1990; Maldonado and Hausback, 1990).	515.6	4086.7	
Oasis Mtn	OASM	This block is structurally high to intermediate, probably detached, but with Tma and Tf successively less rotated eastward by detachment.	522	4098.8	Tma (EW) 1460
Tracking Station	TRAS	This block is structurally intermediate. It is unknown if pre-Tertiary detached from Tm and older volcanics.	516.2	4103.8	Tfn (LF) 1510
Sarcobatus Flat	SAFL	Isostatic gravity (Figure 1) indicates that this block represents an extracaldera basin with pre-Tertiary at intermediate structural levels. A sharp decrease in Bouger gravity (Healey et al., 1978) indicates that the pre-Tertiary in this block has been downfaulted to substantially lower elevations than in the Lower Tolicha Wash block adjacent to the east.	500.8	4096.5	QTa 1250

Table 1 (continued). Descriptions for structural blocks of the SWNVF

Block	Code	Description	Location (km UTM)		Strat, hydrogeol, top elev (m) at location
			E	N	
Central Area 19	**CA19**	Thick Tcbl fills the inner collapse zone of Area 20 caldera, and moderately thin Tbg fills the western end of the Grouse Canyon trap-door caldera in PM1, as supported by data in this table (Warren et al., 2000). This block is structurally still higher than the Eastern Area 20 block adjacent to the west within Th, owing to pre-Th episodic displacement along the West Greeley fault (Warren et al., 1985), but otherwise structurally similar. Data are best represented by U20AP west of the East Greeley fault and by U19AU east of this fault to the top of Th (Warren et al., 2000) Elevations for older units and for the pre-Tertiary surface are estimated from Figure 10 in Ferguson et al. (1994) and Healey et al. (1978).	552.7	4125.9	Tm (EW) 1999, Tp (TC) 1819, Th/Tc (TC) 1646, Tcbl (IN) 1042, Tbd (LF) 396, Tbg (LF) -116, Tbq (LF) -323, TD -393
Eastern Pahute Mesa	**EPME**	Thick Tcbl fills the inner collapse zone of Area 20 caldera, and thick Tbd and thin Tbg fill the outer collapse zone of Grouse Canyon caldera. This block is structurally still higher than the Central Area 19 block adjacent to the west, but otherwise structurally similar down through Tc. It differs from Central Area 19 block in being within outer collapse zone of Grouse Canyon caldera rather than inner collapse zone (Ferguson et al., 1994). Data are best represented in this table by UE19I west of the Scrugham Peak fault, and by UE19P1 east of this fault (Warren et al., 2000). Elevations for the pre-Tertiary surface (>1 km below sea level) are found in Figure 10 in Ferguson et al. (1994).	557.9	4122.6	Tm (EW) 2085, Tp (TC) 1824, Th/Tc (TC) 1427, Tcb (IN) 1201, Tbd (LF) 600, Tbg (EW) 125, TD -354

Table 1 (continued). Descriptions for structural blocks of the SWNVF

Block	Code	Description	Location (km UTM) E	Location (km UTM) N	Strat, hydrogeol, top elev (m) at location
Big Burn Valley	BBVA	Structurally very high Tm through Tn is similar to that of adjacent Southern Split Ridge block. Pre-Tertiary is structurally high to intermediate, even though thick, possibly intracaldera Tor occurs in ER19/1 (Warren et al., 2000), just east of structural block.	567.5	4114.7	Tbg (EW) 1871, Tn (EN) 1761, To (IW) 1545, Tlt 1003, pre-T 987
Rainier Mesa	RAIN	Very high structural levels are documented in UE12E3 (Warren et al., 2000). Westward dipping pre-Tertiary outcrops in eastern part of block.	569.5	4115.3	Tm (EW) 2275, Tp (EN) 2129, Th/Tc (EN) 2086, Tbg (EW) 1052, Tn (EN) 1900, Tub (EN) 1732, To (EN) 1726, TD 1605
Eleana Range/Calico Hills	ERCH	This block is structurally very high. Pre-Tertiary widely crops out, draped with volcanics that thicken westward and over eroded southern end of block.	569.2	4100.1	Tp (EW) 2040, Th/Tc (EN) 1950, Tr (EN) 1800, Tn (EN) 1700, To (EN) 1660, pre-T 1550
Western Yucca Flat	WYFL	Similar to Central Yucca Flat block, with structurally intermediate pre-Tertiary, but with an intermediate thickness of alluvium, and volcanics as represented by TWD (Dixon et al., 1973).	582.2	4103.3	QTa 1266, Tn?? (EN) 804, pre-T 738
Central Yucca Flat	CYFL	Similar to Western Yucca Flat block, with structurally intermediate pre-Tertiary, but with thick alluvium, and an intermediate thickness of volcanics in UE7BA (Warren et al., 2000).	584.9	4104.8	QTa 1259, Tm (EW) 1163, Tp (EN) 946, Th/Tc (EN) 914, Tn (EN) 794, To (EN) 657, pre-T 529
Southern Halfpint Range	SHAR	Pre-Tertiary is structurally high, cropping out in eastern part of block, to low in western part within UE6E (Drellack and Thompson, 1990), dipping southwestward. Alluvium and volcanics thicken strongly southwestward.	587	4093.4	QTa 1200, Tm (EW) 783, Tp (EW) 668, Th/Tc (EN) 526, Tn (EN) 380, To (EN) 310, pre-T -15
			596.3	4087.4	Tm (EW) 1440, Tp (EW) 1370, Th/Tc (EN) 1350, pre-T 1130
CP Hills	CPHI	Pre-Tertiary is structurally very high in eastern part of block, dipping southwestward. Volcanics thicken strongly southwestward.	579.6	4089	Tp (EW) 1620, Th/Tc (EN) 1510, pre-T 1460

Table 1 (continued). Descriptions for structural blocks of the SWNVF

Block	Code	Description	Location (km UTM) E	Location (km UTM) N	Strat, hydrogeol, top elev (m) at location
Eastern Timber Mtn Bench	**ETMB**	Structurally intermediate Tm occurs within ER30/1 (Warren et al., 2000), possibly within Rainier Mesa caldera.	560.8	4100.5	QTa (EW) 1416, Tfb 1300 (IN), Tf (LF) 1127, Tma (IW) 1052, TD 1020
Northeastern Timber Mtn Bench	**NETB**	Structurally intermediate Tm in UE18T (Warren et al., 2000) includes extracaldera Tma, probably deposited within Rainier Mesa caldera. Probably east-dipping block structurally similar to or continuous with Northern Timber Mtn Bench.	559.6	4109.1	QTa 1585, Tt (EW) 1494, Tf (TC) 1454, Tma (EW) 1299, Tmr (I?W) 1145, TD 793
Northern Timber Mtn Bench	**NTMB**	Structurally high extracaldera Tma, probably within Rainier Mesa caldera. Probably east-dipping block structurally similar to or continuous with Northeastern Timber Mtn Bench block. Mankinen et al. (1999) model relatively high isostatic gravity values to calculate a relatively thin section of volcanic rocks above a "basement ridge" within the western part of this block. This feature is contiguous into the adjacent Northwestern Timber Mtn Bench. Elevation layers for the 3-D geologic model of this report show that these two blocks have highly different structural character, so that similar thicknesses of volcanic rock are unlikely. Extreme alteration within ER/EC6, within the Northeastern Timber Mtn Bench block, suggests that the gravity feature instead reflects relatively high densities localized by hydrothermal alteration along the Boxcar fault, which bounds the block on the west and bisects the gravity feature.	548.8	4115.2	Tmat (TC) 1810
Northeastern Timber Mtn Moat	**NETM**	Structurally intermediate Tm in ER18/2 (IT Corporation, 2000a) includes intracaldera Tma, probably also within Rainier Mesa caldera.	555.6	4106.4	Typ (LF) 1657, Tt (EW) 1575, Tf (TC) 1550, Tma (IW) 1428, TD 895
Northern Timber Mtn Moat	**NTMM**	Structurally intermediate to low Tm occurs in UE18R (Warren et al., 2000), within the Ammonia Tanks and Rainier Mesa calderas.	549.3	4109.8	Tt (EW) 1688, Tf (TC) 1585, Tma (IW) 1363, Tmr (IW) 504, TD 163
Northwestern Timber Mtn Moat	**NWTM**	Structurally intermediate to extremely low Tm occurs in ER/EC2A, within the Ammonia Tanks caldera, and probably within the Rainier Mesa caldera. Extremely thick *Tfb fills the Ammonia* [illegible]	538.4	4111.1	Tfb (TC) 1481, Tf (IN) 539, Tma (IN) [illegible]

[illegible]

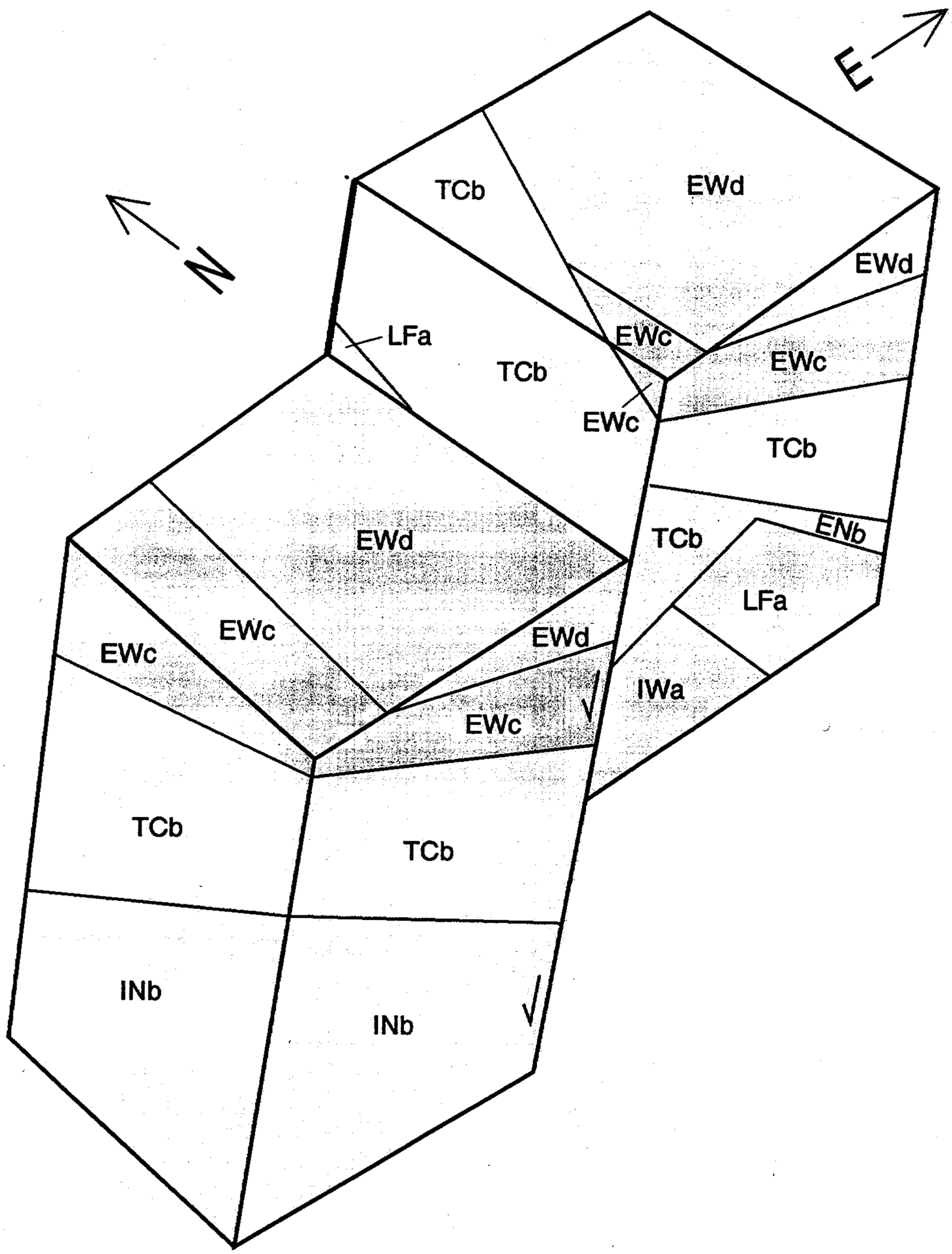


Figure 2. Block diagram that illustrates assignment of hydrogeologic units. First two letters of symbols indicate hydrogeologic unit as shown in Table 6; third letter designates stratigraphic group (e.g., Paintbrush Group). Several structural complexities, all of which occur within the Silent Canyon caldera of Pahute Mesa subsurface, are represented here. Group "d" is an extracaldera welded tuff (e.g., Ammonia Tanks Tuff). It has been rotated eastward in both blocks and downdropped in the western block. The top of this hydrogeologic unit, stripped off in this view, is an east-dipping plane. Group "c" is an older extracaldera welded tuff (e.g., Rainier Mesa Tuff). It has been rotated eastward in both blocks and downdropped in the western block. The top of this hydrogeologic unit is also an east-dipping plane. Below these units is a much thicker sequence of near-caldera and intracaldera units of group "b" (e.g., Calico Hills Formation and lithic-rich Bullfrog Tuff). The units of group "b" have rotated eastward during several episodes, and also the eastern block has rotated southward while the western block rotated northward, resulting in a thickening of these and overlying units in the direction of rotation (NE in the western block, SE in the eastern block). Below group "b" lies still another near-caldera and intracaldera "a" group (e.g., Belted Range Group). Although genetically complex, the layers can be well approximated by one or more planes that define the top of each layer. Hydrogeologic unit TCb was deposited within an eroded caldera wall in the eastern block; here, two planes are needed to define the extent of this unit. **Note that minor structures, most generally faults with displacements <100 m, are ignored within each structural block. Note also that both blocks might be buried by an even younger unit "e", and structurally indistinguishable at young stratigraphic levels.**

on the accompanying map, as illustrated in Figure 2 and in Figures 22 and 27 of Warren et al. (1985). Hudson et al. (1994) have demonstrated that vertical axis rotation is not important for blocks within the central part of the SWNVF. The units, their thicknesses, and attitudes define a unique structural history for each structural block, which can be related to episodic reactivation of faults that bound the block (Figure 25 in Warren et al., 1985). When faults that bound two or more structural blocks are inactive during a certain episode, then these blocks have a similar structural history at that time and they are indistinguishable at the top of that particular stratigraphic level.

Table 2. Key to symbols used for stratigraphic units in Table 1

Stratigraphic unit symbols and definitions follow Warren et al. (2000); ages are from Sawyer et al. (1994) and Warren et al. (2000). Stratigraphic assemblages are in bold, units within three dimensional model are in italics. Hydrogeologic types are: *Weld*, generally welded ash-flow tuff; *Nonw*, intracaldera nonwelded tuff; *LF*, generally lava flows with little associated tuff; *TC*, generally lava flows are associated with tuff-cone precursors. A *p* added to *LF* or *TC* indicates caldera precursor; all others *fill* calderas.

Symbol	Unit	Hydr type	caldera	age (Ma)
QTa	alluvium			
Typ	Pliocene basalts	LF		
Tg	Pliocene through Oligocene alluvium			
Tyb	Post-Thirsty Canyon basalts	LF		
Ts	**Volcanics of Stonewall Mountain**		Stonewall Mtn	7.6
Tyb	Post-Thirsty Canyon basalts	LF		
Tt	**Thirsty Canyon Group**		Black Mtn	9.4
Tth	trachyte of Hidden Cliff	LF	Black Mtn	
Ttt	Trail Ridge Tuff	Weld	Black Mtn	
Ttp	*Pahute Mesa Tuff*	Weld	Black Mtn	
Ttc	*comendite of Ribbon Cliff*	LFp		
Tf	**Volcanics of Fortymile Canyon**			
Tfs	rhyolite of Shoshone Mountain	LF		
Tfn	latite of Donovan Mountain	LF		
Tfm	rhyolite of Max Mountain	TC		
Tfb	*Beatty Wash Formation*	TC		
Tm	**Timber Mountain Group**			
Tma	*Ammonia Tanks Tuff*	Weld	Ammonia Tanks	11.45
Tmat	*rhyolite of Tannenbaum Hill*	TCp	Ammonia Tanks	
Tmr	*Rainier Mesa Tuff*	Weld	Rainier Mesa	11.6
Tmrf	*rhyolite of Fluorspar Canyon*	TCp	Rainier Mesa	
Tmrh	*tuff of Holmes Road*	Nonw		
Tmt	*basalt of Tierra (included with Tmrh)*	LF		
Tmw	*rhyolite of Windy Wash*	LF		
Tp	**Paintbrush Group**			
Tpb	*rhyolite of Benham*	TC		
Tps	*rhyolite of Scrugham Peak*	LF		
Tpc	*Tiva Canyon Tuff*	Weld	Claim Canyon	12.65
Tpd	*rhyolite of Delirium Canyon*	TC		
Tpe	*rhyolite of Echo Peak*	TC		
Tpr	*rhyolite of Silent Canyon*	LF		
Tptx	*Breccia of Topopah Spring Tuff (included with Tpr)*	Nonw		
Tpt	*Topopah Spring Tuff*	Weld		12.7

Table 2. Key to symbols used for stratigraphic units in Table 1 (continued)

Symbol	Unit	Struct type	caldera	age (Ma)
Th	**Calico Hills Formation**			
Thp	*Mafic-poor Calico Hills Formation*	TC		
Thr	*Mafic-rich Calico Hills Formation*	TC		
Tw	**Wahmonie Formation**			
Tc	**Crater Flat Group**			
Tcu	*tuff of Pool (included with Tci)*	Nonw		
Tci	*rhyolite of Inlet*	LF		
Tcf	*basalt of Fontina (included with Tci)*	LF		
Tcj	*rhyolite of Jorum*	TC		
Tcpe	*rhyolite of ER/EC1 (included with Tcps)*	TC		
Tcps	*rhyolite of Sled*	TC		
Tcpk	*rhyolite of Kearsarge*	LF		
Tcg	*andesite of Grimy Gulch (included with Tcpk)*	LF		
Tcb	*Bullfrog Tuff*			
Tcbl	lithic-rich	Nonw	Area 20	13.1
Tcbs	Stockade Wash lobe	Nonw		13.1
Tcbp	rhyolite of Prospectors Pass	LFp		
Tct	*Tram Tuff (included with Tcb)*	Weld		
Tb	**Belted Range Group**			
Tbd	Dead Horse Flat Formation	LF		
Tbg	Grouse Canyon Tuff	Weld	Grouse Canyon	13.6
Tbgb	Bedded Grouse Canyon Tuff	Nonw		
Tbgs	comendite of Split Ridge	LFp		
Tbq	comendite of Quartet Dome	LFp		
Tr	**Tram Ridge Group**			
Tn	**Tunnel Formation**			
Tq	**Volcanics of Quartz Mountain**			

to Recent and thus is contemporaneous with or postdates the silicic volcanism active primarily between 16 and 7.5 Ma (Sawyer et al., 1994) . Therefore all structural blocks define important Tertiary structure developed after 16 Ma. Within structural blocks dominated by pre-Tertiary rocks, older, much more complex structures dominate (Cole and Cashman, 1999; Monsen et al., 1992; Carr and Monsen, 1988; Barnes et al., 1982). We do not address these pre-Tertiary structures.

Byers et al. (1976a) describe an arcuate "tuff dike zone" within the Timber Mountain Dome structural block, which provides direct evidence for the existence of arcuate volcano-tectonic structures within the SWNVF. From this evidence, structural boundaries of the Timber Mountain Dome have been represented as arcuate in the accompanying map. This dome is a relatively young feature in the center of the SWNVF, a volcanic field which appears to have become increasingly resistant to deformation with time (Hudson et al., 1994). The decreased decoupling with regional structure can be explained by an increase in crustal strength as a subvolcanic pluton continued to grow with continued volcanism. The Black Mountain caldera, which postdates the Timber Mountain Dome and lies near the northwestern edge of the little-extended central block of the SWNVF (Hudson et al., 1994), is considered the best example within the SWNVF of a "classic" caldera bounded by arcuate structures (Sawyer et al., 1994; Byers et al., 1976a; Orkild et al., 1969). Yet this caldera is shown on our accompanying map and in Figure 1 with linear structural boundaries as the Black Mountain structural block, because bounding structures are everywhere buried by younger deposits, so that linear and arcuate structural boundaries are equally viable alternatives. Ash flow sheets of the Thirsty Canyon Group are distributed highly asymmetrically with respect to their source, the Black Mountain caldera (Wahl et al., 1997), suggesting a trap-door structure opening along a north-trending linear feature. Valles caldera, a "classic" caldera long thought to be bounded by arcuate structures, has been found to be asymmetric, and bounded by linear fault segments of the Rio Grande Rift beneath recent lake deposits (Nielson and Hulen, 1984). Like the Black Mountain caldera, its present day round topographic expression was thought to reflect original structural boundaries of the Valles caldera, but deep drilling demonstrated the error in this simplistic view. Should arcuate structural boundaries be preferred or later demonstrated for certain calderas, only minor modifications are required to convert the existing trapezoidal structural blocks into rounded ones.

A "top down" three dimensional structural model for the SWNVF

We model the three-dimensional distribution of hydrogeologic units applying a "top down" method separately for each block. We prefer a "top down" approach because structures readily recognized within units that lie near the surface frequently reveal the location and orientation of buried major structures (Warren et al., 1985). Although the 9.4 Ma Pahute Mesa Tuff is widely exposed within the SWNVF, structural features within this unit have never been applied for quantitative structural analysis, certainly because this unit postdates most of the eruptive and structural history of the volcanic field. But elevation, then read these data into separate files for each quadrangle and digitized horizontal coordinates for all points. We confirmed locations using overlays at the 1: 24000 map scale, and map units and elevation by comparing a second reading of each point, correcting all errors during this process. We converted map units to stratigraphic units of Warren et al. (2000), considering updated stratigraphic assignments for units from the most recent regional map (Wahl et al., 1997), and from samples within the [redacted] and/or Tps, as reflected in Table 3. Assumptions in Table 4 define the list of stratigraphic units that can occur within undefined stratigraphic intervals.

Table 4. Assumptions that define the list of stratigraphic units within undefined stratigraphic intervals

Symbols for stratigraphic units are defined in Table 2. Assumptions are invalid when both stratigraphic unit and lithology are not reported, reflecting an absence of information within a drill hole.

Unit	Assumption
Tmr	Lowest depth provided accurately reflects elevation of lower contact.
Tmw	This unit is distinctive and easily recognizable, and therefore accurately represented. Therefore it is absent if an undefined stratigraphic interval includes this unit.
Tpb	Shallowest depth provided accurately reflects elevation of upper contact, but additional tuff may underlie lowest depth provided or unit may not be recognized in the lithologic form of nonwelded tuff.
Tpc	This unit is distinctive and easily recognizable, and therefore accurately represented. Therefore it is absent if an undefined stratigraphic interval includes this unit.
Tpr	This unit is generally distinctive and easily recognizable in the lithologic form of lava. Therefore the shallowest depth provided accurately reflects elevation of upper contact. Additional tuff may underlie [illegible]

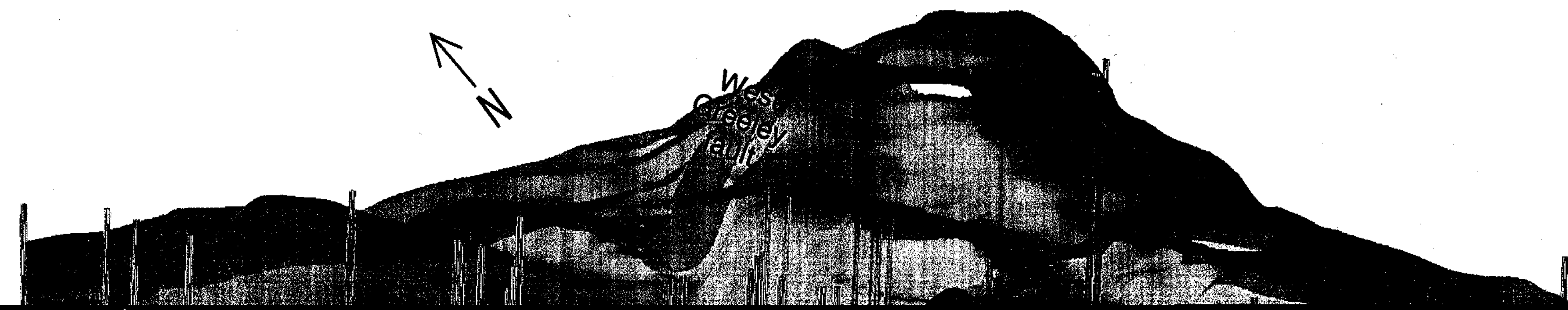
were active contemporaneously with deposition of units and deep basins formed by caldera collapse. Figure 3, which shows the top surface of Rainier Mesa Tuff (Tmr) and the bottom surface of Bullfrog Tuff (Tcb), graphically illustrates the markedly greater offset of 850 m across the West Greeley fault for Tcb, compared to 225 m for Tmr. Offset across this fault, and across the West Boxcar fault systematically increases with age of stratigraphic unit, as shown in Table 5, demonstrating that these faults were continuously active during the entire period that the units of this model were erupted, between 9.6 and 13.1 Ma.

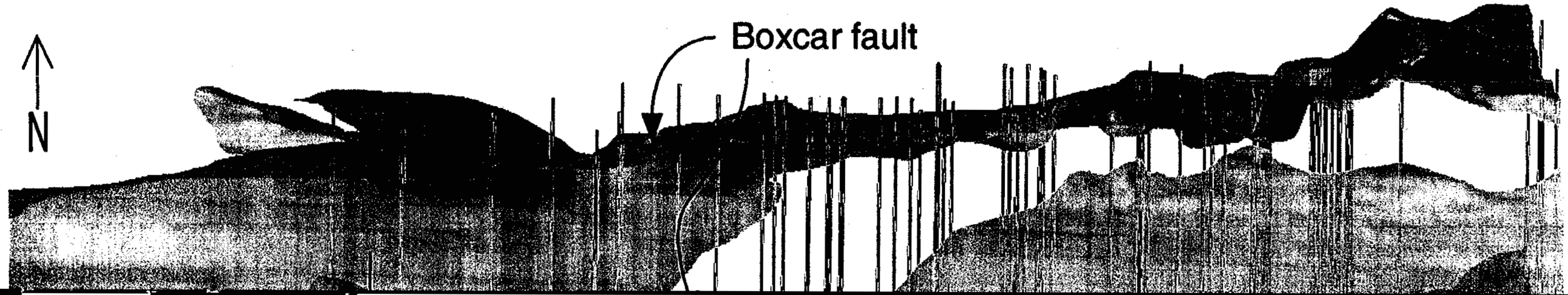
Table 5. Offsets across West Boxcar and West Greeley faults for selected units from three dimensional model

Offsets are in meters, as displayed for top of unit in Appendix A. Unit symbols are defined in Table 2; ages are from Sawyer et al. (1994). Asterisk denotes data for base of unit, reflecting pre-13.1 Ma offset.

Unit	Age (Ma)	W. Boxcar	W. Greeley
Ttp	9.6	75	150
Tma	11.4	100	200
Tmr	11.6	175	225
Tpc	12.65	350	450
Thp	12.8	750	650
Tcb	13.1	850	950
Tcb*	>13.1	1100	850

Figure 4 illustrates the deep basins formed during caldera-forming eruptions in the region. Separate, deep basins have formed within the Ammonia Tanks caldera, divided by the Boxcar fault. The much deeper, westerly basin is here named the Rocket Wash basin. The older Area 20 caldera has been greatly modified into a complex, asymmetric basin by later Basin-Range faulting. Figure 5 illustrates initial filling of the Area 20 caldera with units of the Crater Flat Group. This filling was completed with deposition of the very thick Calico Hills Formation, not shown in Figure 5. Figure 6 demonstrates the


N
West Greeley fault


Boxcar fault
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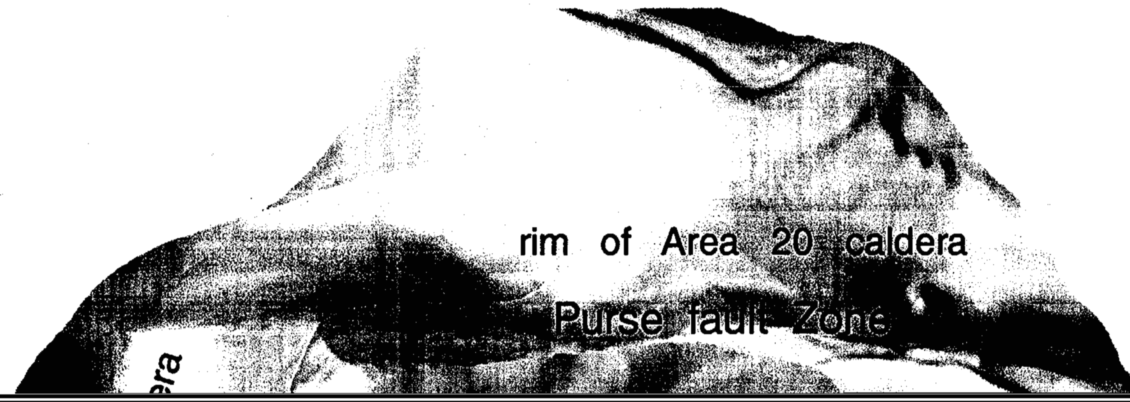

rim of Area 20 caldera
Purse fault Zone

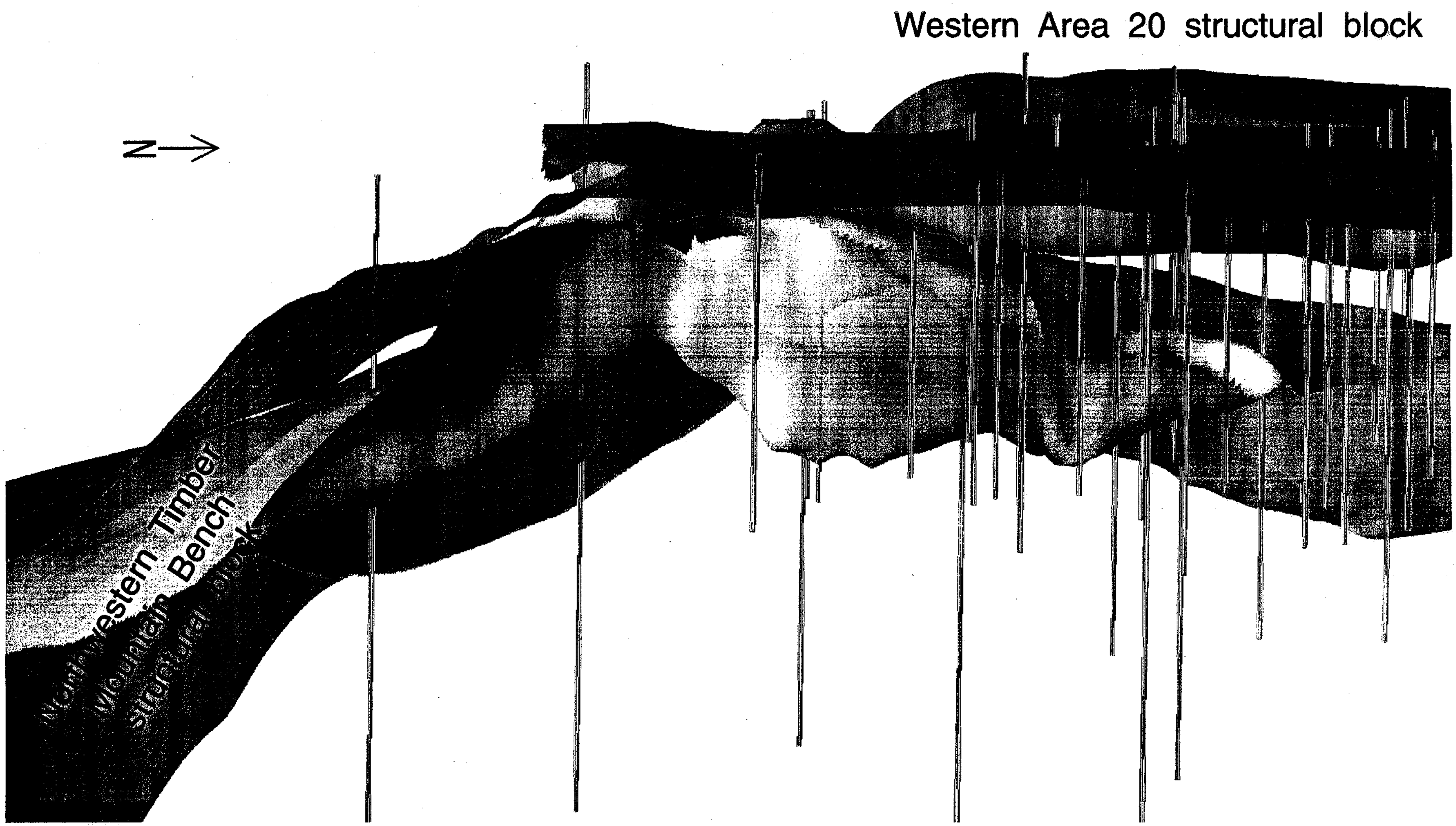


Figure 6. Three-dimensional representation in green for top surface of Rainier Mesa Tuff (Tmr), and in brown for top and bottom of Topopah Spring Tuff (Tpt), looking from east. Vertical bars show that all drill holes penetrate the top of Tmr, and most penetrate Tpt. This view graphically illustrates the dramatic decrease in elevation for each stratigraphic unit southward from the Western Area 20 structural block into the Northwestern Timber Mountain Bench block. The striking decrease may reflect a buried, west-northwest trending fault.

For example, locations or suspected locations are known for many calderas, but without drill holes, the actual lithologies are unknown. In addition to providing predictive hydraulic properties where none are available, a scheme based on structural environment provides subdivisions that seem warranted to add to existing hydrogeologic classification schemes (Drellack and Prothro, 1997; Laczniak et al.,1996; Winograd and Thordarson, 1975). For example, it might be expected that the welded-tuff aquifer of a thick, intracaldera sequence might differ markedly in hydraulic character from that of a thin outflow sheet.

Virtually the entire sequence of volcanic units of the SWNVF was erupted from calderas, and may be generalized into three distinctive groups. *Intracaldera units* are invariably very thick ash-flow tuffs, intercalated with breccia near caldera margins, and generally strongly *welded* and devitrified, but in at least one case *nonwelded* and zeolitic. *Extracaldera units*, the generally much thinner equivalents of *intracaldera units*, are not associated with porous breccia, and also come in two varieties, *welded* and *nonwelded*. *Near-caldera units* are sequences of lavas and associated tuffs that precede, fill, overflow, and erupt near calderas. *Near-caldera units* are either volatile-poor, mostly lava with little associated [illegible]

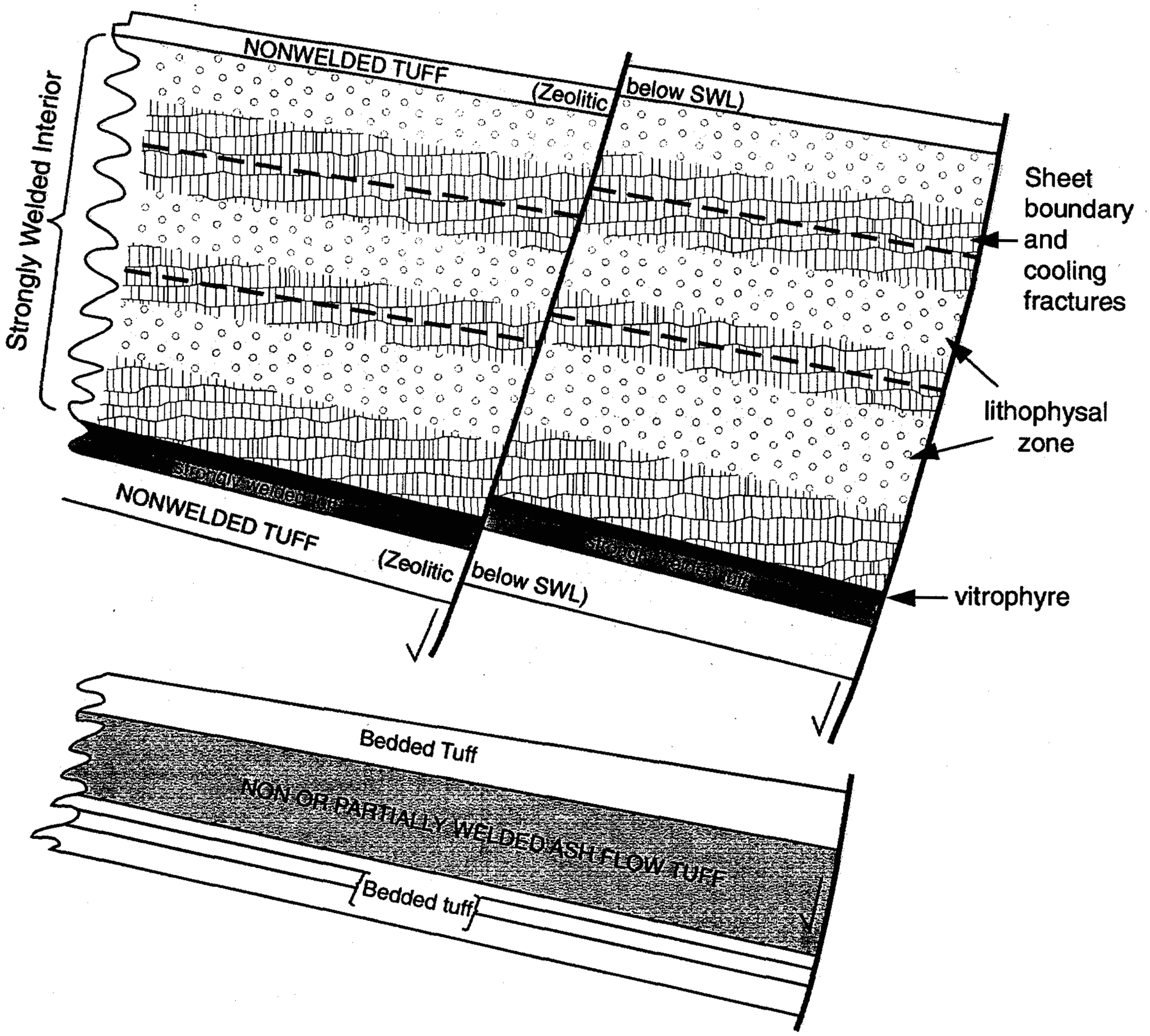
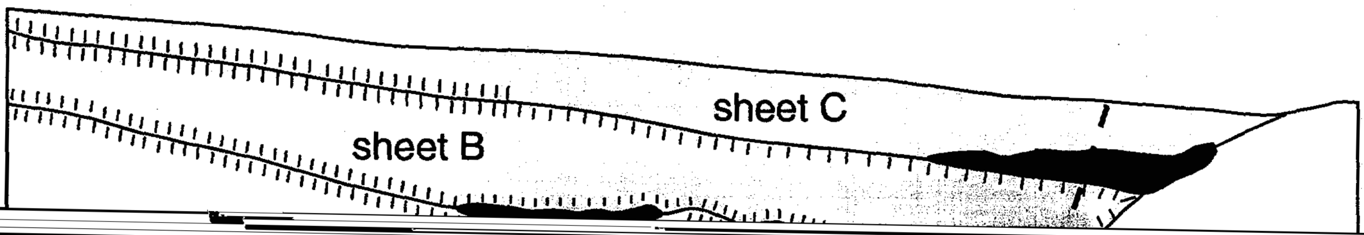


Figure 7. Schematic cross section illustrating idealized hydrogeology of extracaldera units. The upper diagram illustrates thick extracaldera welded tuff, presumed to be erupted in several stages, each separated by a short time interval, and each stage erupting a separate "sheet". Dashed lines represent boundaries between sheets. Extracaldera welded tuffs generally consist of a thick, strongly (moderately to densely) welded interior, a basal vitrophyre, and a thin layer of strongly welded tuff beneath the vitrophyre, all sandwiched between nonwelded tuff. Upper and rarely medial vitrophyres may be developed at the base of each sheet. Locally, the basal part of the sequence may not develop where the extracaldera welded tuff has an intermediate thickness, as for Rainier Mesa Tuff in U20AP (Warren et al., 2000). Erosion of extracaldera tuffs in the SWNVF is minor, so tops are generally well preserved. Examples are the Rainier Mesa Tuff of Pahute Mesa (Ferguson et al., 1994) and the Topopah Spring Tuff of Yucca Mountain (Spengler et al., 1984). Cooling fractures develop most strongly at the top and base of each sheet; lithophysal zones occur between.

Hydraulic flow occurs almost entirely within cooling fractures in the strongly welded interior of extracaldera welded tuff. Thus hydraulic flow should occur in sheetlike fashion. Lithophysal zones between fractured zones are not strongly fractured, and fractures are short, generally only connecting between lithophysae. Because cooling fractures are lengthy, minor faults should not generally disrupt flow paths. Thin extracaldera welded tuff cools as a single unit, even if composed of more than a single sheet (e.g., Tiva Canyon Tuff of Pahute Mesa), and lithophysal zones are seldom observed and poorly developed if present. Therefore thin extracaldera welded tuff can be considered hydrogeologically as a thin, tabular set of hydraulically conductive cooling joints. Due to its thinness, minor faults may disrupt flow paths.

The lower diagram shows a typical sequence of extracaldera nonwelded tuff. Below the static water level (SWL), extracaldera nonwelded tuff invariably includes zeolitic (or potassic) bedded and reworked tuff, and thin to thick nonwelded ash flow tuff, all which have very low matrix permeability. Also included within the extracaldera nonwelded tuff hydrogeologic unit is partially welded (generally vapor phase) ash flow tuff, which probably has a considerably higher matrix permeability than zeolitic tuffs. Cooling fractures do not occur within the zeolitic tuffs, and are poorly developed within partially welded ash flow tuff, so hydraulic pathways are defined almost entirely by regional fractures (faults and joints).


sheet C
sheet B

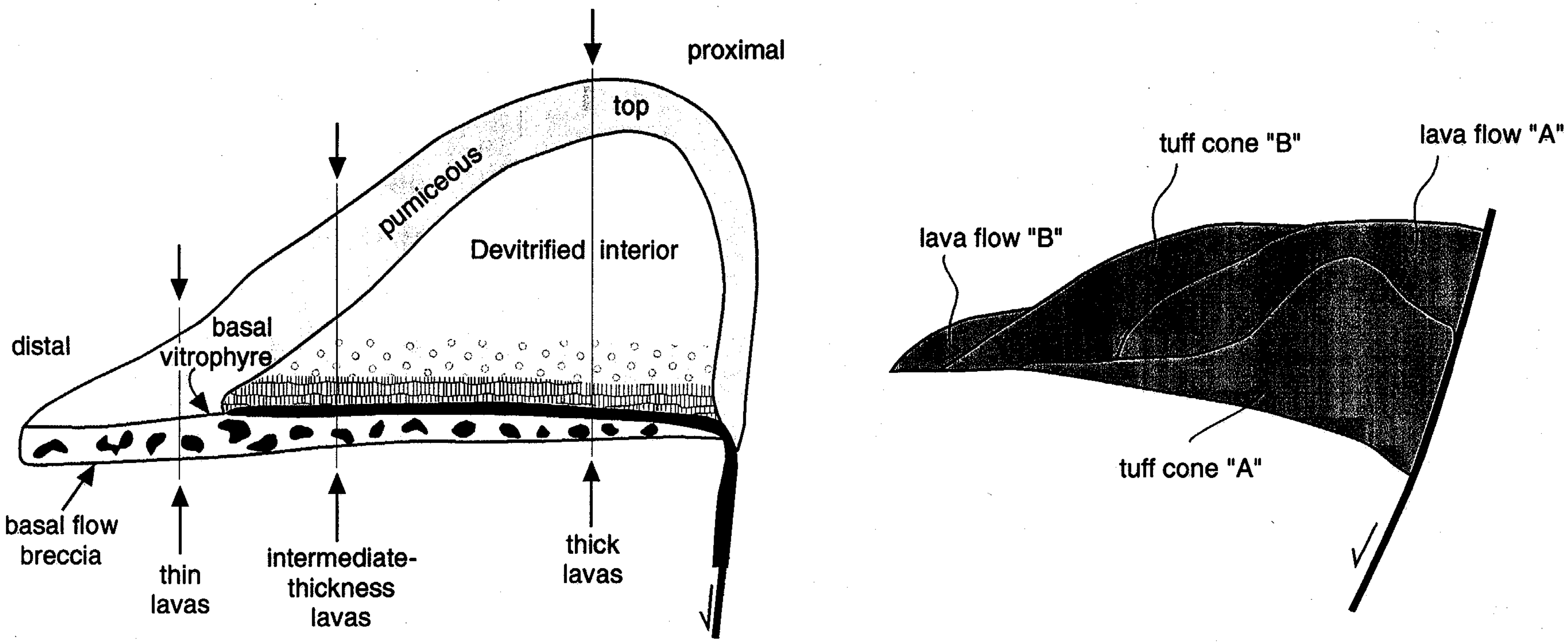


Figure 9. Schematic cross section illustrating idealized hydrogeology of near-caldera units. The left diagram illustrates a thick lava-flow hydrogeologic unit such as rhyolite of Inlet. The lava-flow unit is typically associated with little precursor tephra, and consists of a basal flow breccia, overlying dense, glassy, basal vitrophyre, devitrified interior, and pumiceous (frothy) top. The devitrified interior occurs proximal to the vent, where the lava is thickest, and generally completely disappears in distal parts of the lava-flow unit. Thin lava flows are zoned like distal portions of thick flows, and lava flows of intermediate thickness are zoned like portions of thick lava flows at intermediate distances from the vent; arrows denote zonation for the thickest parts of such flows. Like extracaldera welded tuff, cooling joints are well developed near the base of the lava-flow unit, and overlain by a lithophysal zone. Below the SWL, the pumiceous top may be vitric, zeolitic, or partly vitric, partly zeolitic. Basal flow breccias and the fractured base of the devitrified interior are typically very permeable media, and should provide preferred hydraulic flow paths within the lava-flow hydrogeologic unit. Pumiceous tops grade inward from about 40% porosity to about 20% at the interface with devitrified interior, and so when they are vitric or partly vitric, pumiceous tops probably have good unrestricted hydraulic conductivity, entirely through matrix permeability. Unlike nonwelded tuffs, which have similar physical characteristics, pumiceous lavas are commonly vitric well below the SWL and so generally may be hydraulically conductive down to depths below which they are very likely to be entirely zeolitic, perhaps a few hundred meters below the SWL. Lava-flow units may be bulbous like rhyolite of Inlet, as illustrated, or may be nearly tabular, like rhyolite of Echo Peak, but alteration zones are always developed as shown. Hydraulic flow may be sheetlike, pipelike, or have characteristics between these types of flow, depending on the geometry and detailed lithology of the unit.

The right diagram illustrates the complex nature of the tuff-cone unit, commonly found in Pahute Mesa subsurface. Rhyolite of Fluorspar Canyon, lavas of the Paintbrush Group, and the Calico Hills Formation are examples of this hydrogeologic unit. Tuff-cone units are lavas associated with relatively large-volume precursor hydrovolcanic eruptions that typically form tuff cones or half-cones prior to eruption of lava. The lava then fills, breaches, and overflows the tuff cone as shown. Several individual tuff cones

Greatly simplified, three general types of hydraulic flow might be envisioned within volcanic rocks and alluvium of the SWNVF. The simplest type, which might occur in volcanic rocks only within vitric, massive, nonwelded tuffs, would be characterized by flow that is unrestricted in all three directions (X, Y, and Z), and therefore termed *unrestricted flow.* Such flow should characterize alluvium. The next simplest flow, *sheet flow,* would be characterized by flow that is unrestricted in two directions, but confined to a layer or zone and thus restricted in the third direction. Examples of *horizontal sheet flow* might be welded ash flow tuffs, either intracaldera or extracaldera. Faults could be considered as cases of *horizontal sheet flow.* Finally, lava flows and debris flows along caldera margins provide long, narrow conduits for flow that essentially is unidirectional, and termed *pipe flow.*

The tuff-cone aquifer is important within Western Area 20 structural block, where the Calico Hills tuff-cone aquifer is prevalent at the water table. To properly model groundwater flow, it is important to properly represent such a unit, which there consists of a spatially unpredictable assemblage of lava and zeolitic nonwelded tuff. Field observations indicate that lava within a tuff-cone aquifer, which hosts fracture-dominated hydraulic flow, occurs as an irregular lens that flows from its vent along a channel cut into underlying nonwelded tuff. In the Calico Hills tuff-cone aquifer, successive eruptions repeat the lithologic complexity, as shown in Figure 9. Hydraulic flow in a tuff-cone aquifer can be precisely modeled if each successive eruption is recognizable as a subunit. Prothro and Warren (2000) subdivided that mafic-poor Calico Hills Formation, based on detailed petrographic analyses and mineral chemistry by microprobe. In lieu of unit subdivision, a tuff-cone aquifer is best modeled using a Monte Carlo approach to construct the lithologic complexity (Weissmann et al., 1999; Carle et al., 1998).

References

Barnes, H., E. B. Ekren, C. L. Rodgers, and D. C. Hedlund, Geologic and tectonic maps of the Mercury quadrangle, Nye and Clark Counties, Nevada, **Misc. Geol. Invest. Map I-1197**, U.S. Geol. Survey, 1982.

Barnes, H., R. L. Christiansen, and F. M. Byers, Jr., Geologic Map of the Jangle Ridge Quadrangle, Nye and Lincoln Counties, Nevada, **U.S. Geol. Surv. Map GQ-363**, scale 1:24 000, 1965.

Barnes, H., F. N. Houser, and F. G. Poole, Geology of the Oak Spring Quadrangle, Nye County, Nevada, **U.S. Geol. Surv. Map GQ-214**, scale 1:24 000, 1963.

Bechtel Nevada, "Completion report for well ER-EC-6", **DOE/NV/11718-360**, May 2000.

Carr, W. J., Volcano-tectonic history of Crater Flat, southwestern Nevada, as suggested by new evidence from drill hole USW-VH-1 and vicinity, **U. S. Geol. Survey Open-file Report 82-457**, 23 pp., 1982.

Carr W. J., F. M. Byers, Jr., and P. P. Orkild, Stratigraphic and volcano-tectonic relations of Crater Flat Tuff and some older volcanic units, Nye County, Nevada, **U. S. Geol. Survey Prof. Paper 1323**, 28 pp., 1986.

Christiansen, R. L., and D. C. Noble, "Geologic Map of the Trail Ridge Quadrangle, Nye County, Nevada," **U. S. Geol. Surv. Map GQ-774**, scale 1:24 000, 1968.

Christiansen, R. L., P. W. Lipman, W. J. Carr, F. M. Byers, Jr., P. P. Orkild, and K. A. Sargent, Timber Mountain-Oasis Valley caldera complex of southern Nevada, **Geol. Soc. Amer. Bull.**, 88, 943-959, July 1977.

Cole, J. C., and P. H. Cashman, Structural relationships of Pre-Tertiary rocks in the Nevada Test Site region, southern Nevada, **U. S. Geol. Survey Prof. Paper 1607**, 39 pp., 1999.

Cummings, D., Mechanical Analysis of the Effect of the Timber Mountain Caldera on Basin and Range Faults, **J. Geophys. Res.**, Vol. 73, No. 8, p. 2787-2794, 1968.

Dixon, G. L., W. J. Carr, and P. L. Aamodt, Lithologic logs and stratigraphic identification of exploratory and emplacement drill holes in Area 4, Nevada Test Site, **U. S. Geol. Survey NTS-249 (USGS-474-173)**, 37 pp., October 1973.

Drellack, S. L., and L. B. Prothro, "Descriptive narrative for the hydrogeologic model of western and central Pahute Mesa Corrective Action Units", **Interim documentation report for the UGTA project, Bechtel Nevada, Las Vegas, NV**, 90 pp., 1997.

[redacted]

IT Corporation, "Western Pahute Mesa – Oasis Valley well ER-EC-5 data report for development and hydraulic testing (preliminary, revision no.: 0)", **ITLV/13052-XX**, August 2000d.

Kane, M. F., M. W. Webring, and B. K. Bhattacharyya, A preliminary analysis of gravity and aeromagnetic surveys of the Timber Mountain area, southern Nevada, **U. S. Geol. Survey Open-file Report 81-189**, 40 pp., 1981.

Laczniak, R. J., J. C. Cole, D. A. Sawyer, and D. A. Trudeau, "Summary of hydrogeologic controls on

Davis, E. G., D. P. Elston, and W. J. Cox, "Geologic Map of the [illegible] Series, Quadrangle, N[illegible]

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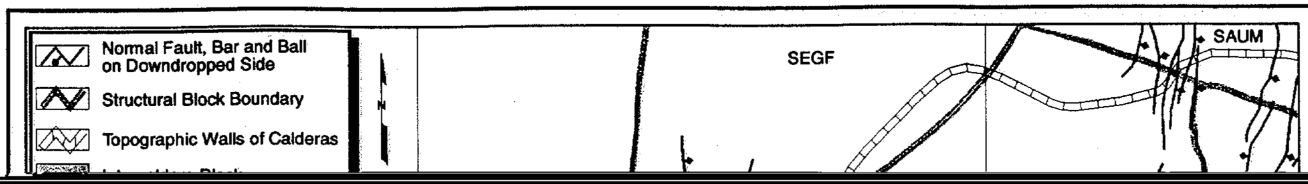
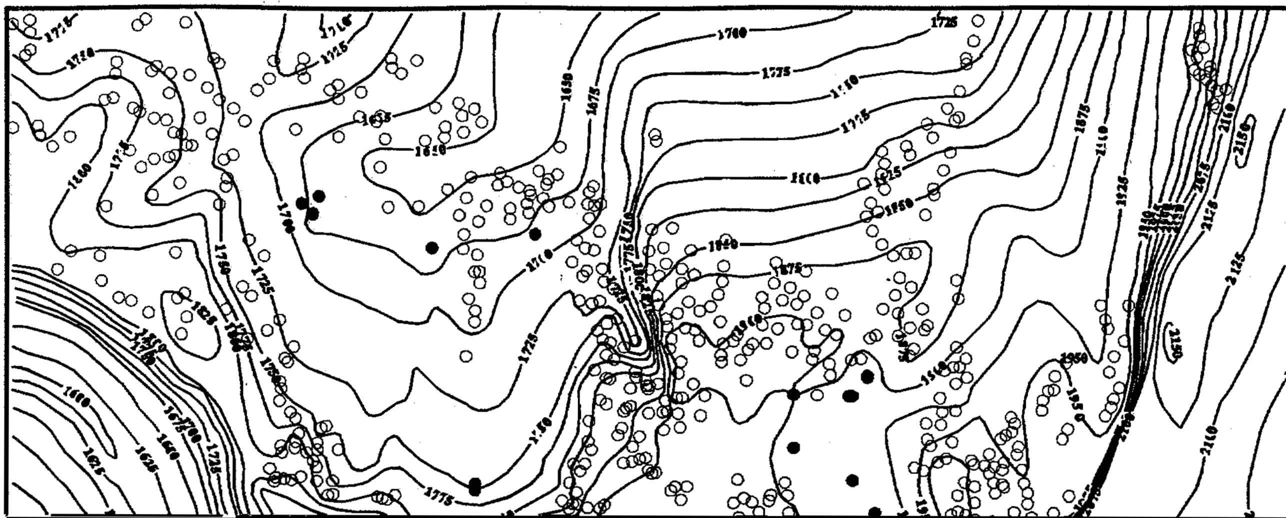

Normal Fault, Bar and Ball on Downdropped Side
Structural Block Boundary
Topographic Walls of Calderas
SEGF
SAUM



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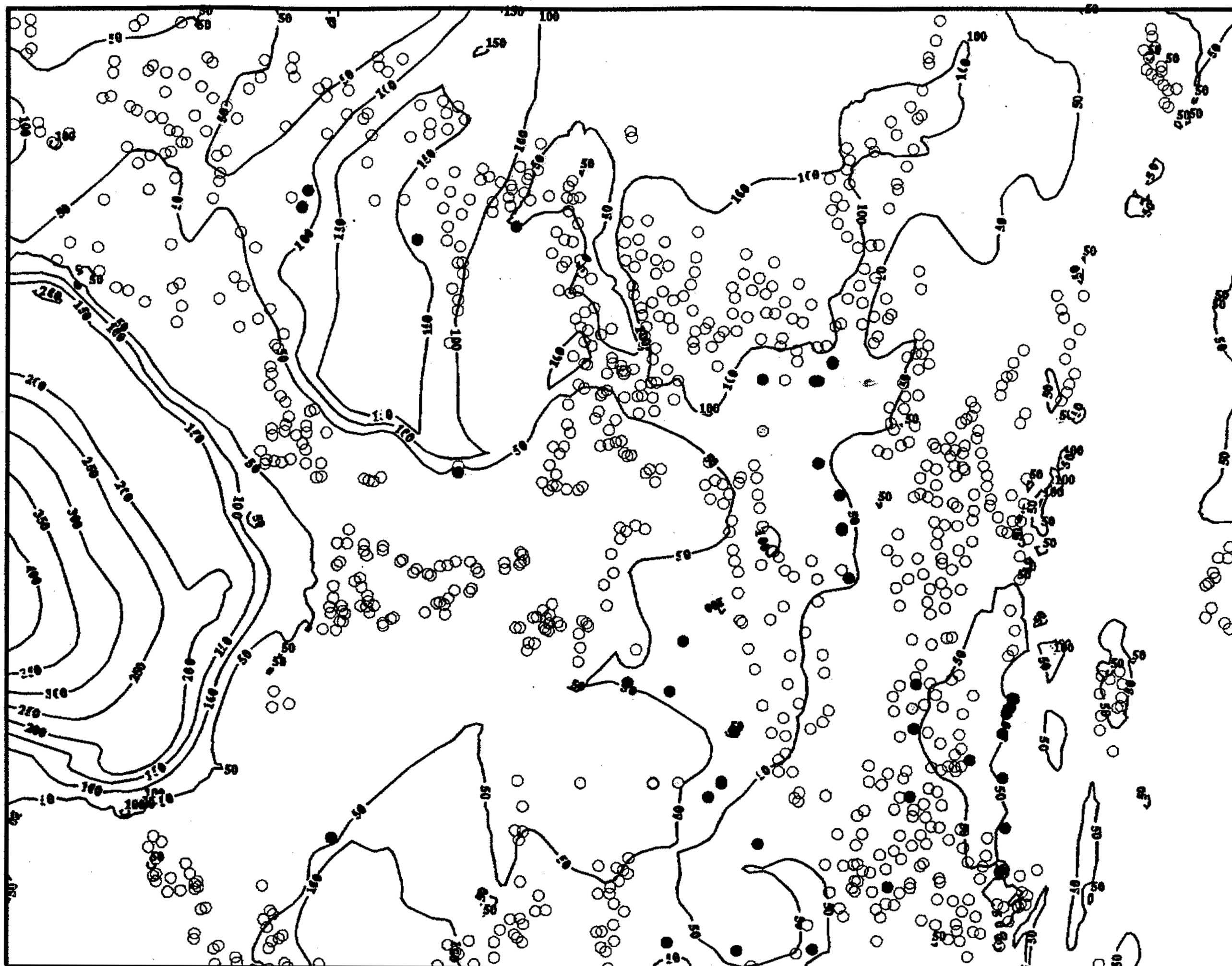
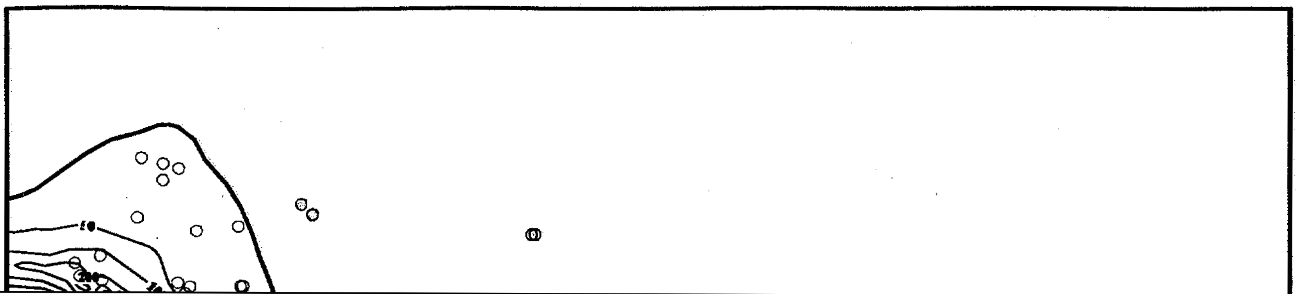


Figure A4. Model elevations for top of comendite of Ribbon Cliff (Ttc) within region defined in Figure 1. Structural features can be identified by comparison with Figure A1. Unit is absent outside contoured region. Small circles show location of control points; filling colors define differences between observations and model as described for Figure A2.



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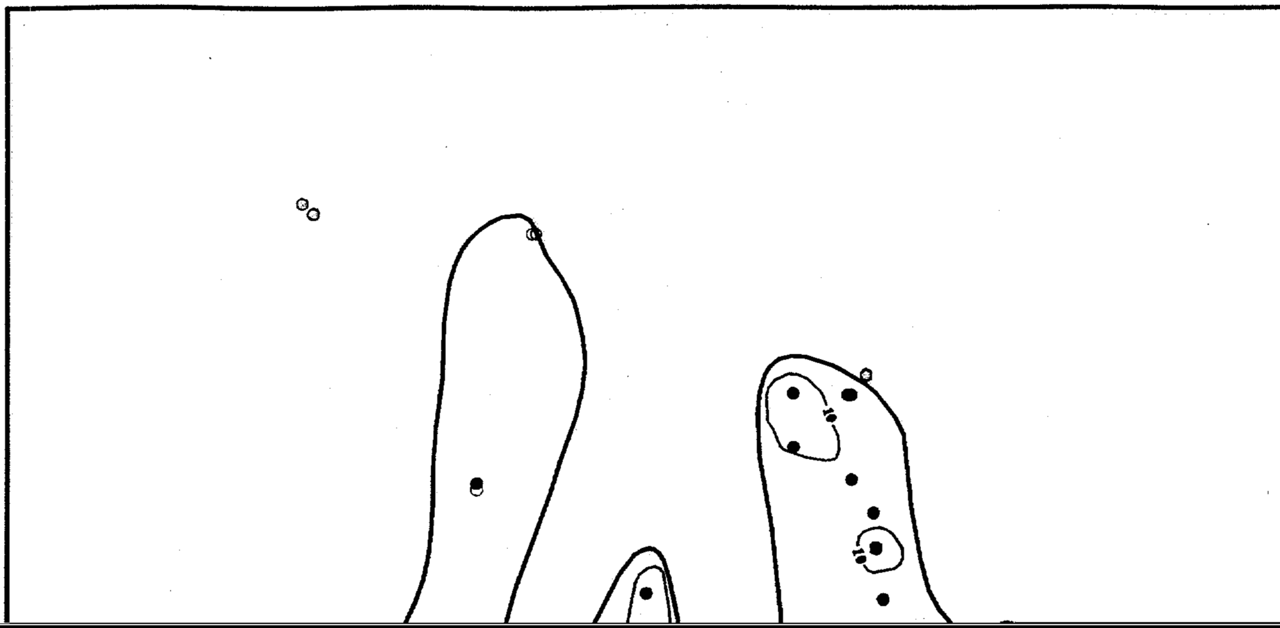


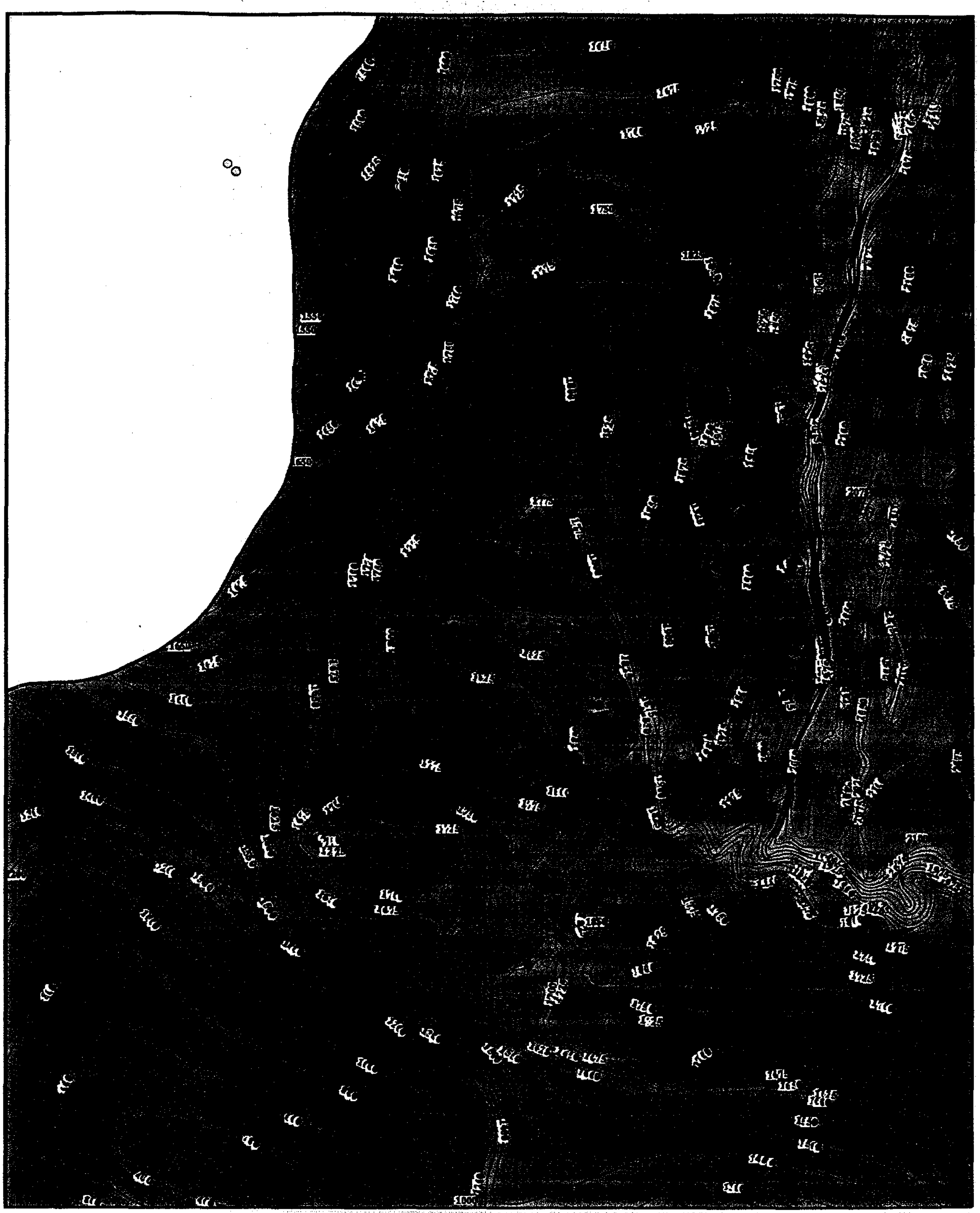
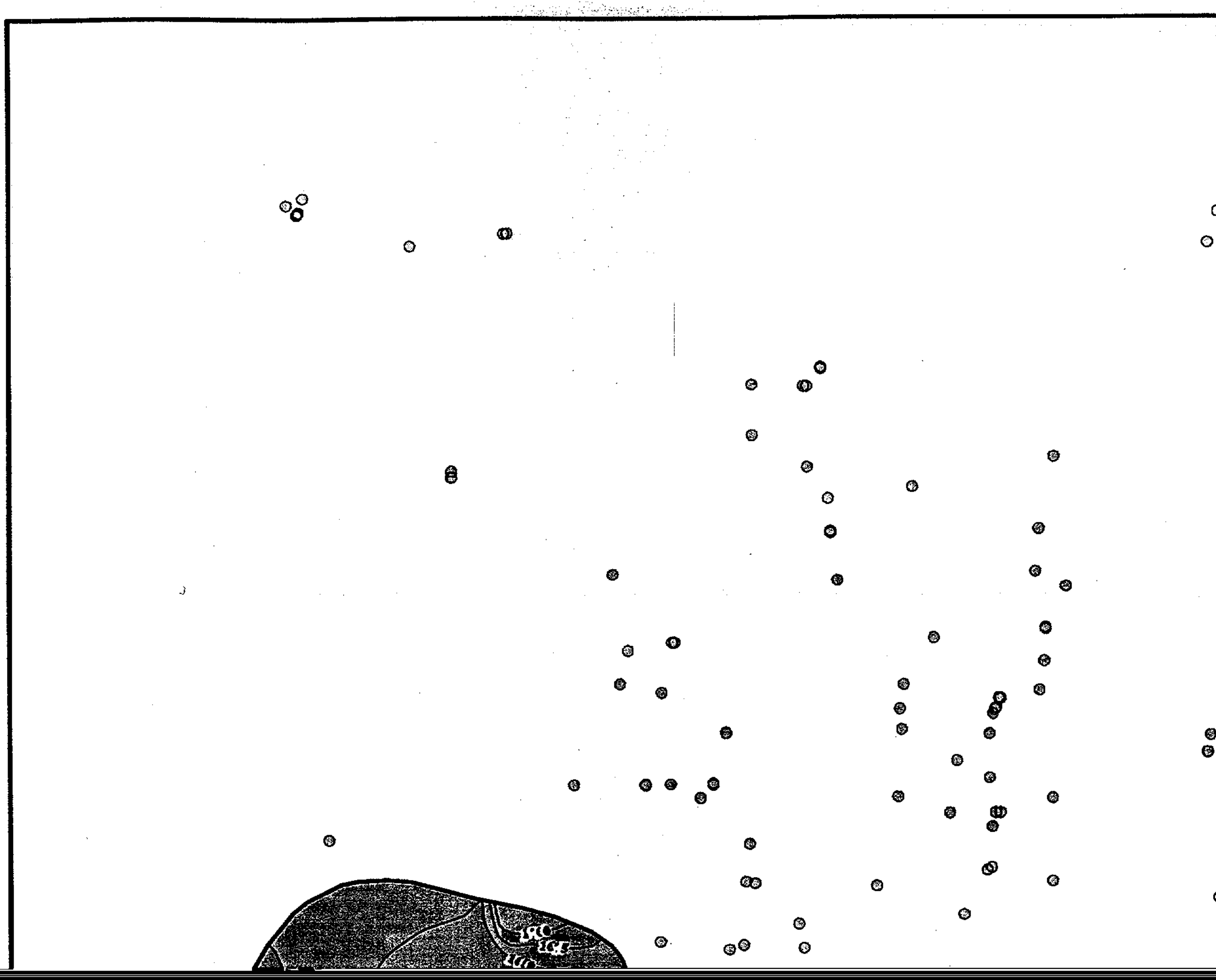
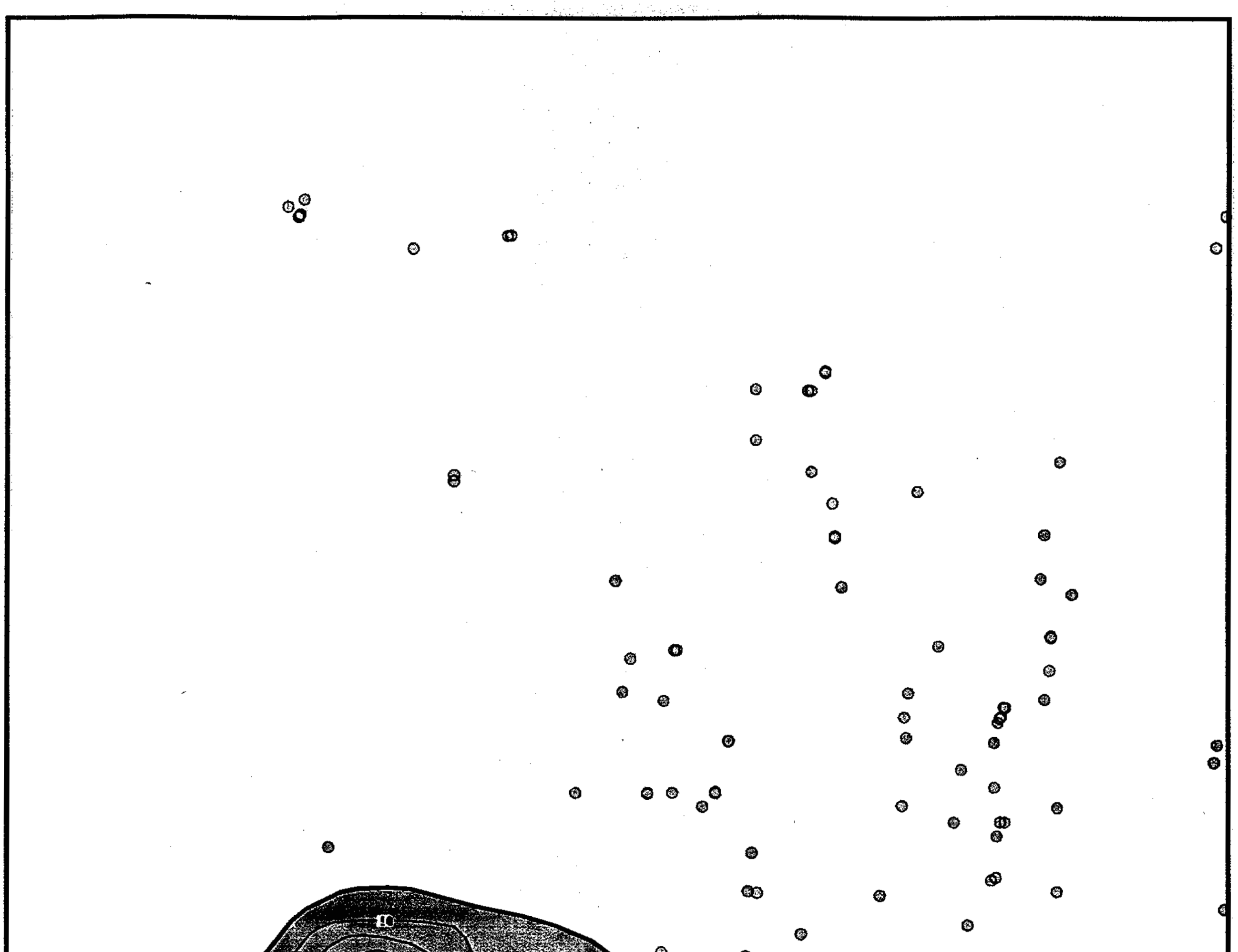
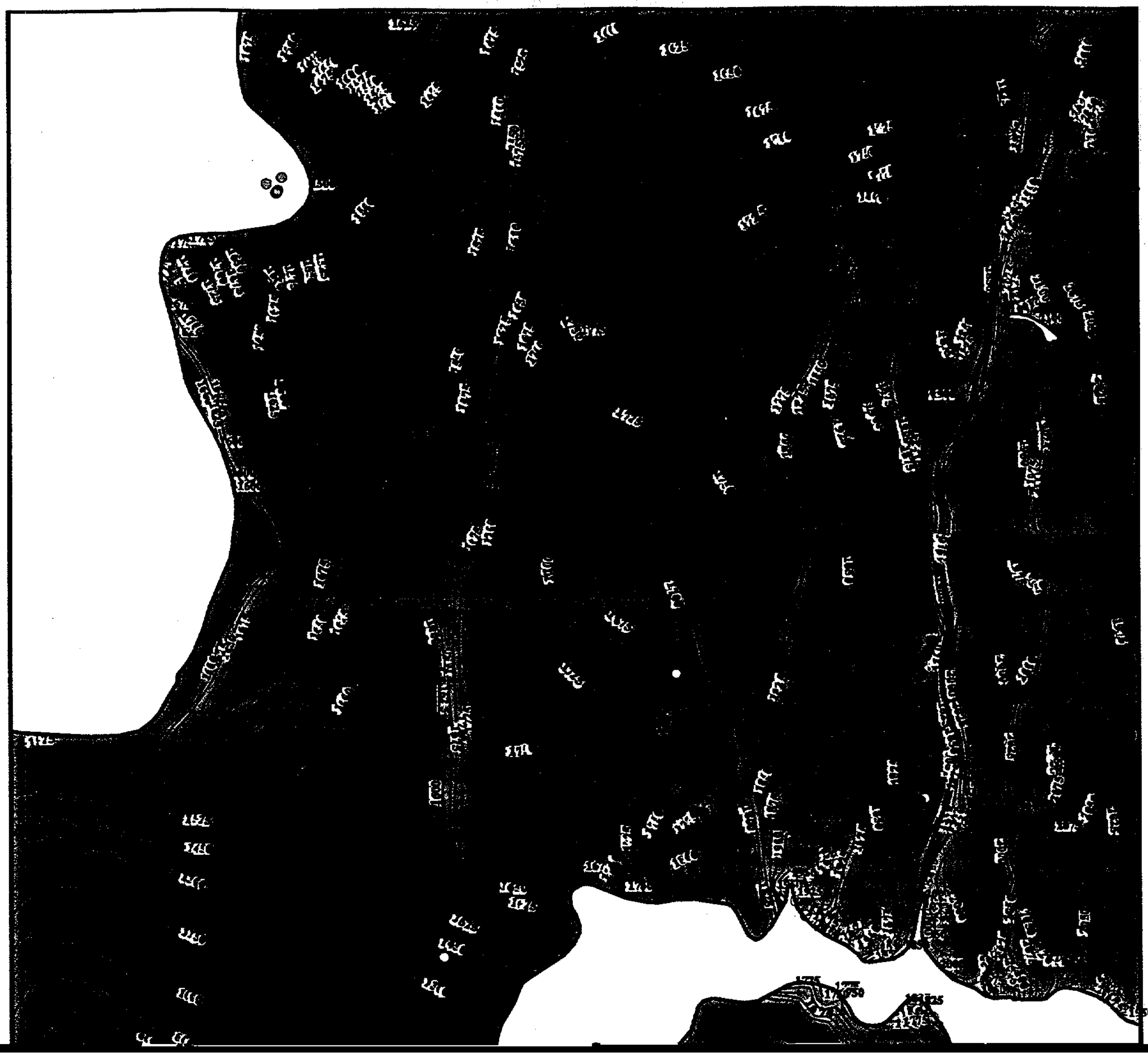


Figure A8. Model elevations for top of Ammonia Tanks Tuff (Tma) within region defined in Figure 1. Structural features can be identified by comparison with Figure A1. Unit is absent outside contoured region, and is locally absent within a few areas, as defined in Figure 3-12 of Prothro and Warren, 2000. Small circles show location of control points; filling colors define differences between observations and model as described for Figure A2. Displacement of Tma is 200 m across the West Greeley fault, and 100 m across the West Boxcar fault. Sparse control by ER/EC4 and ER/EC2A (Table 1) do not mandate a structural division of the Rocket Wash basin into western and eastern halves.







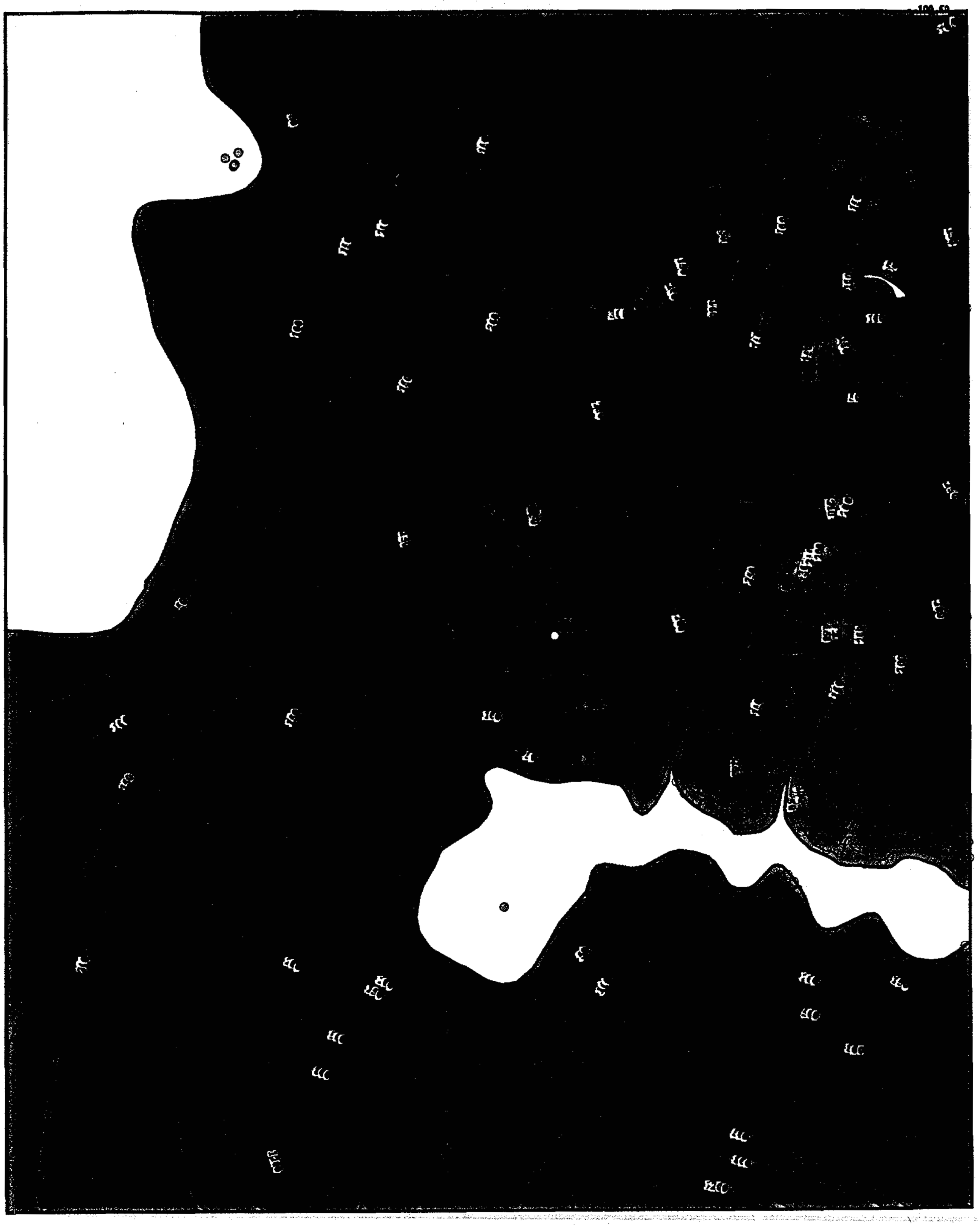
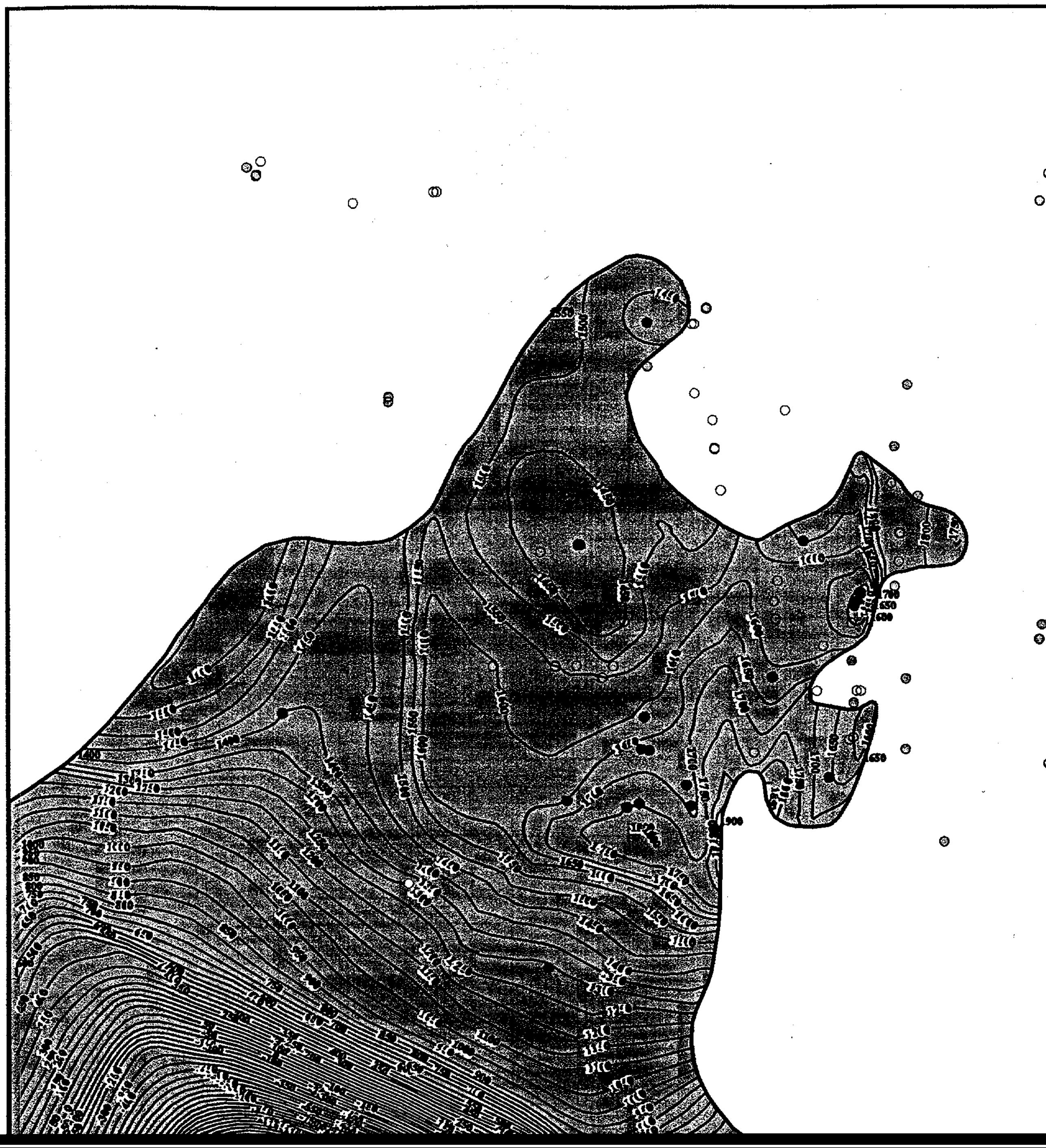
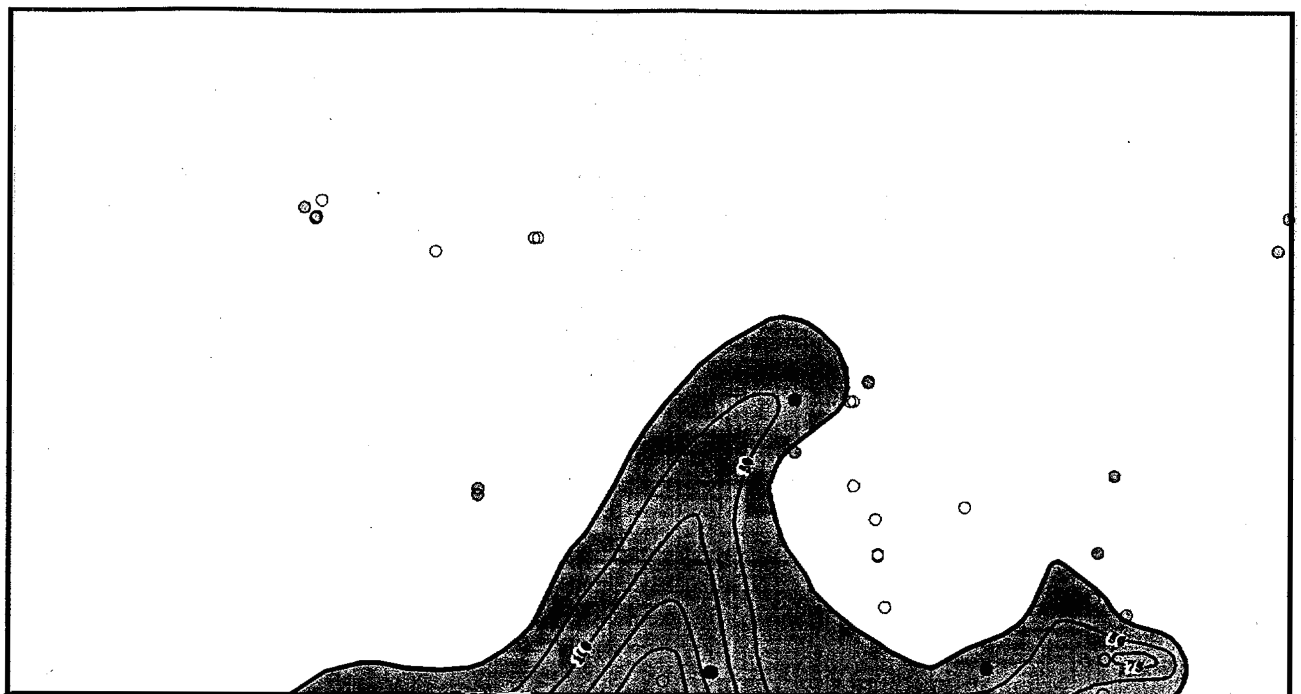
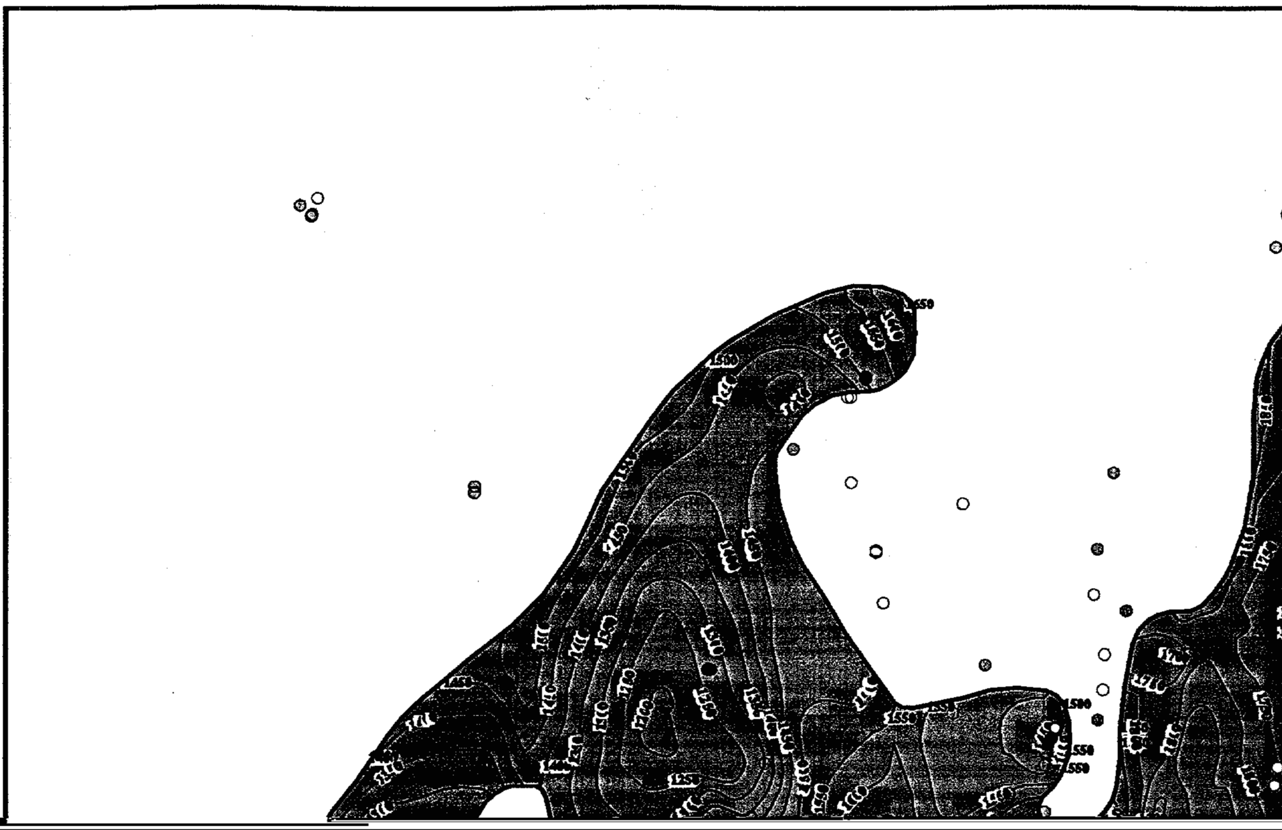


Figure A13. Model isopachs for Rainier Mesa Tuff (Tmr) within region defined in Figure 1. Structural features can be identified by comparison with Figure A1. Unit is absent outside contoured region. Small circles show location of control points; filling colors define differences between observations and model as described for Figure A2.







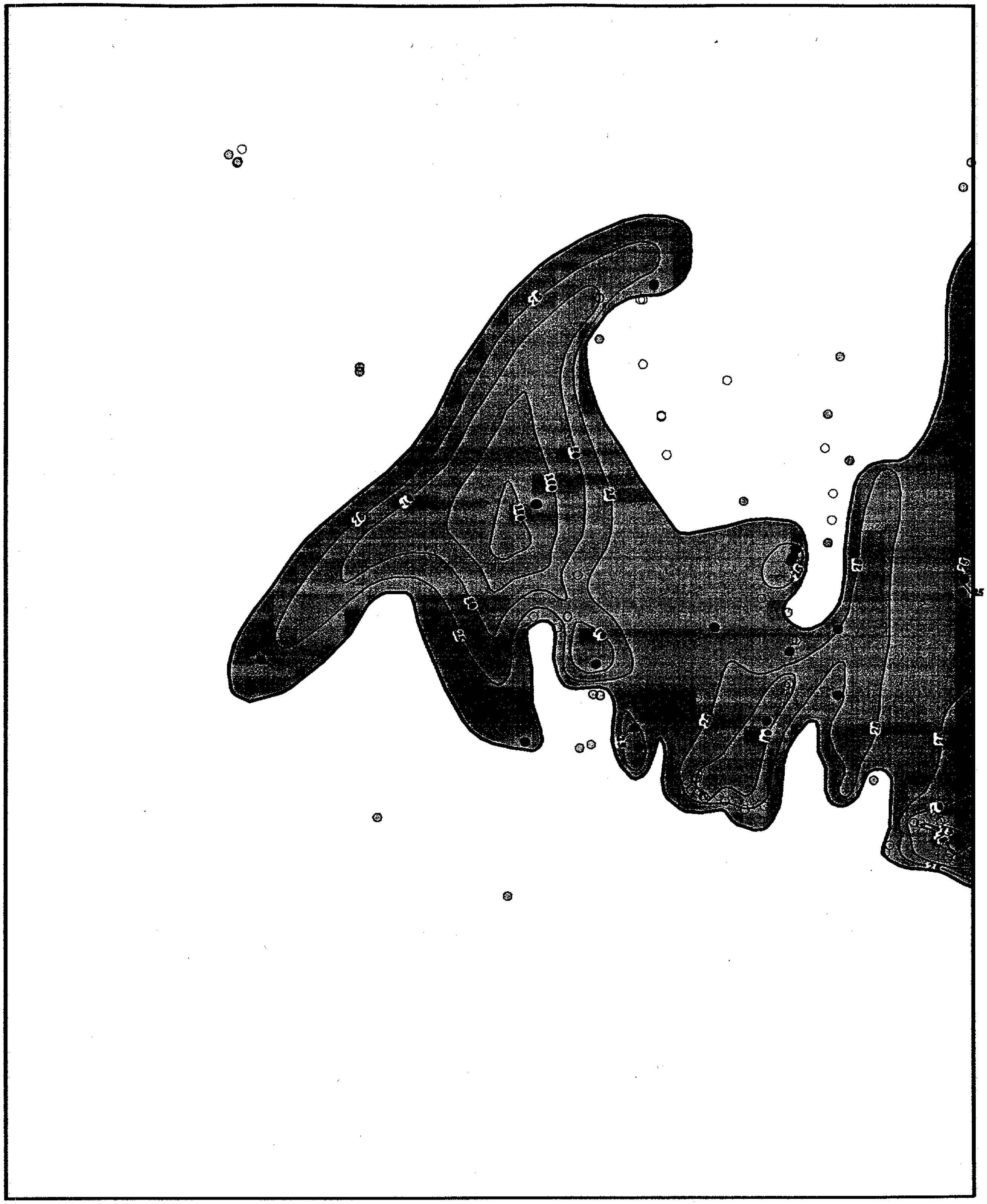


Figure A17. Model isopachs for tuff of Holmes Road (Tmrh) within region defined in Figure 1. Structural features can be identified by comparison with Figure A1. Unit is absent outside contoured region. Small circles show location of control points; filling colors define differences between observations and model as described for Figure A2. The thickest Tmrh known within the SWNVF occurs within the Boxcar Trough, where overlying Tmrf and Tmr are also thick.

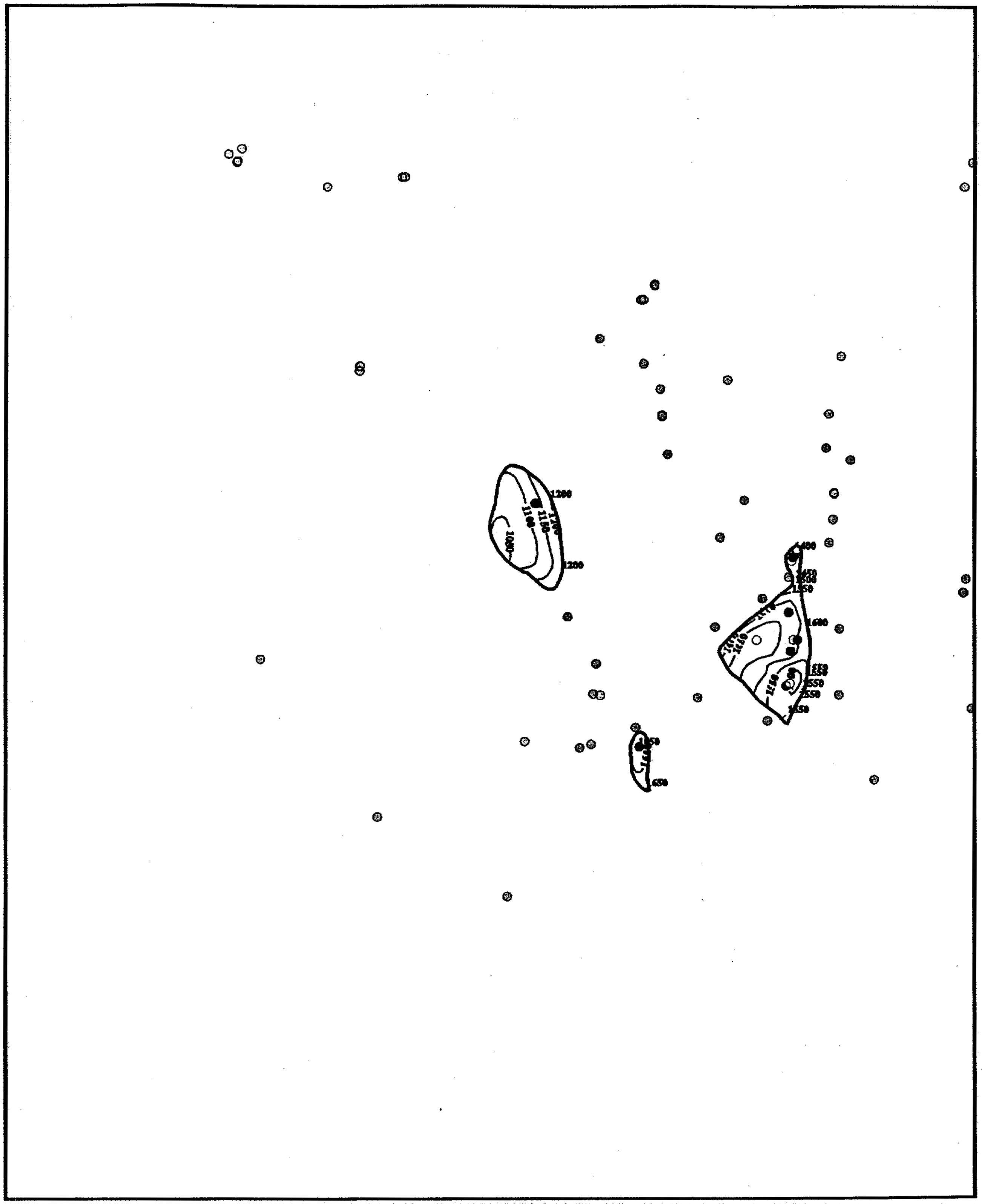


Figure A18. Model elevations for top of rhyolite of Windy Wash (Tmw) within region defined in Figure 1. Structural features can be identified by comparison with Figure A1. Unit is absent outside contoured region. Small circles show location of control points; filling colors define differences between observations and model as described for Figure A2.

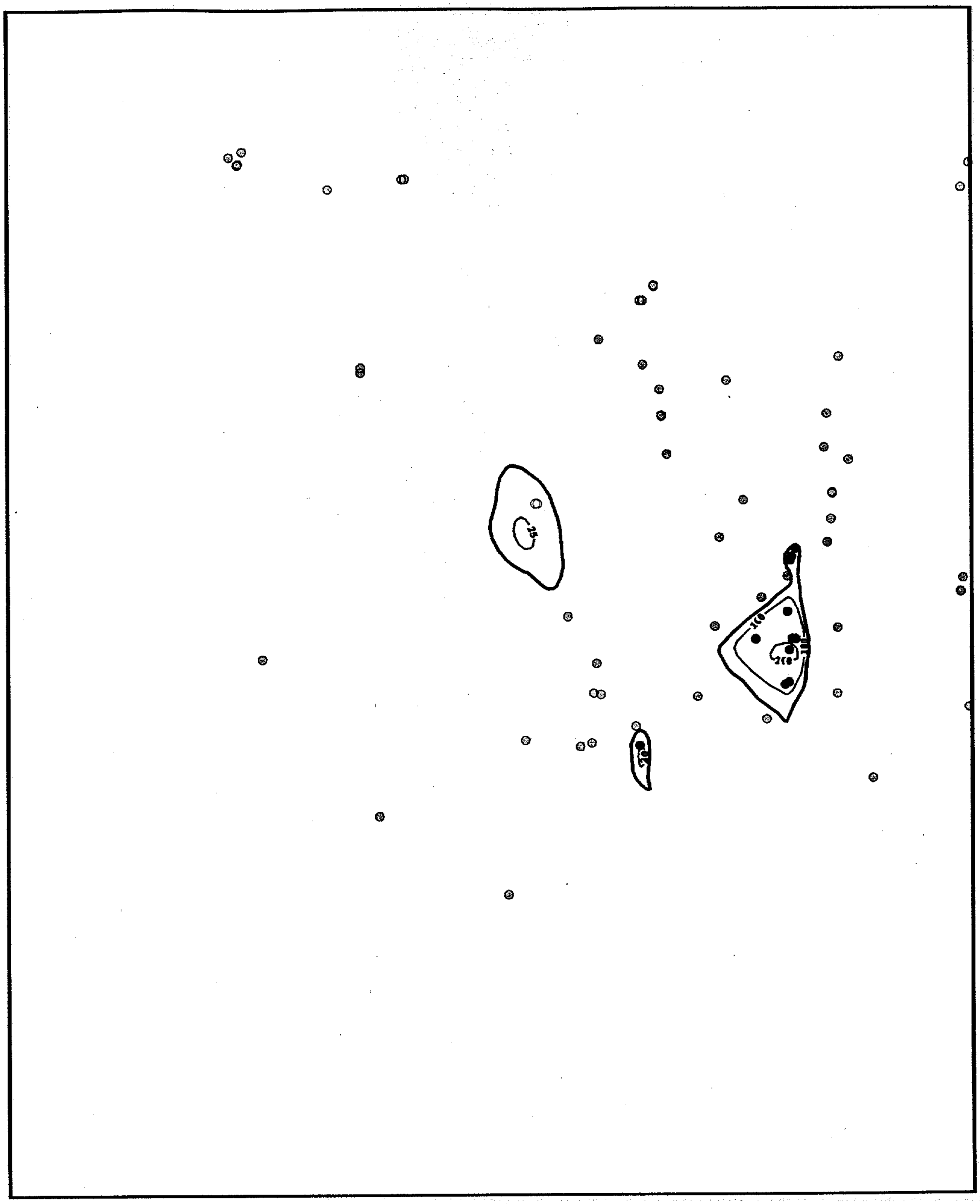


Figure A19. Model isopachs for rhyolite of Windy Wash (Tmw) within region defined in Figure 1. Structural features can be

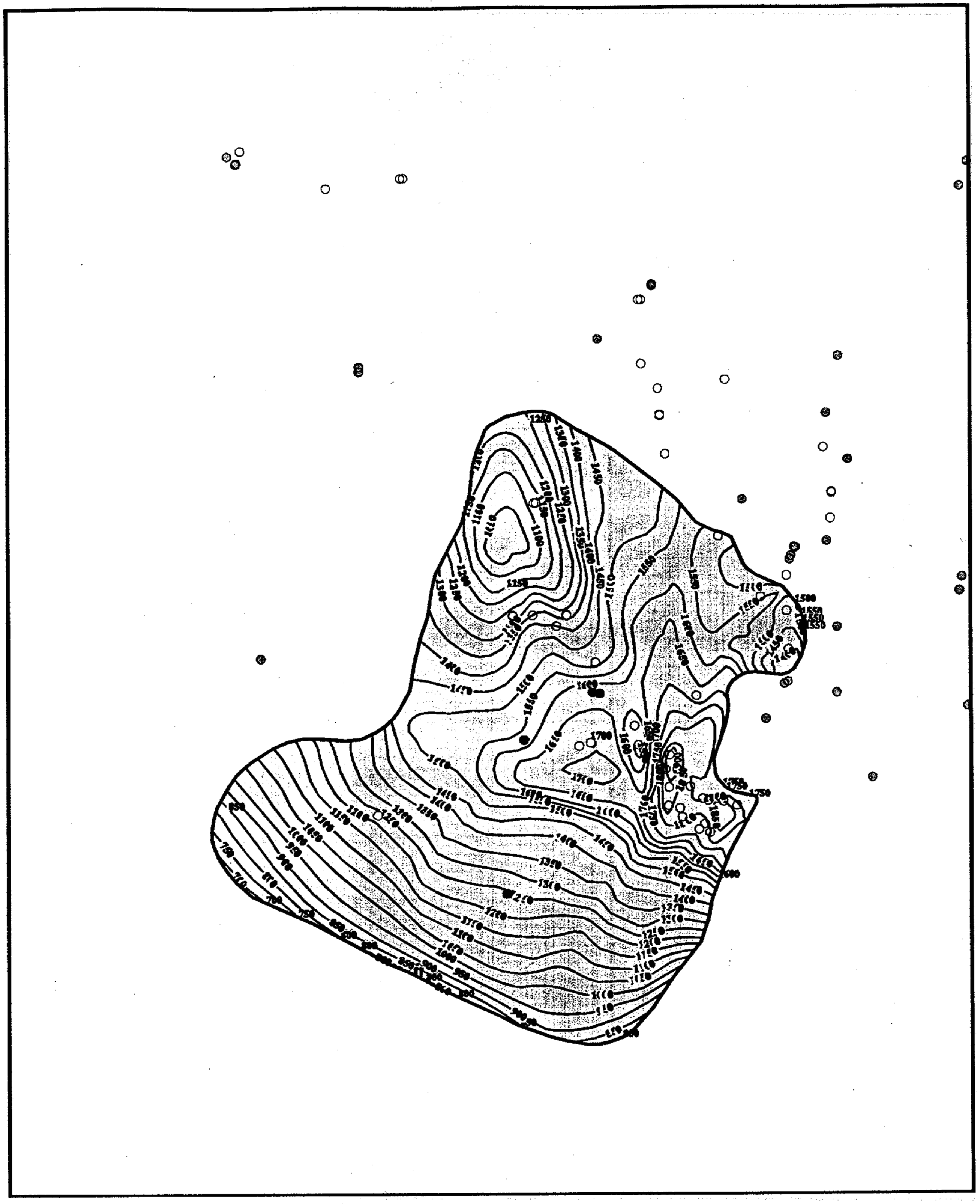


Figure A20. Model elevations for the top of rhyolite of Benham (Tpb) within region defined in Figure 1. Structural features can be identified by comparison with Figure A1. Unit is absent outside contoured region. Small circles show location of control points; filling colors define differences between observations and model as described for Figure A2.

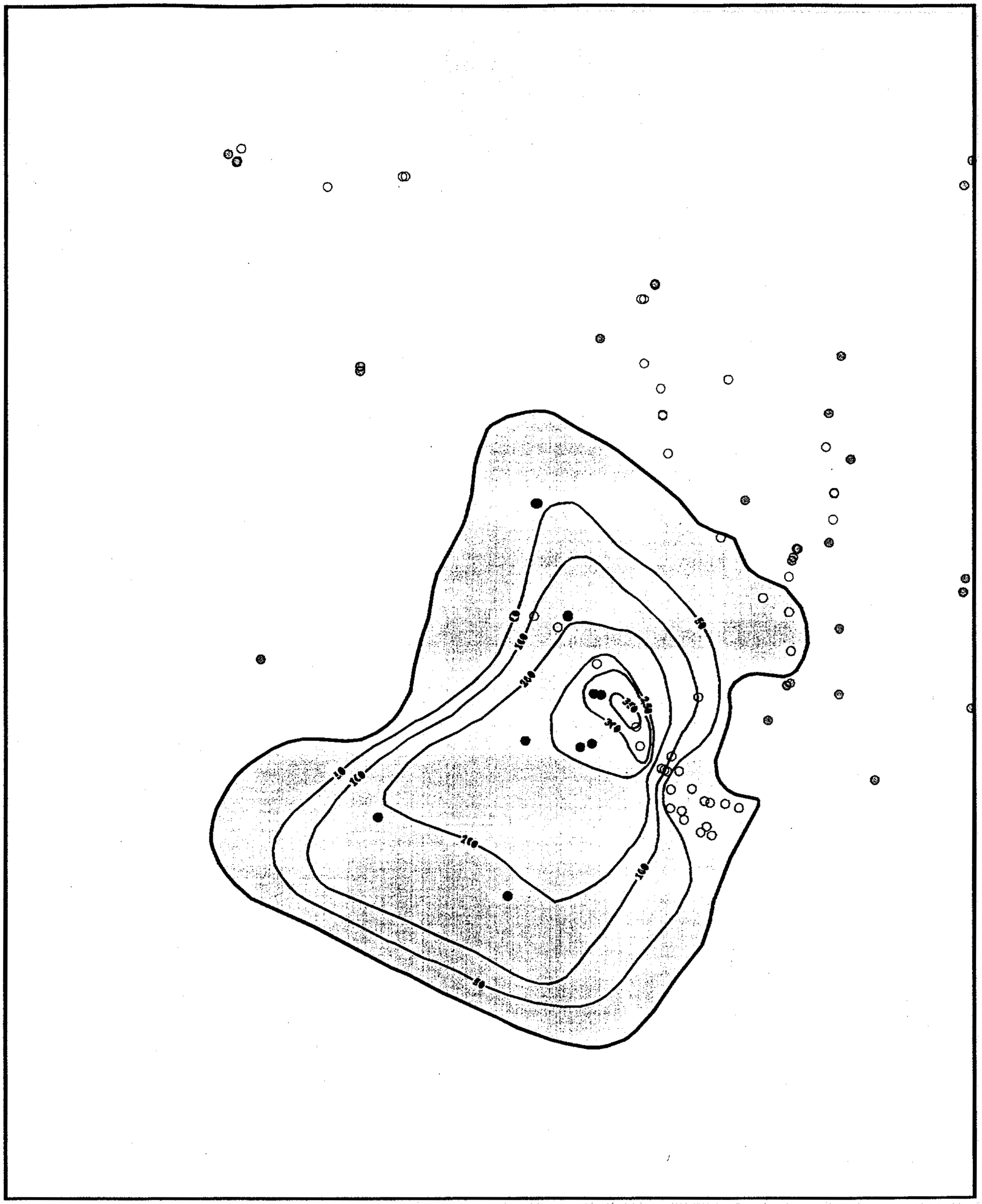
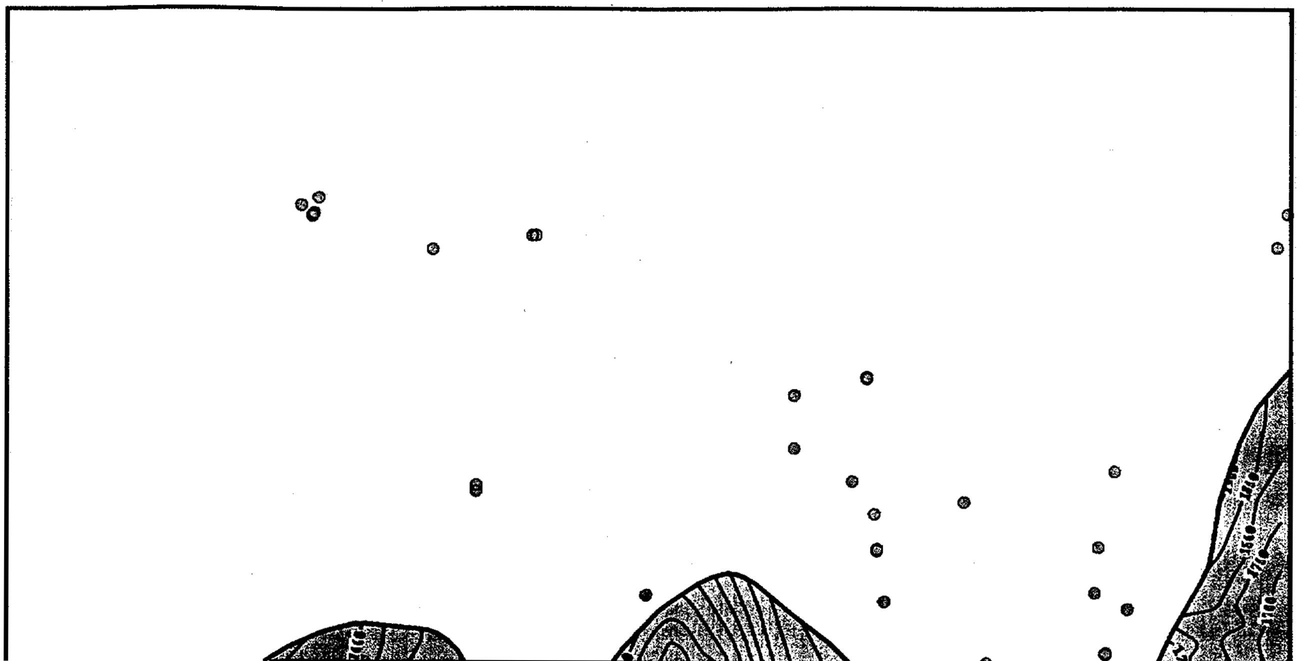
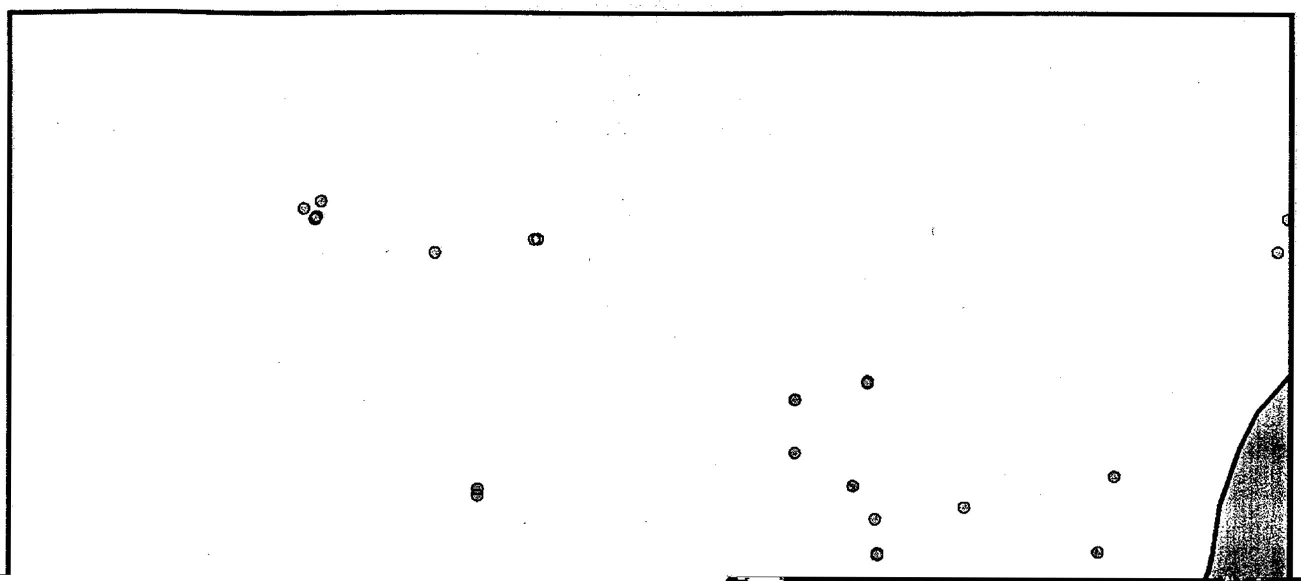
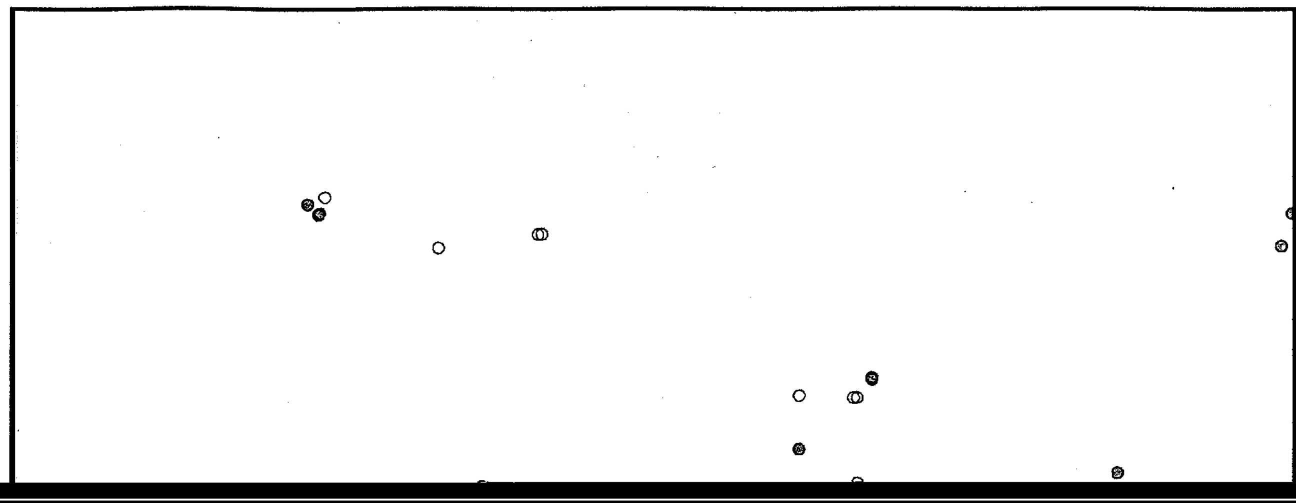
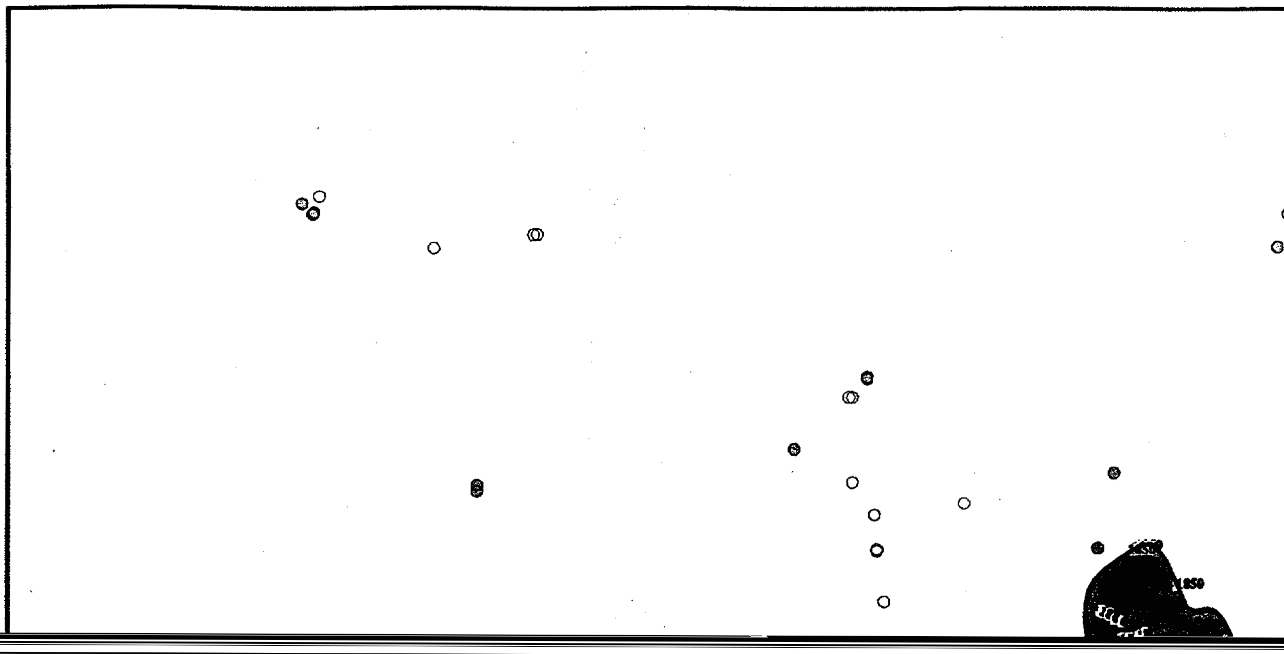


Figure A21. Model isopachs for rhyolite of Benham (Tpb) within region defined in Figure 1. Structural features can be identified by comparison with Figure A1. Unit is absent outside contoured region. Small circles show location of control points; filling colors define differences between observations and model as described for Figure A2. Tpb was certainly erupted from the West Boxcar fault, where it is thickest on the downthrown side. Tpb formed a prominent topographic high, resulting in relatively thin deposits for overlying units within the southern part of the Boxcar Trough. Thicknesses of Tpb are similar within the Western Area 20 and Northwestern Timber Mountain Bench structural blocks, indicating that these blocks rotated as a single block prior to eruption of Tpb.









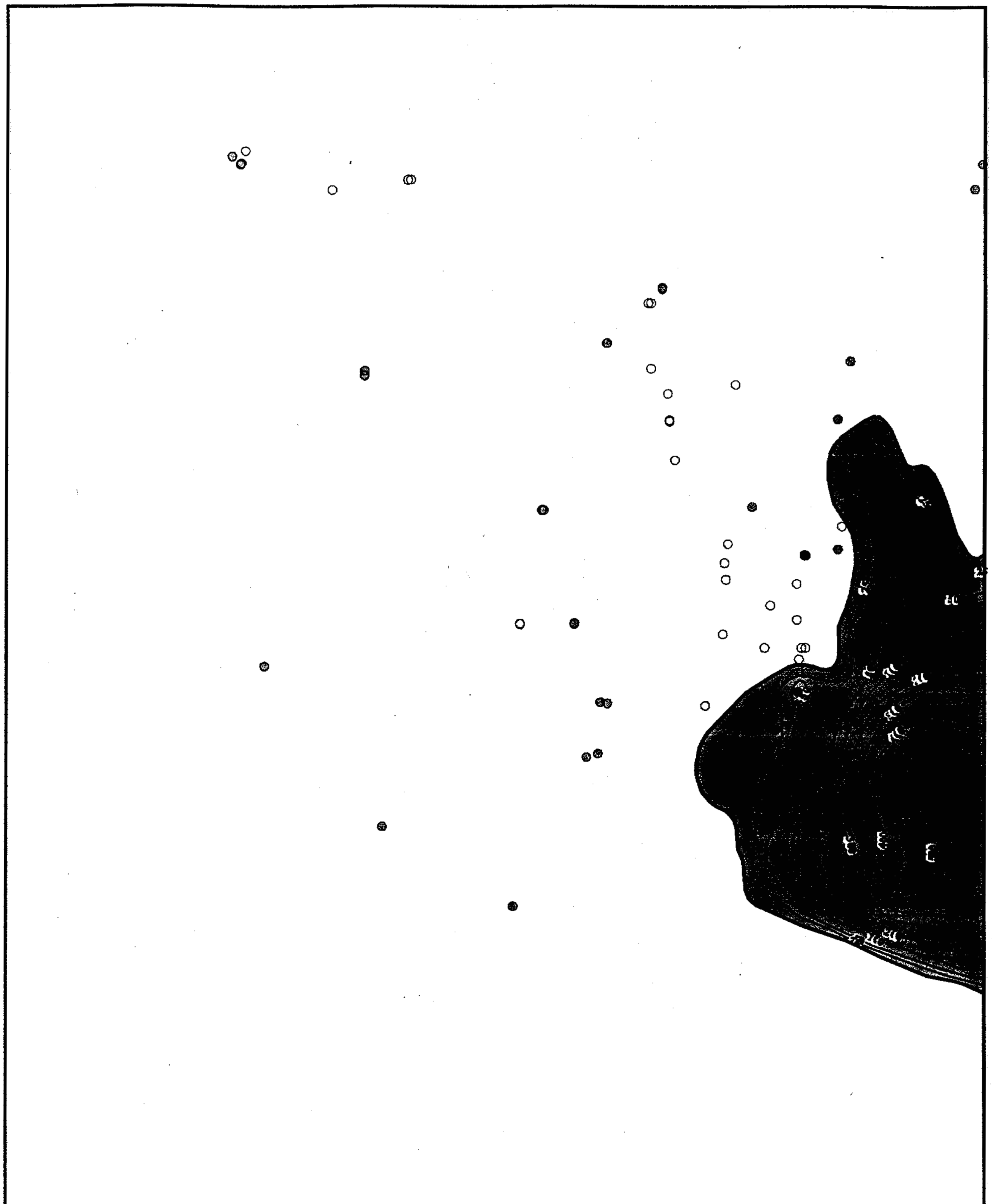


Figure A29. Model isopachs for rhyolite of Echo Peak (Tpe) within region defined in Figure 1. Structural features can be identified by comparison with Figure A1. Unit is absent outside contoured region. Small circles show location of control points; filling colors define differences between observations and model as described for Figure A2. A rapid southward thinning suggests that the topographic wall of Rainier Mesa caldera coincides with a structure that formed a barrier to the southward spread of Tpe.

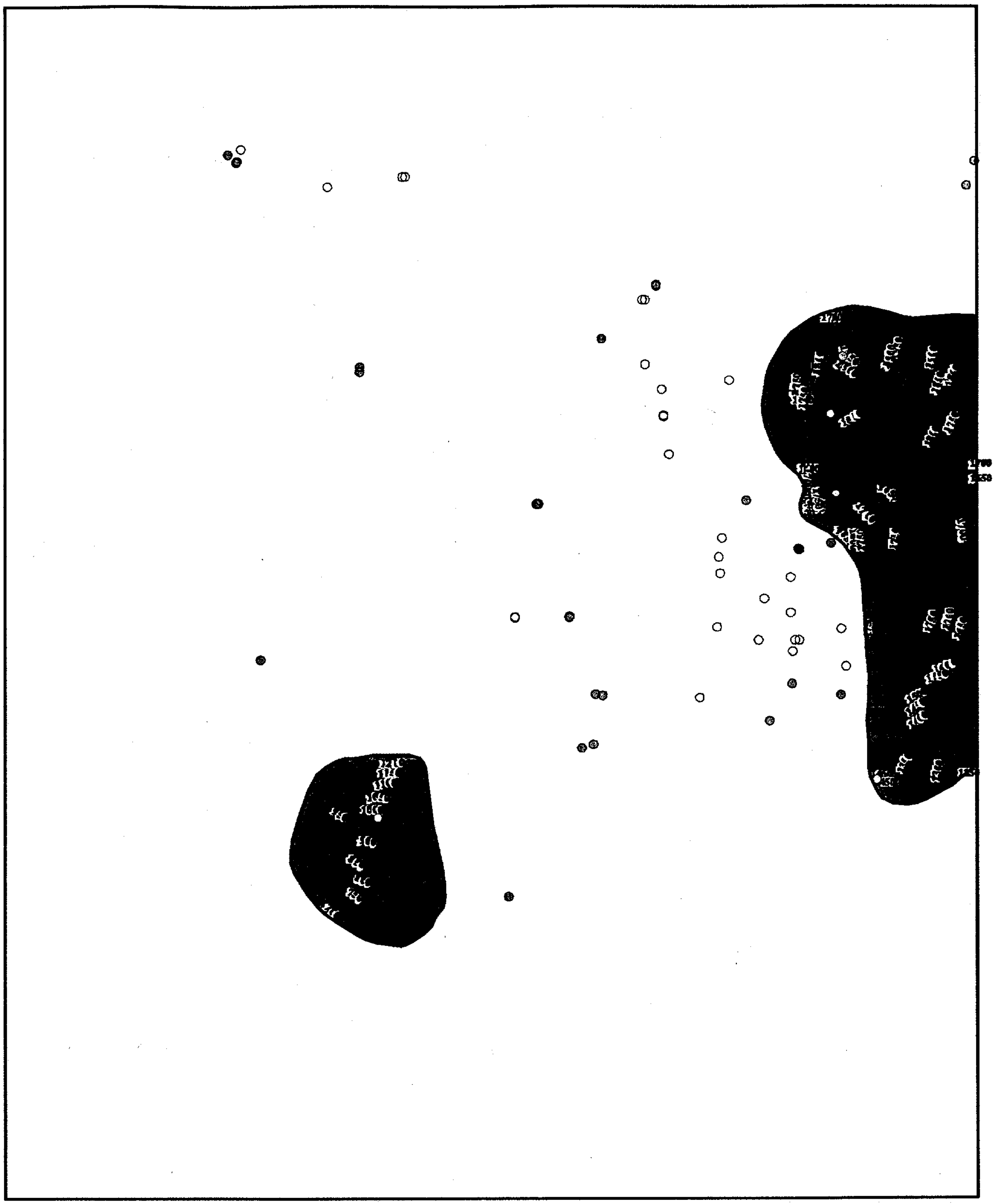
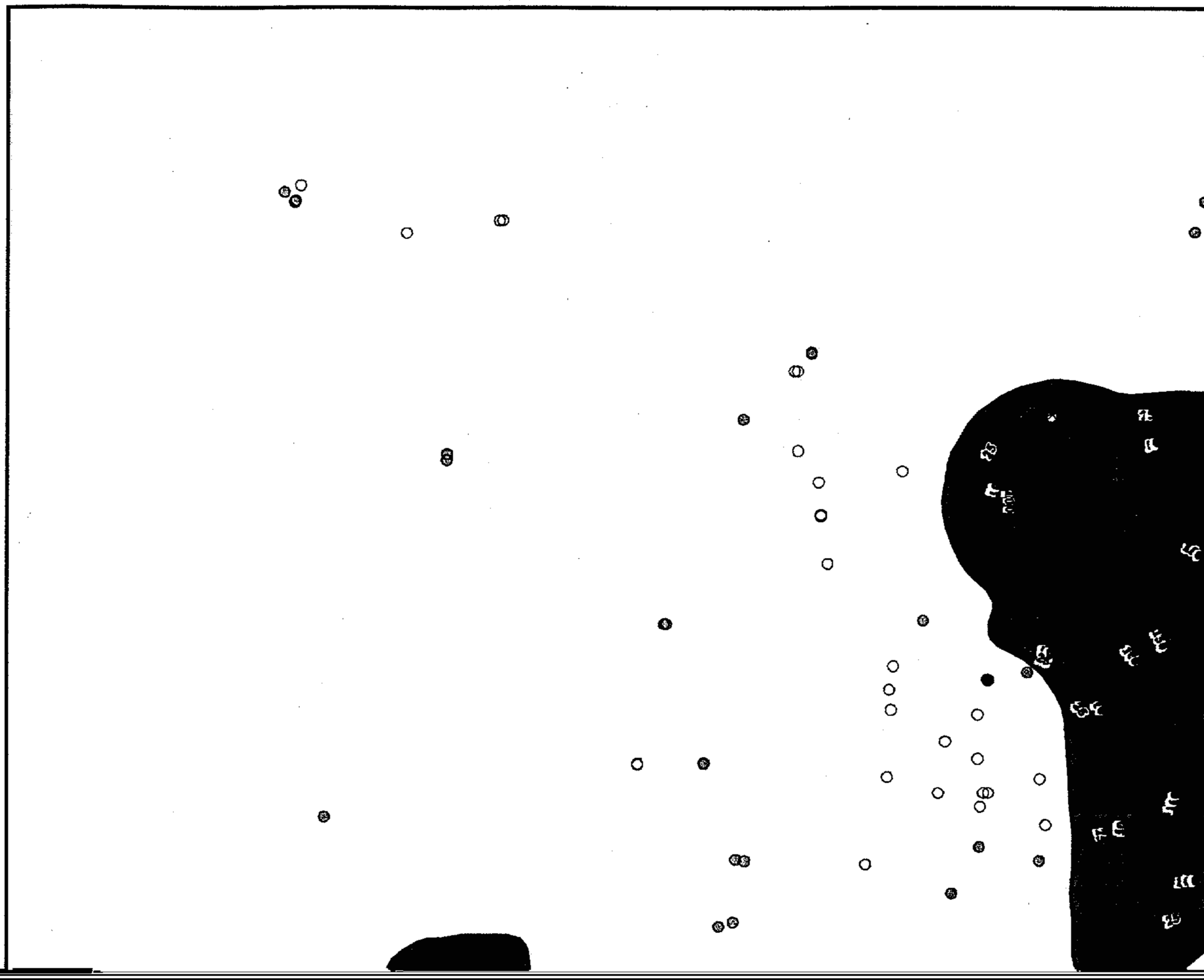


Figure A30. Model elevations for top of rhyolite of Silent Canyon (Tpr) within region defined in Figure 1. Structural features can be identified by comparison with Figure A1. Unit is absent outside contoured region. Small circles show location of control points; filling colors define differences between observations and model as described for Figure A2. Note that the southwestern area instead represents landslide breccia of Topopah Spring Tuff (Tptx) in drill hole ER/EC1. This landslide, primarily mafic-rich Calico Hills Formation, originated from a topographically high ridge of that unit north from ER/EC1.

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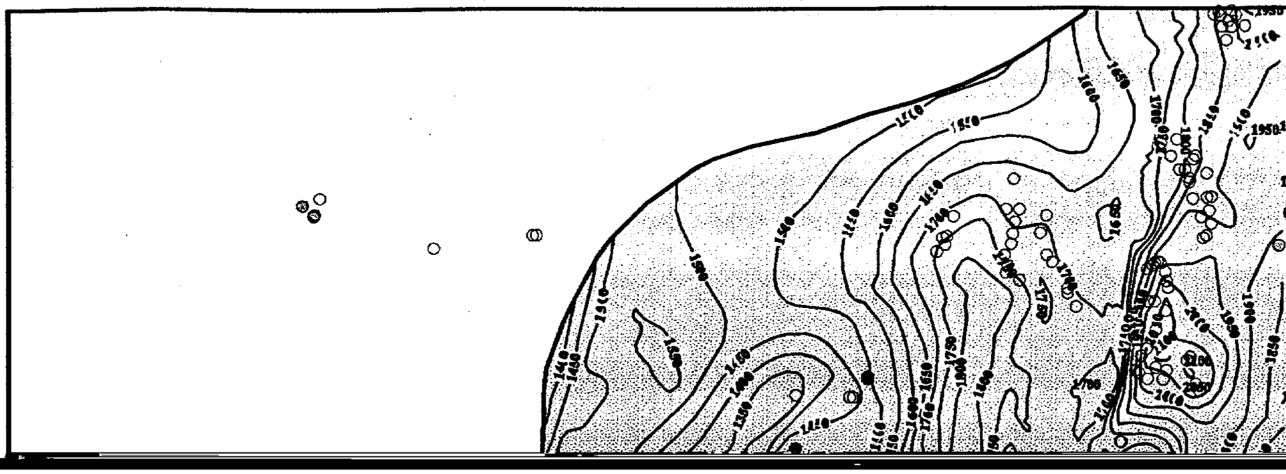

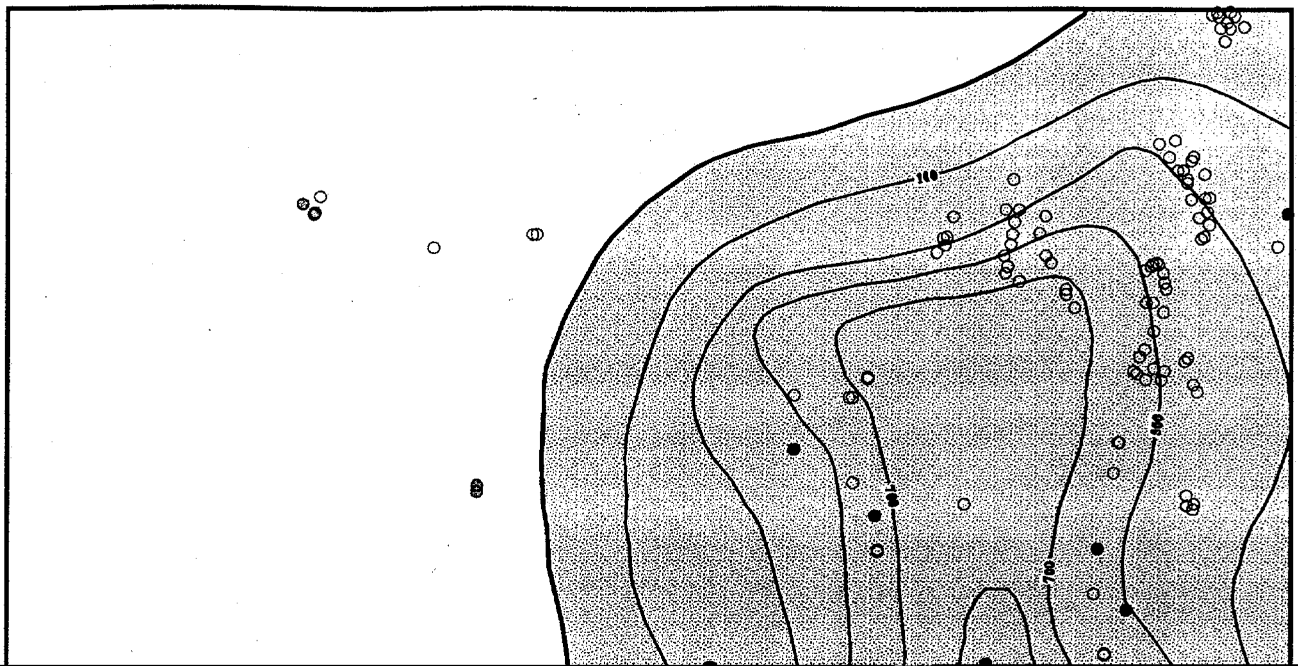

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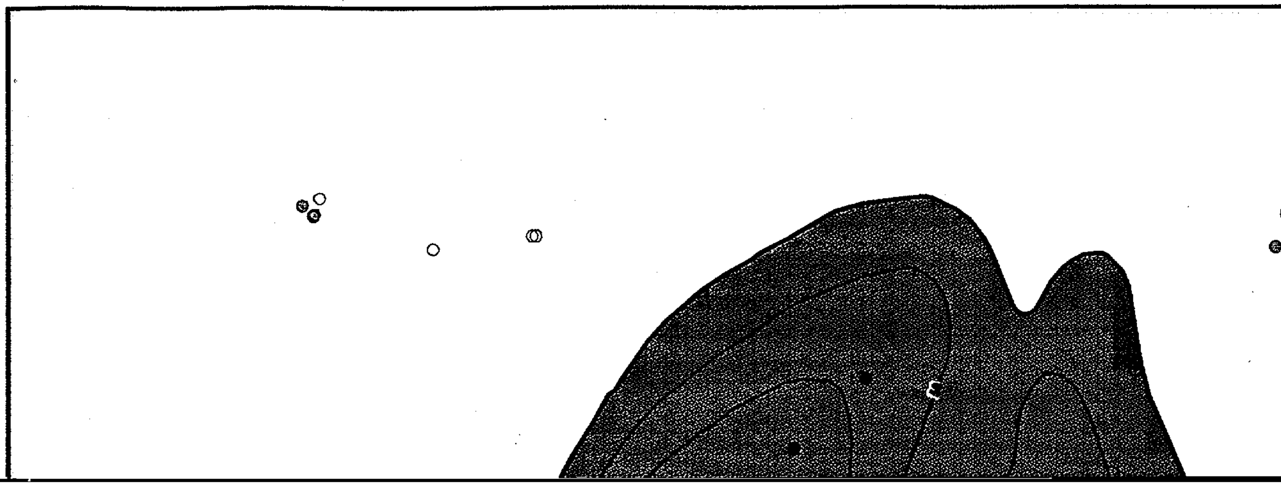

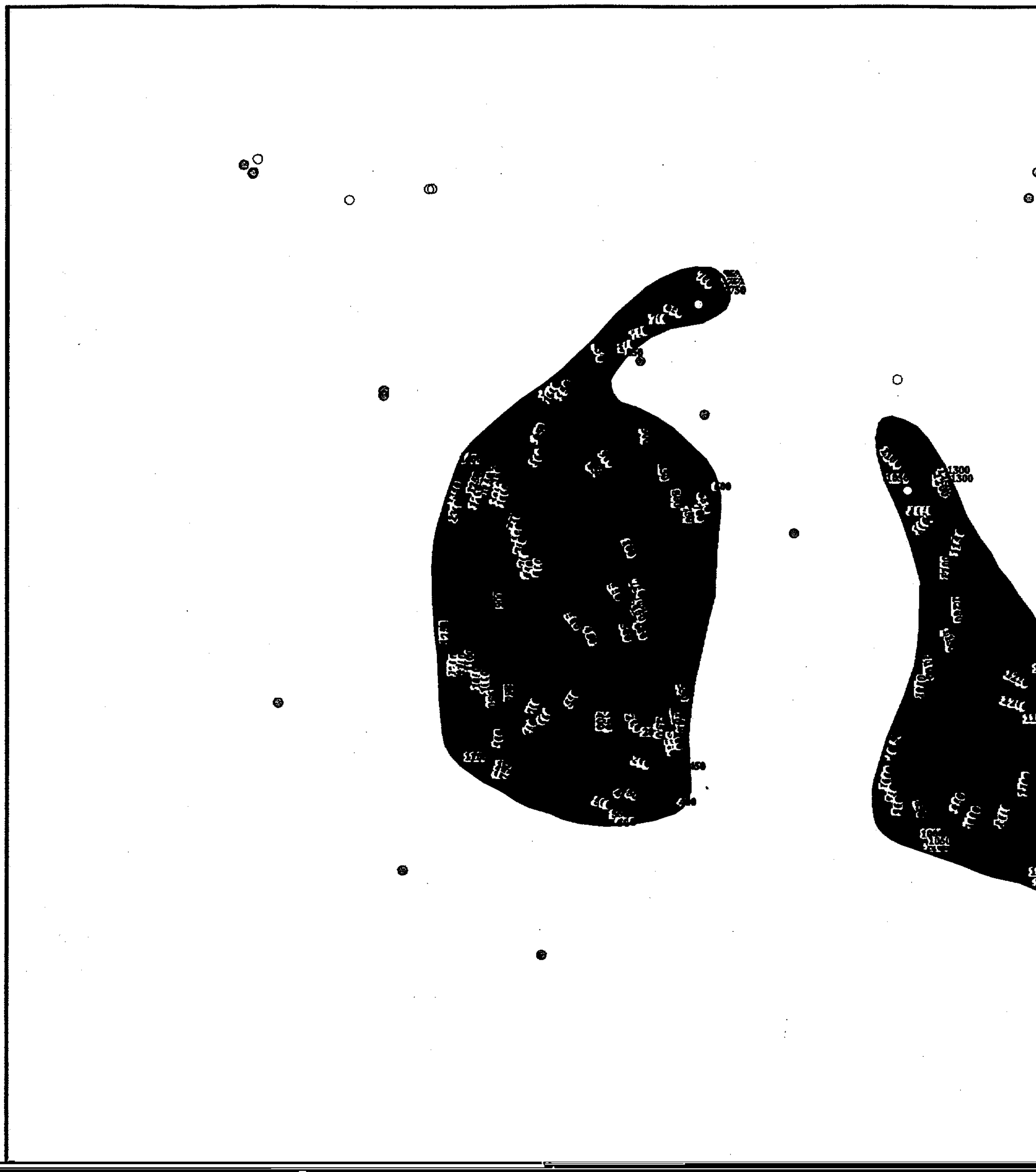

Figure A39. Model isopachs for rhyolite of Inlet (Tci) within region defined in Figure 1. Structural features can be identified by comparison with Figure A1. Unit is absent outside contoured region. Small circles show location of control points; filling colors define differences between observations and model as described for Figure A2. Tci is very thick in UE20F and in UE19F\S, but thin or absent at all other subsurface locations where the datum is penetrated. The unit evidently fills the Area 20 caldera west of the Boxcar fault, and a region southeast of this caldera that collapsed to enlarge the caldera during or prior to eruption of Tci.

Figure A40. Model elevations for top of rhyolite of Jorum (Tcj) within region defined in Figure 1. Structural features can be identified by comparison with Figure A1. Unit is absent outside contoured region. Small circles show location of control points; filling colors define differences between observations and model as described for Figure A2.

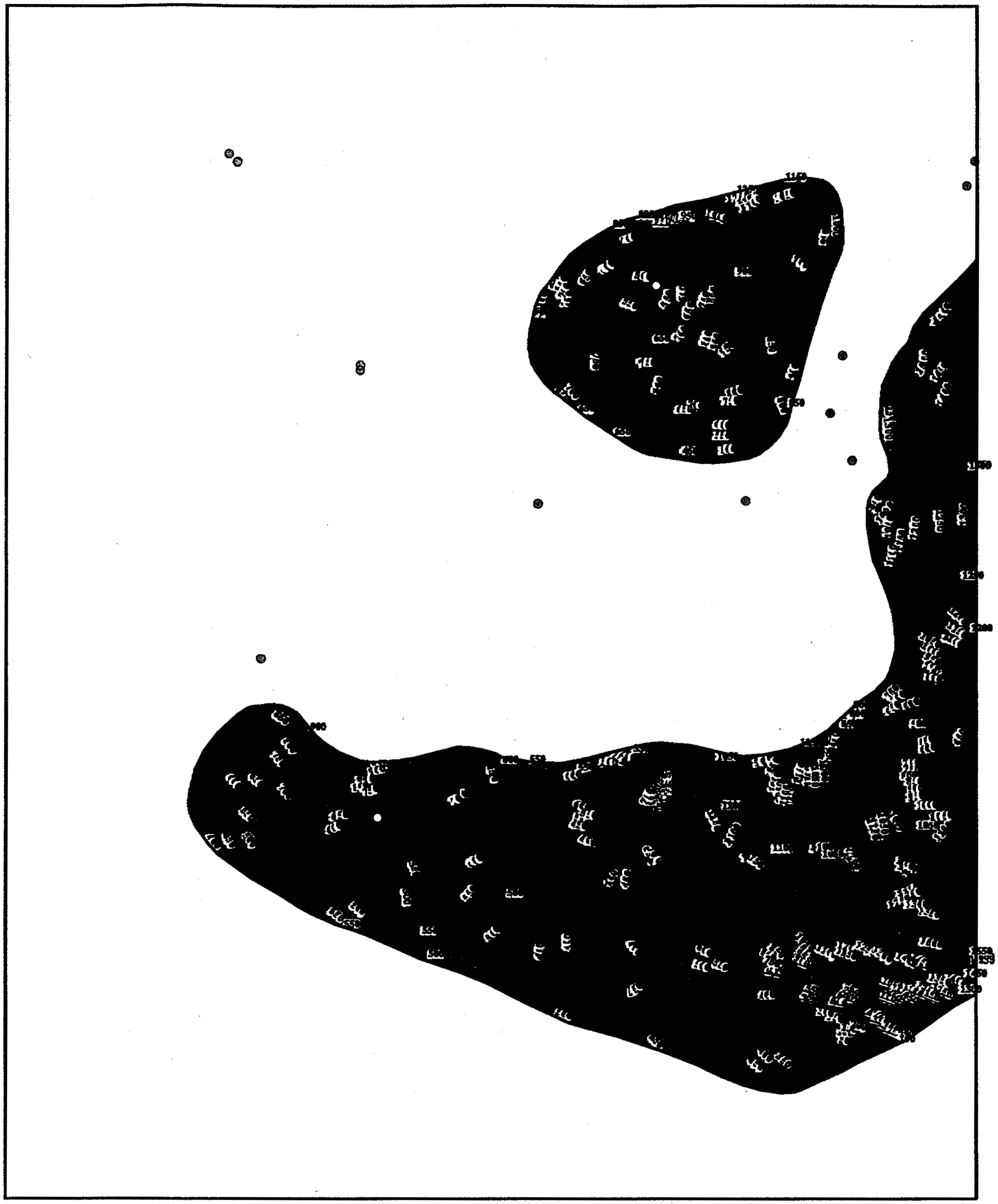

Figure A42. Model elevations for top of rhyolite of Sled (Tcps) within region defined in Figure 1. Structural features can be identified by comparison with Figure A1. Unit is absent outside contoured region. Small circles show location of control points; filling colors define differences between observations and model as described for Figure A2. Southern arm of unit represents rhyolite of ER/EC1 (Tcpe), a very closely related unit that appears to have been deposited outside the southwestern boundary of the Area 20 caldera. Tcps appears to have been deposited outside the northwestern boundary of the Area 20 caldera.

Figure A43. Model isopachs for rhyolite of Sled (Tcps) within region defined in Figure 1. Structural features can be identified by comparison with Figure A1. Unit is absent outside contoured region. Small circles show location of control points; filling colors define differences between observations and model as described for Figure A2.

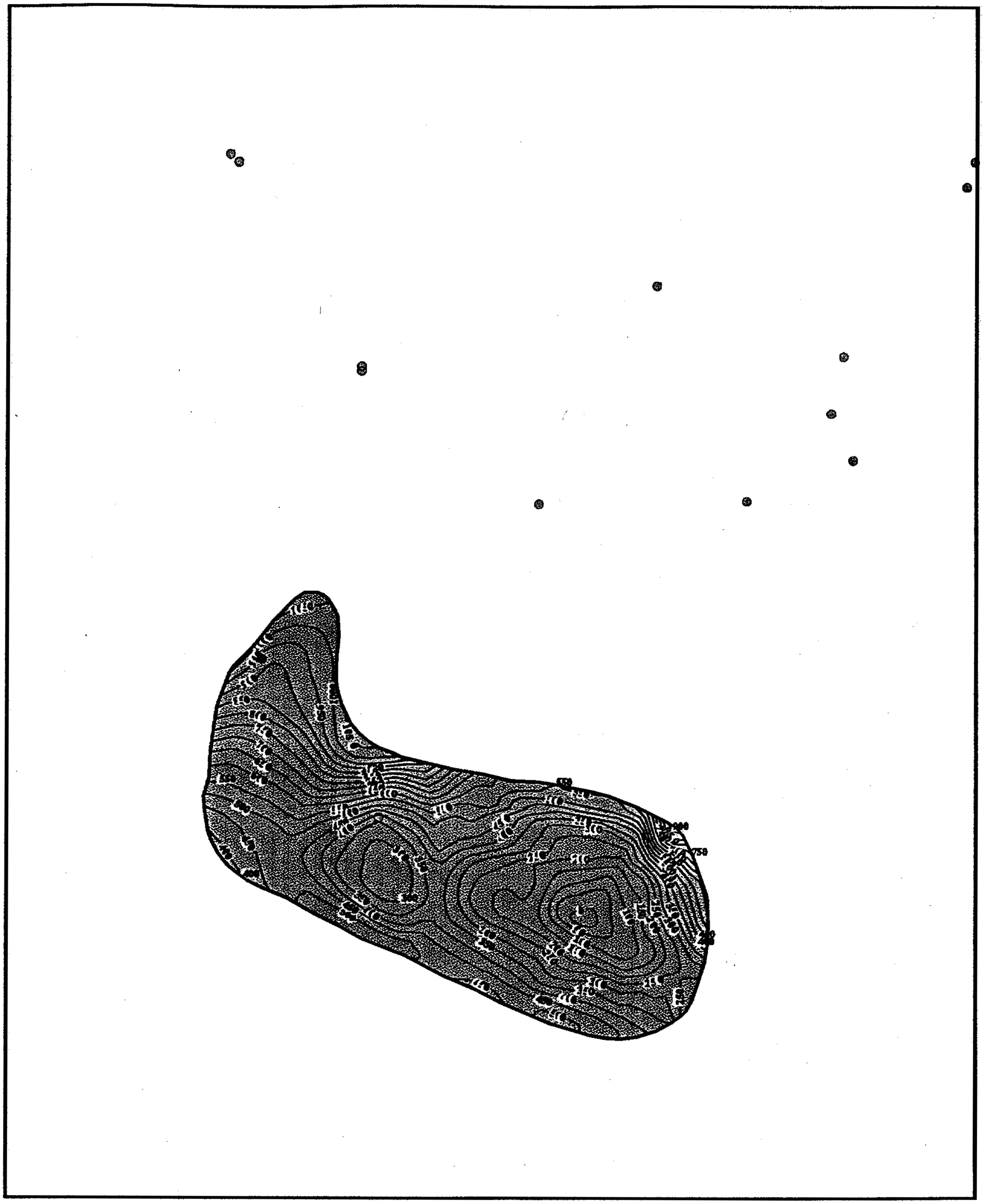

Figure A44. Model elevations for top of rhyolite of Kearsarge (Tcpk) within region defined in Figure 1. Structural features can be identified by comparison with Figure A1. Unit is absent outside contoured region. Small circles show location of control points; filling colors define differences between observations and model as described for Figure A2. West of West Greeley fault, Tcpk was penetrated only in ER/EC1, where it apparently was deposited outside the southwestern boundary of the Area 20 caldera. Tcpk was also deposited outside the northeastern boundary of the Area 20 caldera, east of the region shown in this figure. Note that the northwestern arm instead represents andesite of Grimy Gulch (Tcg) in drill hole PM3.