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7. Abstract

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This report describes the regional and site specific geology of the Hanford Sites low-level burial grounds in the 200 East and West Areas. The report incorporates data from boreholes across the entire 200 Areas, integrating the geology of this area into a single framework. Geologic cross-sections, isopach maps, and structure contour maps of all major geologic units from the top of the Columbia River Basalt Group to the surface are included. The physical properties and characteristics of the major suprabasalt sedimentary units also are discussed.

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GEOLOGIC SETTING OF THE LOW-LEVEL BURIAL GROUNDS

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1.0 INTRODUCTION

The Low-Level Burial Grounds (LLBG) are situated in a highly variable geologic setting in the 200 East and 200 West Areas of the Hanford Site (Figure 1). Chapters 2 and 3 of the report summarizes the geologic setting of the Hanford Site. Geologic features specific to the 200 Areas are the focus of Sections 4.1 through 4.6 and Sections 5.1 through 5.5. Sections 4.7 and 5.6 of the report focus on site-specific characteristics for each of the five groups of burial grounds.

Primary geologic data sources for the interpretations presented here include geologic logs from LLBG boreholes, from boreholes throughout the 200 East and 200 West Areas, and from boreholes in the area adjacent to the 200 Areas. These interpretations were constrained by core logs of cored boreholes located in the west-central Hanford Site, and mapping and measured sections in surface exposures of strata analogous to deposits underlying the LLBGs. The constraints provided by these studies offered the only opportunities to analyze intact sediments typical of those underlying the burial grounds. Borehole geophysical logs were used to supplement primary data. Additional data and insights were taken from several recent reports on the geology of the Hanford Site (Delaney et al. 1991; Lindsey 1991; Reidel et al. 1992) and the 200 East Area (Lindsey et al. 1991; Lindberg et al. 1993) and 200 West Area (Lindsey et al. 1992). Hydrologic information is in large part taken from hydrogeologic modeling reports on the 200 East Area (Connelly et al. 1992a) and 200 West Area (Connelly et al. 1992b). Other information discussed in the report is cited as necessary.

In the report geologic cross sections and contour maps are used to illustrate geologic features discussed in the text. The geologic features shown on the cross sections are the authors' interpretations of the available data. The contour maps were made using the geologic modeling software and gridding algorithms in the Earthvision[1] and Stratifact[2] software packages. These grid-generated maps were modified by hand where data points were closely spaced and where the grid-generated maps fail to match inferred or known geologic features.

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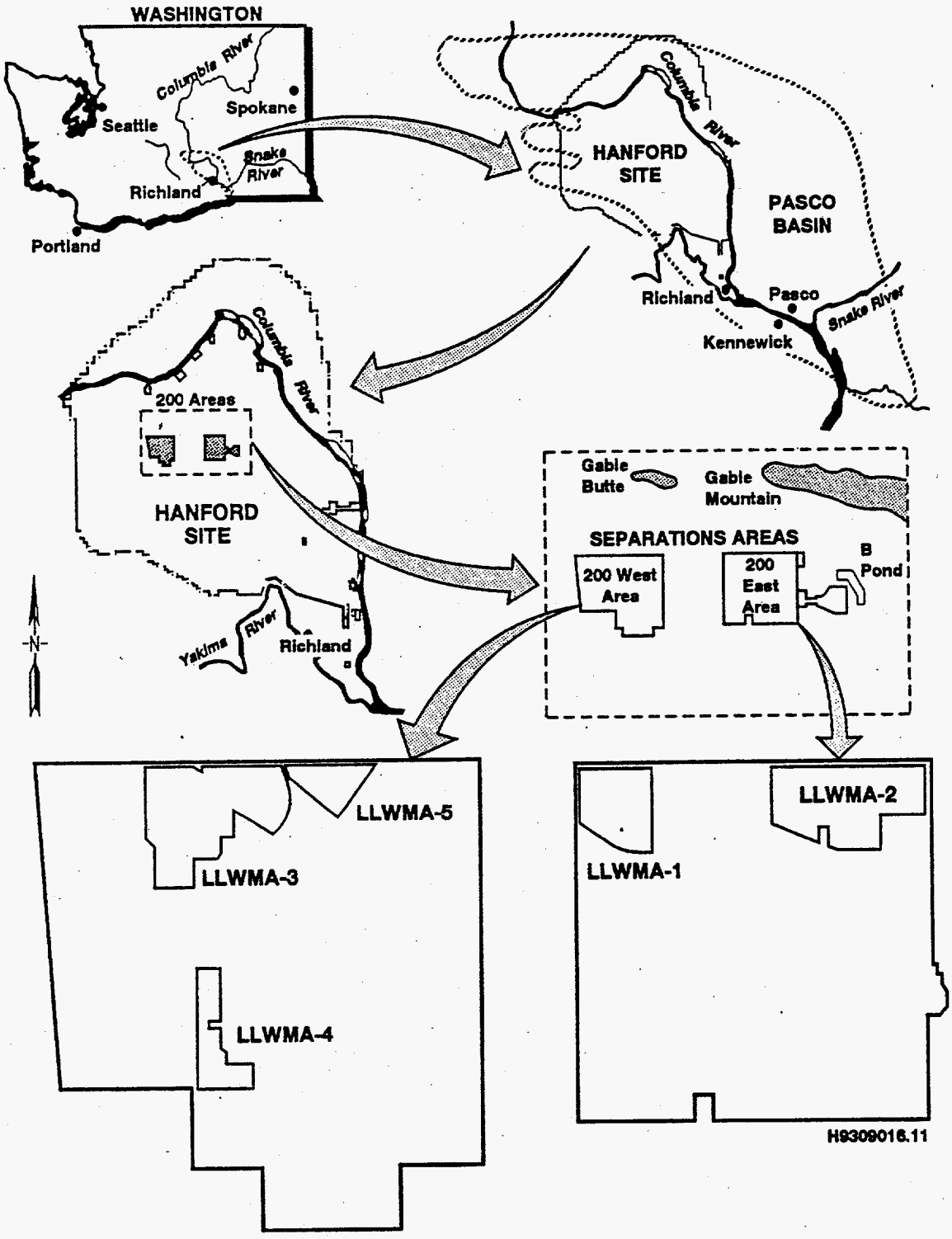
[1]Earthvision is a trademark of Dynamic Graphics.

[2]Stratifact is a trademark of GRG Corporation.

Figure 1. Geographic Setting of the 200 East and 200 West Areas and the Low-Level Burial Grounds.



2.0 REGIONAL GEOLOGIC SETTING

The Hanford Site is underlain by Miocene-aged (17.5 to 6 Ma) basalts of the Columbia River Basalt Group (CRBG) (Myers et al. 1979; Reidel and Fecht 1981; DOE 1988; Tolan et al. 1989; Reidel et al. 1989, 1992), sedimentary interbeds within the basalts assigned to the Miocene Ellensburg Formation (Reidel and Fecht 1981; DOE 1988; Smith 1988), and late Miocene to Holocene-aged (<8.5 Ma to present) suprabasalt sedimentary units (Myers et al. 1979; Tallman et al. 1981; DOE 1988; Smith et al. 1989; Lindsey 1991; Reidel et al. 1992) (Figure 2). Pre-Miocene sedimentary and crystalline rocks underlie the basalt (Campbell 1989), but will not be discussed in this report.

2.1 COLUMBIA RIVER BASALT GROUP

The CRBG is an assemblage of tholeiitic, continental flood basalts that cover an area of more than 163,157 km^2 (63,000 mi^2) in Washington, Oregon, and Idaho and have an estimated volume of about 174,356 km^3 (40,800 mi^3) (DOE 1988; Reidel and Hooper 1989; Tolan et al. 1989). Beneath the Hanford Site the CRBG is divided, from oldest to youngest, into four formations: Imnaha Basalt, Grande Ronde Basalt, Wanapum Basalt, and Saddle Mountains Basalt (DOE 1988; Tolan et al. 1989) (see Figure 2). The Saddle Mountains Basalt is divided, from oldest to youngest, into the Umatilla, Wilbur Creek, Asotin, Esquatzel, Pomona, Elephant Mountain, and Ice Harbor Members at the Hanford Site (Reidel and Fecht 1981). Descriptions and interpretations of CRBG characteristics and evolution are complied in Reidel and Hooper (1989).

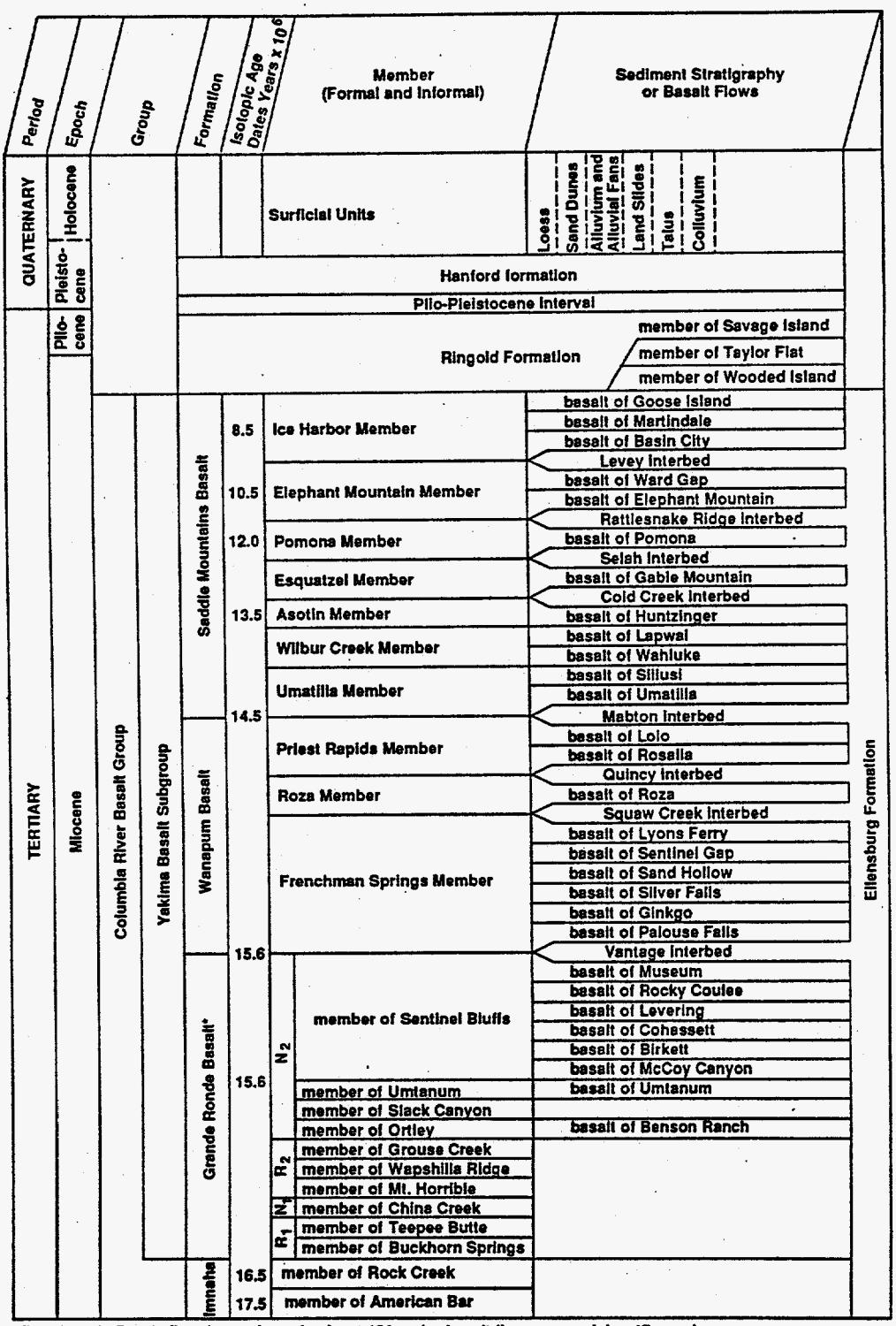
2.2 ELLENSBURG FORMATION

The Ellensburg Formation consists of volcaniclastic and silisiclastic deposits that occur between CRBG basalt flows (Swanson 1979; DOE 1988; Smith 1988) (see Figure 2). At the Hanford Site the three uppermost units of the Ellensburg Formation are, from oldest to youngest, the Selah interbed, the Rattlesnake Ridge interbed, and the Levy interbed. A detailed discussion of the Ellensburg Formation at the Hanford Site is given in Reidel and Fecht (1981). Smith (1988) and Smith et al. (1989) discuss the Ellensburg Formation and correlative units throughout the region.

2.3 SUPRABASALT SEDIMENTS

The uppermost geologic units at the Hanford Site are generally referred to as the suprabasalt sediments. These units are the focus of this report. Discussions of various aspects of suprabasalt sediment geology are found in Myers et al. (1979), Tallman et al. (1979, 1981), PSPL (1982), Bjornstad (1984), Fecht et al. (1987), DOE (1988), Baker et al. (1991), Last et al. (1989), Smith et al. (1989), Delaney et al. (1991), Lindsey (1991, 1992), Lindsey et al. (1991, 1992), and Reidel et al. (1992). Delaney et al. (1991), Lindsey (1991), and Reidel et al. (1992) provide the most recent synopsis of Hanford Site suprabasalt sedimentary geology. The following discussion is summarized from these recent reports as well as field data.

Figure 2. Neogene Stratigraphy of the Pasco Basin.



*The Grande Ronde Basalt consists of at least 120 major basalt flows comprising 17 members. N_2, R_2, N_1, and R_1 are magnetostratigraphic units.

The suprabasalt sedimentary sequence (Figures 2 and 3) is up to 229 m (750 ft) thick at the Hanford Site and is dominated by the laterally extensive late-Miocene to Pliocene Ringold Formation and the Snipes Mountain Conglomerate and Pleistocene Hanford formation. Laterally discontinuous deposits, collectively referred to as the Plio-Pleistocene unit, separate the Hanford formation and Ringold Formation locally. Holocene-aged alluvial and eolian deposits cap the suprabasalt sequence.

2.3.1 Ringold Formation

The Ringold Formation is up to 183 m (600 ft) thick beneath the Hanford Site. It consists of uncemented to locally well-cemented clay, silt, fine- to coarse-grained sand, and pebble to cobble gravel. Ringold deposits are grouped into five facies associations that are defined on the basis of lithology, petrology, stratification, and pedogenic alteration (Lindsey 1991, Reidel et al. 1992). The facies associations, fluvial gravel, fluvial sand, overbank-paleosol, lacustrine, and basaltic alluvium are summarized in Table 1.

The distribution of facies associations within the Ringold Formation forms the basis for stratigraphic subdivision (Lindsey 1991; Reidel et al. 1992). The lower half of the Ringold Formation is informally referred to as the member of Wooded Island. It is subdivided into several subunits, designated as units A, B, C, D, and E (Figures 3, 4, and 5), that are characterized by strata typical of the fluvial gravel and fluvial sand facies association. Grain-size analysis of core and surface exposures indicates the gravel facies association typically has a bimodal grain-size distribution with the dominant sizes being pebble-to-cobble gravel and medium- to fine-grained sand (Tables 2, 3, and 4). These distributions differ from those reported for the LLBGs by Last et al. (1989). Data presented in that report, which indicated Ringold gravels were sand rich, were based on driven split-spoon and drive barrel samples. Consequently, those samples probably were not intact and the grain size data presented in the report should be used with caution. Typical grain size distributions for intercalated sand and silt in units A and E are shown in Table 5.

Units A, B, C, D, and E are interbedded with fine-grained deposits typical of the overbank-paleosol and lacustrine facies association. The lowest of these fine-grained intervals is designated the lower mud unit (see Figures 3, 4, and 5). Interstratified deposits of the fluvial sand and overbank-paleosol facies association, informally referred to as the member of Taylor Flat, and strata dominated by the lacustrine facies association, informally referred to as the member of Savage Island, form the upper half of the Ringold Formation (commonly referred to as the upper unit). Sand beds from the member of Taylor Flat have grain-size ranges similar to those found in the underlying member of Wooded Island (Table 6). The 200 Areas are underlain by a combination of units A, D, and E and the lower mud unit of the member of Wooded Island and the lowermost part of the member of Taylor Flat (see Figure 5).

Figure 3. Generalized Suprabasalt Stratigraphy of the Pasco Basin and Hanford Site.

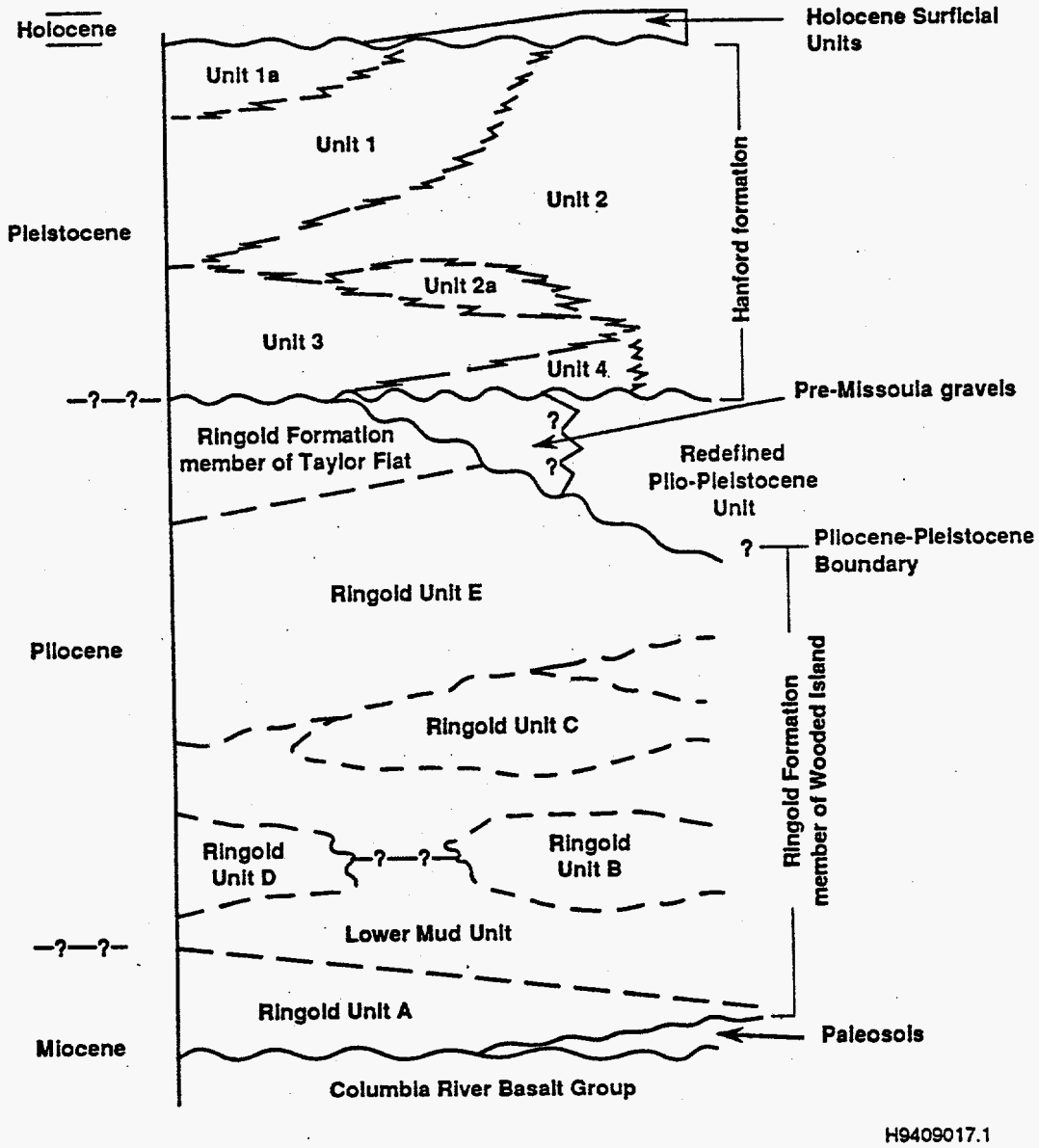


Table 1. Summary of Ringold Formation Facies Associations, Characteristics, and Depositional Setting.

Facies association	Lithology	Sedimentary structure	Bedding geometry and contacts	Depositional environments
Fluvial gravel	Pebble to cobble gravel dominated, clast and lesser matrix support, sand matrix dominant, lenticular silt and sand interbeds <2 m thick	Massive bedding, planar and trough cross-bedding, low angle plane beds, minor deep (2-4 m) scours	Lenticular to low angle tabular gravel beds, low angle (<20°) bounding surfaces dominate, deeply scoured contacts rare	Gravelly fluvial braidplain characterized by shallow, shifting channels
Fluvial sand	Fine- to coarse-grained sand dominates, lenses of gravel (<0.5 m thick) and silt (<3 m thick) present	Planar and trough cross-bedding, ripple cross-lamination, plane bedding, and massive bedding	Lenticular beds combine to form large tabular sand bodies with scoured bases, sand bodies are multi-story, fining upwards into silts present	Sandy, low sinuosity channels on low relief flood plain
Overbank-paleosol	Silty fine-grained sand, silt, and clay, pedogenic $CaCO_3$ encountered locally	Massive bedding, plane bedding, ripple cross-lamination, and mottled disrupted bedding, burrow and root fills, soil peds and slickensides present	Laterally continuous sheets, flat to gradational contacts	Proximal to distal overbank, crevasse splay
Lacustrine	Clay, silt, and fine-grained sand, minor medium-grained sand	Planar bedding and lamination, normal grading, ripple cross-lamination, minor soft sediment deformation	Laterally extensive sheets, sharp basal contacts, upwards fining common, minor low angle packages	Lacustrine basin plain to proximal distributary
Alluvial fan	Basaltic gravel, matrix support dominates	Massive bedding dominates, minor planar bedding and planar cross-bedding	Sheets, planar contacts	Debris flow dominated deposition on alluvial fans

Figure 4. Explanation for Symbols Used on Cross Sections.

Explanation

Additional Lithologic Symbols, Includes Subordinate Lithologies

- **Gravel with Sand Matrix** (open-framework in Hanford formation, partially cemented in Ringold Formation)
- **Sand with Minor Gravel and Gravel Interbeds**
- **Fine- to Coarse-grained Sand** (may contain granules and very minor gravel in Hanford formation)
- **Interbedded (?) Sand and Silt**
- **Silt and Clay**
- **Calcium Carbonate-rich**
- **Paleosol**
- **Basalt**
- **Measured Water Level** (reported in Kasza et al., 1994)

Grain Size Scale, Indicates Dominant Lithology in Interval

- **Pebble/Cobble/Boulder Gravel**
- **Sand and Granule**
- **Clay and Silt**

Other Symbols

- **Formational Contact, ? where inferred**
- **Unit/Member Contact, ? where inferred**
- **Significant Facies Contact, ? where inferred**

Unit Abbreviations

H1, H1a, H2, H2a, H3, H4 = Hanford formation Units
PP = Redefined Plio-Pleistocene Unit
UR = Upper Ringold Formation, member of Taylor Flat
RE = Ringold Formation, Unit E
RLM = Ringold Formation, Lower Mud unit
RA = Ringold Formation, Unit A
RRI = Ellensburg Formation, Rattlesnake Ridge Interbed

(RE, RLM, RA: **member of Wooded Island**)

H9407003.1

Figure 5. East-West Cross Section of the Suprabasalt Sediments through the 200 East and 200 West Areas and Across the May Junction Fault.

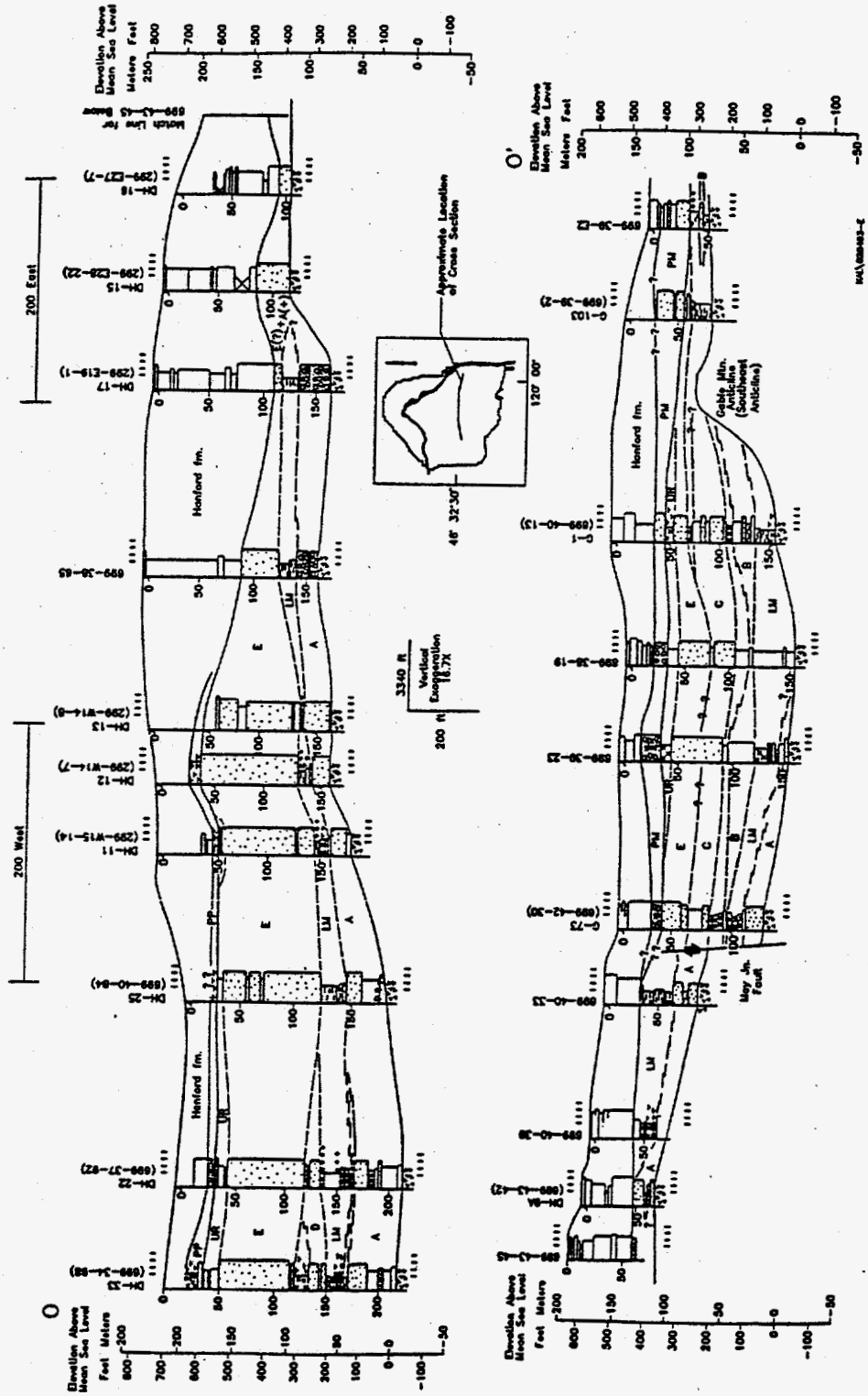


Table 2. Grain-Size Distribution (Weight Percent) for Ringold Unit A, Member of Wooded Island.

	%cob	%peb	%gr	%vcs	%cs	%ms	%fs	%vfs	%z
DH-6, 438	0	77	2	5	6	6	2	2	0
DH-6, 448	0	78	3	3	4	6	4	2	0
DH-6, 455	0	70	5	2	2	11	7	3	0
DH-6, 464	0	67	3	4	4	12	6	4	0
DH-6, 473	0	76	3	4	3	9	3	2	0
DH-6, 503	0	78	3	4	5	7	3	0	0
DH-13, 483	0	71	0	3	3	18	4	1	1
DH-13, 498	0	63	0	5	6	11	12	2	1
DH-13, 524	0	55	2	7	9	21	4	2	0
Mean	0	71	2.3	4.1	4.7	11.2	5.0	2.0	0.2
Standard deviation	--	7.9	1.6	1.4	2.1	5.2	3.0	1.1	0.4
Range	--	55-78	0-5	2-7	2-9	6-21	2-12	0-4	0-1

Table 3. Grain-Size Distribution (Weight Percent) from Cores of Ringold Unit E, Member of Wooded Island.

	%cob	%peb	%gr	%vcs	%cs	%ms	%fs	%vfs	%z
DH-6, 178	0	74	2	0	0	9	8	5	2
DH-6, 213	0	73	1	1	1	12	8	4	0
DH-6, 227	0	82	1	5	4	4	3	1	0
DH-6, 240	0	71	1	0	1	14	12	1	0
DH-6, 270	0	64	2	1	1	8	13	11	0
DH-6, 313	0	82	4	2	2	4	3	3	0
DH-6, 316	0	73	2	4	3	12	3	2	1
DH-6, 330	0	72	1	2	1	12	8	4	0
DH-6, 393	0	72	2	4	4	12	4	2	0
DH-6, 399	0	69	3	5	4	13	5	1	0
DH-12, 243	0	88	2	1	1	2	4	1	1
DH-12, 285	0	76	1	1	3	12	5	1	1
DH-12, 342	0	75	2	2	1	9	7	2	2
DH-12, 378	0	71	2	4	3	10	6	1	3
DH-12, 412	0	79	1	3	4	10	2	1	0
DH-13, 284	0	88	0	0	1	3	6	2	0
DH-13, 330	0	84	2	0	0	9	3	2	0
DH-13, 347	0	87	2	2	2	2	3	2	0
DH-13, 389	0	77	2	3	4	9	5	0	0
DH-13, 398	0	80	1	4	5	8	2	0	0
DH-13, 419	0	74	3	3	4	11	5	0	0
DH-13, 438	0	75	1	2	2	7	7	6	0
DH-28, 308	0	80	6	2	2	6	2	1	1
DH-28, 429	0	79	2	1	1	9	5	3	0
DH-28, 450	0	76	5	3	3	7	2	4	0
DH-28, 461	0	78	4	1	5	5	4	3	0
DH-28, 543	0	78	1	2	2	13	2	2	0
Mean	0	76.9	2.1	2.1	2.4	8.6	5.1	2.4	0.4
Standard deviation	--	5.8	1.4	1.5	1.5	2.5	2.9	2.3	0.8
Range	--	64-88	0-6	0-5	0-5	2-14	2-13	0-11	0-3

Table 4. Grain-Size Distribution (Weight Percent) from Outcrops of Ringold Unit E, Member of Wooded Island.

	%cob	%peb	%gr	%vcs	%cs	%ms	%fs	%vfs	%z
SC-1	27	44	0	2	2	21	3	1	0
SC-2	14	62	0	2	2	16	3	1	0
SC-4	23	63	0	0	1	8	4	1	0
SC-5	10	71	0	1	1	15	1	1	0
SC-6	8	82	0	0	0	7	2	1	0
SC-7	0	69	1	2	3	20	4	1	0
SC-10	0	81	1	1	1	12	3	1	0
SC-11	8	73	1	2	1	9	5	1	0
SC-12	6	79	0	1	1	9	3	1	0
SC-15	16	74	0	0	0	6	3	1	0
SC-17	26	67	1	1	1	2	1	1	0
SC-18	0	82	2	1	1	9	3	2	0
SC-20	0	87	1	1	1	8	1	1	0
SC-21	17	70	0	1	0	9	2	1	0
SC-22	33	57	1	1	0	6	1	1	0
SC-23	8	79	1	1	1	6	3	1	0
SC-24	0	86	0	1	1	7	4	1	0
SC-25	40	56	0	0	0	2	1	1	0
Mean	13.1	71.2	0.5	1.0	0.9	9.6	2.6	1.1	0
Standard deviation	12.4	11.6	0.6	0.7	0.8	5.4	1.2	0.2	--
Range	0-40	44-87	0-2	0-2	0-3	2-21	1-5	1-2	--

Table 5a. Grain-Size Distribution (Weight Percent) from Sand and Silty Sand Interbeds in Ringold Gravels, Member of Wooded Island (Data Acquired from Core).

	%gr	%vcs	%cs	%ms	%fs	%vfs	%z	%cl
DH-6, 269	0	2	4	39	42	9	4	0
DH-6, 370	0	16	18	28	16	6	13	3
DH-12, 258	0	2	2	57	33	1	5	0
DH-12, 369	0	6	5	49	32	4	4	0
DH-12, 405	1	1	2	24	43	15	11	3
DH-13, 263	0	1	1	15	49	15	16	3
DH-13, 275	0	7	7	38	36	6	3	3
DH-13, 280	0	6	7	74	7	1	5	0
DH-13, 302	0	4	4	72	14	1	2	3
Mean	0.1	5.0	5.6	44	30	6.4	7.0	1.7
Standard deviation	0.3	4.7	5.1	21	15	5.6	5.0	1.6
Range	0-1	1-16	1-18	15-74	7-49	1-15	2-16	0-3

Table 5b. Grain-Size Distribution (Weight Percent) from Sand and Silty Sand Interbeds in Outcrops of Ringold Unit E, Member of Wooded Island.

	%gr	%vcs	%cs	%ms	%fs	%vfs	%z	%cl
SC-3	0	1	1	63	32	3	0	0
SC-8	0	12	12	64	9	1	2	0
SC-9	1	1	1	6	30	30	27	4
SC-19	0	4	4	20	50	18	4	0
Mean	0.2	4.5	4.5	38	30	13	8.2	1.0
Standard deviation	0.5	5.2	5.2	30	17	14	13	2.0
Range	0-1	1-12	1-12	6-64	9-50	1-30	0-27	0-4

Table 6. Grain-Size Distribution (Weight Percent) from Sand and Silt Beds in the Ringold Formation, Member of Taylor Flat.

	%gr	%vcs	%cs	%ms	%fs	%vfs	%z	%cl
DH-6, 137	0	3	4	26	19	10	15	3
SC-13	0	7	8	68	13	2	2	Trace
SC-14	0	1	1	29	50	12	5	2
SC-26	0	1	1	69	25	2	2	Trace
SC-27	1	2	3	21	48	20	7	Trace
SC-28	0	0	1	40	51	5	3	Trace
Mean	0.17	2.3	3.0	42	34	8.5	5.7	--
Standard deviation	0.41	2.5	2.8	21	18	7.0	5.0	--
Range	0-1	0-7	1-8	21-69	13-51	2-20	2-15	--

2.3.2 Plio-Pleistocene Unit

The Plio-Pleistocene unit includes all material overlying the Ringold Formation and underlying the Hanford formation. This interval formerly was divided into three units: (1) the Plio-Pleistocene unit, (2) early Palouse soil, and (3) pre-Missoula gravels (Myers et al. 1979; Tallman et al. 1979, 1981; DOE 1988; Last et al. 1989; Lindsey et al. 1991; Reidel et al. 1992). Recent core logging, borehole sampling, and outcrop studies indicate a unified Plio-Pleistocene unit consisting of two subunits (locally derived and distally derived) better represents this interval because of uncertainties in stratigraphic relationships among the three formerly used units.

Major rivers (Columbia, Yakima, and Snake Rivers), local sidestreams, and wind deposited Plio-Pleistocene-aged alluvium in the Pasco Basin. Differentiating the two subunits of the Plio-Pleistocene unit are based on recognition of deposits from these different sources. Major rivers transported clastic detritus from the northern Rocky Mountains, Okanagen highlands, Idaho Batholith, Cascade Range, and Wallowa Terrane that consist predominantly of quartzite, gneiss, basalt, andesite, rhyolite, and low-grade metamorphics. The distally derived subunit corresponds to the pre-Missoula gravels and is found southeast of the 200 East Area.

The locally derived subunit consists of poorly sorted, locally derived, interbedded reworked loess, silt, sand, and basaltic gravel. Reworked Ringold-derived silt, sand, and gravel also may be present. These strata are bedded to massive; carbonate is irregularly distributed throughout. The gravels mark the course of alluvial channels, whereas the fine-grained material represents overbank, lacustrine, and eolian deposits.

Several forms of carbonate are developed in the subunit, including disseminated (which lightens the matrix and reacts strongly with hydrochloric acid but is otherwise indistinct), filamentous, nodular, massive (which impregnates the matrix imparting a white color and reacts strongly to violently with hydrochloric acid), and partial to complete carbonate coatings on clasts. Most of this carbonate developed subaerially during hiatuses in deposition. However, the absence of associated soil horizons, no apparent decrease in carbonate content with depth (as would be expected in pedogenic carbonates) in some carbonate layers, and some carbonates with textures that are not common to pedogenic carbonates indicates that groundwater (or capillary fringe) processes may have influenced the morphology of these horizons.

Silt and sand in the upper part of the locally derived subunit has been previously described as a loess and referred to as the early Palouse soil (Myers et al. 1979; Tallman et al. 1981; Bjornstad 1984; DOE 1988; Last et al. 1989; Lindsey et al. 1991; Last and Rohay 1993). In fact, this interval consists of thin, planar-laminated fine sandy silts with little evidence of the bedding disruption and massive character typical of loess deposits. Consequently, the term early Palouse soil is dropped and these laminated deposits are assigned to the Plio-Pleistocene unit.

The thickness (up to 20 m [66 ft]) of the locally derived subunit and facies distribution are related to depositional environment, the topography of the erosional surface on top of the Ringold Formation, and post-depositional erosion by the catastrophic Missoula floods (Hanford formation). Cold Creek, Dry Creek, and unnamed drainages off Umtanum Ridge, Yakima Ridge, and Rattlesnake Mountain deposited this subunit on a northwest-trending channel or fan complex.

2.3.3 Hanford Formation

The Hanford formation (see Figure 3) consists of uncemented gravel, sand, and silt deposited by Pleistocene cataclysmic flood waters (Fecht et al. 1987; DOE 1988; Baker et al. 1991). The Hanford formation is thickest in the central Hanford Site where it can be up to 107 m (350 ft) thick. The Hanford formation is divided into three facies (gravel, sand, and silt dominated) that are gradational with each other (Lindsey et al. 1991, 1992). These correspond to the gravel, laminated sand, and graded rhythmites facies, respectively, of Baker et al. (1991).

The silt-dominated facies consists of interbedded silt and fine- to coarse-grained sand forming well stratified normally graded rythmites. Some of the strata identified as loess dominated early Palouse soil in previous studies (Tallman et al. 1979; Bjornstad 1984; DOE 1988; Last et al. 1989; Last and Rohay 1993) are in fact deposits of the silt-dominated facies. The silt-dominated facies is differentiated from massive, unbedded loess and the lacustrine deposits of the Plio-Pleistocene unit by the presence of interbedded sand. The facies was deposited in backflooded areas during highstands of cataclysmic Pleistocene flood events (Baker et al. 1991).

Well-stratified, fine- to coarse-grained sand and granule gravel form the sand-dominated facies. Silt content is variable. Open framework texture is

common where the silt content is low. Small pebbles and rip-up clasts may be present in addition to lenticular, pebble-gravel interbeds and silty interbeds. Deposits comprising this facies accumulated in areas transitional from low-energy backflooded areas to main high-energy channel tracts, and as flood flows wained in areas adjacent to channelways and downstream of flow constrictions (Baker et al. 1991).

The gravel-dominated facies consists of cross-stratified, coarse-grained sand and granule to boulder gravel. Intercalated, lenticular silt-rich horizons that commonly display evidence of pedogenic activity are found locally. Interbedded, gravelly, well-stratified coarse-grained to granular sands are present. This facies is generally uncemented and matrix poor, displaying an open framework texture. The facies was deposited in high-energy main channelways (Baker et al. 1991).

In addition to these three facies, clastic dikes are found in the Hanford formation as well as locally in other sedimentary units in the Pasco Basin (Black 1979). Clastic dikes throughout the Pasco Basin usually consist of alternating vertical to subvertical layers of silt, sand, and granule gravel less than 1 cm (0.4 in.) up to 2 m (6.6 ft) thick. They generally cross-cut bedding, although they do locally parallel bedding. A feature known as patterned ground is observed where the dikes intersect the ground surface.

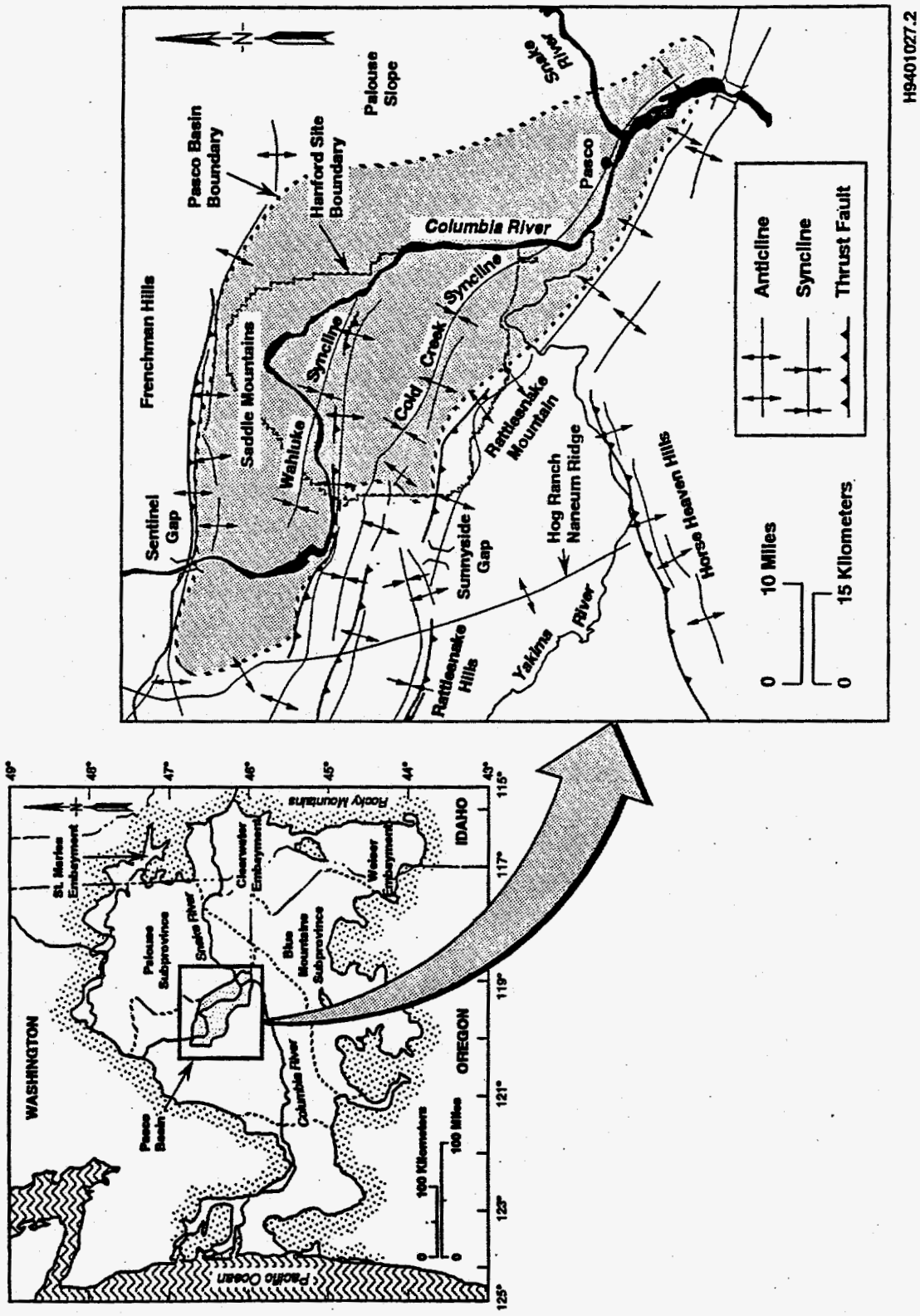
2.3.4 Holocene Deposits

Holocene surficial deposits consist of a mix of silt, sand, and gravel deposited by a combination of eolian and alluvial processes. These Holocene deposits form a thin (4.9 m [<16 ft]) veneer across much of the Hanford Site.

2.4 STRUCTURAL GEOLOGY

The Hanford Site is located in the eastern Yakima Fold Belt near its junction with the Palouse subprovince (DOE 1988). A series of segmented, narrow, asymmetric, and generally east-west trending anticlines that separate broad, low-amplitude structural basins characterizes the Yakima Fold Belt (Reidel 1984; Reidel et al. 1989; Tolan and Reidel 1989). One of the largest structural basins within the Yakima Fold Belt is the Pasco Basin. The Hanford Site is situated in the Pasco Basin, which is bounded on the north by the Saddle Mountains anticline, on the west by the Hog Ranch-Naneum Ridge anticline, and on the south by the Rattlesnake Mountain anticline (Figure 6) (DOE 1988). The Palouse slope, a west-dipping monocline, bounds the Pasco Basin on the east (see Figure 6) (DOE 1988). The Pasco Basin is divided into the Wahluke and Cold Creek synclines by the Gable Mountain anticline, the easternmost extension of the Umtanum Ridge anticline (see Figure 6) (DOE 1988).

Figure 6. Structural Geologic Setting of the Pasco Basin and Surrounding Area.



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3.0 HYDROLOGIC SETTING

The following summary of Hanford Site hydrologic conditions is taken largely from DOE (1988), Delaney et al. (1991), and Connelly et al. (1992a, 1992b).

3.1 SURFACE HYDROLOGY

Primary surface water features near the Hanford Site are the Columbia and Yakima Rivers. The freeflowing stretch of the Columbia River adjacent to the Hanford Site is known as the Hanford Reach. It extends from Priest Rapids Dam to the headwaters of Lake Wallula (the reservoir behind McNary Dam) at about the 300 Area. Flow along the Hanford Reach is controlled by Priest Rapids Dam. Approximately one-third of the Hanford Site is drained by the Yakima River system. West Lake, about 4 ha (10 acres) in size and less than 1 m (3 ft) deep, is the only natural lake on the Hanford Site (DOE 1988). Wastewater ponds, cribs, and ditches associated with nuclear fuel reprocessing and waste disposal activities are also present on the site.

3.2 SUBSURFACE HYDROLOGY

3.2.1 Saturated Zone

The Hanford Site is underlain by a multiaquifer system consisting of four hydrogeologic units that correspond to the upper three formations of the CRBG (Grande Ronde, Wanapum, and Priest Rapids Basalt) and the suprabasalt sediments (DOE 1988; Delaney et al. 1991). The basalt aquifers generally are confined and found within sedimentary interbeds of the Ellensburg Formation and permeable zones that occur between flows.

Recharge to the shallow basalt aquifers in the Saddle Mountains and upper Wanapum Basalts is from infiltration of precipitation and runoff along the margins of the Pasco Basin. Recharge of the deep basalt aquifers in the lower Wanapum and Grande Ronde Basalts is inferred to occur northeast and northwest of the Pasco Basin in areas where the Wanapum and Grande Ronde Basalts crop out extensively (DOE 1988). Groundwater discharge from shallow basalt aquifers is probably to overlying aquifers and to the Columbia River. Discharge areas for the deeper aquifers are uncertain, but are inferred to be south of the Hanford Site (DOE 1988). Erosional "windows" through dense basalt flow interiors at the top of the basalt aquifer system allow direct interconnection between the suprabasalt aquifer system and the uppermost basalt aquifers (Graham et al. 1984).

The suprabasalt sediment aquifer is contained within the Hanford formation and the Ringold Formation. The top of this aquifer lies at depths ranging from less than 30 cm (1 ft) near West Lake and the Columbia and Yakima Rivers, to greater than 107 m (350 ft) near the center of the Hanford Site. The base of the uppermost aquifer system is the top surface of the underlying basalt. Beneath the western part of the Hanford Site the water table generally is within gravels of Ringold unit E. In the northern and

eastern portions of the Hanford Site the water table is generally at or near the Hanford-Ringold contact. In the east-central part of the Hanford Site the water table lies up to 24 m (80 ft) above the top of the Ringold Formation. Widespread intervals dominated by the paleosol-overbank and lacustrine facies associations form at least partially confining layers between the main Ringold gravel-bearing units (A, B/D, C, and E) (see Figure 5). The uppermost aquifer system is bounded laterally by anticlinal basalt ridges and is approximately 152 m (500 ft) thick near the center of the basin. Hydraulic conductivities for the Hanford formation are much greater than those of the gravel facies of the Ringold Formation (Connelly et al. 1992a, 1992b).

Natural recharge to the uppermost aquifer system consists of rainfall and runoff from the hills bordering the Hanford Site, water infiltrating from small ephemeral streams, river water along influent reaches of the Yakima and Columbia Rivers, and water rising from underlying confined basalt aquifers along faults and fractures. The movement of moisture from precipitation through the unsaturated (vadose) zone varies. Gee (1987) and Routson and Johnson (1990) indicate that the downward movement of moisture from surface recharge is nonexistent across much of the Hanford Site, while Rockhold et al. (1990) suggest that downward water movement below the root zone is common in the 300 Area. Artificial recharge occurs from the disposal of wastewater on the Hanford Site (principally in the 200 Areas) and from large irrigation projects surrounding the Hanford Site.

3.2.2 Unsaturated Zone

Strata in the vadose zone across the Hanford Site and the 200 Areas show variations similar to those displayed in the uppermost aquifer system. The Hanford formation, Plio-Pleistocene unit, and Ringold Formation are all present in the vadose zone in the 200 West Area. In the 200 East Area the vadose zone is situated almost entirely within the Hanford formation. The distribution of fine-grained layers, cemented zones, and clastic dikes within these units probably have the greatest influence on vadose zone flow and transport properties.

Van Genuchten curve fitting parameters for the major stratigraphic units beneath the 200 East and 200 West Areas are summarized in Connelly et al. (1992a, Table 3-1; 1992b, Table 3-1), respectively. Close examination of the values in these tables reveals a large amount of variability. Because of this high degree of variation, known heterogeneities in the geology of the area, borehole sampling techniques inappropriate for intact sediment sampling, and the limited number of data points, these data are not representative of vadose conditions.

4.0 GEOLOGIC SETTING OF THE 200 WEST AREA LOW-LEVEL BURIAL GROUNDS

4.1 BASALT GEOLOGY AND STRUCTURE

The 200 West Area is situated on the generally southward dipping north limb of the Cold Creek syncline approximately 1 to 5 km (0.6 to 3.1 mi) north of the syncline axis (see Figures 5 and 6). The Gable Mountain-Gable Butte segment of the Umtanum Ridge anticline lies approximately 4 km (2.5 mi) north of the 200 West Area. The axes of the anticline and syncline are separated by a distance of 9 to 10 km (5.6 to 6.2 mi), with structural relief of over 250 m (820 ft).

The Elephant Mountain Member of the Saddle Mountains Basalt is the uppermost basalt unit beneath the 200 West Area and it is continuous beneath the entire area. The top of the Elephant Mountain Member dips to the southwest and south into the Cold Creek syncline, reflecting the structure of the area (Figures 7 and 8). There is little evidence for significant erosion into the top of the Elephant Mountain Member and no indication of erosional "windows" through the basalt into the underlying Rattlesnake Ridge interbed of the Ellensburg Formation.

4.2 RINGOLD FORMATION

Ringold stratigraphic units present beneath the 200 West Area are unit A, the lower mud unit, and unit E of the member of Wooded Island and erosional remnants of the member of Taylor Flat (Figures 5, 9, and 10). Unit B/D also is present, but the limited distribution of silty marker horizons at the site makes it difficult to determine its lateral continuity. Unit C also may be present but the absence of any marker strata necessary to differentiate it from unit E makes identification of unit C impossible.

Unit A and the lower mud unit, the two lowest Ringold units in the 200 West Area, display similar trends. Unit A thickens to the south and southwest towards the axis of the Cold Creek syncline. The top of the unit is relatively flat, dipping to the west and southwest (Figure 11). Intercalated lenticular sand and silt is common in unit A in the western and southern parts of the area. The overlying overbank and lacustrine deposits of the lower mud unit also thicken and dip to the south and southwest. However, unlike unit A, the top of the lower mud sequence is irregular and the interval pinches out along the northeast edge of the 200 West Area (Figure 12).

At least locally throughout the 200 West Area, gravelly strata of unit B/D overlies the lower mud unit. These gravels are similar in composition to unit A below and unit E above. Unit B/D is differentiated from the other gravelly Ringold units by its stratigraphic position overlying the lower mud unit and below paleosols underlying unit E. Where the paleosols underlying unit E are absent, unit B/D is not identified.

Unit E generally thins from the north-northwest to the east-southeast. The top of the unit is irregular, displaying highs in the northern and

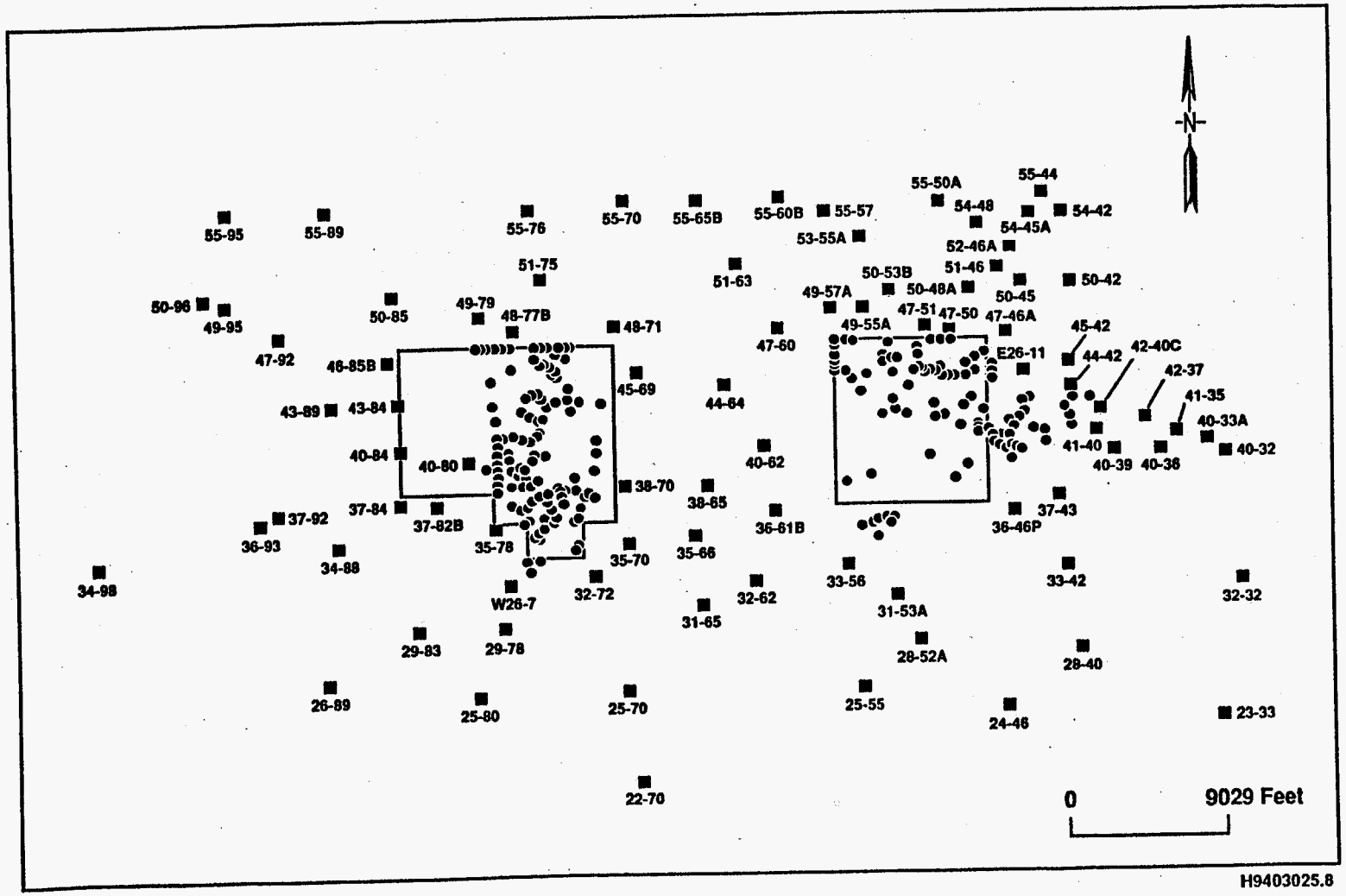

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Figure 7. Index Map to Boreholes Used for Geologic Intepretations in this Report Outside of the 200 East and 200 West Areas.

Figure 8. Structure Contour Map, Top of the Basalt, Cold Creek Syncline.

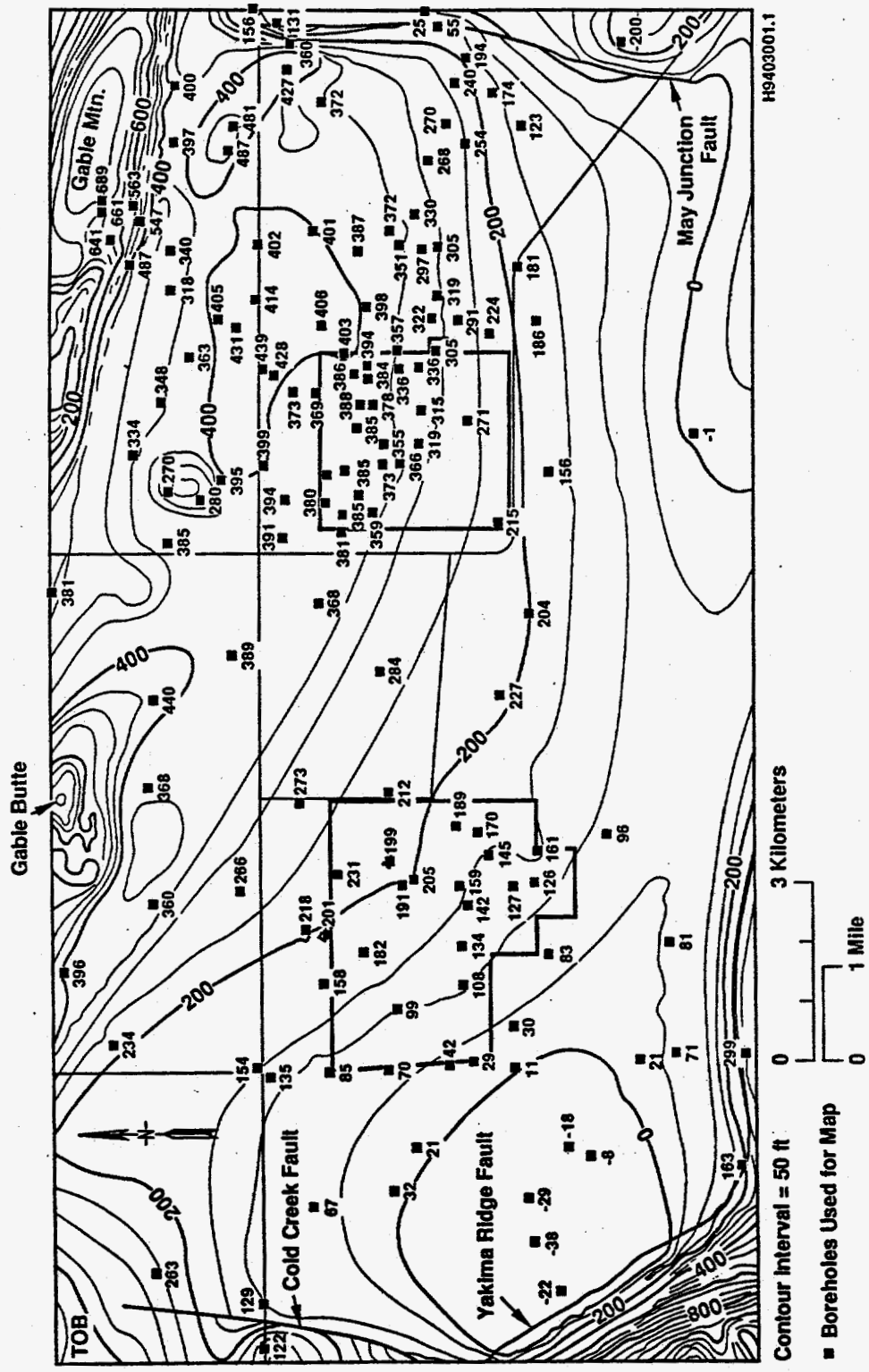


Figure 9. North-South Cross Section of the Suprabasalt Sediments, 200 West Area.

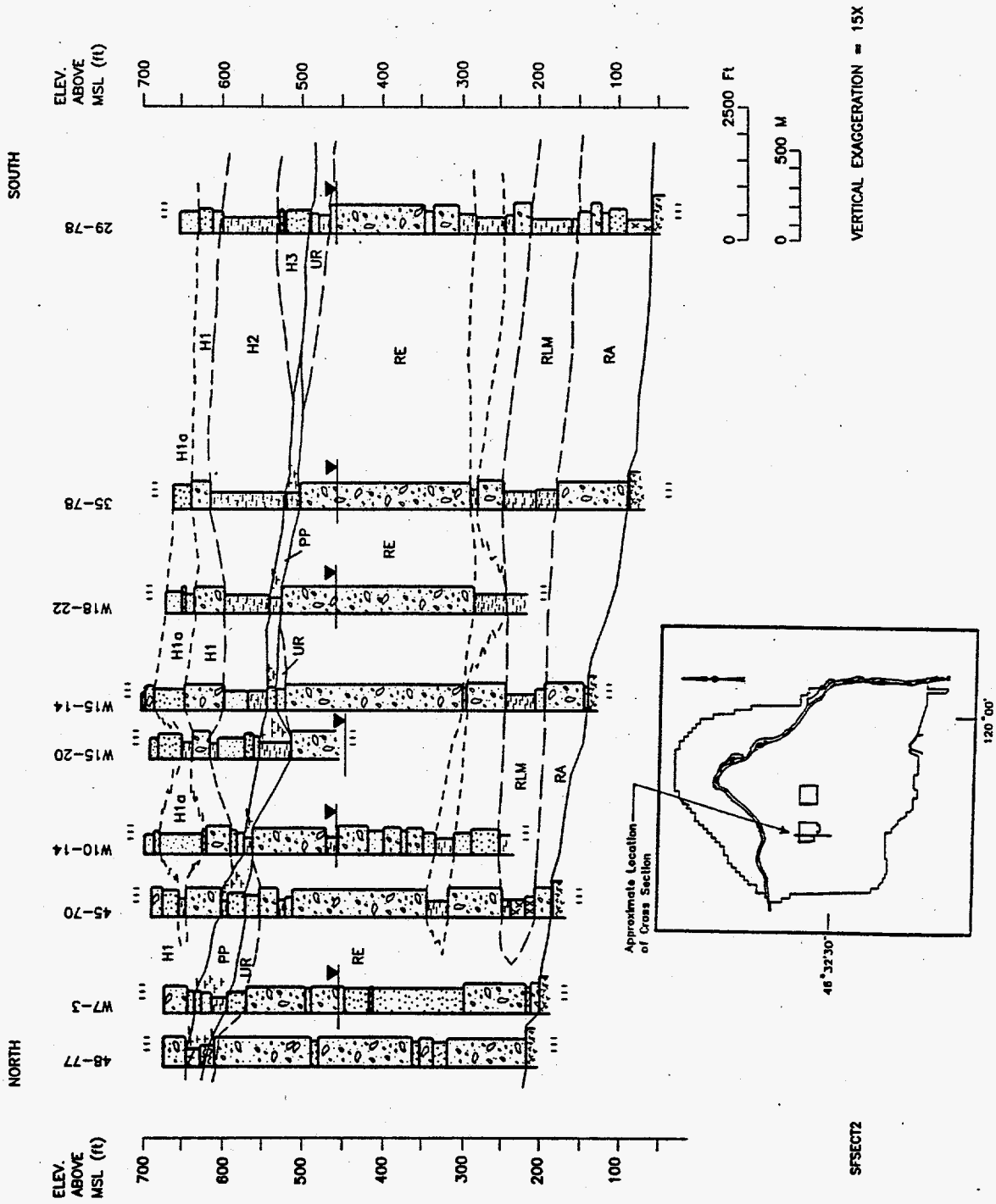


Figure 10. East-West Cross Section of the Suprabasalt Sediments, 200 West Area.

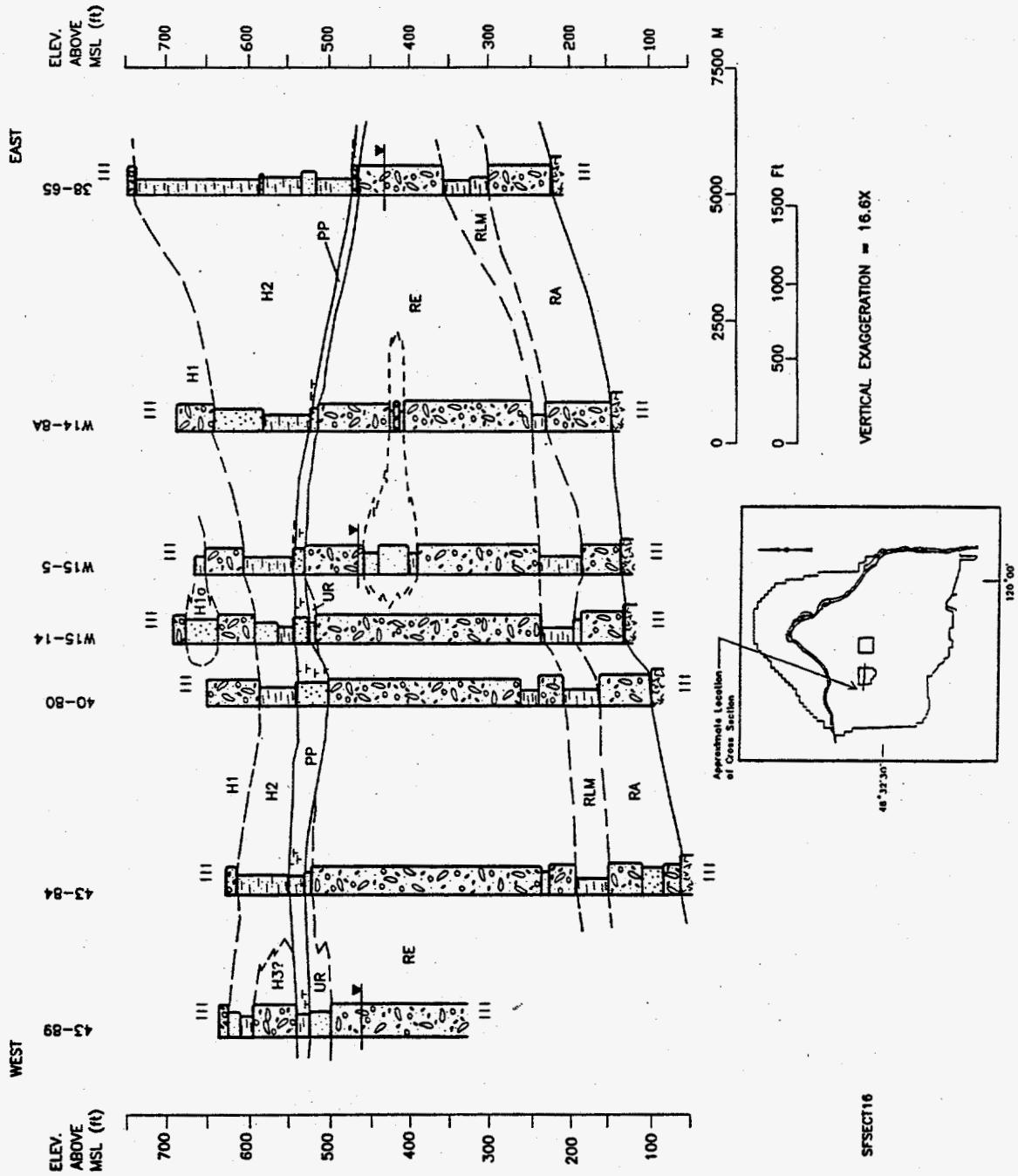


Figure 11. Generalized Surface Map, Top of Ringold Unit A, Beneath the Central Hanford Site.

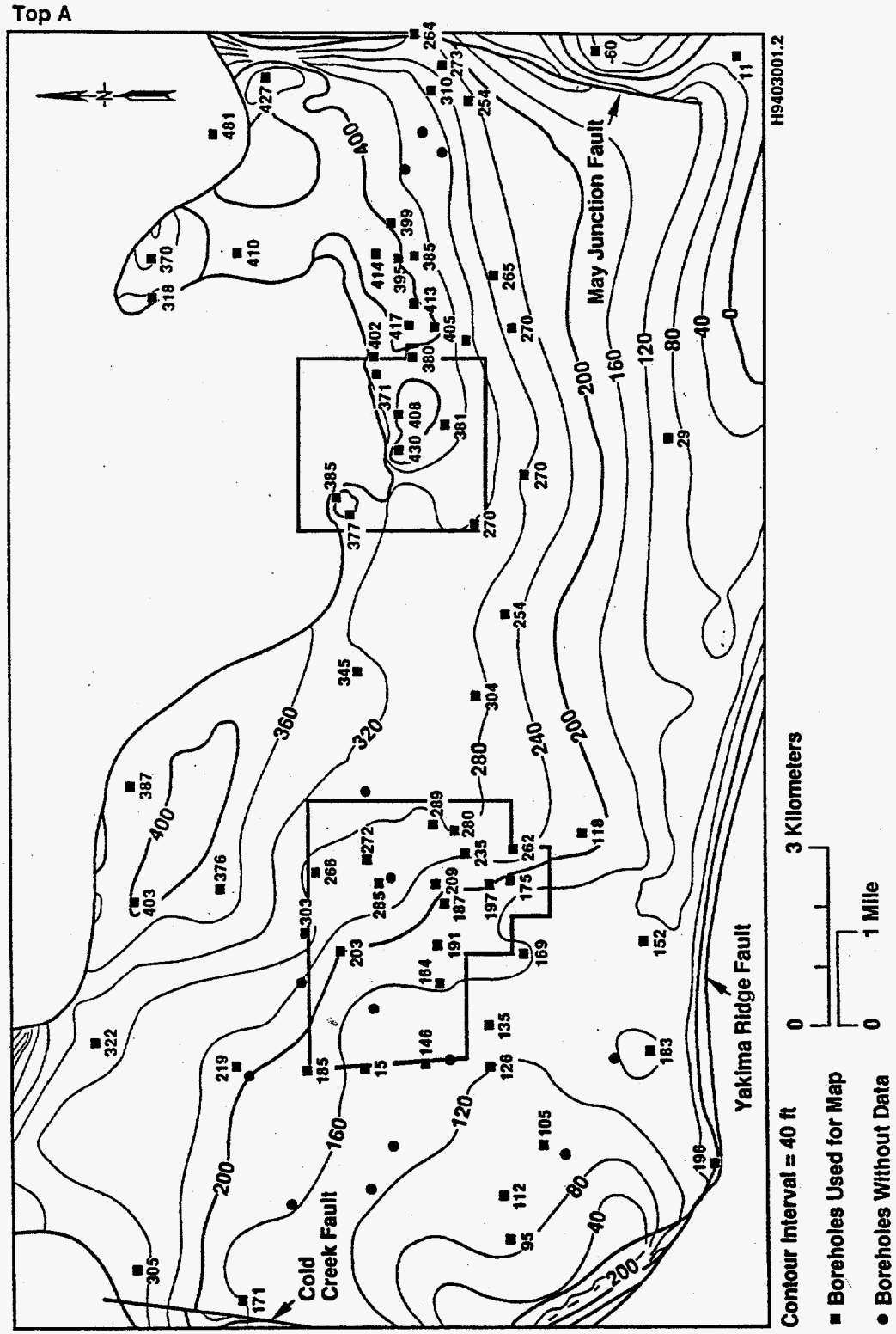
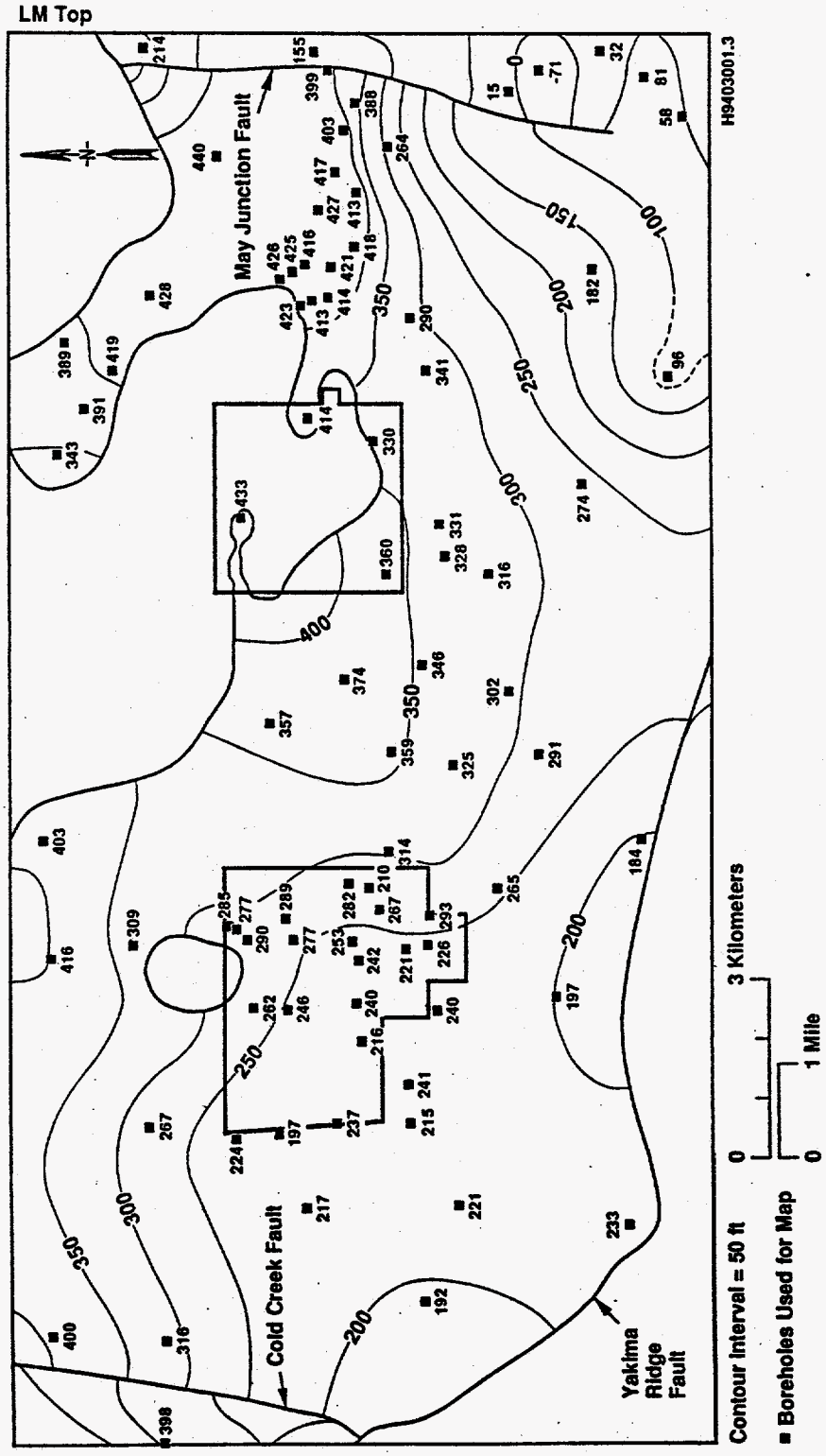


Figure 12. Generalized Surface Map, Top of Ringold Lower Mud Unit, Beneath the Central Hanford Site.



southern parts of the area, lows in the central part of the area, and generally dipping to the southeast (Figure 13). Intercalated lenticular beds of sand and silt occur throughout the 200 West Area, although predicting where they will occur is difficult.

The member of Taylor Flat (Figures 14 and 15) is discontinuous across the 200 West Area because of post-Ringold erosion. It only is found in the northern, western, and southern parts of the 200 West Area. In these areas the top of the unit generally is dipping to the south-southwest. The member of Taylor Flat in the 200 West Area consists of interstratified deposits of the overbank-paleosol facies and the fluvial sand facies. Figure 16 shows the boreholes used for geologic interpretations in the 200 West Area.

4.3 PLIO-PLEISTOCENE UNIT

The Plio-Pleistocene unit is irregularly distributed beneath the 200 West Area (Figures 17 and 18); it consists of a combination of facies ranging from pedogenic calcium carbonate to stratified silt-rich deposits.

4.4 HANFORD FORMATION

The Hanford formation consists of uncemented gravel, sand, and silt that were deposited by Pleistocene cataclysmic floods (Fecht et al. 1987; DOE 1988; Baker et al. 1991). The contact between the Hanford formation and underlying strata is everywhere a disconformity and commonly an angular unconformity. This contact is irregular (Figure 19) and reflects an erosion surface associated with Pleistocene cataclysmic flooding, pre-Hanford incision, or a combination of the two.

Studying the distribution of Hanford formation facies types and identifying similarities in lithologic succession across the 200 West Area indicates the Hanford formation can be divided into two widely distributed stratigraphic units: a gravelly unit referred to as unit 1, and a sand-rich unit that is referred to as unit 2. Also, three localized units are found in the 200 West Area. These units consist of a sandy unit overlying unit 1, referred to as unit 1a; a second gravel interval near the bottom of the section, referred to as unit 3; and a silt-rich unit at the base of the section, referred to as unit 4. Mineralogic and geochemical data are not used in differentiating units because of no comprehensive mineralogic and geochemical data set.

4.4.1 Unit 4

Unit 4 is dominated by strata typical of the silt-dominated facies and lesser sand-dominated facies. It is largely restricted to the west-central part of the 200 West Area where it underlies and interfingers with gravels of unit 3. Where unit 3 is absent it may not be possible to differentiate unit 4 from other silt- and sand-dominated parts of the Hanford formation. However, some borehole data reported in Last and Rohay (1993) and Rohay et al. (1993) indicate unit 4 may be separable from other silt and sand units on the basis of decreased grain size.

Figure 13. Generalized Surface Map, Top of Ringold Unit E, Beneath the Central Hanford Site.

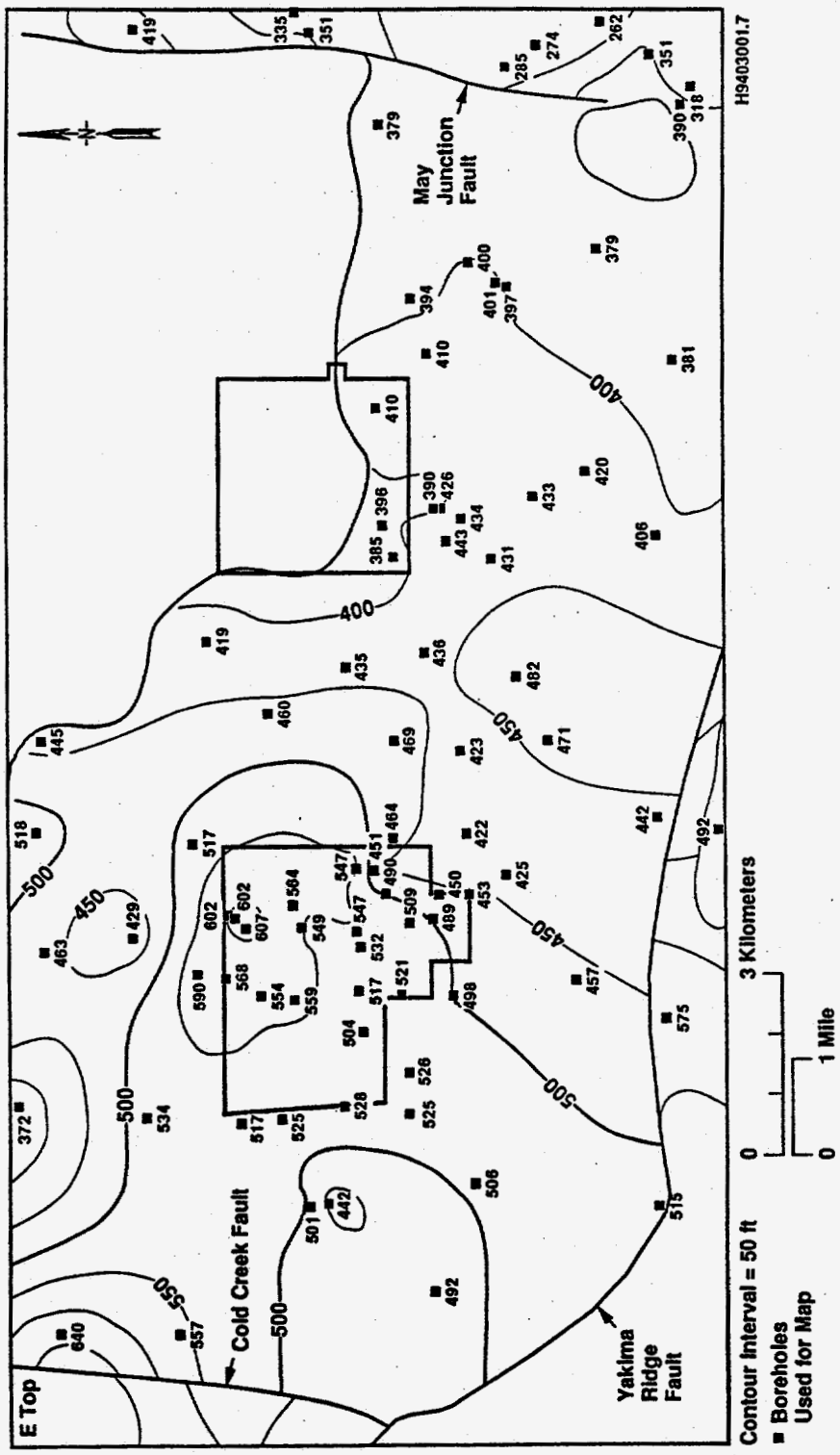
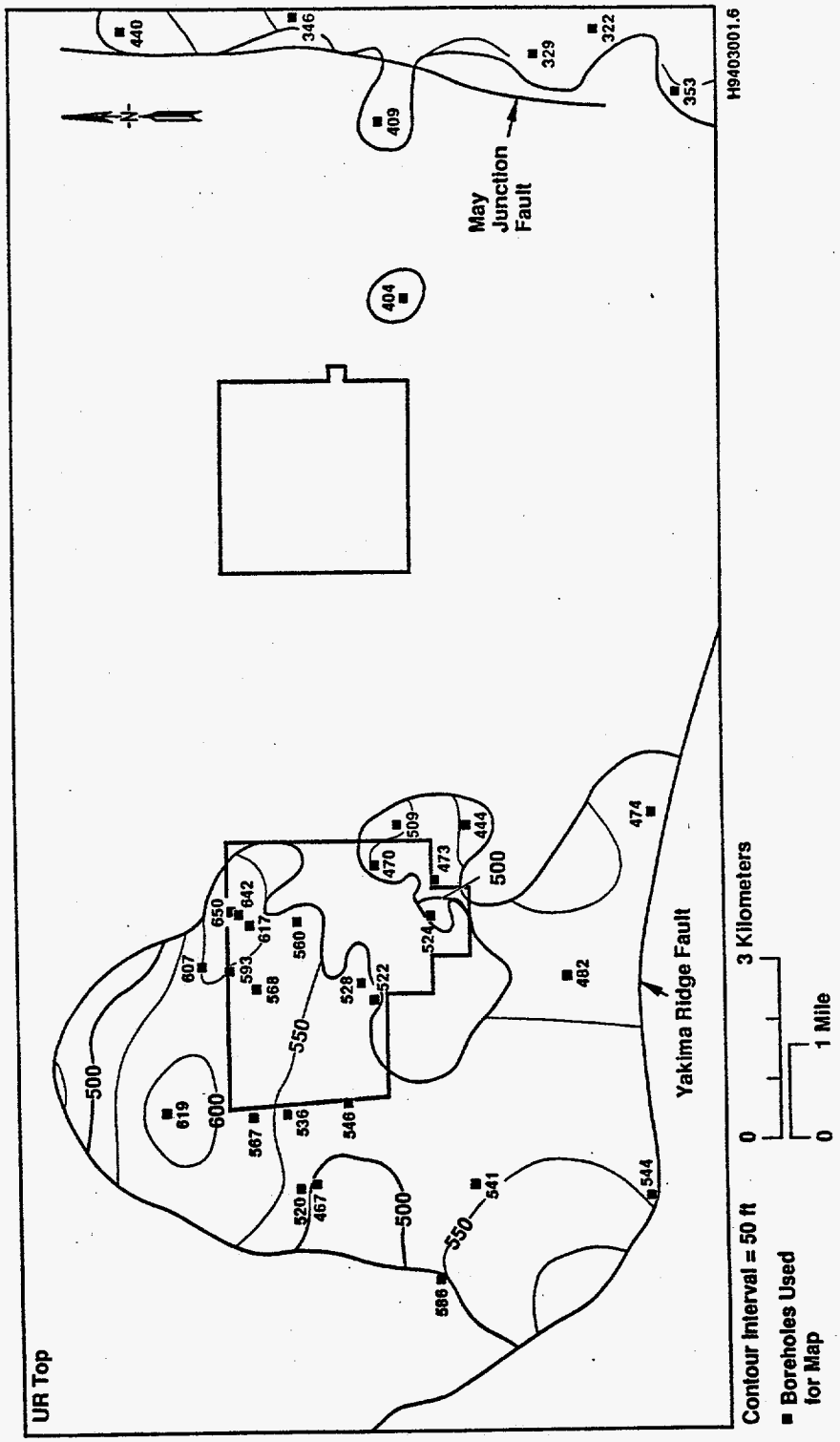


Figure 14. Generalized Surface Map, Top of Member of Taylor Flat, Ringold Formation, Beneath the Central Hanford Site.



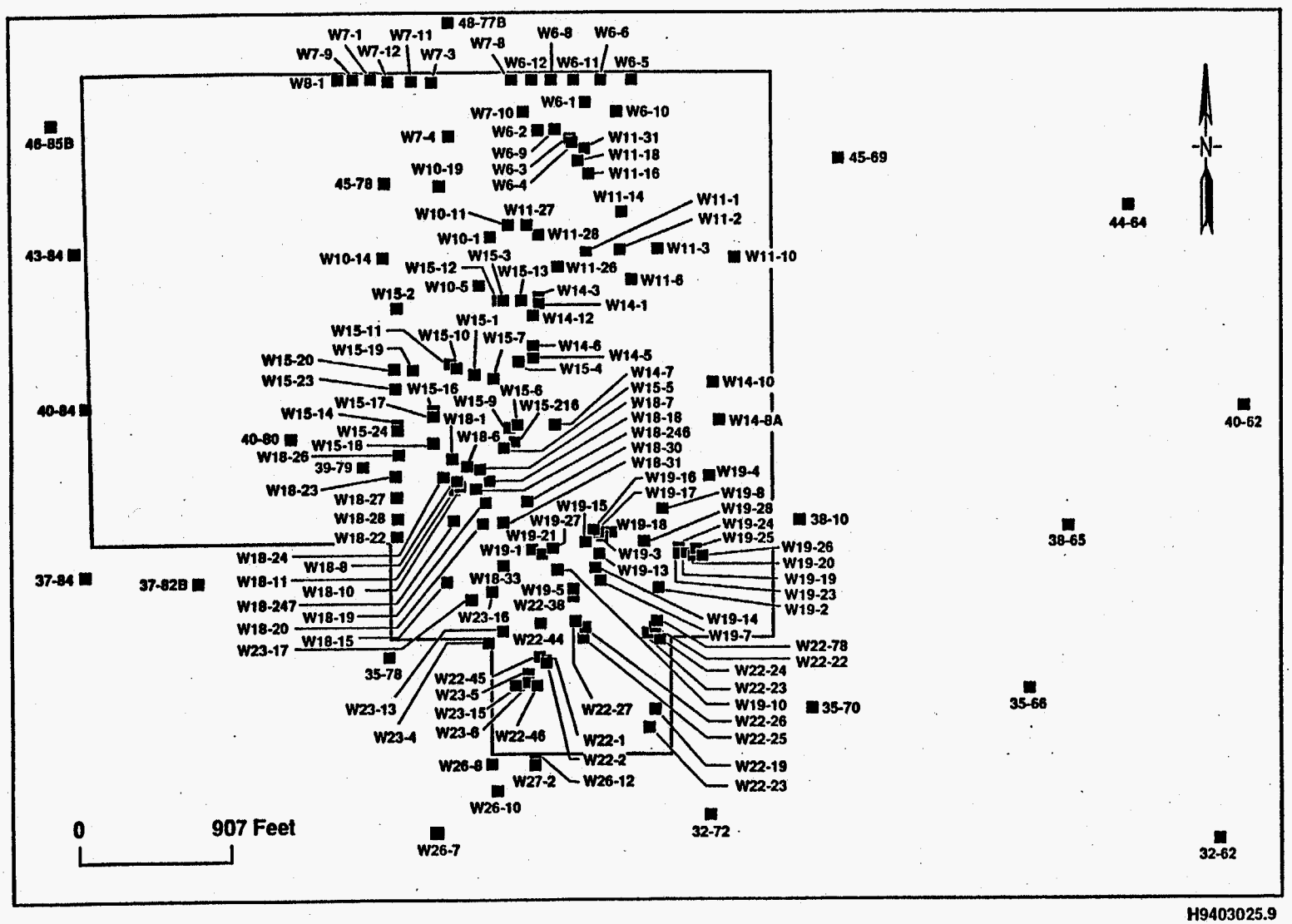


Figure 15. Isopach Map, Member of Taylor Flat, Ringold Formation, 200 West Area.

Figure 16. Index Map to Boreholes Used for Geologic Intepretations in this Report in the 200 West Area.

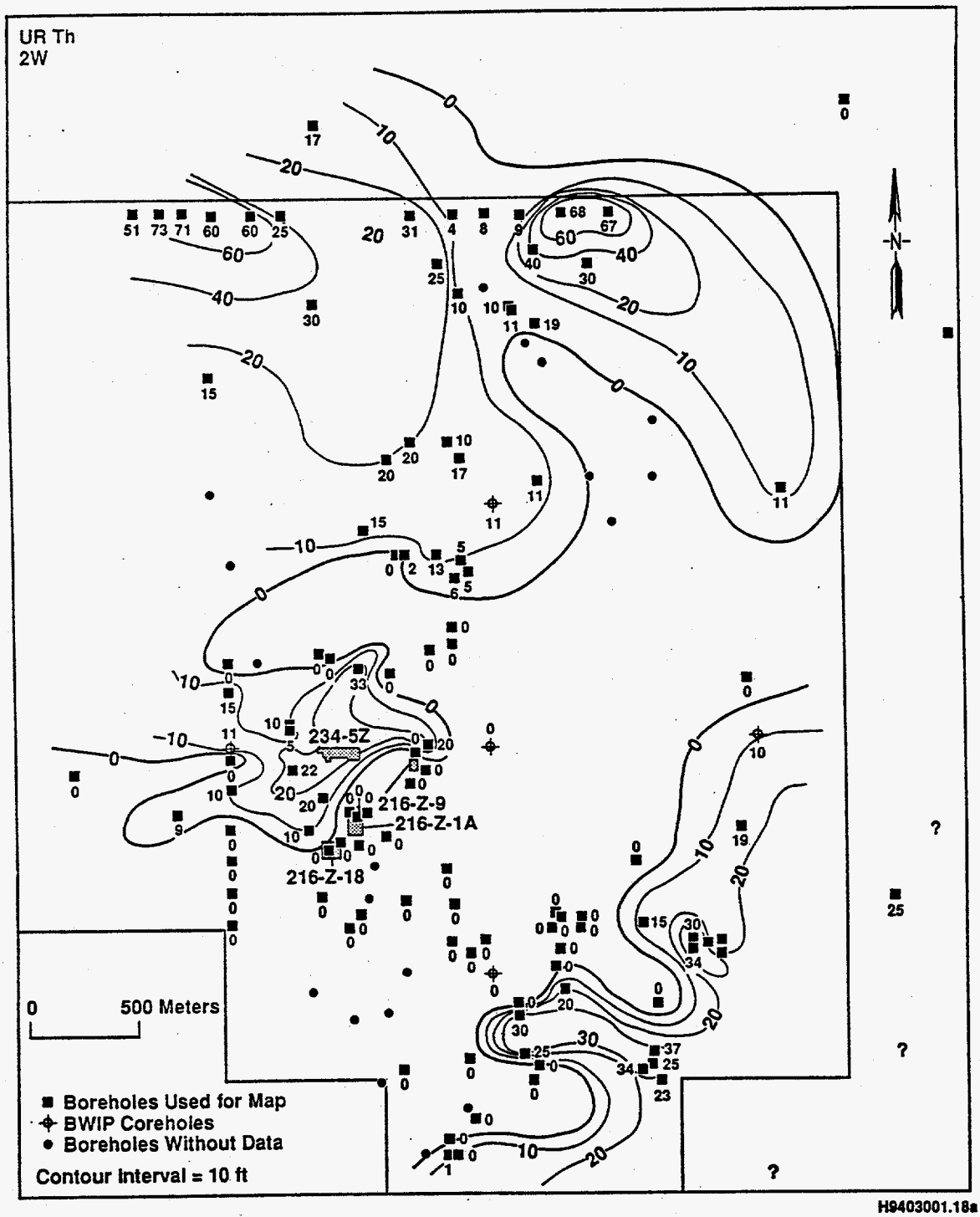


Figure 17. Generalized Surface Map, Top of Plio-Pleistocene Unit, Beneath the Central Hanford Site.

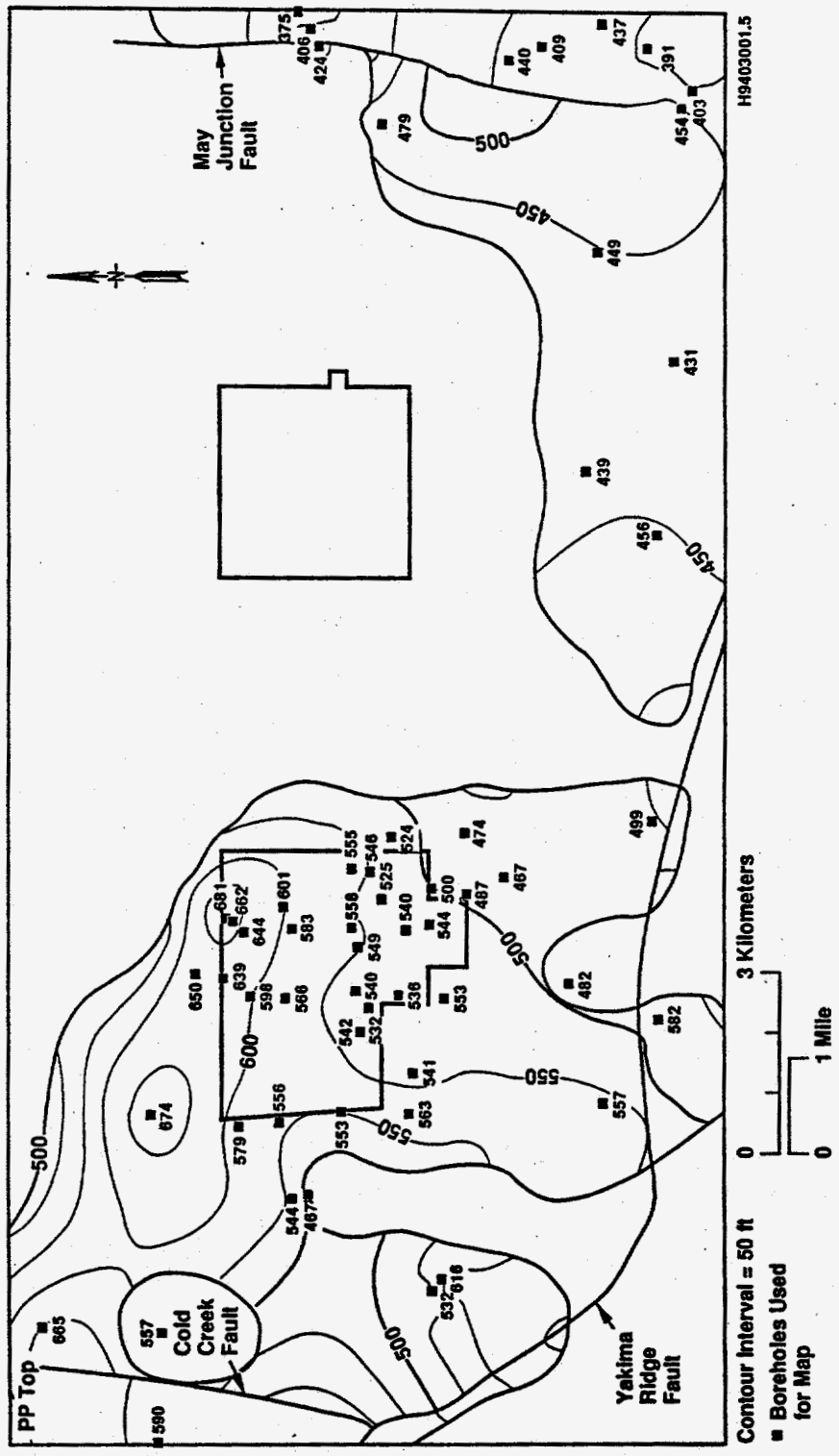


Figure 18. Surface Map, Top of Plio-Pleistocene Unit, 200 West Area.

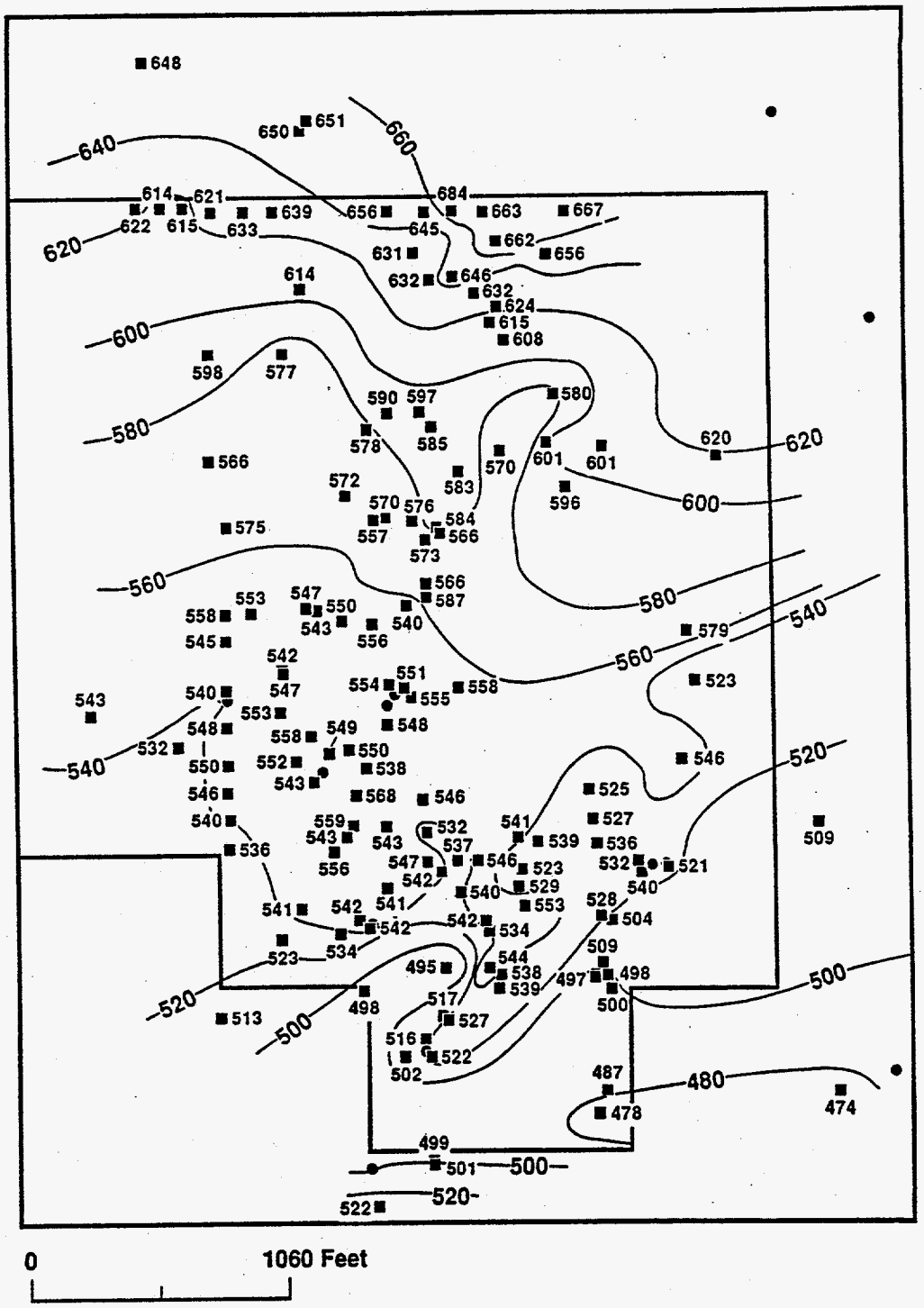
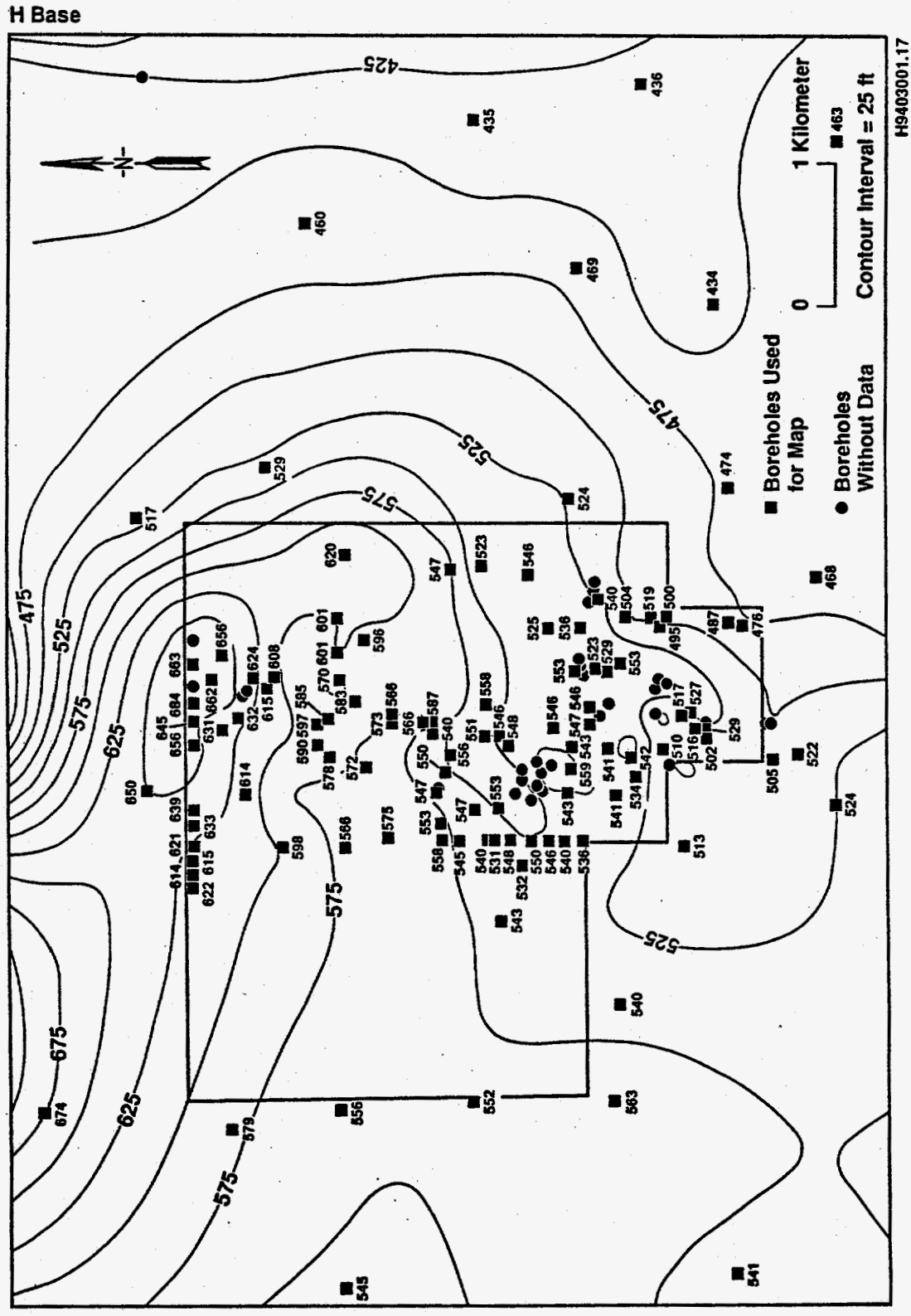


Figure 19. Surface Map, Base of Hanford Formation, 200 West Area.



4.4.2 Unit 3

Deposits of the gravel- and sand-dominated facies form the bulk of unit 3. Unit 3 is most common in the west-central part of the area (Rohay et al. 1993). Because there are no distinctive marker lithologies and beds, it is impossible to determine whether unit 3 in the 200 West Area is correlative to unit 3 in the 200 East Area. It is also not possible to differentiate the gravels of unit 3 from other gravelly Hanford units, such as unit 1, where intervening sandy strata are absent.

4.4.3 Unit 2

Unit 2 consists dominantly of silt, silty sand, and sand typical of the silt-dominated facies interbedded with coarser sands like those comprising the sand-dominated facies. Thin (<3 m [<9.8 ft]) intervals dominated by the gravel facies are found locally. The distribution of facies within the unit is variable, although the unit generally fines to the south where silt-dominated facies become more common. Unit 2 pinches out in the northern part of 200 West Area and it generally thickens to the south (Figures 20 and 21).

4.4.4 Unit 1

Unit 1 consists of interstratified gravel facies, sand facies, and lesser silt facies. At some localities deposits typical of the sand-dominated facies dominate. This is especially common in the west-central 200 West Area where a sandy interval, referred to as unit 1a, gradationally overlies unit 1 gravels (Rohay et al. 1993). Minor, laterally discontinuous silty deposits like those that form the silt facies are found locally. The thickness and distribution of individual facies within unit 1 is variable. Fining upwards sequences of coarse to fine gravel and gravel to gravelly sand are present at some locations. The base of unit 1 is incised into underlying strata. However, where the unit thins to the south the contact is less well defined as unit 1 interfingers with the sand and silt of unit 2 (Figure 22).

4.5 HOLOCENE SURFICIAL DEPOSITS

Holocene deposits in the 200 West Area consist of thin (<3 m [<9.8 ft]) eolian sheet sands. These sands are very fine to medium grained and occasionally silty. These deposits have been removed from much of the area by construction activities.

4.6 200 WEST HYDROLOGY

The surface of the unconfined aquifer in the 200 West Area is situated entirely within partially cemented fluvial gravels of Ringold unit E (Connelly et al. 1992b). Transmissivity and hydraulic conductivity values summarized in Connelly et al. (1992b, Table 3-2) indicate ranges of 1.7 to 4,738 m^2/day and 0.3 to 1,554 m/day (18 to 51,000 ft^2/day and 1 to 5,100 ft/day), respectively. The vadose zone beneath the 200 West Area is

Figure 20. Isopach Map of Hanford Formation, Unit 2, 200 West Area.

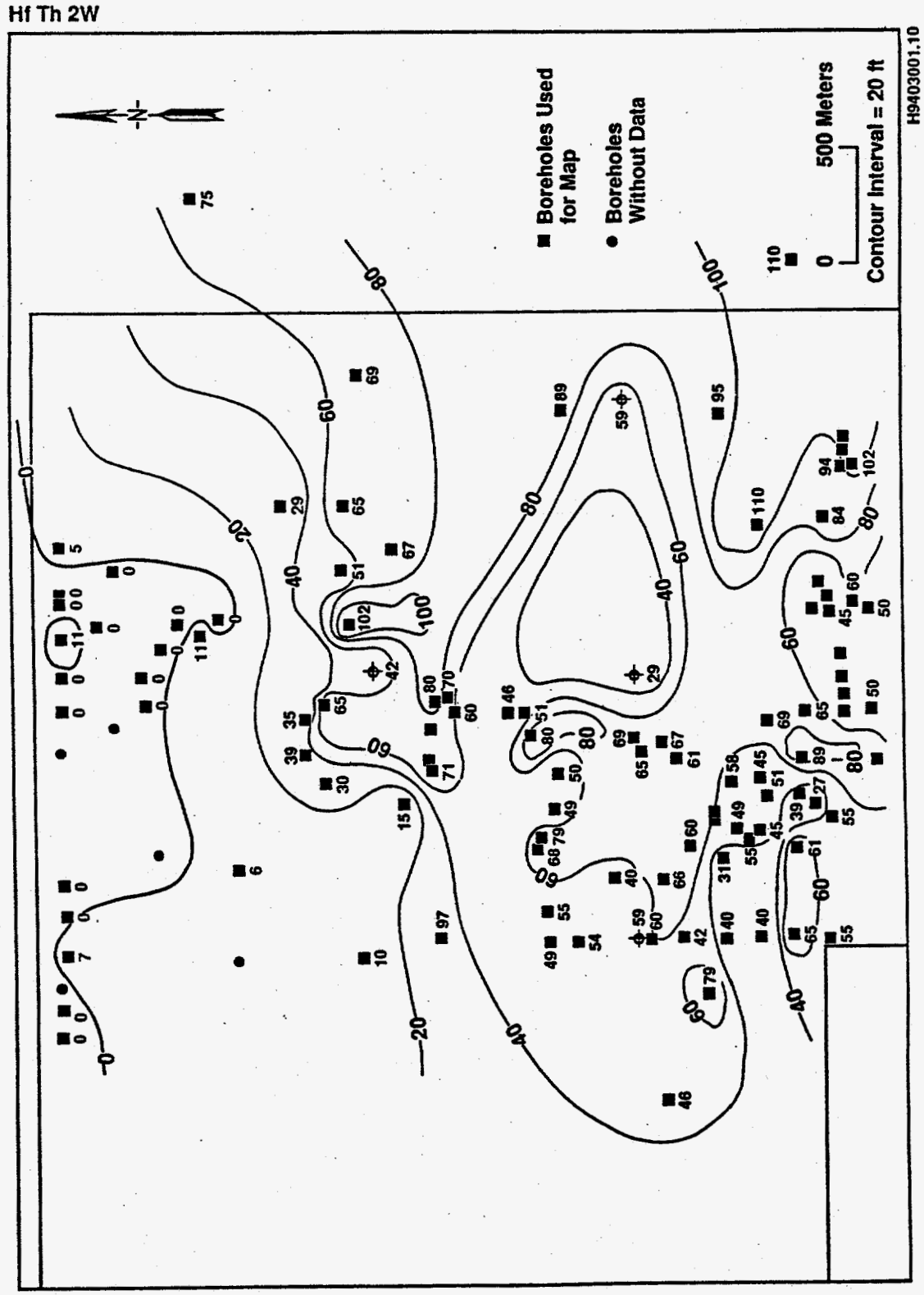


Figure 21. Surface Map, Top of Hanford Formation, Unit 2, 200 West Area.

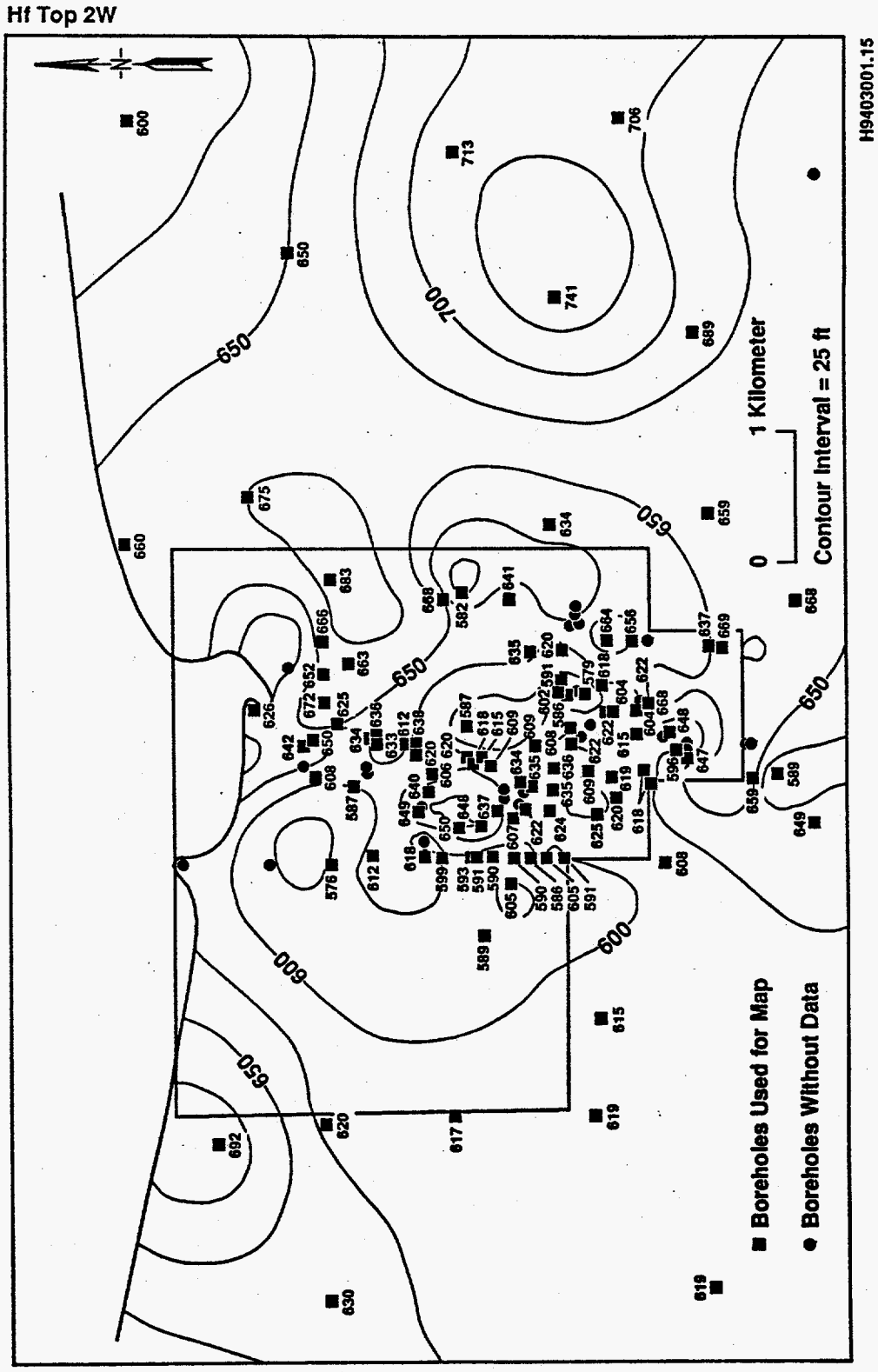
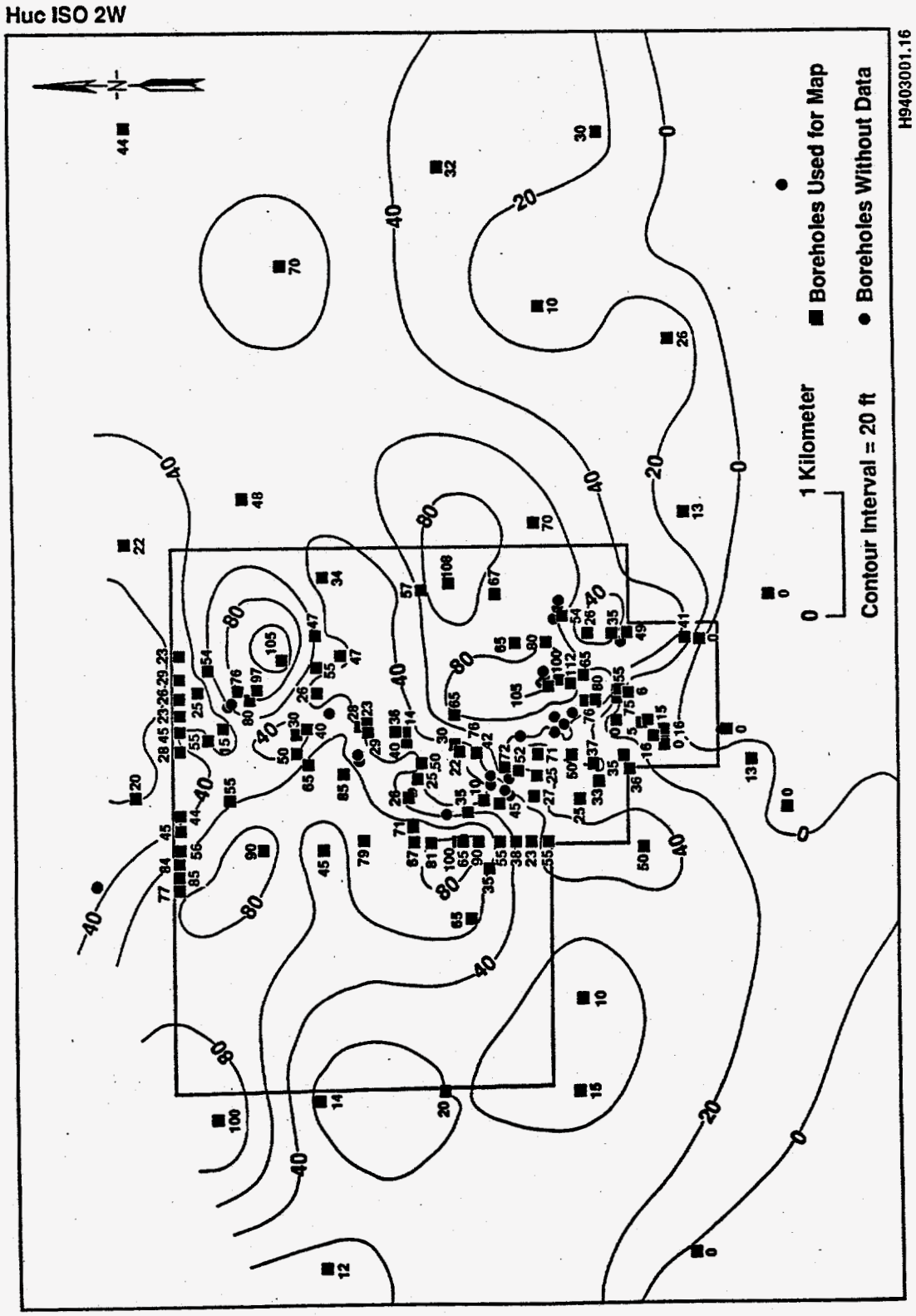


Figure 22. Isopach Map of Hanford Formation, Unit 1, 200 West Area.



situated in the Hanford formation, the Plio-Pleistocene unit, the Ringold member of Taylor Flat, and the upper part of Ringold unit E. Van Genuchten curve fitting parameters for lithologies that typically comprise these units are listed in Connelly et al. (1992a, Table 3-1; 1992b, Table 3-1).

Clastic dikes also are common in the vadose zone in the 200 West Area. Data describing the physical characteristics and hydrologic properties of clastic dikes are not available. However, some empirical observations have been made that allow the following generalized conclusions to be made:

- Clastic dikes are most common within strata typical of the sand- and silt-dominated facies. However, the dikes are very difficult to detect in the subsurface.
- Clastic dikes can potentially act as barriers or pathways to fluid transport. Their behavior depends on the content of the dike and the type of sediment the dike transects.
- The lateral extent of the spreading of individual perched water zones is limited where dikes appear to form pathways for vertical fluid transport.

4.7 200 WEST AREA LOW-LEVEL BURIAL GROUNDS

There are sufficient data available with which to establish the basic geologic setting of each of the LLBGs. Data also exist from which it is possible to estimate hydrologic properties of the sediments underlying the LLBGs. However, these data do not support detailed interpretations of aquifer properties. Using available data, conceptual geologic models for the LLBGs are presented in the following sections.

4.7.1 218-W-6 Burial Ground

The 218-W-6 Burial Ground (Figure 23) is underlain, from the surface to the top of basalt, by: (1) Hanford formation gravel and lesser sand facies, (2) the Plio-Pleistocene unit, (3) the lower part of the Ringold Formation member of Taylor Flat, and (4) unit E, the lower mud unit, and unit A of the Ringold Formation member of Wooded Island (Figures 24, 25, and 26).

The Hanford formation ranges from 7 to 24 m (23 to 80 ft) thick and is dominated by the gravel facies. Sands also occur in several wells at the base of the Hanford formation. Stratigraphic trends throughout the 200 West Area indicate the gravels are part of Hanford formation unit 1. The sands are assigned to Hanford formation unit 2. Unit 2 pinches out in the northern part of the 200 West Area and is not continuous beneath the burial ground.

The Plio-Pleistocene unit is continuous beneath the entire burial ground (Figure 27). It ranges from approximately 3 m (10 ft) thick in the eastern part of the site to as much as 18 m (60 ft) thick in the north-central part of the site. The top of the unit ranges from 7 to 24 m (23 to 80 ft) below the surface, generally becoming deeper to the south. Beneath the burial ground the unit consists of a combination of all its sediment types except laminated

Figure 23. Location Map for the 218-W-6 Burial Ground (Low-Level Waste Management Area 5) Showing Location of Cross Sections.

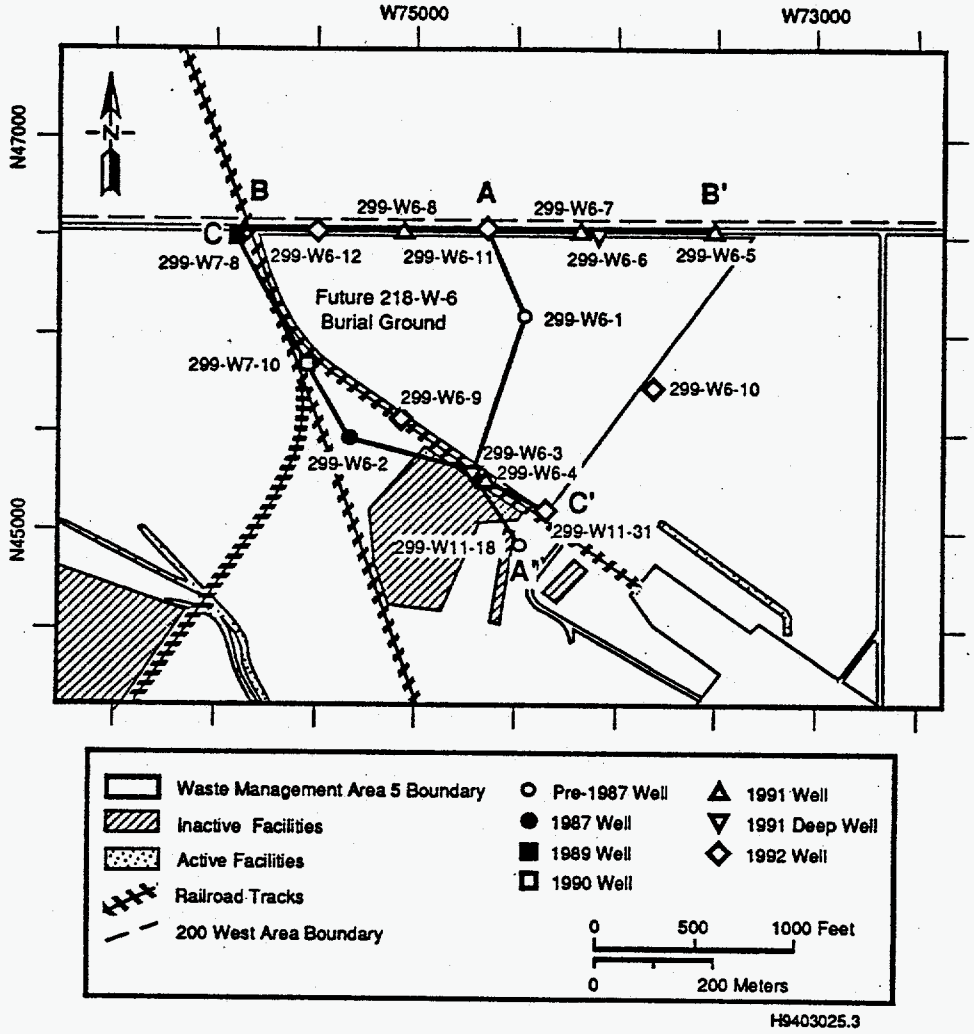


Figure 24. Cross Section A-A' through the 218-W-6 Burial Ground.

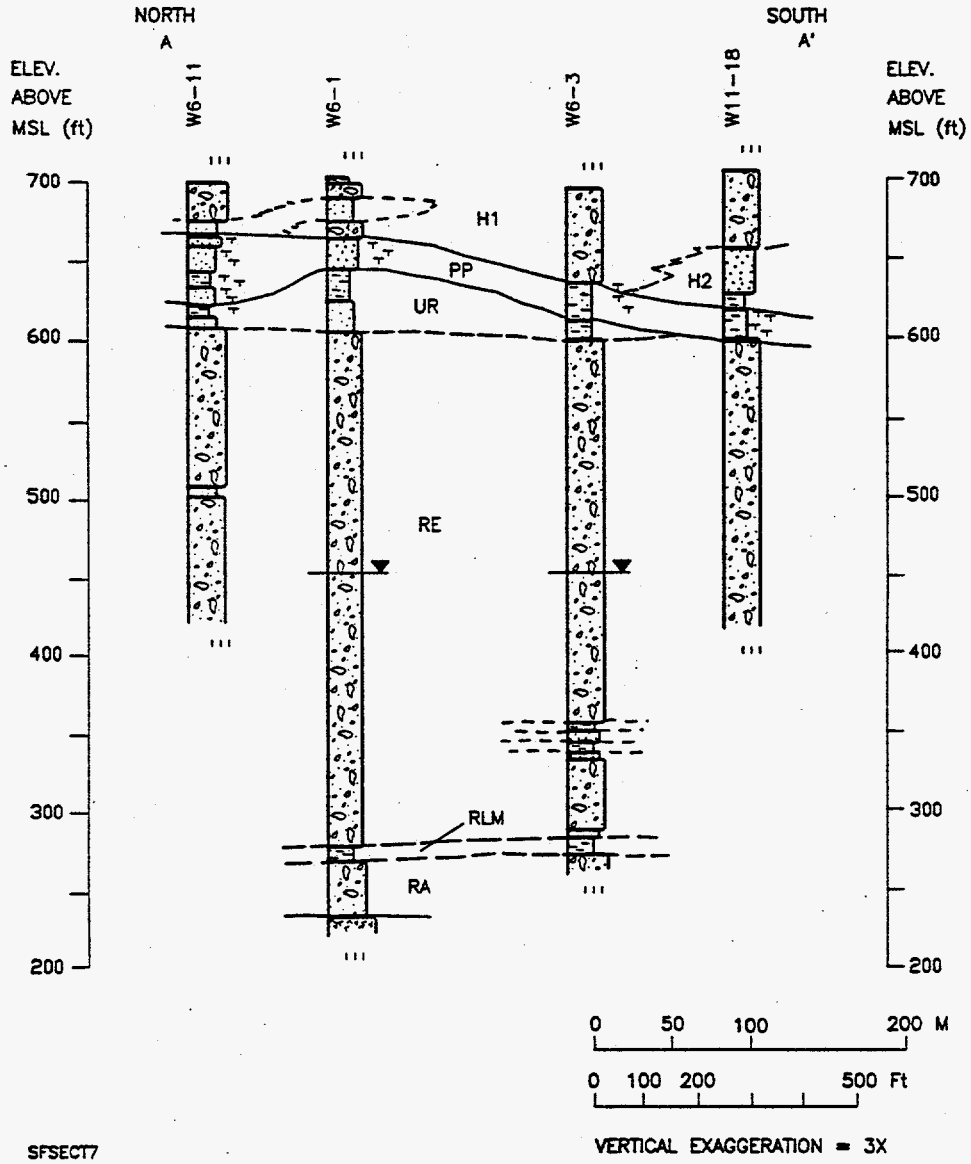


Figure 25. Cross Section B-B' through the 218-W-6 Burial Ground.

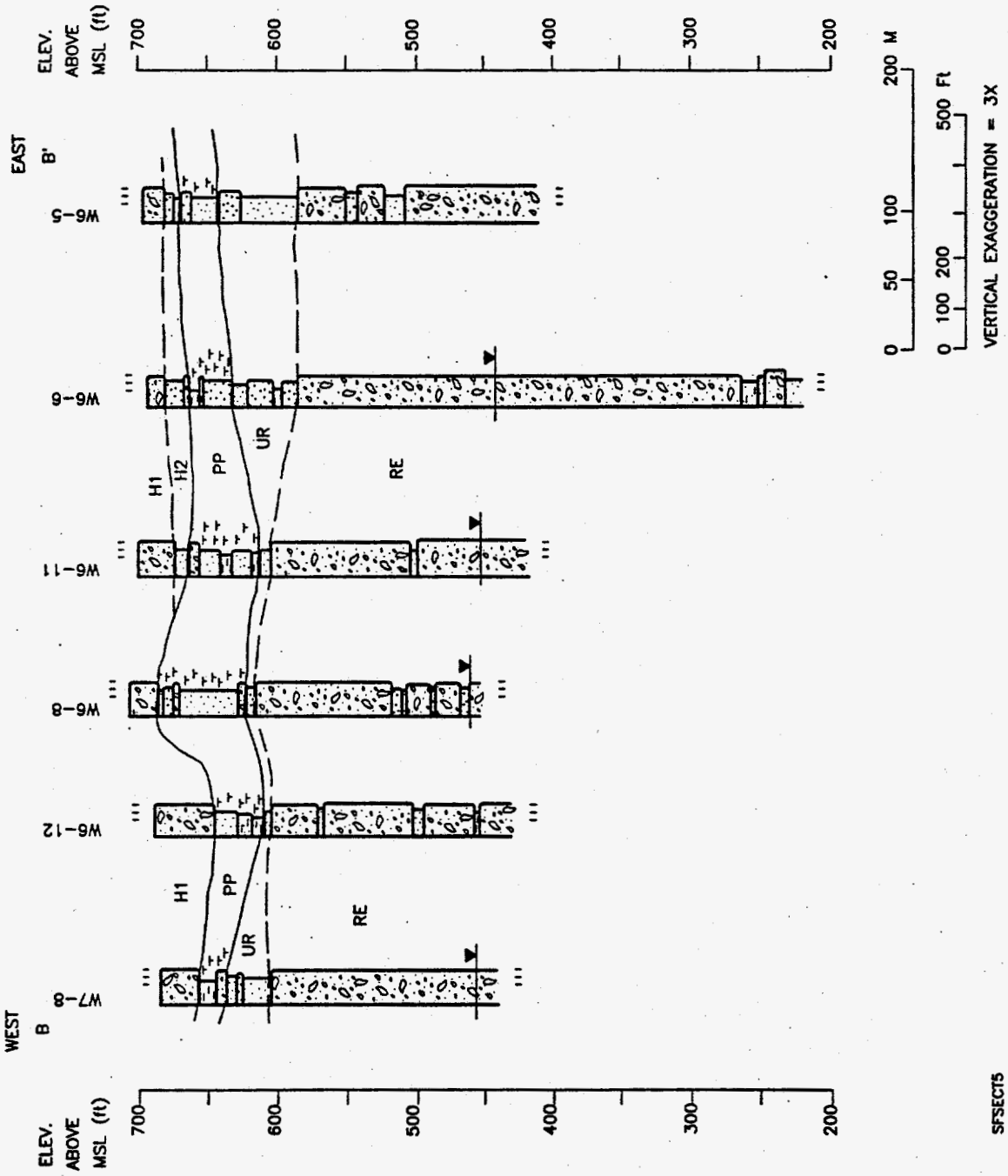


Figure 26. Cross Section C-C' through the 218-W-6 Burial Ground.

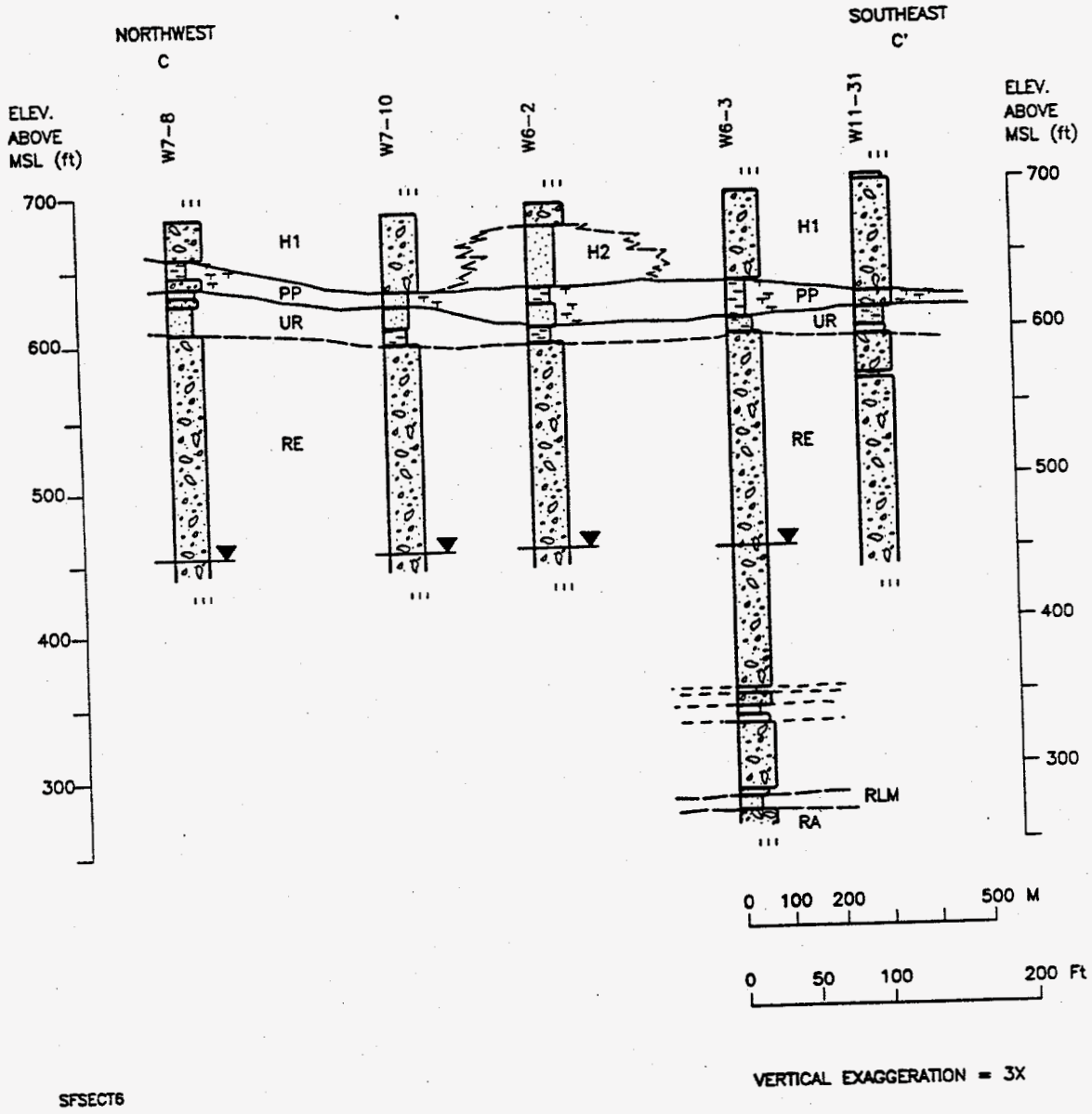
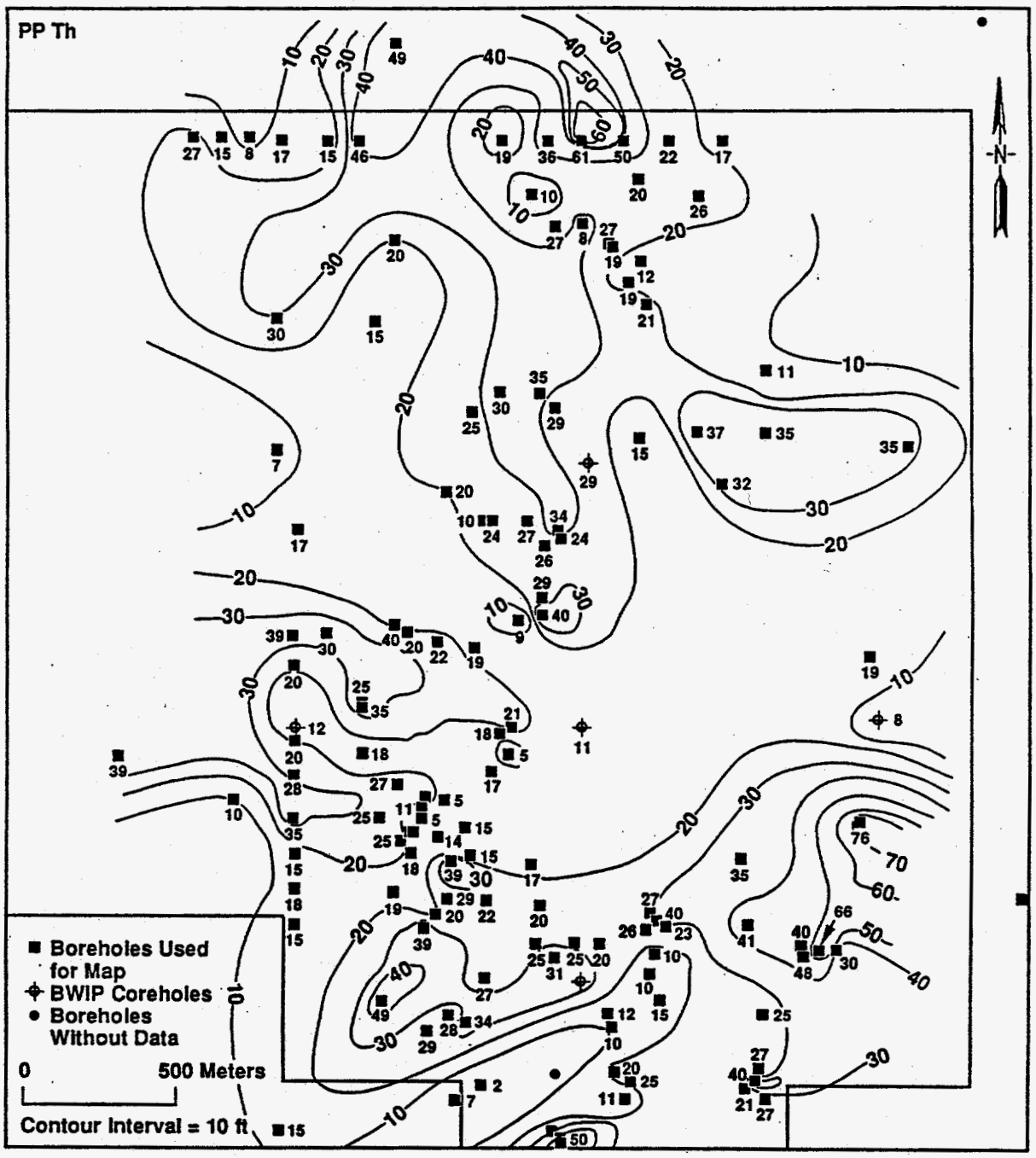


Figure 27. Isopach Map, Plio-Pleistocene Unit, 200 West Area.



H9403001.19

silts. Consequently, a complex vadose zone transport system should be expected. The Plio-Pleistocene unit commonly grades downward into underlying Ringold strata, and the top of the Plio-Pleistocene unit generally is placed at the base of the lowest calcium carbonate-rich layer, which is greater than 8 cm (0.25 ft) thick.

Except for the southernmost borehole examined for this site (W11-18), erosional remnants of the Ringold Formation member of Taylor Flat are present everywhere beneath the burial ground. These strata vary from 1.5 to 17 m (5 to 55 ft) thick because of the gradational nature of the contact between it and the overlying Plio-Pleistocene unit. Consequently, the contact between the two units is not everywhere at the same horizon. Beneath the burial ground the member is dominated by the fluvial sand facies and contains lesser occurrences of the overbank-paleosol and fluvial gravel facies.

Ringold unit E is present everywhere beneath the burial ground. Three wells (W6-6, W6-3, and W6-1) penetrate the full thickness of unit E at the site, i.e., 96 to 100 m (315 to 329 ft). Unit E is dominated by the fluvial gravel facies while minor laterally discontinuous occurrences of the fluvial sand and overbank-paleosol facies are also present. Well-cemented zones throughout the unit can generate locally confined conditions beneath the water table and have the potential to generate local perched water conditions in the vadose zone.

Wells W6-6, W6-3, and W6-1 also fully penetrate fine-grained strata of the lower mud unit. The lower mud unit is 3 to 4.5 m (10 to 15 ft) thick beneath the site. Trends throughout the 200 West Area (see Figures 24, 25, and 26) indicate the unit pinches out north of the burial ground. It is not known if the lower mud unit generates confined or partially confined conditions in underlying strata.

Approximately 11 m (35 ft) of fluvial gravel of Ringold unit A separate the lower mud unit from the top of the Saddle Mountains Basalt. Both unit A and the overlying lower mud unit dip and thicken southward.

4.7.2 218-W-5, 218-W-3A, and 218-W-3A-E Burial Grounds

This group of burial grounds, located in the northwestern part of the 200 West Area (Figure 28), is underlain by essentially the same stratigraphic units (Figure 29) that underlie the 218-W-6 Burial Ground to the east.

The Hanford formation at this site is dominated by gravels assigned to unit 1. However, unlike the burial grounds to the east, the gravels of unit 1 show fining upward trends beneath the southern part of the burial grounds into the sands of unit 1a. Unit 1a interfingers with gravelly strata of unit 1 in all directions. Silty sands at the base of the Hanford formation in well W10-14 are the northernmost extension of unit 2 in this area.

The Plio-Pleistocene unit underlies the entire site and dips to the south. Throughout the area it consists of calcium carbonate-rich silt, sand, and gravel and ranges from 2 to 14 m (7 to 46 ft) thick (see Figures 27, 28, and 29).

Figure 28. Location Map for the 218-W-3 and 218-W-5 Burial Grounds (Low-Level Waste Management Area 3) Showing Location of Cross Section.

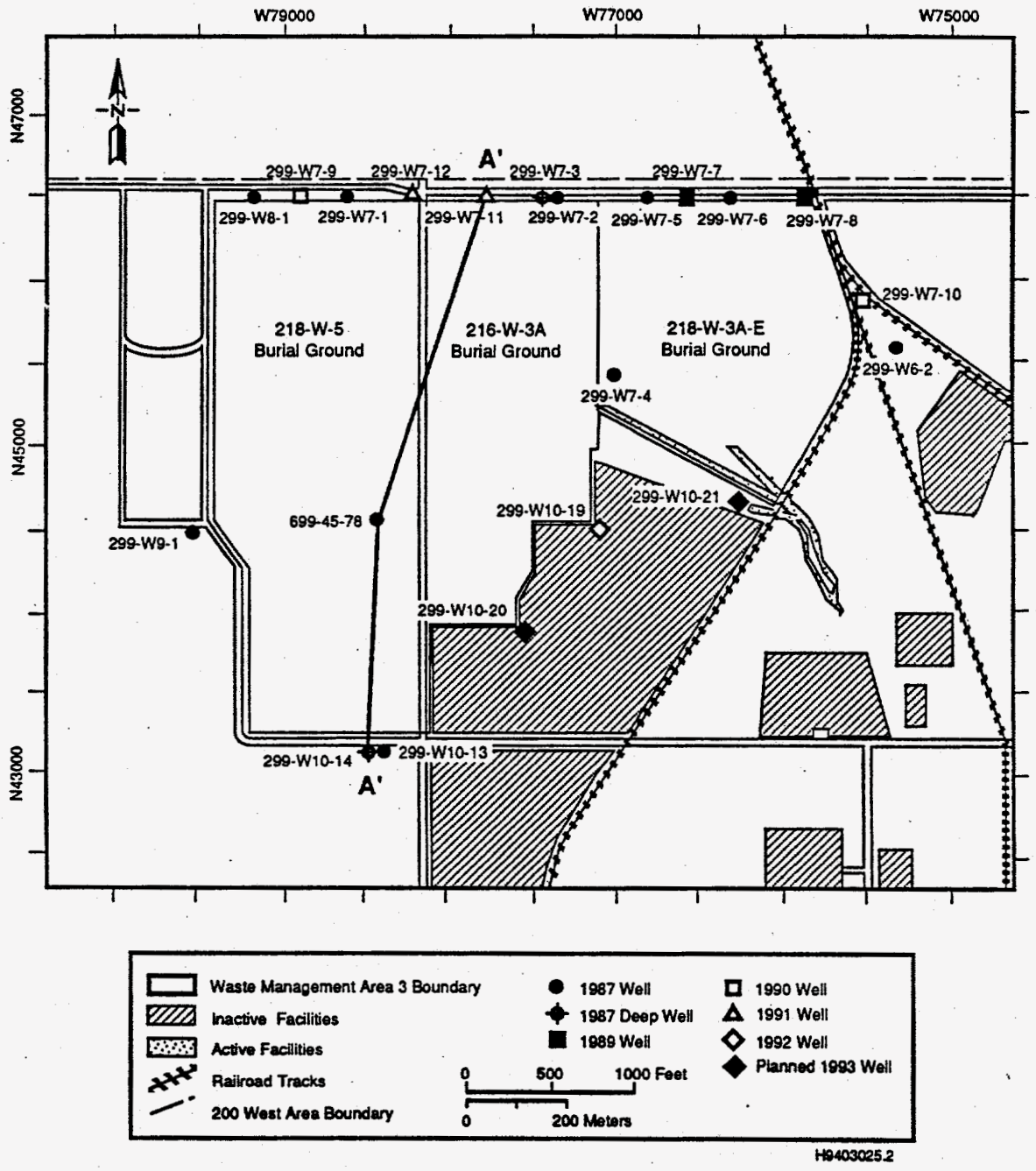
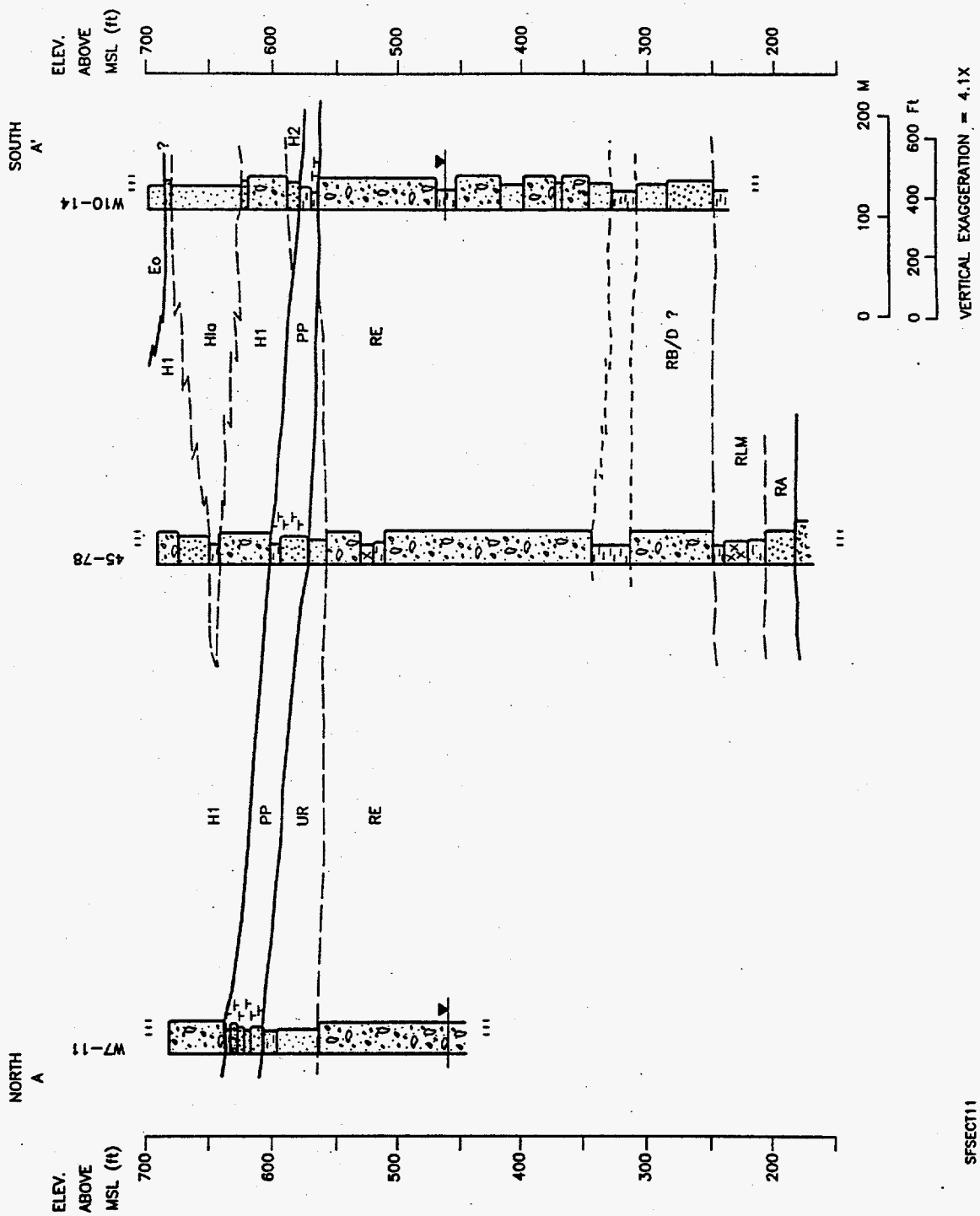


Figure 29. Cross Section A-A' through the 218-W-3 and 218-W-5 Burial Grounds.



Erosional remnants of the Ringold Formation member of Taylor Flat underlie all but the southern part of the site. In the north it is approximately 18 m (60 ft) thick while it is absent from borehole W10-14 (see Figures 14 and 16). It consists dominantly of the fluvial sand facies with minor intercalated deposits of the fluvial gravel and overbank-paleosol facies. The contact between the unit and the overlying Plio-Pleistocene unit is gradational.

Ringold unit E is approximately 64 to 70 m (210 to 230 ft) thick beneath the site and primarily consists of strata typical of the fluvial gravel facies. Two deep boreholes in the area of the burial grounds (45-78 and W10-14) penetrate a muddy interval 64 to 70 m (210 to 230 ft) below the top unit E that ranges from 6 to 9 m (20 to 30 ft) thick. This mud overlies 18 to 20 m (60 to 65 ft) of fluvial gravel that overlies the lower mud unit. Strata in this same relative stratigraphic position 8 km (5 mi) southwest of the 200 Areas show a similar succession, i.e., fines over gravel (unit B/D) over the lower mud unit (see Figure 5, borehole DH-33). This interval of fines over gravel just above the lower mud unit at the burial grounds is correlated to unit B/D and overlying fines found in borehole DH-33.

One borehole (45-78) penetrates the entire thickness of the lower mud unit. It is approximately 14 m (45 ft) thick and probably consists of the lacustrine and the overbank-paleosol facies associations. The top of the unit dips gently to the southwest into the Cold Creek depression (see Figure 12). The unit probably is present beneath the entire site, thus separating overlying Ringold gravels from underlying gravels. However, because it is missing from the area immediately north of the burial grounds (see Figure 12), the underlying unit A gravels may not be under confined conditions.

Unit A is only found in a single borehole (45-78). It is approximately 6 m (20 ft) thick and, like overlying Ringold units, generally dips and thickens to the south (see Figures 9 and 11). Unit A consists of strata typical of the fluvial gravel facies.

4.7.3 218-W-4B and 218-W-4C Burial Grounds

Eight stratigraphic units underlie the 218-W-4 Burial Grounds (Figures 30 through 33). The eight units are the gravels and sands of Hanford formation units 1 and 1a, sands of Hanford formation unit 2, localized gravels of unit 3, mixed lithologies of the Plio-Pleistocene unit, unit E, the lower mud unit, and unit A of the Ringold Formation member of Wooded Island.

Strata of both the gravel facies-dominated Hanford formation unit 1 and the sand facies-dominated unit 1a form the upper part of the Hanford formation beneath the burial grounds (see Figures 31, 32, and 33). Combined units 1 and 1a range from 9 to 32 m (30 to 105 ft) thick. In the northeastern and eastern part of the Hanford Site, only unit 1 is present. In addition to the sands assigned to unit 1a numerous sandy interbeds up to 6 m (20 ft) thick are found in unit 1 gravels. These interbeds, although assigned to unit 1, may represent interfingered sediments of unit 1a.

Sands and minor intercalated silt and gravel of unit 2 underlie unit 1 beneath the entire burial ground (see Figures 31, 32, and 33). Generally the

Figure 30. Location Map for the 218-W-4B/C Burial Ground (Low-Level Waste Management Area 4) Showing the Location of Cross Sections.

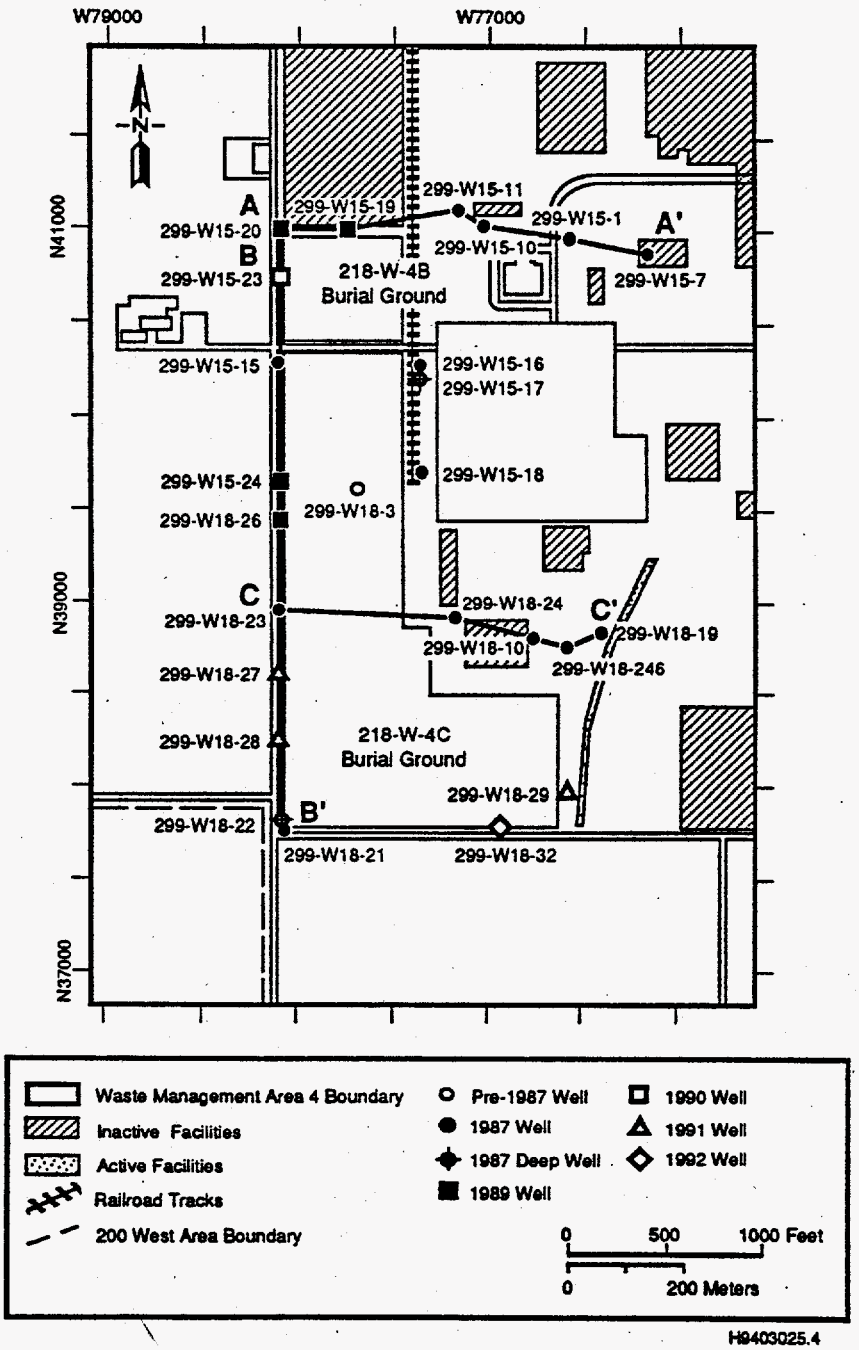


Figure 31. Cross Section A-A' through the 218-W-4B/C Burial Ground.

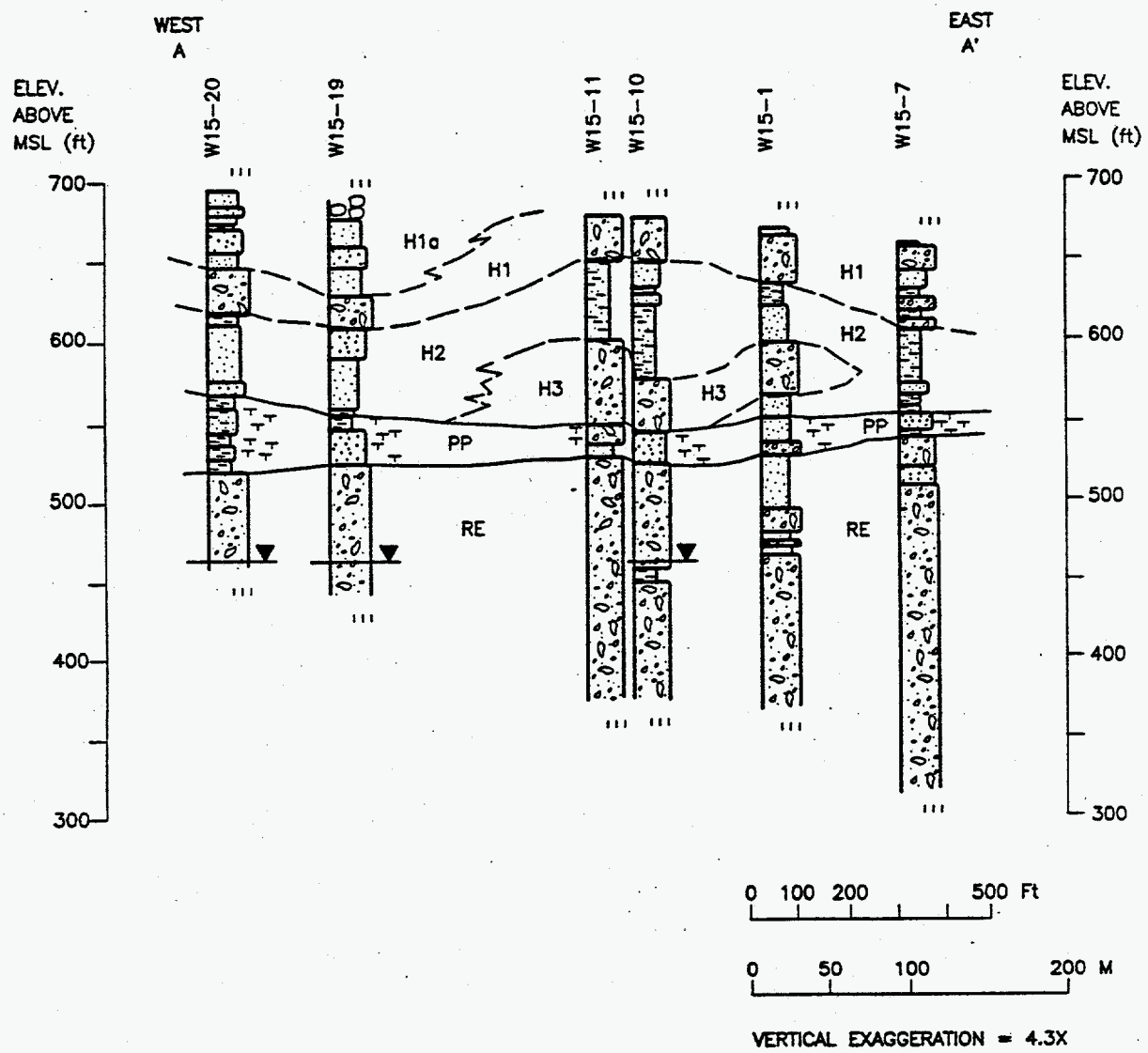


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Figure 32. Cross Section B-B' through the 218-W-4B/C Burial Ground.

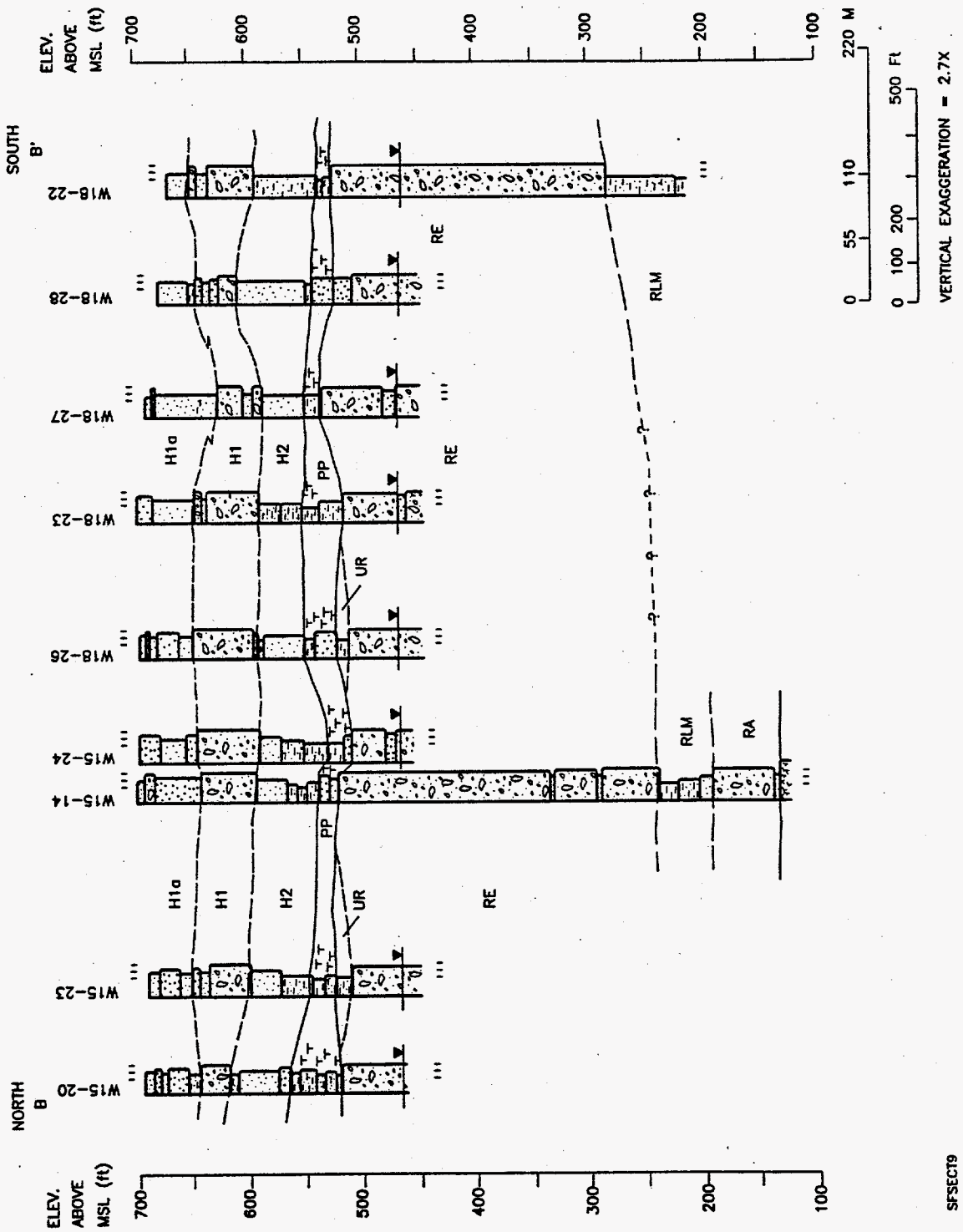
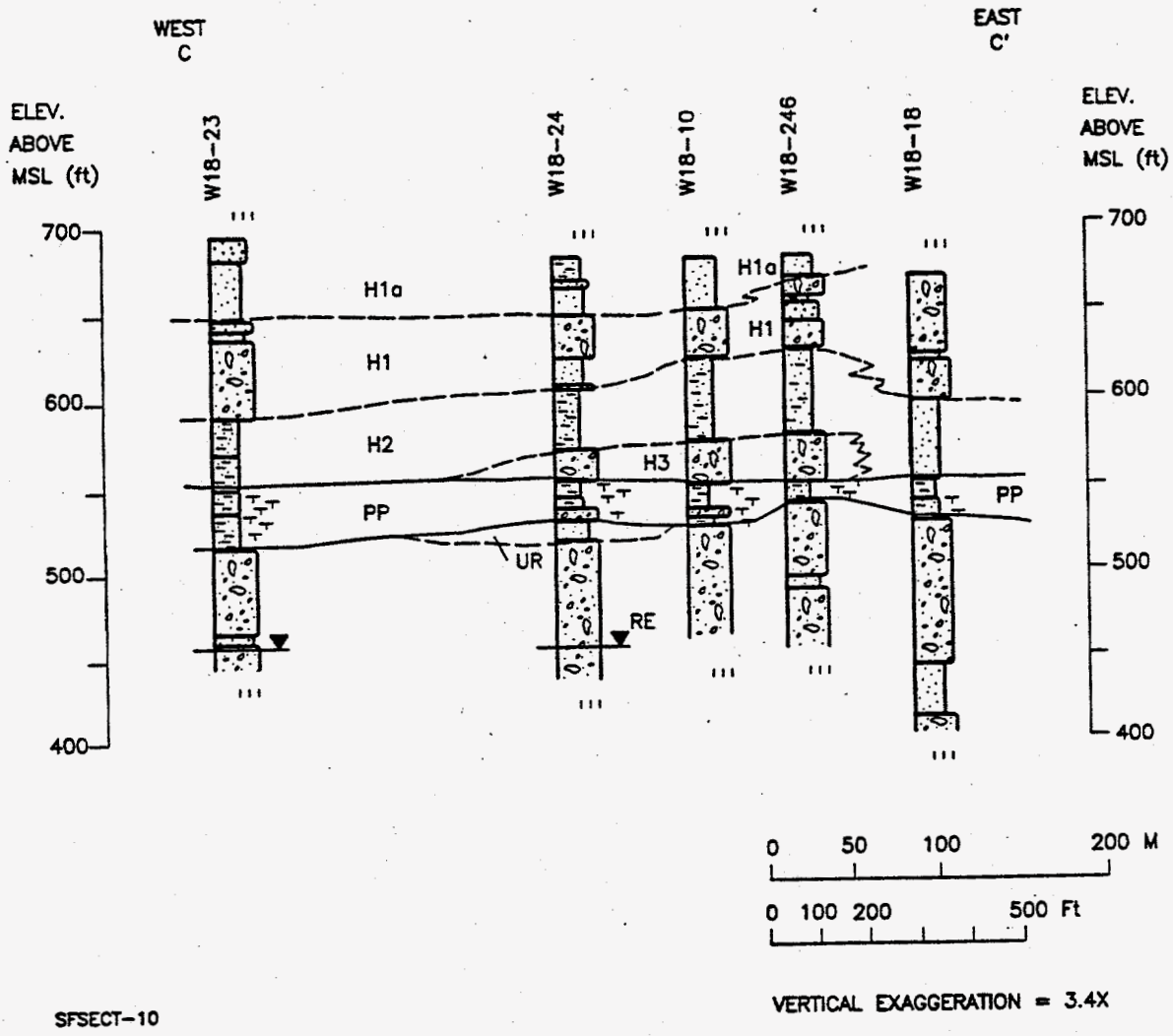


Figure 33. Cross Section C-C' through the 218-W-4B/C Burial Ground.



contact between the units is sharp, although some interfingering may occur. Unit 2 ranges from 11 to 23 m (35 to 75 ft) thick with the total thickness dependent on the depth of incision of the overlying gravels (unit 1) and the vertical extent of underlying gravel (unit 3). Silt beds within unit 2 can potentially form perched water zones. However, discontinuities in these silts encountered elsewhere in the 200 West Area indicate that the lateral extent of perched water probably is limited (Singleton and Lindsey 1994).

The lowermost Hanford formation unit beneath the burial ground is a laterally discontinuous gravel that forms unit 3 (see Figures 31, 32, and 33). This unit forms a roughly north-south-oriented band beneath the eastern part of the site and the adjacent areas (Rohay et al. 1993). The unit is up to 17 m (55 ft) thick and probably interfingers with fines of unit 2.

The Plio-Pleistocene unit underlies the entire site and is up to 12 m (40 ft) thick. It is generally thickest to the north and west while thinning to the east and south (see Figures 31, 32, and 33). Beneath the burial ground the top is very irregular with only a minor overall dip to the south (see Figure 18). Like to the north, the unit is dominated by a mix of carbonate-rich and alluvial facies. In addition, laminated silts are present, forming the upper 3 to 5 m (10 to 15 ft) of the unit beneath the burial grounds. Perched water is possible on carbonate-rich layers in the unit, but because of the presence of numerous lateral discontinuities such as pinchouts and clastic dikes in the unit across the 200 West Area (Rohay et al. 1993; Singleton and Lindsey 1994), the lateral distribution of perched water (if any is present) probably is limited.

Ringold unit E, the uppermost Ringold unit beneath the burial ground, ranges from 66 to 79 m (215 to 260 ft) thick. The top of the unit is irregular (see Figure 13) and reflects post-Ringold erosion associated with generation of the Plio-Pleistocene unit. As elsewhere, the unit is dominated by fluvial gravels containing lesser intercalated fluvial sands and overbank-paleosol facies. Intercalated fines, as well as zones of cemented gravels, have the potential to generate locally confined conditions in the saturated zone and perched conditions in the vadose zone.

The lower mud unit is thicker here than beneath the burial grounds to the north, ranging from approximately 12 to over 18 m (40 to over 60 ft) thick. Core from borehole W15-14 (DH-11) indicates the unit consists of an upper lacustrine zone and a lower overbank-paleosol zone. Regional data indicate this is a trend typical for the lower mud unit beneath the western Hanford Site.

5.0 200 EAST GEOLOGY AND LOW-LEVEL BURIAL GROUNDS

5.1 SADDLE MOUNTAINS BASALT AND ELLENSBURG FORMATION

The uppermost basalt unit beneath most of the 200 East Area is the Elephant Mountain Member of the Saddle Mountains Basalt. The Rattlesnake Ridge interbed of the Ellensburg Formation underlies the Saddle Mountains Member in this area and separates it from the next basalt downsection, the Pomona Member of the Saddle Mountains Basalt. In and between Gable Gap and the 200 East Area, the Elephant Mountain Member locally has been removed by erosion and the Rattlesnake Ridge interbed is in direct contact with overlying suprabasalt sediments (Graham et al. 1984; Hoffman et al. 1992). Because of the relatively small number of boreholes north of the 200 East Area, the size of these windows is not clearly delineated. Detailed descriptions of the basalt beneath the 200 East Area are found in Fecht (1978) and Reidel and Fecht (1981).

The Rattlesnake Ridge interbed of the Ellensburg Formation is present beneath the entire 200 East Area (Fecht 1978; Reidel and Fecht 1981). Three facies comprise the Rattlesnake Ridge interbed in this area: (1) clay or tuffaceous sandstone, (2) micaceous-arkosic and/or tuffaceous sandstone, and (3) tuffaceous siltstone or sandstone. In the 200 East Area the interbed thickens from north to south from 6 to 24 m (20 ft to 80 ft).

5.2 RINGOLD FORMATION

Ringold strata are present beneath approximately the southern half of the 200 East Area. Local erosional remnants also are found locally under the northwestern part of the 200 East Area. Unit A, the lower mud unit, and unit E of the member of Wooded Island comprise the Ringold Formation beneath the 200 East Area (Figures 34, 35, and 36).

The lowest Ringold unit in the 200 East Area, unit A, thickens and dips to the south and southwest toward the axis of the Cold Creek syncline (see Figure 11). Unit A generally pinches out against structural highes in the underlying basalt in the central part of the area (see Figure 11). Thin, lenticular occurrences of unit A are found locally in the area between the northeast corner of the 200 East Area and Gable Mountain (Lindsey et al. 1992). The distribution of unit A is related to a combination of nondeposition against basalt highes and post-Ringold erosion. Intercalated lenticular sand and silt of the fluvial sand and overbank facies associations are found locally in the middle part of the unit in the southeastern part of the area.

The lower mud unit, like unit A, thickens and dips to the south and southwest. The lower mud unit generally is absent in and north of the northern part of the 200 East Area (see Figure 12). However, in the area between the 200 East Area and Gable Mountain (see cross sections I-I' and E-E' on Figure 6b in Lindsey et al. [1992]) and near the BX and BY Tank Farms (Lindsey and Law 1993), the lower mud unit occurs locally. North of the 200 East Area, unit A is absent and the lower mud unit directly overlies basalt.

Figure 34. North/South-Oriented Cross Section through the 200 East Area.

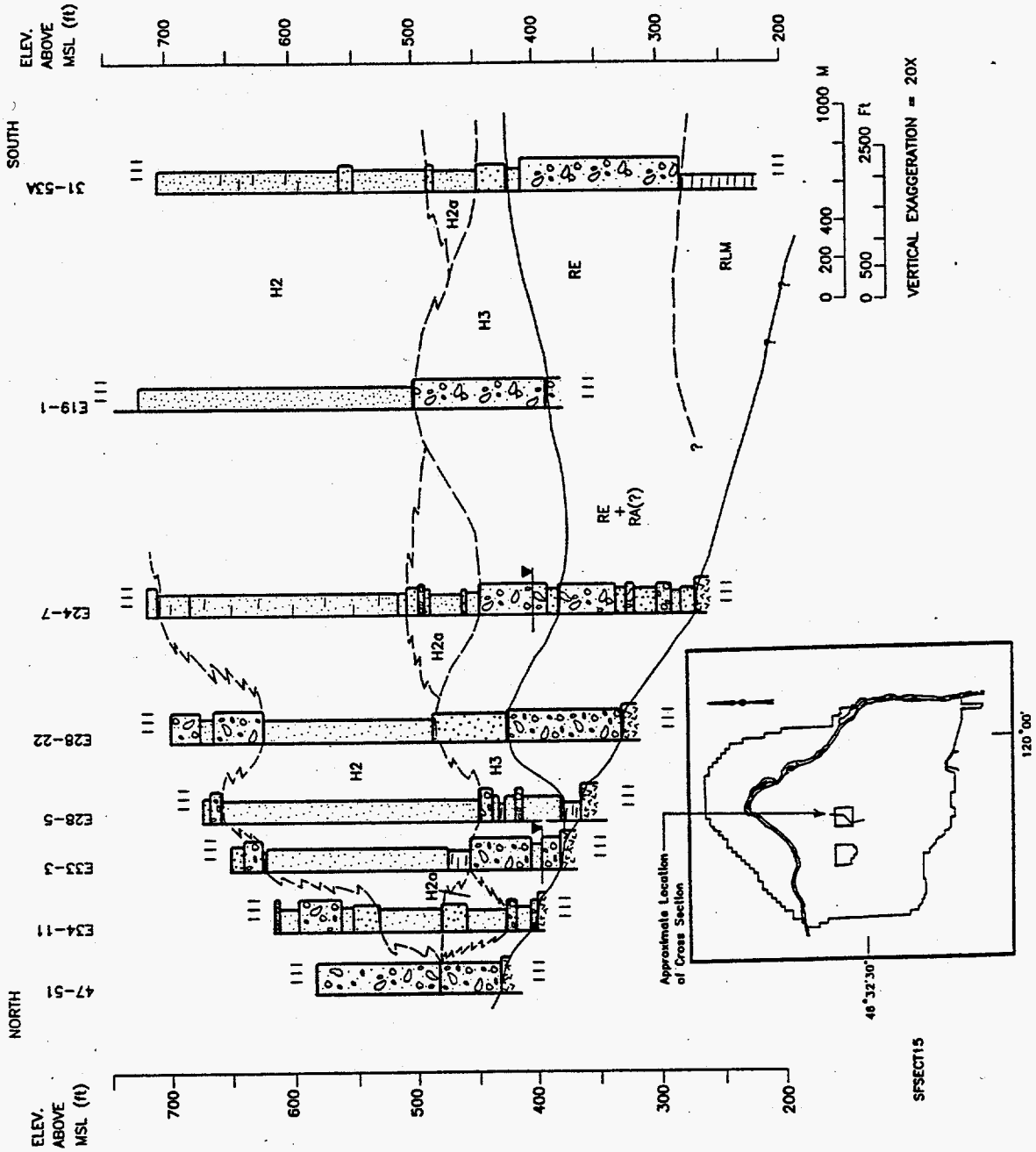
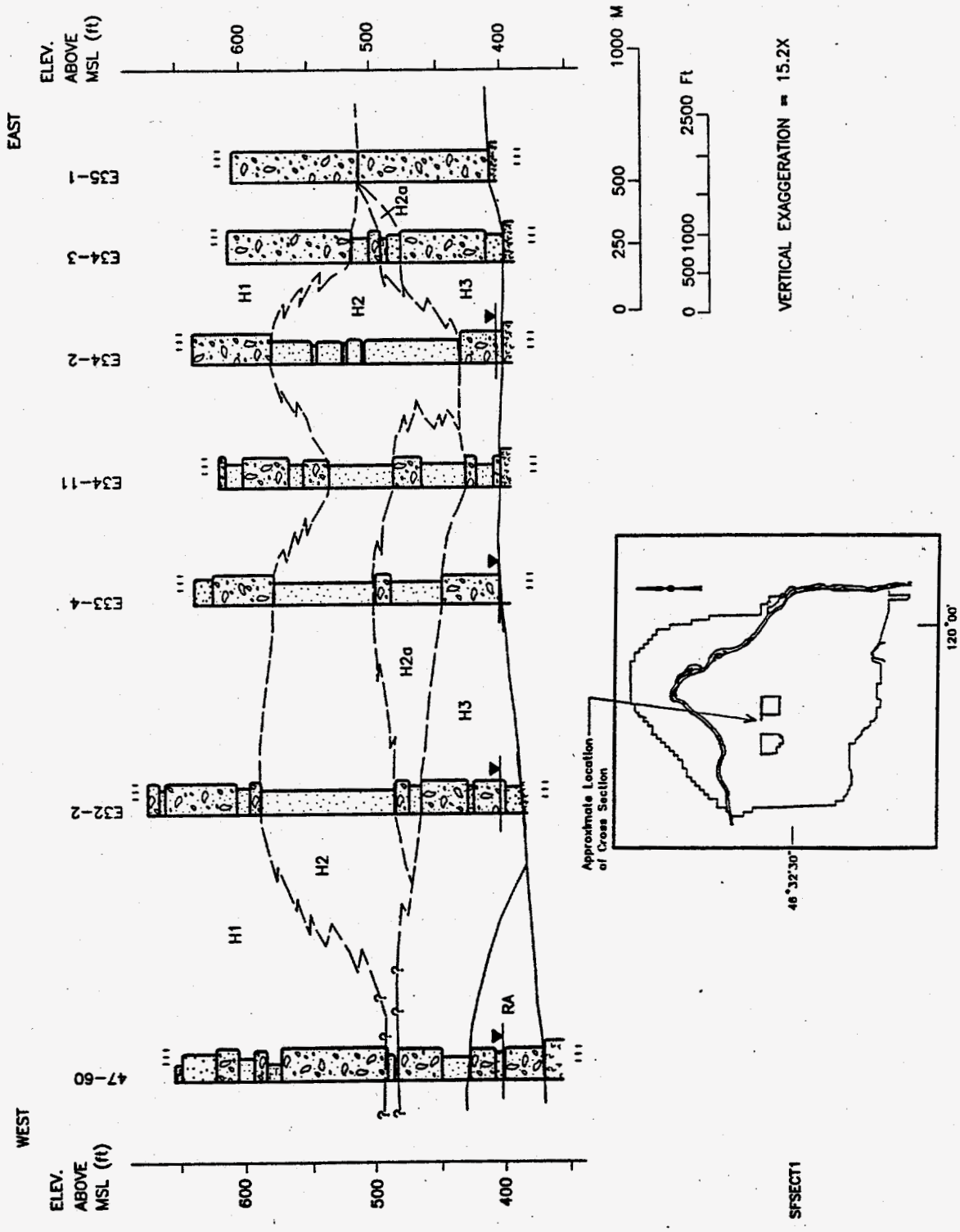


Figure 35. East/West-Oriented Cross Section through the 200 East Area.



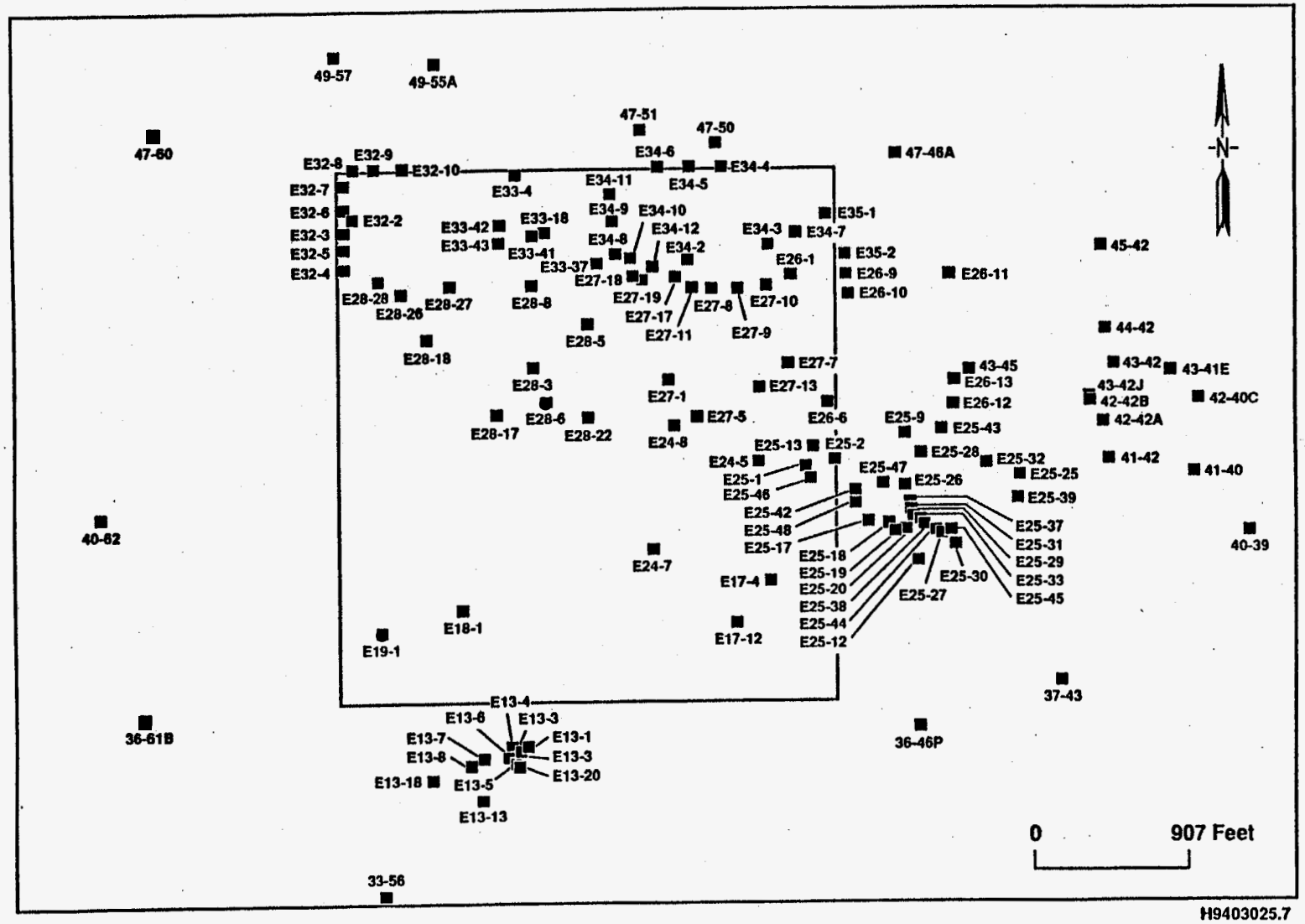


Figure 36. Index Map to Boreholes Used for Geologic Interpretations in this Report in the 200 East Area.

The line along which the lower mud unit pinches out tends to be very irregular (see Figure 12). At some locations the unit pinches out against uplifted basalt while at other locations the unit is truncated by overlying deposits (Lindsey et al. 1992; Connelly et al. 1992a). In the area between Gable Mountain and the 200 East Area and in the vicinity of the B Ponds, the lower mud unit is overlain by the Hanford formation (Lindsey et al. 1992). Throughout the rest of the area the lower mud unit is overlain by Ringold unit E.

Unit E is present beneath the southwest corner of 200 East Area, the Grout Treatment Facility site and surrounding vicinity, and throughout the area between the 200 East and 200 West Areas (see Figure 13). Ringold gravels encountered beneath the central part of the 200 East Area are part of unit A and not unit E.

The remaining two Ringold units in the vicinity of the 200 East Area, unit C and the member of Taylor Flat, are only encountered in borehole 699-37-43, located southeast of the 200 East Area. These two Ringold units pinch out immediately north and west of the borehole. South of the borehole these units thicken into the Cold Creek syncline (Lindsey 1991).

5.3 HANFORD FORMATION

The distribution of Hanford formation facies across the 200 East Area indicates the Hanford formation can be divided into four main units (see Figures 34 and 35). However, because of the variability of Hanford deposits, definition of these sequences is arbitrary and the contacts between them can be difficult to identify. Two of the units, 1 and 2, are laterally continuous with and correlated to units 1 and 2 of the Hanford formation in the 200 West Area. The rest of the Hanford formation in the 200 East Area consists of laterally discontinuous, interbedded sands and gravels in the lower part of unit 2, referred to as unit 2a, and a basal gravel sequence referred to as unit 3. As stated in the discussion of the 200 West Area geology, it is not clear if unit 3 in the two areas are correlative, although they do occupy similar stratigraphic positions at the base of the Hanford formation. The Hanford formation in the 200 East Area has an irregular base (Figure 37) and overlies several different Ringold units as well as basalt (see Figures 34 and 35).

5.3.1 Unit 3

Unit 3 is defined by deposits typical of the gravel-dominated facies lying at the base of the Hanford formation. Local intercalated intervals of the sand-dominated facies are also present. Unit 3 ranges from 0 to 41 m (0 to 135 ft) thick and it is present throughout most of the 200 East Area (Figure 38). However, it is absent in the area separating the 200 East Area from the 200 West Area and in the east-central part of the 200 East Area.

Figure 37. Surface Map, Base of Hanford Formation, 200 East Area.

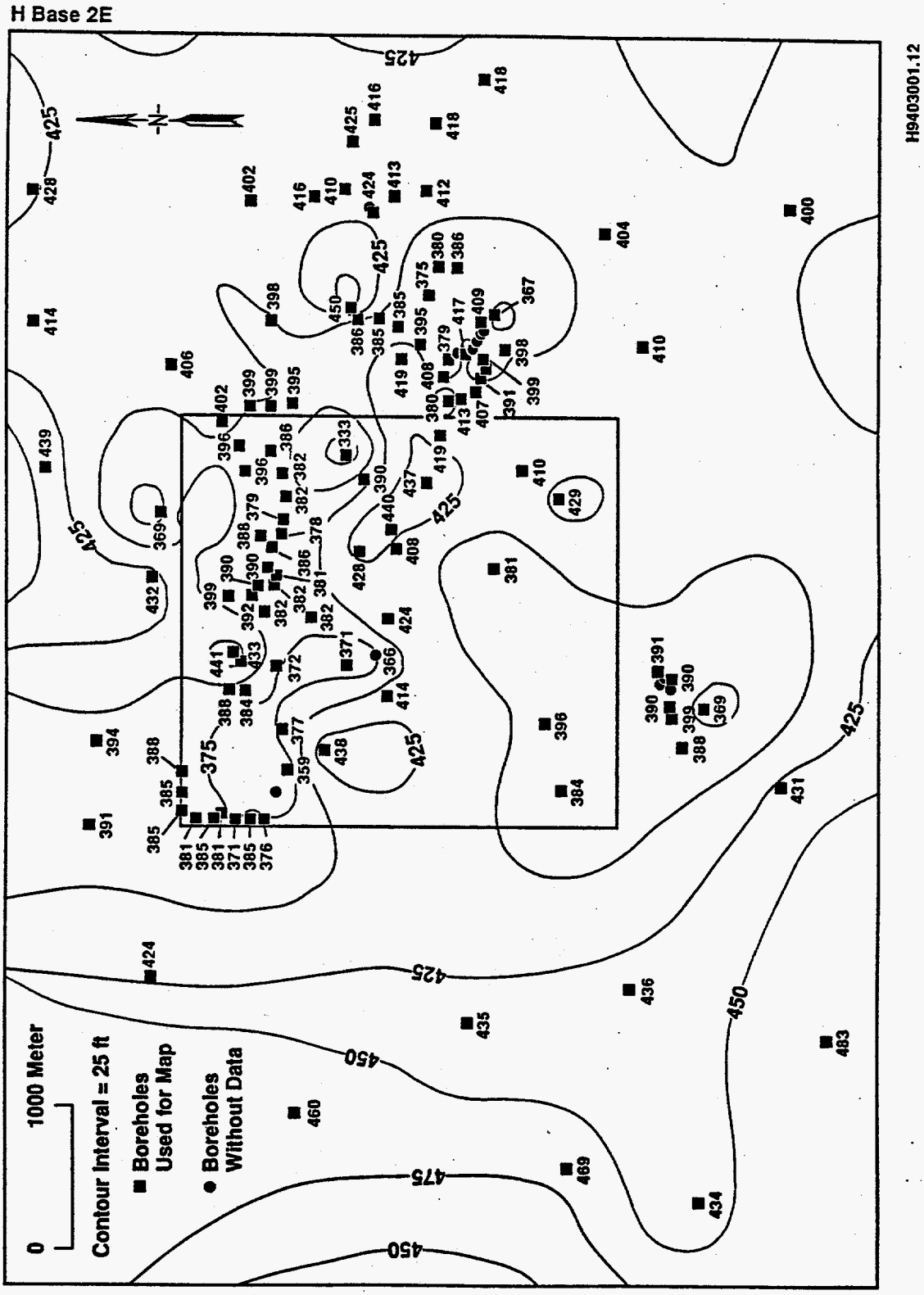
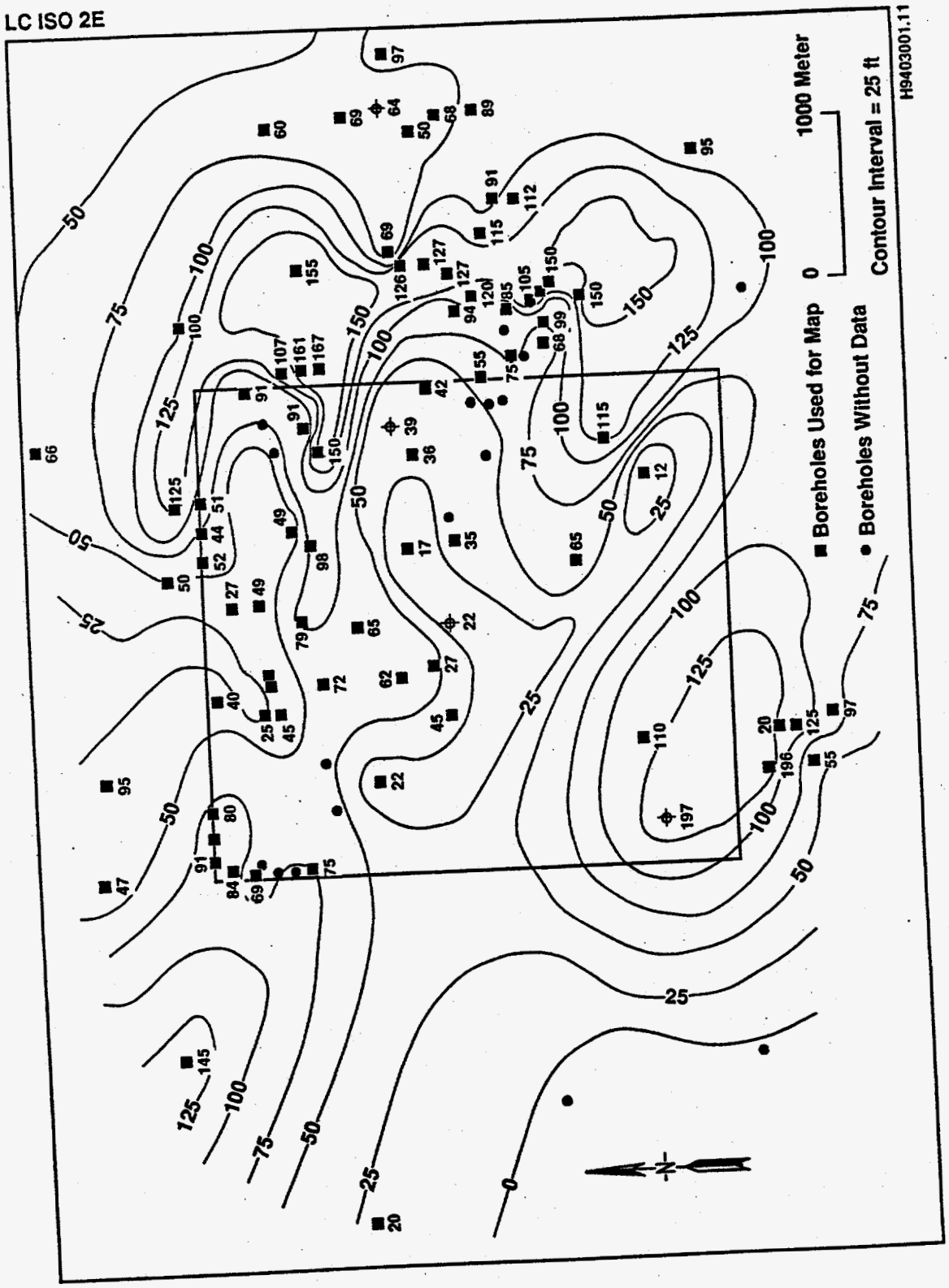


Figure 38. Isopach Map of Hanford Formation, Unit 3, 200 East Area.



Throughout all but the northernmost part of the 200 East Area unit 3 is overlain by sand of unit 2. This changes along the northern perimeter of the 200 East Area where unit 2 begins to pinch out. Here, and to the north, the gravels of unit 3 are overlain by, and possibly interfinger with, gravels of unit 1. Where this occurs the position of the contact between units 1 and 3 is speculative. For this reason Hanford formation deposits north of the 200 East Area also may be undifferentiated (Lindsey et al. 1992).

5.3.2 Unit 2

Unit 2 ranges from 0 to 85 m (0 to 280 ft) thick (Figure 39) and is dominated by the sand-dominated facies in the north. To the south intercalated strata typical of the silt-dominated facies become more common. Gravel content increases toward the north, and thin intervals typical of the gravel facies may be present. Unit 2 probably contains many clastic dikes. The unit is differentiated from the gravelly strata of units 1 and 3 on the basis of the relative abundance of sand-dominated versus gravel-dominated facies. The base of unit 2 is placed at the top of the highest gravelly interval (>7 m [>20 ft] thick) that underlies sand-dominated strata. Beneath much of the 200 East Area the lower part of unit 2 contains gravelly horizons less than 7 m (20 ft) thick. Where these occur the lower part of unit 2 appears to coarsen downward into unit 3. This coarsening downward interval is referred to as unit 2a. The top of unit 2 (Figure 40) is placed at the top of the highest thick (>7 m [>20 ft]) sand-dominated interval.

5.3.3 Unit 1

Unit 1 consists predominately of deposits typical of the gravel-dominated facies. The sand-dominated facies is encountered locally. Unit 1 thins from as much as 55 m (182 ft) thick in the north to zero in the south (Figure 41). Where unit 1 is thickest in the north it forms an elongate northwest- to southeast-oriented body. Units 1 and 3 are not differentiated in those areas where the intervening sands of unit 2 are absent (e.g., in the northern part of the study area). The area where unit 2 is absent is shown in Figures 33 and 34. Unit 1 is laterally contiguous with unit 1 strata described in the 200 West Area (Lindsey et al. 1991).

5.4 HOLOCENE SURFICIAL DEPOSITS

In the study area Holocene-aged deposits are dominated by eolian sheet sands. These deposits tend to consist of thin (<3 m [9.8 ft]) sheets of very fine- to medium-grained sand to occasionally silty sand. The eolian deposits have been removed from much of the area by construction activities. Southwest- to northeast-trending longitudinal dunes are well developed in the southern part of the study area. Holocene surficial deposits are not delineated on cross sections and maps because they are relatively thin and because of the lack of data on so many of the borehole geologic logs available for the 200 East Area upon which to base any identification.

Figure 39. Isopach Map of Hanford Formation, Unit 2, 200 East Area.

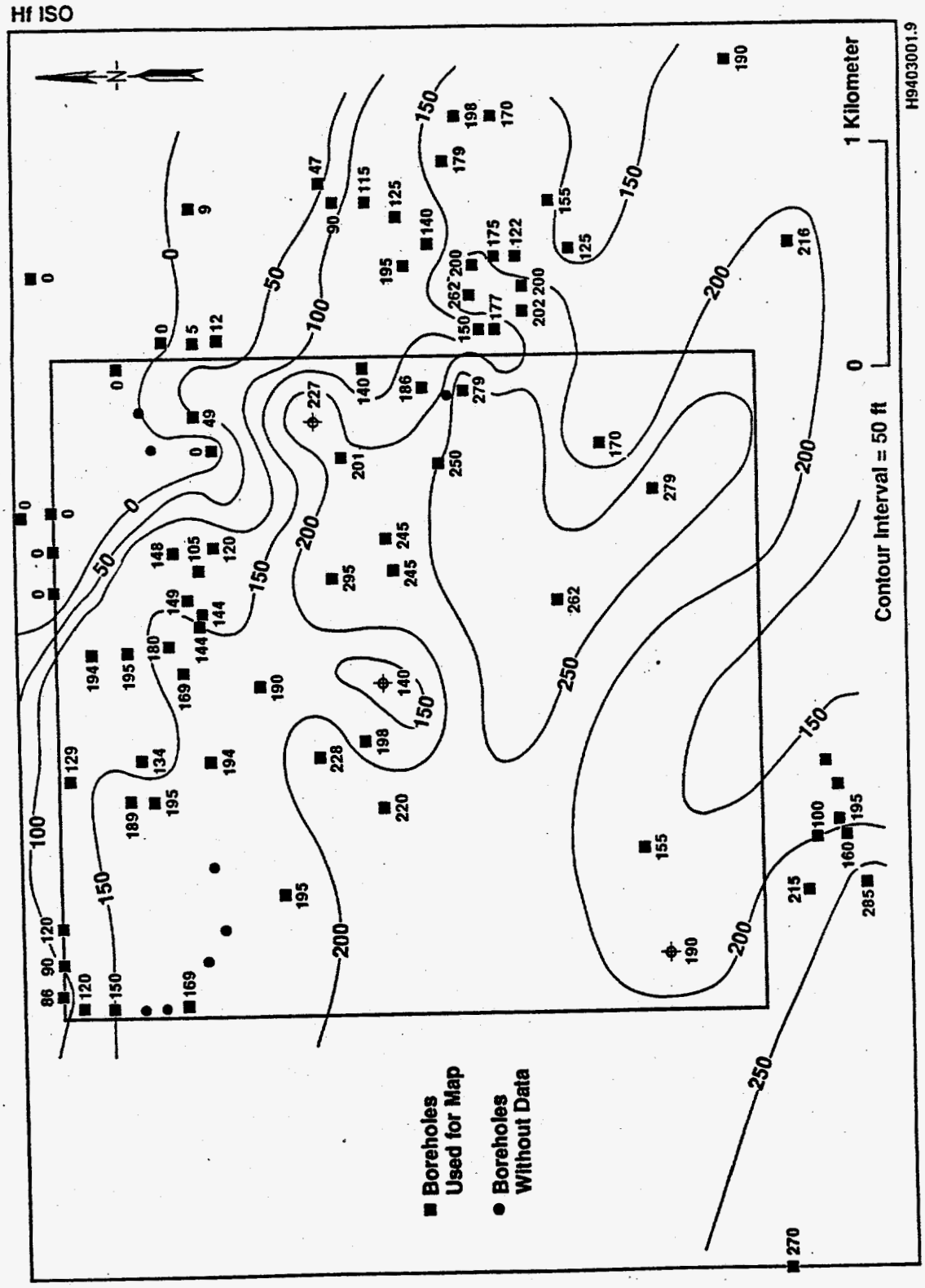


Figure 40. Surface Map, Top of Hanford Formation, Unit 2, 200 East Area.

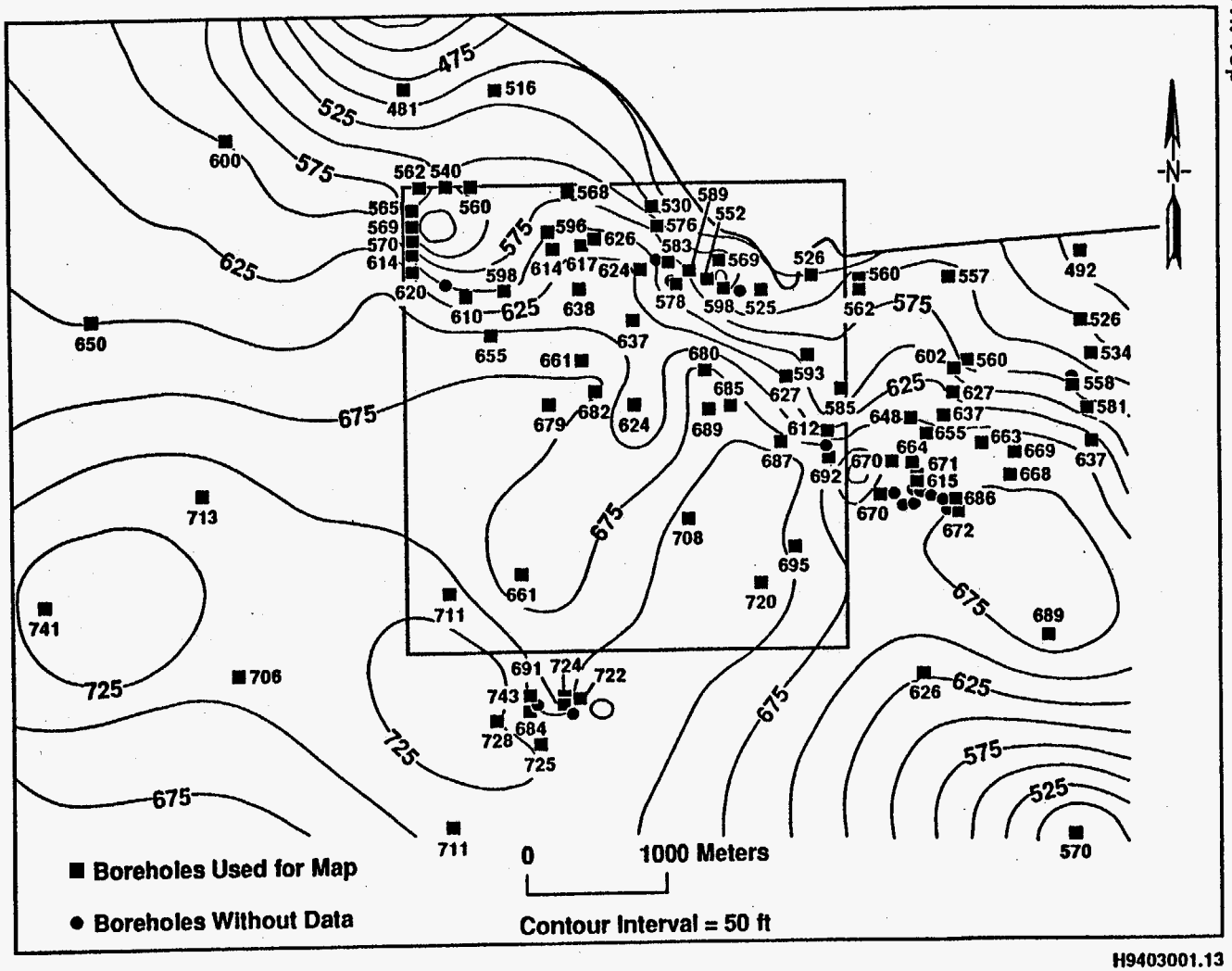
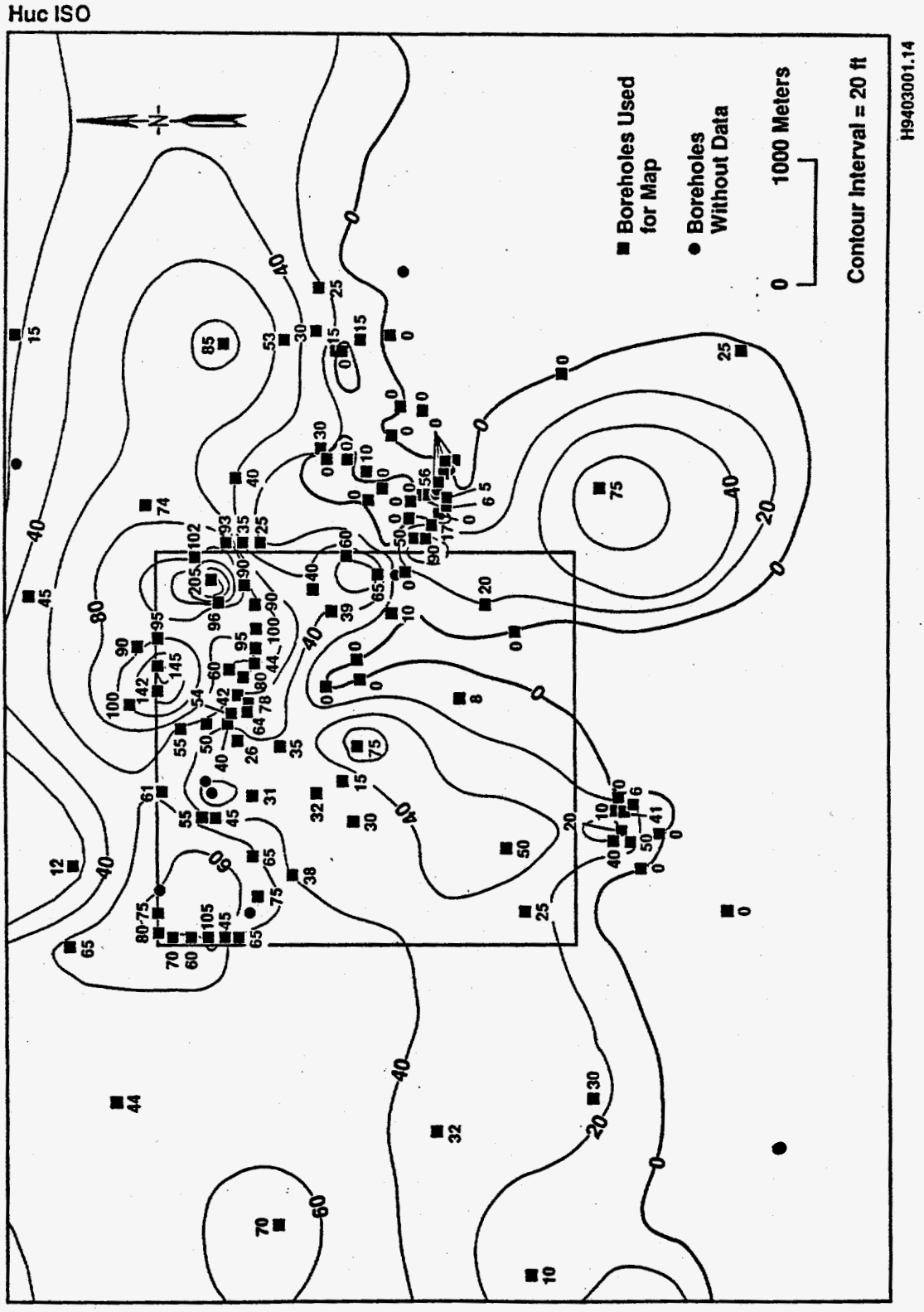


Figure 41. Isopach Map, Hanford Formation, Unit 1, 200 East Area.



5.5 HYDROLOGY

In the northern half of the 200 East Area the water table is situated within gravel- to sand-dominated facies of the Hanford formation. To the south and east it more commonly can be found within gravels of Ringold units A and E and silts of the lower mud unit. Transmissivity and hydraulic conductivity data are summarized in Connelly et al. (1992a, Table 3-2).

The vadose zone beneath the 200 East Area burial grounds consists dominantly of Hanford formation sediments. Van Genuchten curve fitting parameters for these strata are listed in Connelly et al. (1992a, Table 3-1; 1992b, Table 3-1). While the parameters listed in the Connelly reports are generally applicable to strata beneath the 200 East Area it cannot be stressed enough that these data are from a limited number of locations and probably are not representative of the true range of geologic conditions.

Generalizations discussed in the 200 West Area LLBG section concerning the potential influence of clastic dikes on vadose transport models also apply in the 200 East Area.

5.6 200 EAST AREA LOW-LEVEL BURIAL GROUNDS

5.6.1 218-E-12B Burial Ground

Suprabasalt sediments beneath this burial ground (Figure 42) consist entirely of the Hanford formation (Figures 43, 44, and 45). From the surface down, the Hanford units are: (1) gravel of unit 1, (2) sand of unit 2, and (3) gravel of unit 3. The interstratified sand and gravel found at the base of unit 2, referred to as unit 2a, are locally well developed beneath the eastern to central part of the site. Although each of these units are defined on the basis of a dominate lithology, significant subordinate lithologies are intercalated in each unit.

Unit 1 is variable in thickness and distribution. It ranges from 11 to 37 m (35 to 120 ft) thick, is dominated by the gravel facies, and contains significant interstratified horizons dominated by the sand facies. The unit is thinnest in the southwestern part of the site and thickens to the north and east. Outcrop observations show that silt-rich interbeds are present and are normally a few to tens of centimeters thick. Silty horizons as much as 1 m (3 ft) thick and continuous up to distances of at least several hundred meters also are present in the unit. These horizons are capable of generating perched water conditions. The contact between unit 1 and underlying strata generally is very irregular. These irregularities are the result of the interfingering nature of these deposits, which results in the absence of a distinct bounding surface.

The sands of unit 2 are thickest (up to 55 m [180 ft]) in the southwestern part of the site while pinching out toward the east and north (see Figure 39). Silty beds and horizons in this unit have the potential to form perched water zones although the lateral continuity of these zones is questionable because of the presence of clastic dikes and pinchouts found in

Figure 42. Location Map for the 218-E-12B Burial Ground (Low-Level Waste Mangagement Area 2) Showing Locations of Cross Sections.

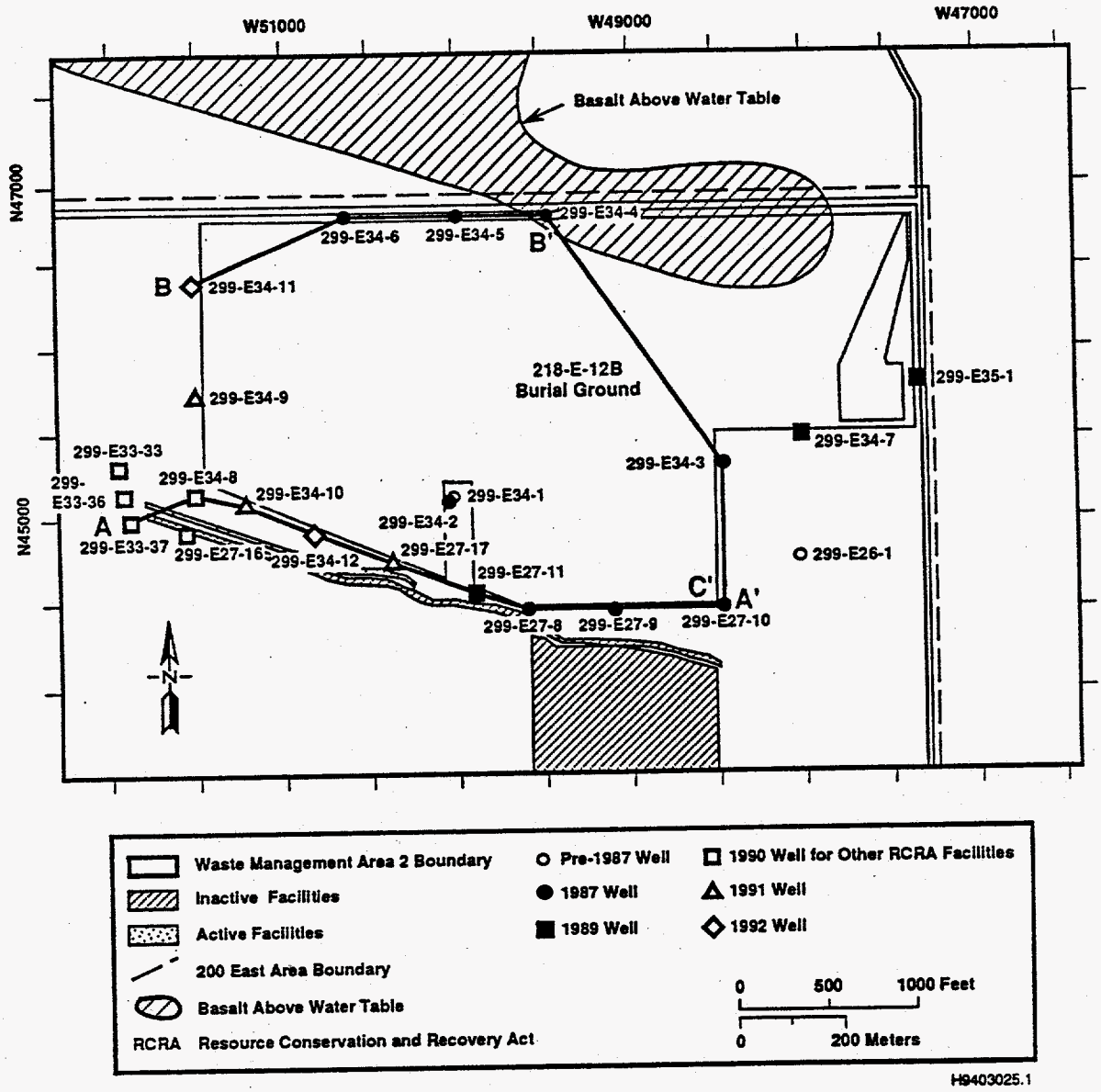


Figure 43. Cross Section A-A' through the 218-E-12B Burial Ground.

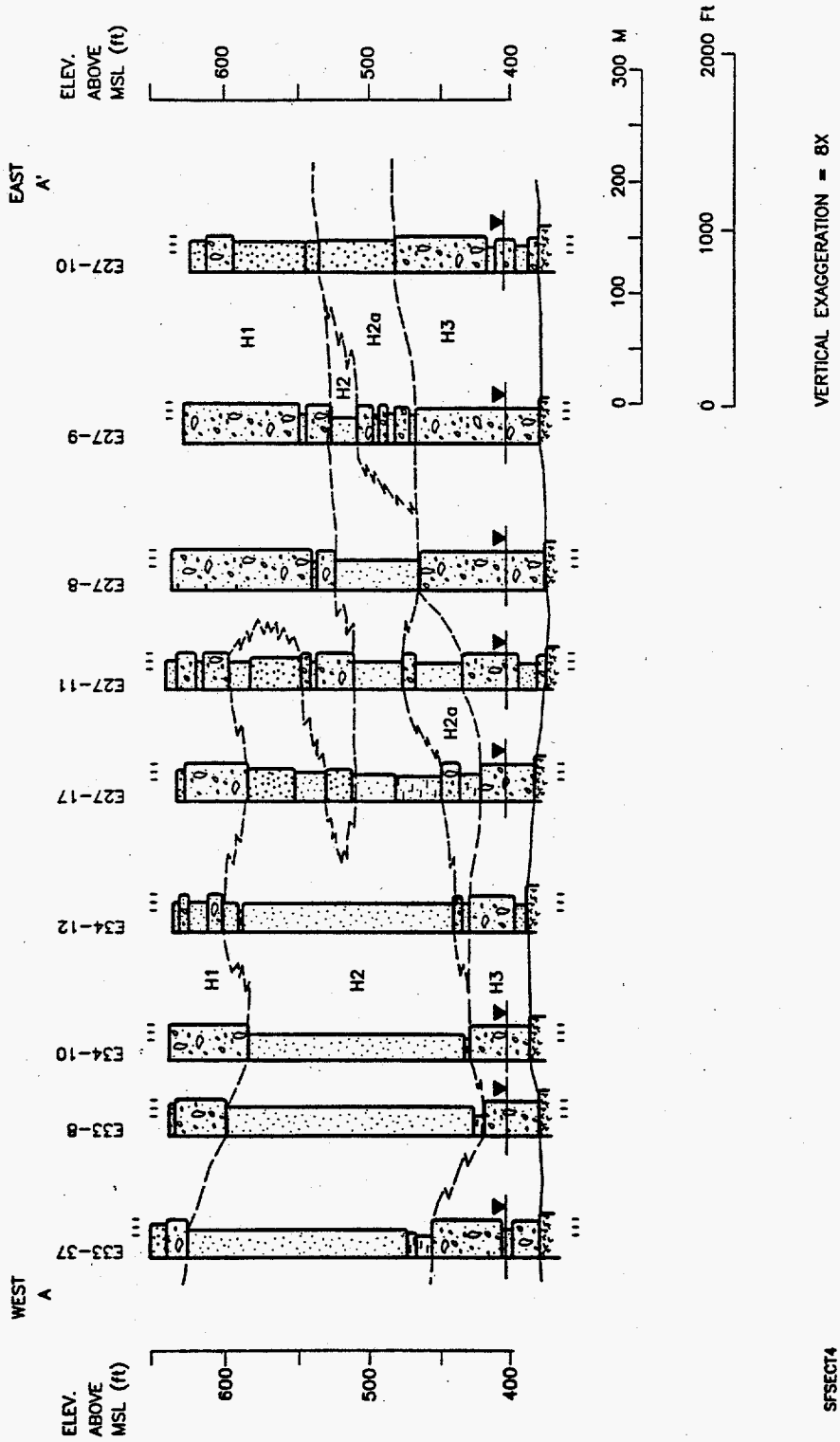


Figure 44. Cross Section B-B' through the 218-E-12B Burial Ground.

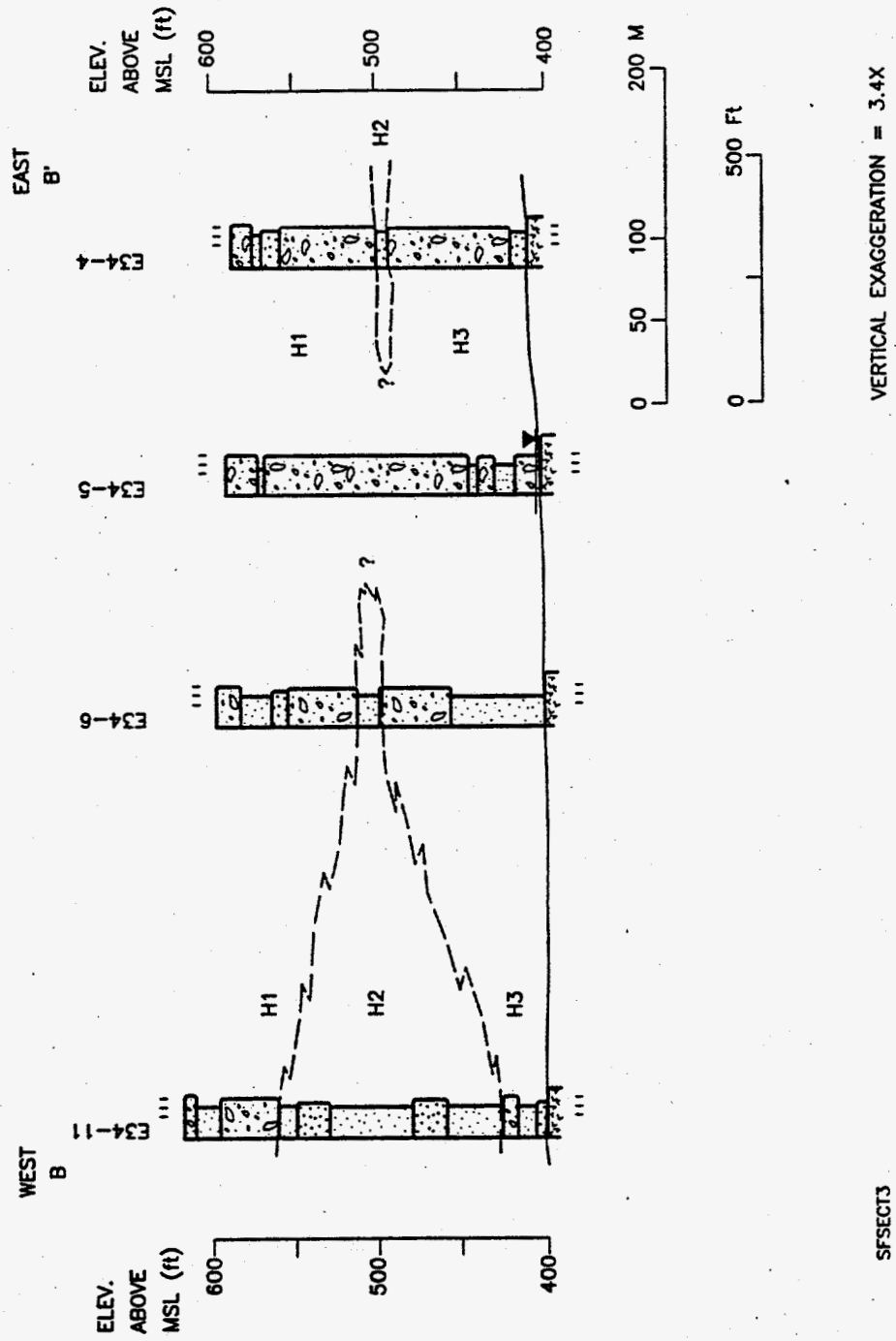
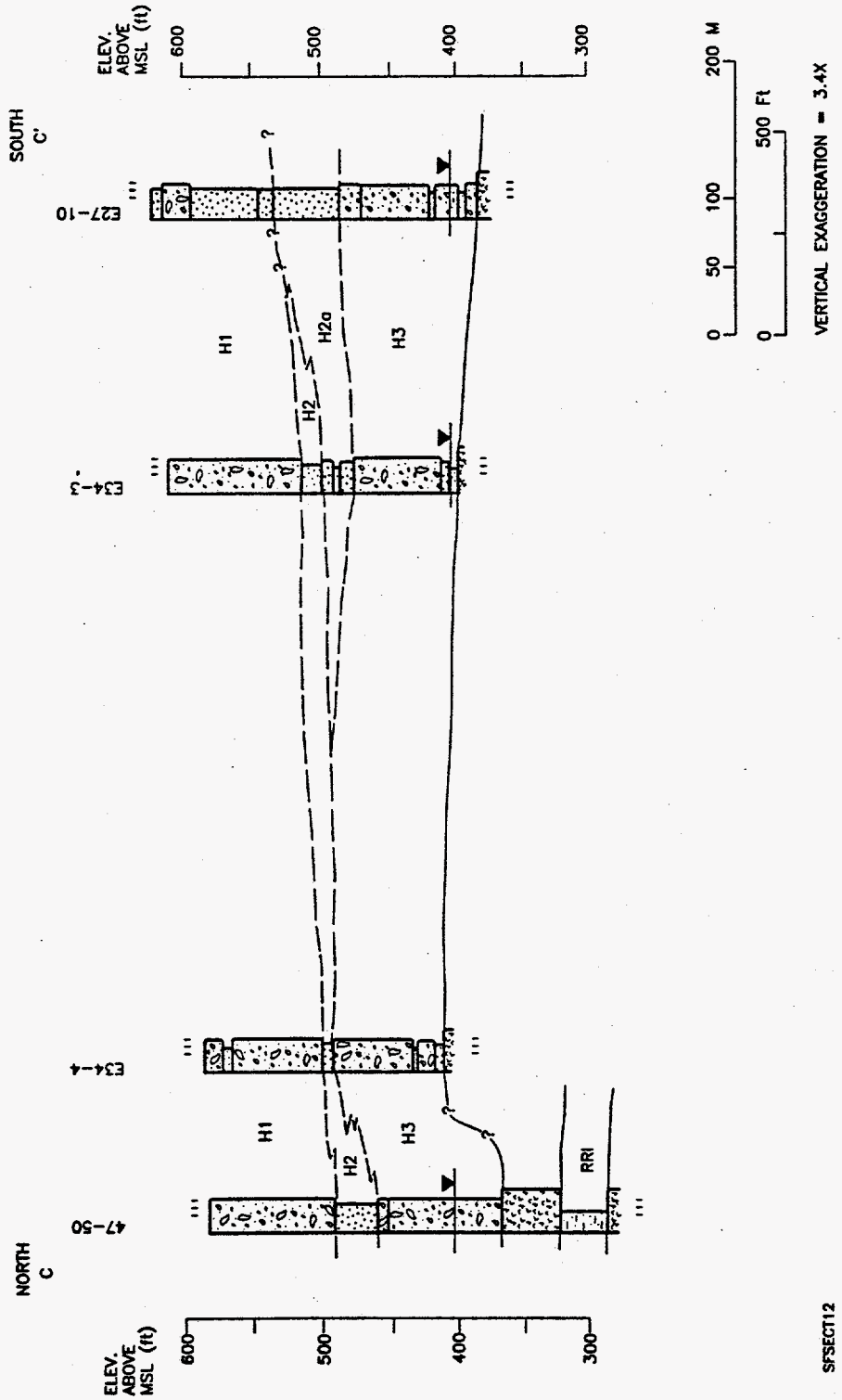


Figure 45. Cross Section C-C' through the 218-E-12B Burial Ground.



outcrops of analogous strata. Interbedded sand and gravel of unit 2a is locally well developed, especially to the east where unit 2 pinches out and interfingers with gravelly units (units 1 and 3). Unit 2a represents a transition zone between units 2 and 3.

Unit 3, defined by the abundance of the gravel facies, thickens to the north and northeast, from 12 to 46 m (40 to 150 ft) thick (see Figure 38). Like unit 1, interbeds of the sand and silt facies are present throughout unit 3. Also like unit 1, these silts have the potential to generate perched water conditions.

The top of the basalt gently dips to the south beneath the site. This surface is gently undulating and enclosed depressions 3 to 4.5 m (10 to 15 ft) deep may be present on it. A much deeper depression, approximately 12 m (40 ft), is inferred to exist just to the north of the site in the vicinity of borehole 47-50 (Graham et al. 1984).

5.6.2 218-E-10 Burial Ground

The same sequence of units that underlies the 218-E-12B burial ground underlie the 218-E-10 burial ground (Figures 46, 47, and 48). Hanford formation units 1, 2, 2a, and 3 are all present. Ringold Formation deposits are not present beneath the site although boreholes adjacent to the BX-BY Tank Farms encountered a thin sequence of Ringold-like deposits suggestive of the lower mud unit and unit A.

Unit 1 ranges from 12 to 33.5 m (40 to 110 ft) thick beneath the burial ground (see Figure 41). While it is dominated by the gravel facies, numerous interbeds of the sand facies also are present. The unit is thickest to the northwest and thins to the east and south. However, even though it is thickest to the northwest it also contains more interbedded sands in that direction.

The sands of unit 2 range from 27 to 40 m (90 to 130 ft) thick, generally thickening to the south and west (see Figure 39). Several gravel intervals 3 to 5 m (10 to 15 ft) thick occur locally in the middle part of the unit in the northeastern part of the area. In addition, significant gravelly intervals exist in the lower part of the unit and are referred to as unit 2a. Unit 2a is up to 15 m (50 ft) thick.

As much as 34 m (110 ft) of gravelly strata assigned to unit 3 occur beneath the site (see Figure 38). Most of the boreholes drilled at this burial grounds did not reach the top of the basalt. Consequently, thickness estimates for this unit are difficult to make. As is the case throughout the 200 East Area, minor interbedded sequences dominated by the sand facies occur in these gravels.

Data from the boreholes that reach the top of basalt beneath the burial ground indicate the strata dip to the west and south beneath the site. This is consistent with regional data.

Figure 46. Location Map for the 218-E-10 Burial Ground (Low-Level Waste Management Area 1) Showing Locations of Cross Sections.

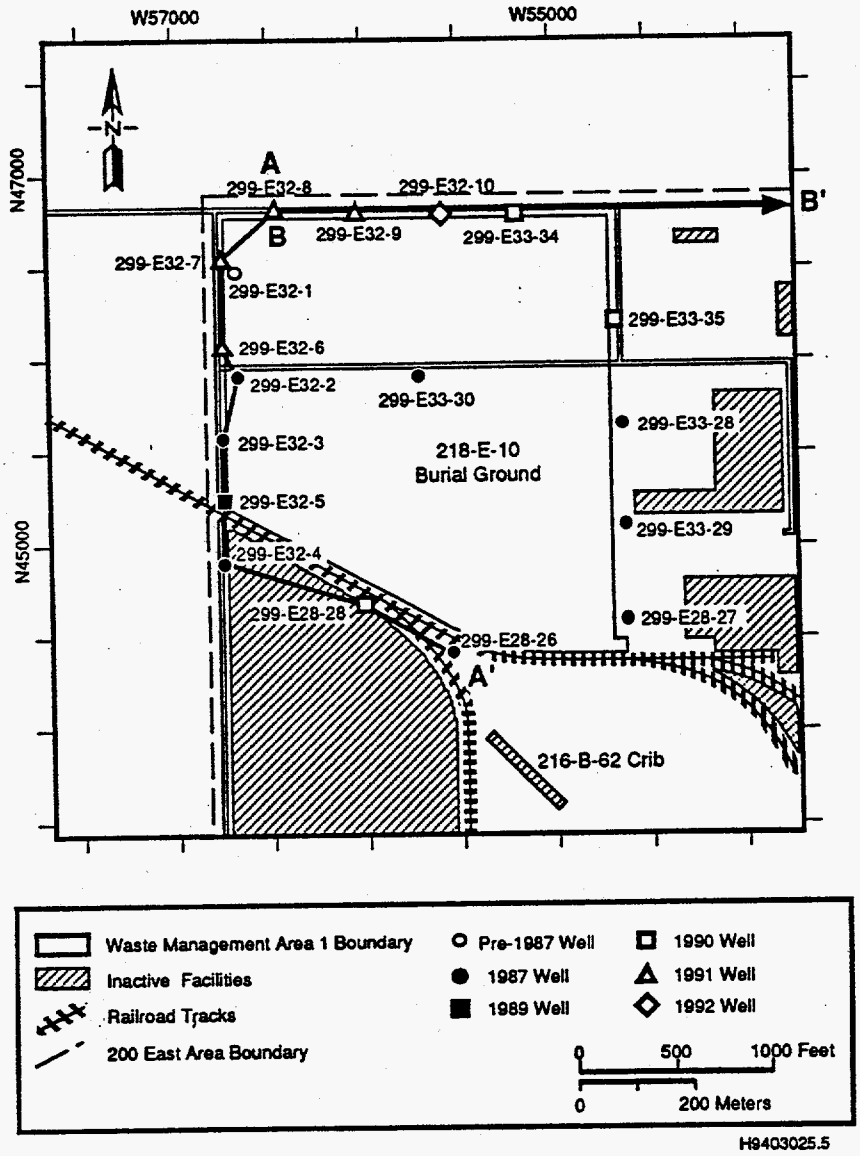


Figure 47. Cross Section A-A' through the 218-E-10 Burial Ground.

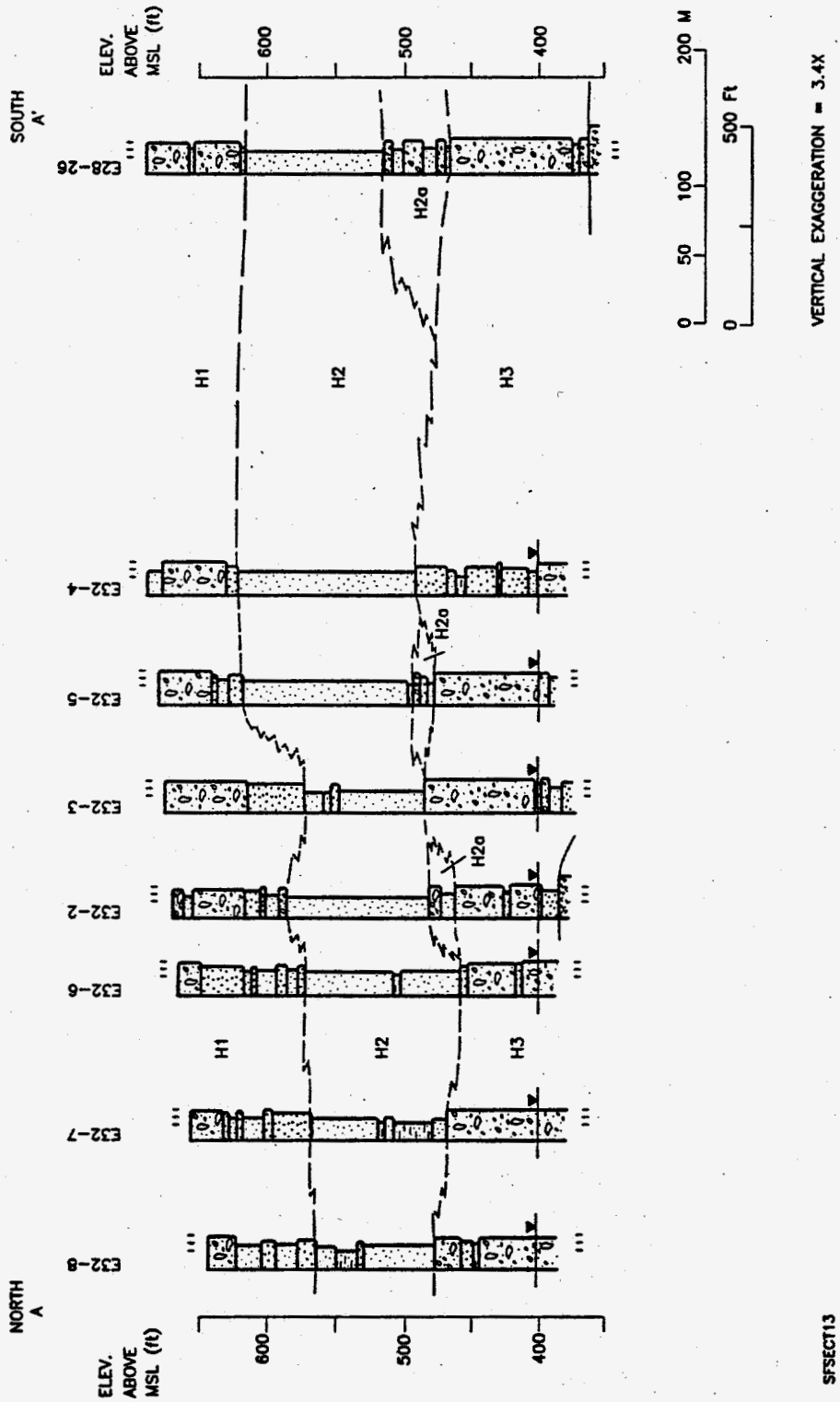
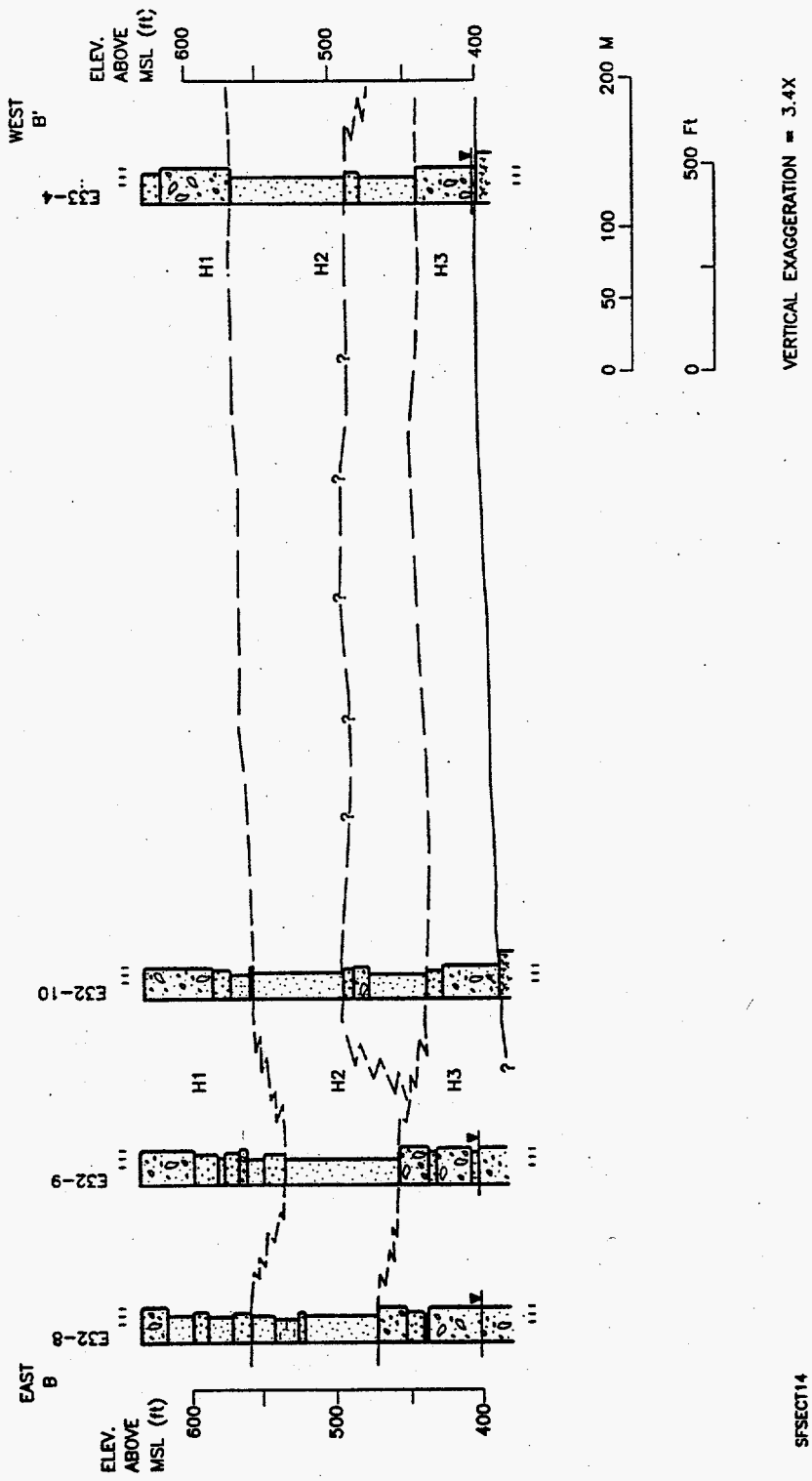


Figure 48. Cross Section B-B' through the 218-E-10 Burial Ground.



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