DIA DVI-TI-293

0015559

Rockwell Hanford Operations

RHO-BWI-TI--293

TI90 005949

BWIP SUPPORTING DOCUMENT

End Function Activity: Site Department	Project No.: NA	CIN No.: N/A Date: N/A	Rev./Chg. No.: Rev. 0
			Page 1 Of 35
			Total Pages 152

Document Title: Preliminary Stratigraphic and Structural Model of the Reference Repository Location, Hanford Site

Baseline Doc.: Yes ☐ No ☒ Class: N/A

WBS No. or Work Package No.: L3C6 CEI No.: 003

Borehole No.:	Stratigraphic Formations:	Doc. Type	Subj. Code
NA	Columbia River Basalt Group	2070	E902

Prepared by (type & sign name): R. D. Landon, B. N. Bjornstad — See reverse side for additional approvals — Date: 1/86

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Abstract

A preliminary stratigraphic and structural model has been developed for the Reference Repository Location (RRL), Hanford Site, Washington State. The model is based on integration of outcrop, borehole, and geophysical data. It is a three-dimensional representation of the RRL subsurface. The model provides a stratigraphic and structural framework for use in geologic and hydrologic studies of the RRL. This model can serve as a predictive tool for future borehole locations within the RRL. The model is in a flexible computer format, which will allow for efficient updating of the model as new data become available, and for display of contour maps, block diagrams, and cross sections.

35 Text Pages

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PRELIMINARY STRATIGRAPHIC AND STRUCTURAL MODEL OF THE REFERENCE REPOSITORY LOCATION, HANFORD SITE, WASHINGTON

INTRODUCTION

A preliminary stratigraphic and structural model has been developed for the Reference Repository Location (RRL), Hanford Site, Washington State (Figure 1). The model is based on integration of outcrop, borehole, and geophysical data. It is a three dimensional representation of the RRL subsurface. The model provides a stratigraphic and structural framework for use in geologic and hydrologic studies of the RRL. This model can serve as a predictive tool for future borehole locations within the RRL. The model is in a flexible computer format, which will allow for efficient updating of the model as new data become available, and for display of contour maps, block diagrams, and cross sections.

The model is an integrated geologic representation, which combines the stratigraphy and structural setting of the RRL. It assumes that the buried top of basalt approximates the structure of underlying strata (Myers, 1981, p. 8-8 to 8-12, Myers, Price, and others, 1979, p. III-138 to III-141). The model was constructed by subtracting basalt or sediment unit thicknesses from the top of basalt (TOB) surface to generate structure contour maps. Structural surfaces of the suprabasalt sedimentary units were contoured directly from contact elevations. Cross sections and block diagrams were then constructed from the structure contour maps. This document presents the model as a series of structure contour maps, cross sections, and block diagrams for the RRL and immediate vicinity.

The modeled area is located within the Cold Creek syncline (Figure 1), a structural low, in the western Pasco Basin. The Cold Creek syncline is between the Yakima Ridge and the Umtanum Ridge-Gable Mountain structures. These structures have steeply dipping northern limbs and more gently dipping southern limbs. The model includes flows of the Grande Ronde, Wanapum, and Saddle Mountains Basalts, interbedded sediments of the Ellensburg Formation, and suprabasalt sediments. The suprabasalt sediments include the Ringold Formation, a unit referred to as the Plio-Pleistocene unit (Bjornstad, 1984), and the Hanford Formation (Figure 2).

MODEL SCOPE

The modeled area extends about 1500 ft beyond the lateral boundaries of the RRL (Figure 3). The upper and lower stratigraphic boundaries are ground surface and the base of the very-high Mg flow in the Grande Ronde Basalt (Figure 2). All modeled surfaces are listed on Table 1. Horizons below the very-high Mg flow are not modeled due to lack of data below that flow, within the RRL. The limited data available for the deep horizons suggests that they are more appropriately discussed in a broader, more

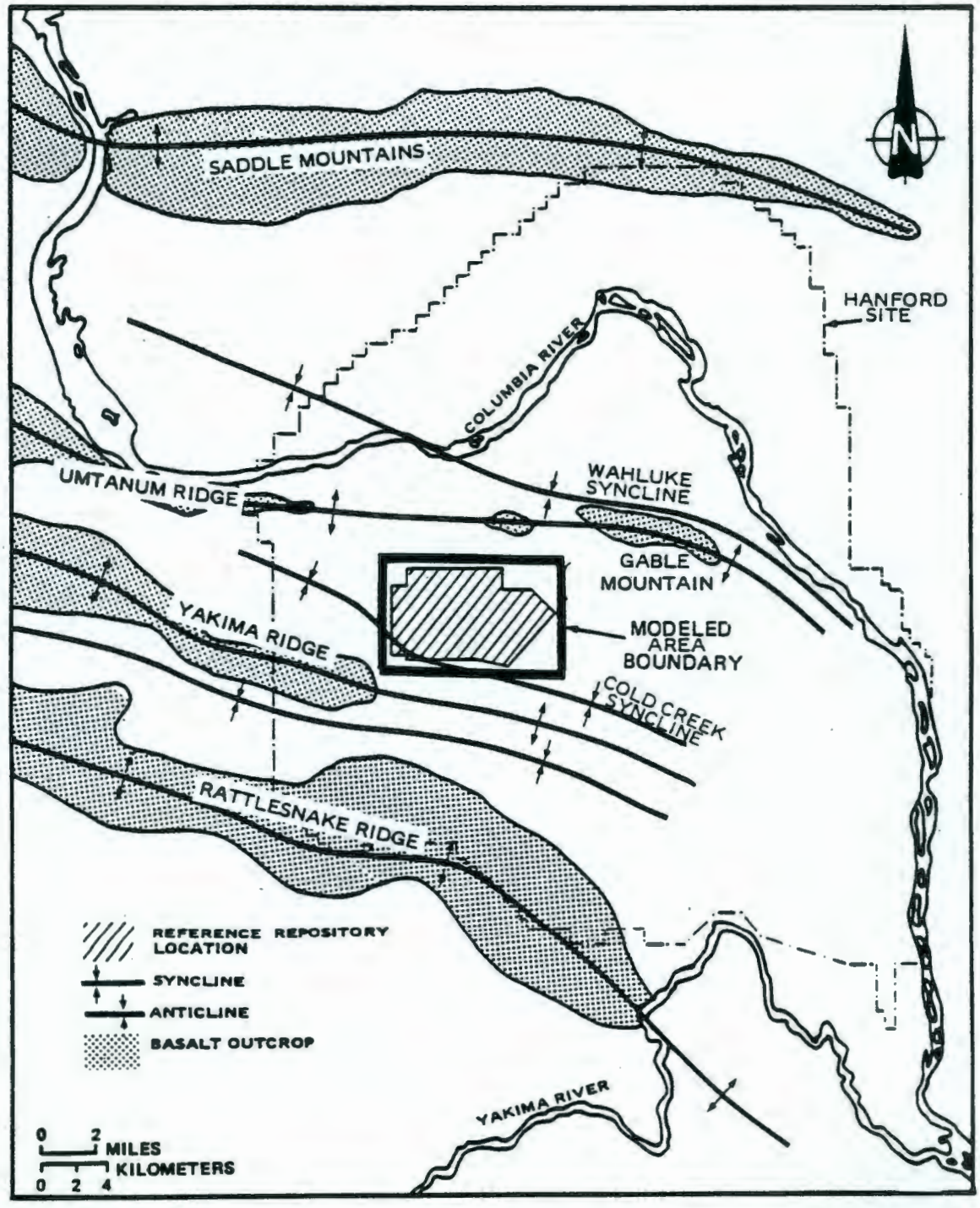

Figure 1. Location Map of the Modeled Area, Reference Repository Location, and the Hanford Site.

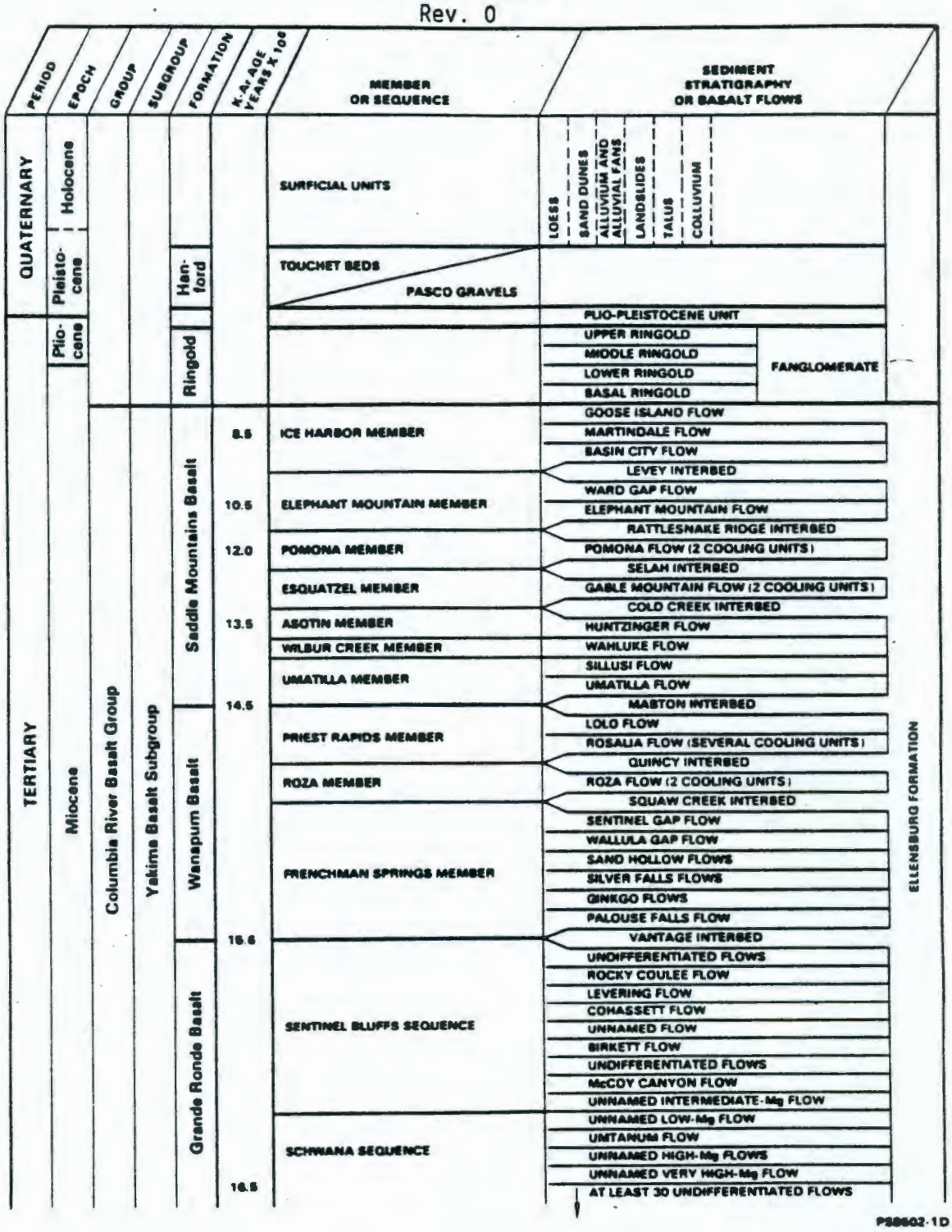

Figure 2. Stratigraphic Nomenclature for the Columbia River Basalt Group, Pasco Basin.

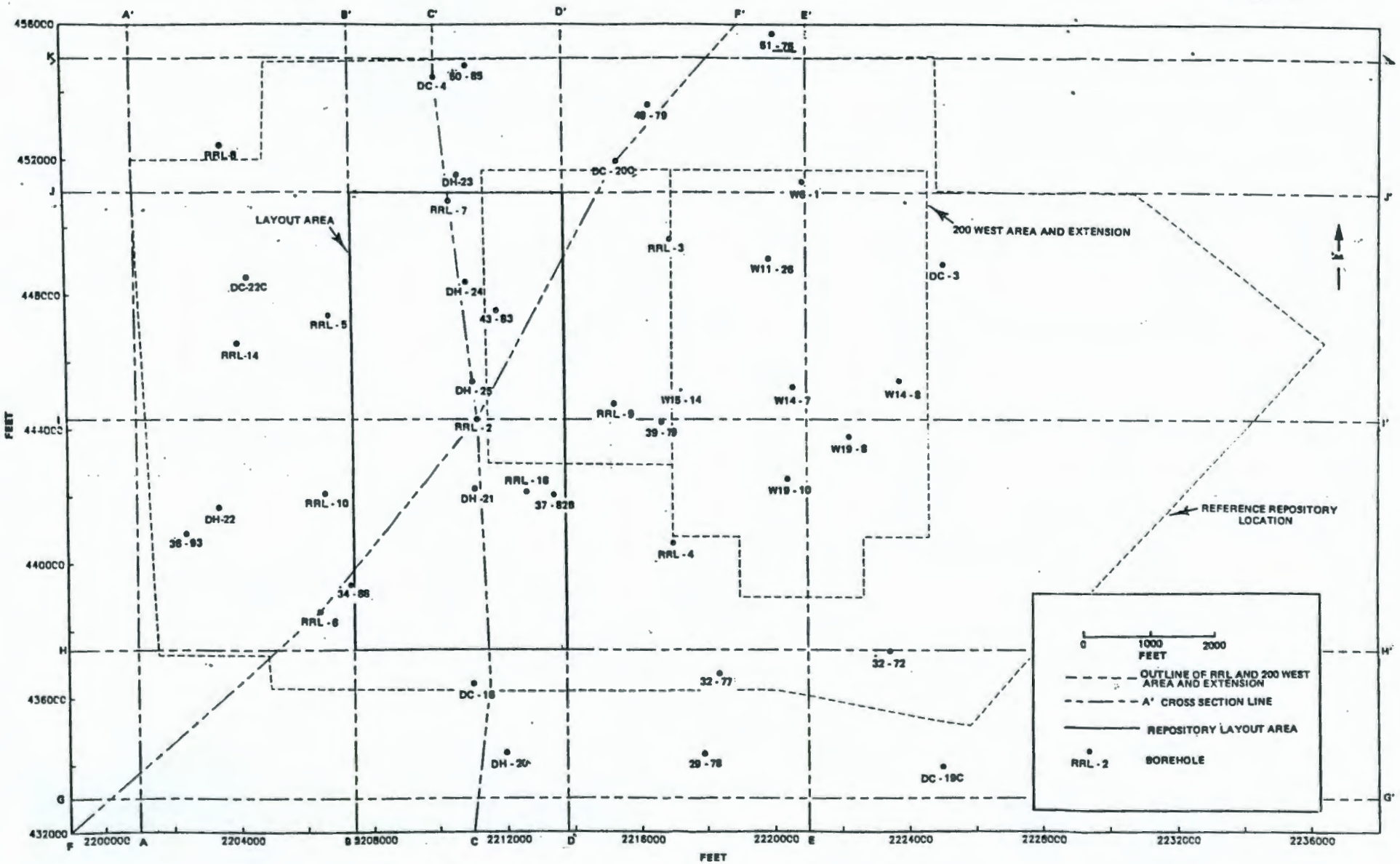

Figure 3. Location Map showing Boreholes, 200 West Area, RRL Outline, Repository Layout Area Boundary, and Cross Section Lines.

Table 1. Modeled Surfaces

TOP OF PLIO-PLEISTOCENE UNIT
TOP OF UPPER RINGOLD UNIT
TOP OF MIDDLE RINGOLD UNIT
TOP OF LOWER RINGOLD UNIT
TOP OF BASAL RINGOLD UNIT
TOP OF BASAL RINGOLD - GRAVEL SUBUNIT
TOP OF BASALT
TOP OF RATTLESNAKE RIDGE INTERBED
TOP OF POMONA MEMBER
TOP OF SELAH INTERBED
TOP OF ESQUATZEL MEMBER
TOP OF COLD CREEK INTERBED
TOP OF UMATILLA MEMBER
TOP OF MABTON INTERBED
TOP OF WANAPUM (LOLO FLOW)
TOP OF ROSALIA FLOW
TOP OF QUINCY INTERBED
TOP OF ROZA MEMBER
TOP OF SQUAW CREEK INTERBED
TOP OF SENTINEL GAP FLOW
TOP OF SAND HOLLOW FLOWS
TOP OF SILVER FALLS FLOWS
TOP OF GINKGO FLOWS
TOP OF UNNAMED INTERBED
TOP OF PALOUSE FALLS FLOW
TOP OF VANTAGE INTERBED
TOP OF GRANDE RONDE (GR-2 FLOW)
TOP OF GR-3 FLOW
TOP OF ROCKY COULEE FLOW (GR-4)
TOP OF GR-5 FLOW
TOP OF COHASSETT FLOW (GR-6)
TOP OF GR-8 FLOW
TOP OF GR-9 FLOW
TOP OF GR-10 FLOW
TOP OF GR-11 FLOW
TOP OF MCCOY CANYON FLOW (GR-13)
TOP OF UMTANUM FLOW (GR-15)
TOP OF VERY-HIGH Mg FLOW (GR-19)
TOP OF LOW Mg FLOWS

regional model. Intraflow structures, such as dense interiors, are not shown in the model. The Cohassett flow is the preferred candidate repository horizon.

DATA SOURCES

The TOB surface was constructed from outcrop, borehole, and geophysical data. The borehole data served as control points within the map area. Outcrop data from immediately outside of the model area, provided control of the TOB surface in the southwest corner. Geophysical data (Berkman, 1984, Plate 29) were used qualitatively to constrain the TOB surface between borehole control points.

Data for the ground surface contour map (Appendix A, Figure A-1) were obtained in digital format from the United States Geological Survey (USGS). The digital data were collected by digitizing the 1:250,000 scale Walla Walla quadrangle on approximately a 200 ft grid point spacing. The Basalt Waste Isolation Project (BWIP) converted the data into files with a 656 ft grid point spacing. The converted file was used in this report.

Borehole and surface data were used to construct the structural surfaces of the units within the suprabasalt sediments. These data are from Bjornstad (1984) and are listed in Appendix B (Table B-1). Several of Bjornstad's data points were updated and these are identified by underscore. The isopach maps (Appendix C) used to develop the subsurface structural surfaces were constructed from borehole data collected throughout the Pasco Basin. These data are from a variety of sources and are identified in Appendix B, Tables B-2 to B-4.

All values used in this model are in feet with no metric conversions given. Borehole locations are in the State Plane coordinate system. They are in feet east and north of the Washington State reference meridian and parallel respectively.

The flow numbering system for the Grande Ronde Basalt flows is based on outcrop and borehole correlations of individual flows from throughout the Pasco Basin. Nineteen separate flows have been identified by rock chemistry, paleomagnetic characteristics, stratigraphic position, and thickness using techniques described in Long and Landon (1981, p. 4-2 to 4-10). Because only six of these flows are continuous in the Pasco Basin, no one area contains all nineteen flows. For example, in the RRL the uppermost Grande Ronde flow is GR-2 not GR-1 and flows GR-7,12,14,16,17,and 18 are absent. Table 2 cross references the flow numbering system used in this report with that used in Landon (1985).

METHODS

The thicknesses of basalt flows and sedimentary units were subtracted from the TOB using a computer technique termed grid subtraction. The resulting set of structural surfaces were used to construct cross sections and block diagrams. The technique involves subtraction of calculated thicknesses of rock units at regularly spaced intervals from the overlying

TABLE 2. GRANDE RONDE BASALT FLOW
CROSS REFERENCE CHART

FLOW NUMBER IN GRANDE RONDE BASALT	1	2	3	4[a]	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
	<----------FLOW # IN BOREHOLE---------->																		
BOREHOLE																			
DDH-3	1	2		3	4	5		6	7	8	9	10	11		12			13	14
DC-15	1	2	3	4	5	6		7	8	9	10	11	12		13			14	15
DC-7/8	1	2	3	4	5	6		7		8	9		10		11	12		13	14
DC-12	1	2	3	4	5	6	7	8		9	10		11		12		13	14	
DC-6			1	2	3	4		5			6		7		8				9
DC-2		1	2	3	4	5		6		7	8		9		10				11
DC-3 *		1	2	3	4	5		6		7	8		9		10				11
DC-4 *		1	2	3		4		5	6		7		8		9				10
DH-4		1	2	3	4	5		6			7		8	9	10				
DH-5			1	2	3	4		5			6		7		8				
DC-14			1	2	3	4	5	6			7		8		9	10			11
RRL-2 *		1	2	3		4		5	6		7		8		9				10
RRL-6 *		1	2	3		4		5	6		7		8		9				10
RRL-14 *		1	2	3		4		5	6		7		8		9				10
DC-16 *		1	2	3	4	5		6	7		8		9		10				11
DC-19C *		1	2	3	4	5		6	7		8		9		10				11
DC-20C *		1	2	3		4		5	6		7		8		9				10
DC-22C *		1	2	3		4		5	6		7		8		9				10
MCGEE		1	2	3	4	5		6	7		8		9		10				
RSH-1		1	2	3		4		5		6	7		8		9		10		

Note : Flow numbers for new Grande Ronde flow numbering system are at the top of the chart, with flow numbers based on the borehole numbering system below.

* indicates boreholes that are within the modeled area.

[a] Flow 4 = Rocky Coulee flow
5 = Levering flow
6 = Cohassett flow
8 = Birkett flow
13 = McCoy Canyon flow
15 = Umtanum flow
19 = Very-high Mg flow

structural surface. The computer program used for the model is Interactive Surface Modeling (ISM; version 6.91e), marketed by Dynamic Graphics of Berkeley, California. This program utilizes gridding algorithims adapted from Briggs (1974). This technique provides a more consistent and reproducible representation of the elevations and thicknesses between contour lines than are achievable by conventional hand methods. The computerized model can make rapid updates as new data become available. ISM can produce maps, cross sections, and perspective block diagrams at any scale, from any view point.

To construct the model, the TOB map was digitized and a grid file was calculated. The computer generated TOB map (Figure 4) was reviewed to insure accurate representation of the original TOB map. Grid files for isopach maps (Figure 5) were then created by ISM, from available outcrop and borehole data within the Pasco Basin. These grids were contoured and the resulting maps were reviewed by staff geologists for representativeness of contour depiction. Following review, comments were incorporated into the ISM grid files.

Following the development of isopach grid files, gridded data for the study area were "lifted" out of the larger Pasco Basin-wide grid files. These "lifted" files were then regridded to match the areal extent and grid point spacing of the TOB grid file. Grids were subtracted, in stratigraphic order (top to bottom), from the TOB grid file to produce underlying surfaces. Resulting structure contour maps were then reviewed. Structural surfaces for suprabasalt sedimentary units were constructed by gridding the contact elevations (Appendix B, Table B-1) and contouring the resulting grid files.

Computer subtraction of grids from a structural surface is an extension of hand calculation techniques. Hand calculations subtract measured thicknesses from the overlying surface. The contour placement between known data points is adjusted using the nearest data points. Computer techniques, such as ISM, use not only the nearest data points but also others nearby, to determine a trend in the data. This trend is used to interpolate between point values. These values are then subtracted from the overlying surface. This produces a new surface with contour placement based on the calculated regional trend of the data. Figure 6 shows that ISM uses known thickness values to calculate thicknesses for each grid point. These thickness values are subtracted from the overlying surface to produce a new estimated surface.

A grid point spacing of 200 ft was chosen for this model to accurately reproduce the original hand contoured TOB map and to account for closely spaced boreholes. Within the model area there are 195 grid points in the horizontal west - east (X) direction and 121 grid points in the horizontal south - north (Y) direction.

MODEL LIMITATIONS

Data limitations: The sources, the amount, and spatial distribution of data limit the accuracy of this model. Borehole data are subject to several

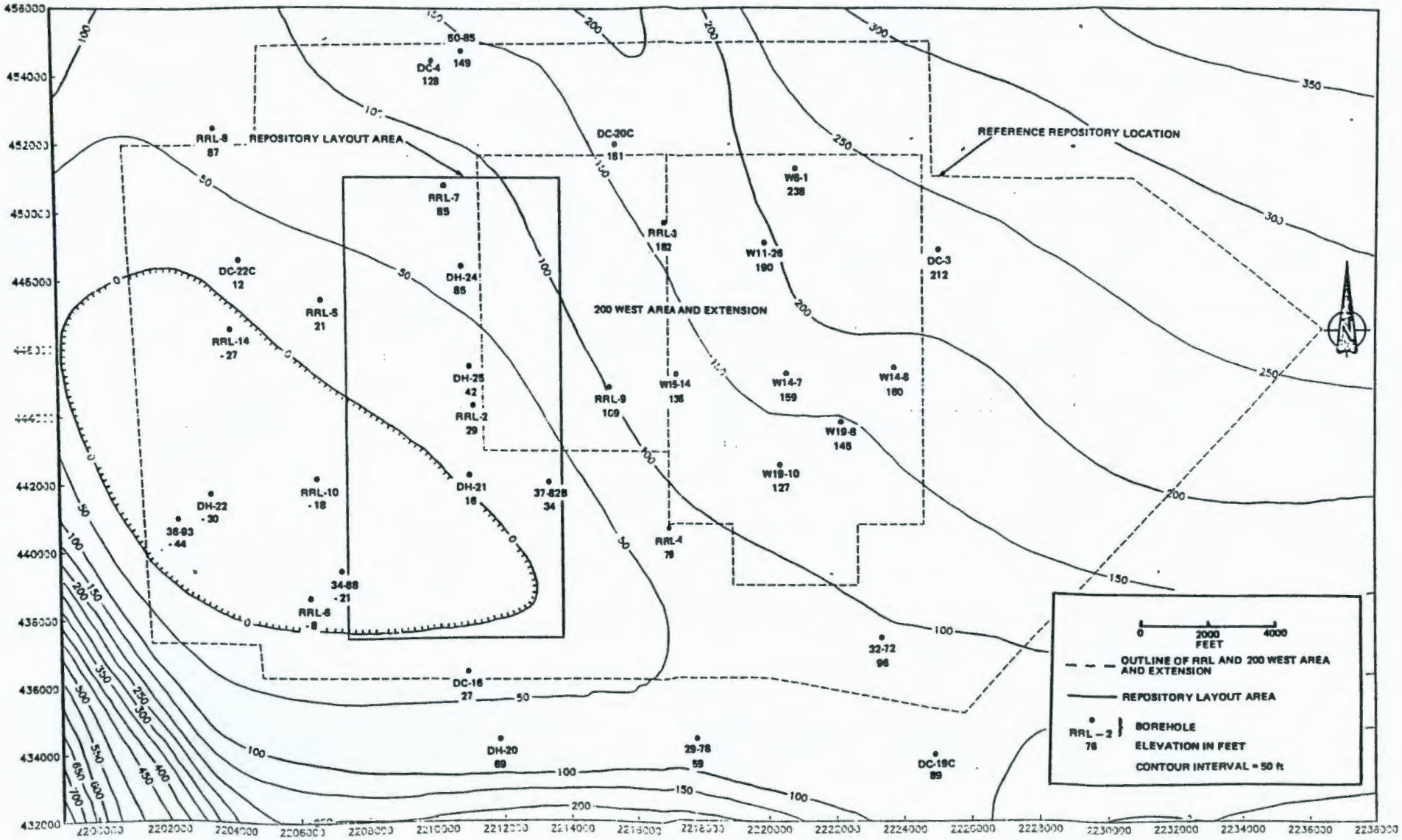

Figure 4. Top of Basalt Map.

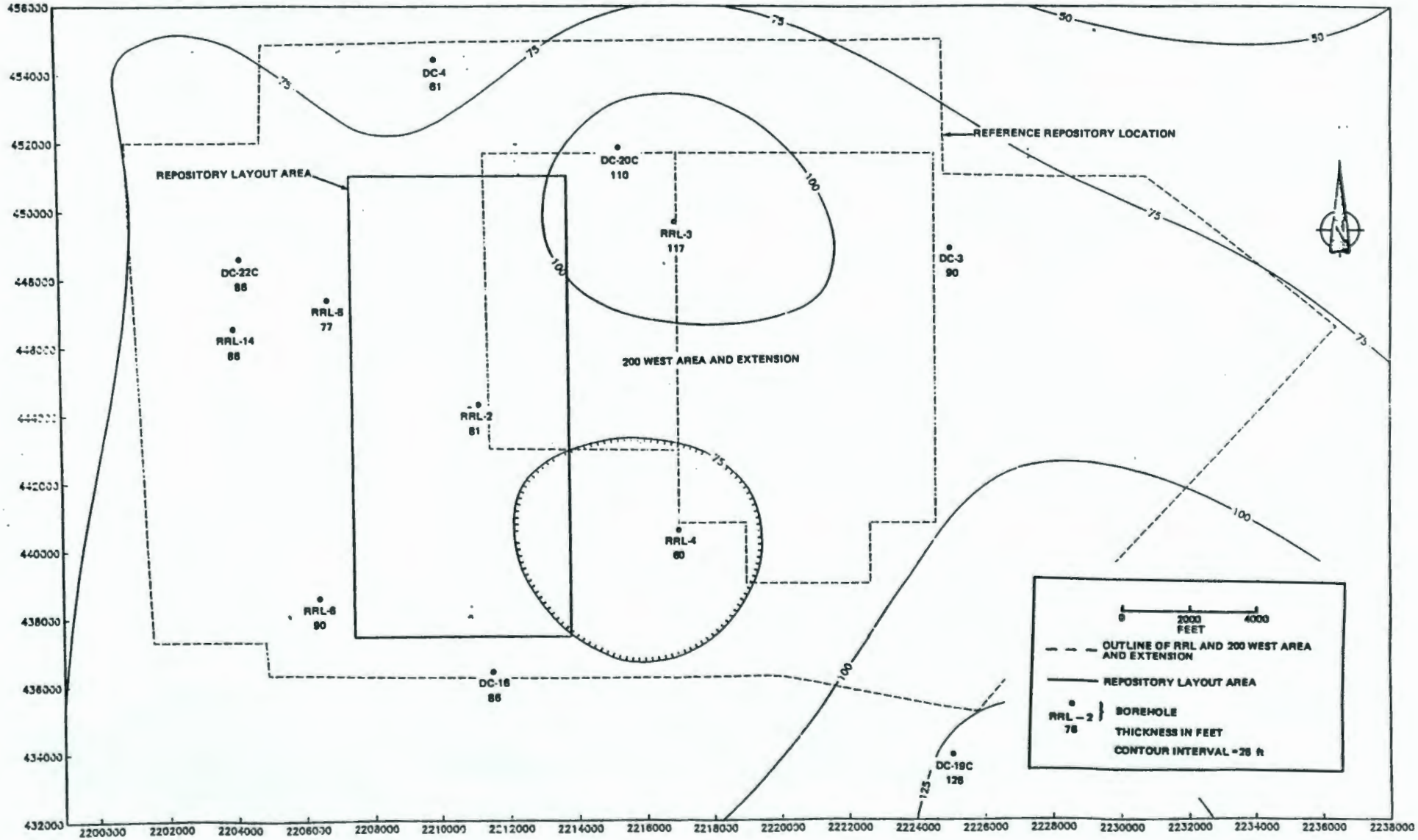

Figure 5. Isopach Map of the Elephant Mountain Member.

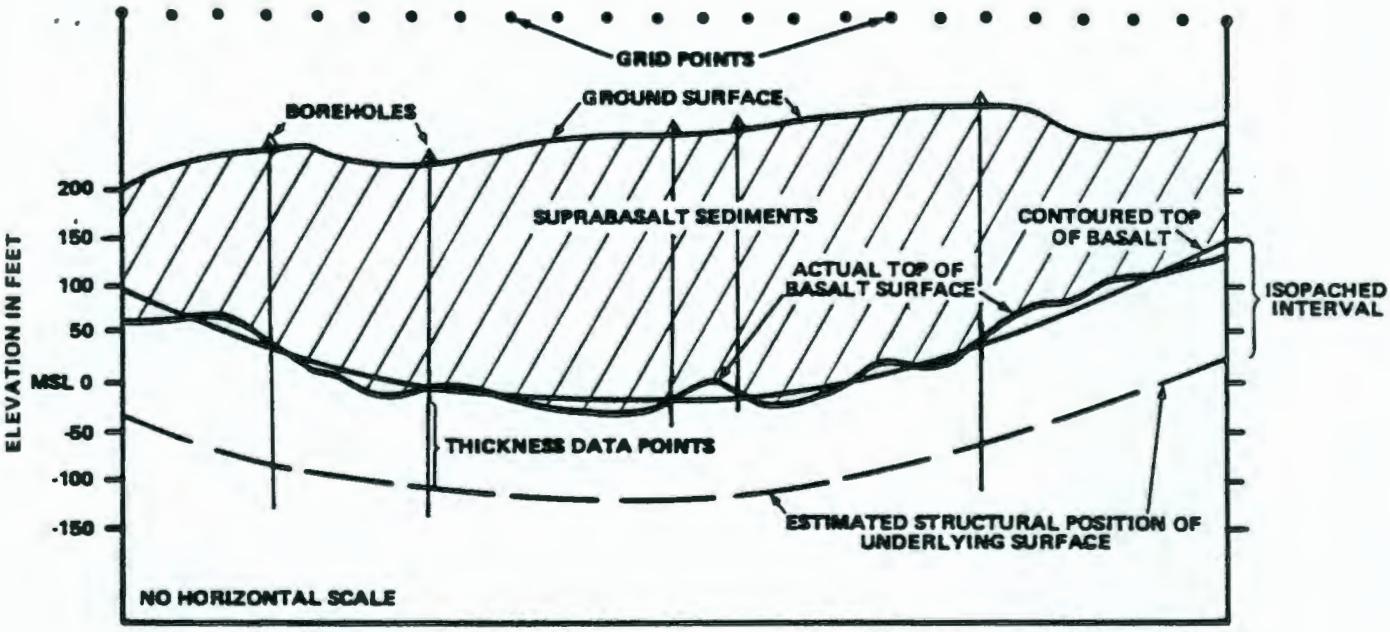

Figure 6. Hypothetical Cross Section showing the Contoured Top of Basalt Surface. See text for explanation.

errors. They are; depth measurement and method of drilling, borehole deviation, dipping strata, changing surface reference measurement points, varying strata thickness, and uncertainty due to varying density of data points.

The first error is a measurement error, i.e. how accurately the drilled depth and contact positions are measured. Contacts in cored boreholes are more accurately measured (± 1 ft) than are contacts penetrated by rotary or cable tool drilled boreholes. This is because cored boreholes provide a continuous record of the rock penetrated while in rotary or cable tool drilled boreholes provide rock chips only. Contacts in rotary and cable tool boreholes are determined from drill chips, drill rates, and from down-hole geophysical logs. Older rotary and cable tool drilled boreholes often do not have geophysical logs. Therefore chip logs and drill rate logs must be relied on for contacts. These logs may contain an error of as much as five feet. Contacts picked from recent rotary and cable tool drilled boreholes have geophysical logs completed for them and contacts are probably identified within two feet of the actual drilled depth (most geophysical logging tools used at BWIP are accurate to only ±2 ft, due to tool measurement precision). Uncertainty exists in selection of the contact position between flow top and the overlying flow bottom. This uncertainty is only on the order of one foot for cored boreholes. In rotary drilled boreholes this uncertainty is larger (<10 feet), because flow bottom may sometimes be vesicular or brecciated and geophysical logs cannot uniquely distinguish the contact between flow top and flow bottom.

A second type of error associated with borehole data is deviation from vertical. This is not considered significant for the data used in this report because deviations are less than three degrees. A deviation of three degrees in a 600 ft deep borehole is less than one ft and for a 3000 ft deep borehole it is approximately four ft.

A third type of error is dip correction for thicknesses and depths of units. This is not considered large enough to require correction for this report. Dips within the RRL are low (<3 degrees) and would require a correction of only 0.4 ft for a 250 ft thick flow. Correction for a drilled depth of 3000 ft would be approximately 4 ft. Moreover, the method used for construction of the model is more appropriately done using uncorrected thicknesses for grid subtraction.

A forth type of error is borehole surface elevation. Elevations of boreholes are surveyed to within ±1 ft, but the measurement points may be inconsistent. For example borehole elevations may be measured at the top of the drill casing, the top of the concrete collar (slightly above ground surface), or at the ground surface. Standards for construction of boreholes on the Hanford Site were used to establish a reasonable estimate for the expected variation in borehole elevation. Groundwater monitoring well standards for the Hanford site require the casing to extend 2.5 ft above ground surface ; all boreholes penetrating the water table follow this standard. Based on the borehole standards and the three different borehole elevation measurement points, borehole elevations are expected to vary as much as 2.5 ft.

A fifth error, or uncertainty, associated with borehole data is due to irregularities in unit thickness. Stratigraphic thickness can vary up to 15 ft in short distances (about 1500 feet). This is due to irregularities in the basalt surface (Reidel, 1984). These irregularities are caused by the mechanics of flow emplacement or local erosion. This amount of variation is significant and is included in the overall assessment of error. Similar irregularities exist for the suprabasalt sediments due to erosional channels and facies changes. As shown by the data tables (Appendix B), the amount of available data decreases as depth increases. Therefore the uncertainty of the isopach and structure contour maps is less for the shallower units than it is for the deeper units.

A sixth type of error is the areal distribution of data points. Figure 3 shows that the majority of borehole data are from the central RRL. There are only limited data in the western RRL, and no data in the eastern RRL. Therefore, greater certainty can be placed on the central RRL than on the boundaries.

A contour interval of 50 ft was chosen for structure contour maps. This is because 50 ft is the best estimate of proper contour placement for the TOB with a high degree of certainty. This estimate was determined by considering the error factors discussed above (stratigraphic thickness variation ±15 ft, drilled depth uncertainty ±5 ft, and borehole elevation uncertainty ±2.5 ft). The total of these errors is 22.5 ft, and twice this value, about 50 ft, was chosen as a conservative contour interval. Uncertainty for the TOB is carried down to each subsequent layer.

A geostatistical study of the uncertainties is underway to estimate better the uncertainty of the TOB map. The results of this study will provide a quantitative estimate of uncertainties for this model. It will aid in the planning of future drilling activities to reduce uncertainty.

Methodology Limitations: A key limitation to the computer generation of structure contour maps is that expert judgement is not readily introduced at each structural surface. For example, if translation of a structural axis is known to occur at depth, it is difficult to introduce it into the model. Editing of the structural surface grid files can be done with ISM. Features such as translations can be introduced, but such editing is labor intensive. ISM may show features, such as wandering contour lines (see discussion below), that are due to either an artifact of the method or to lack of data. At this stage of model development, no attempt has been made to perform any correction to the surfaces to remove such artifacts.

ISM may introduce small errors on individual isopach maps between known data points due to the gridding algorithim. These errors are small and less than errors introduced by geologic variation. The effect of these small errors is that if any two or more isopach maps are added, the resulting surface would be slightly different from a surface generated only from the total thickness, at known data points, across the stratigraphic intervals represented by the isopach maps.

In the model the TOB surface is assumed to be a true structural surface. This is reasonable for the level of accuracy implied by a 50 ft

contour interval. Figure 6 illustrates that the contoured surface would not change more than one contour interval (50 ft) even if the error was 25 ft. Erosion of the basalt surface is not thought to be appreciable. Some erosion could be present and not detected, due to the wide spacing of boreholes. Large areas of extensive erosion on the TOB surface, if they are present, would be partially accounted for by subtraction of the Elephant Mountain Member. The Elephant Mountain Member would be thinner in eroded than in noneroded areas. Subtraction from the TOB has the effect of correcting for this. This type of correction accounts for average thickness variations but not for any localized channeling.

Contours on the maps may appear in places to follow somewhat irregular courses over the map area. This is because in areas where structure is very flat with very little relief the difference between the computer generated contour and a "smoothed" contour would be small. Therefore "smoothing" of contours would not enhance the maps and was not done. The contours are, in fact, a true representation of the grid and the grid represents points calculated by the grid-producing algorithm.

MODEL RESULTS

The model consists of 38 structural surfaces (Appendix A), from which 5 perspective block diagrams (Figures 7 to 11), and 11 cross sections (Appendix D) were produced.

The five perspective block diagrams (Figures 7 to 11) show the major stratigraphic horizons and the Cohassett flow (preferred candidate repository horizon). Figure 7 is a cutaway perspective view of the center of the repository layout area. Figures 8 and 9 are southeast and northwest perspective views of the repository layout area and Figures 10 and 11 are southeast and northwest perspective views of the modeled area. Cross sections locations are shown on Figure 3. These cross sections are near the south (G - G′), west (A - A′), and north (K - K′) boundaries of the modeled area; along all sides of the current repository layout area (B - B′, D - D′, H - H′, and J - J′); through the center of the repository layout area (C - C′ and I - I′); one section through the approximate center of the 200 west area (E - E′); and one section traversing southwest to northeast (F - F′) (see Figure 3). The cross sections in Figures 12a to 12k are shown with no vertical exaggeration, and illustrate the relatively flat nature of the modeled area. The cross sections in Appendix D are shown with a 10 times vertical exaggeration.

The structure contour maps, cross sections, and block diagrams show that the surfaces below the TOB conform to the same general structural trends as does the TOB. That is, the main low of the Cold Creek syncline (Figure 4), remains in the same relative position down to the lowermost modeled layer (see Figures 13 to 16).

At the eastern boundary of the layout area, the 50 and 100 ft contours on the TOB trend in a north-northwesterly direction (Figure 4). After subtraction of the Elephant Mountain Member (Figure 5) contours for the surface of the Rattlesnake Ridge interbed (Figure 17) change to a more

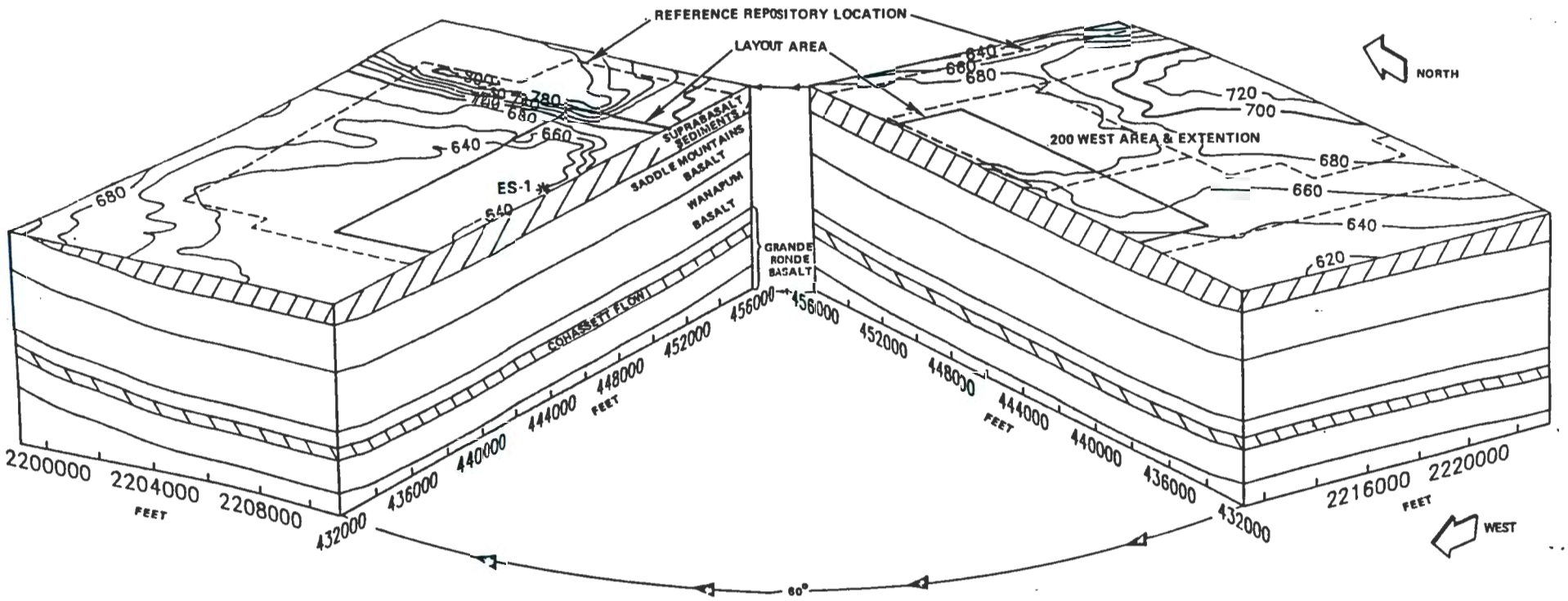

Figure 7. Cutaway View of Perspective Block Diagram through the Center of the Repository Layout Area. Major stratigraphic surfaces are shown. Vertical exaggeration = 1X.

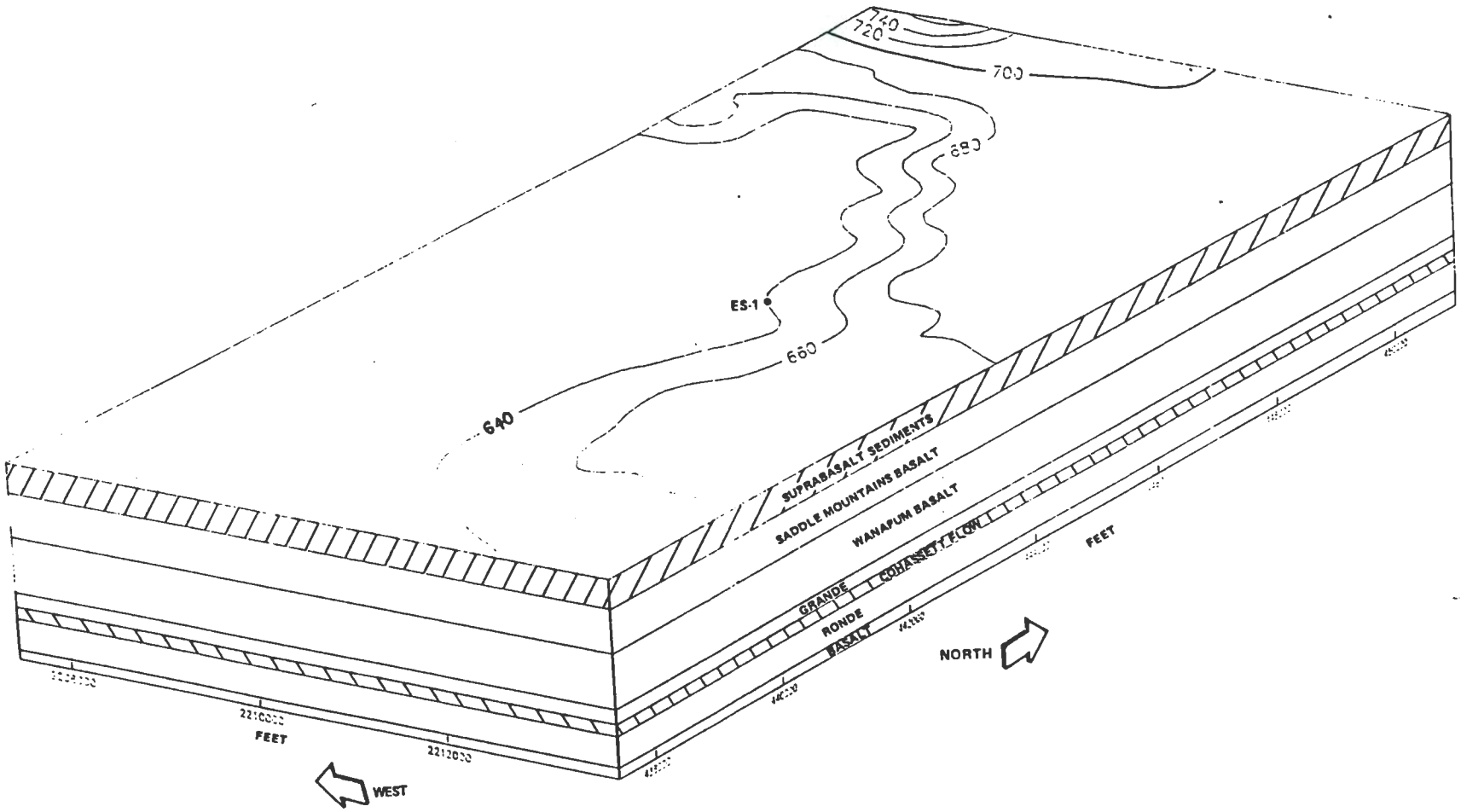

Figure 8. Perspective Block Diagram of Repository Layout Area, looking Northwest. Vertical exaggeration = 1X.

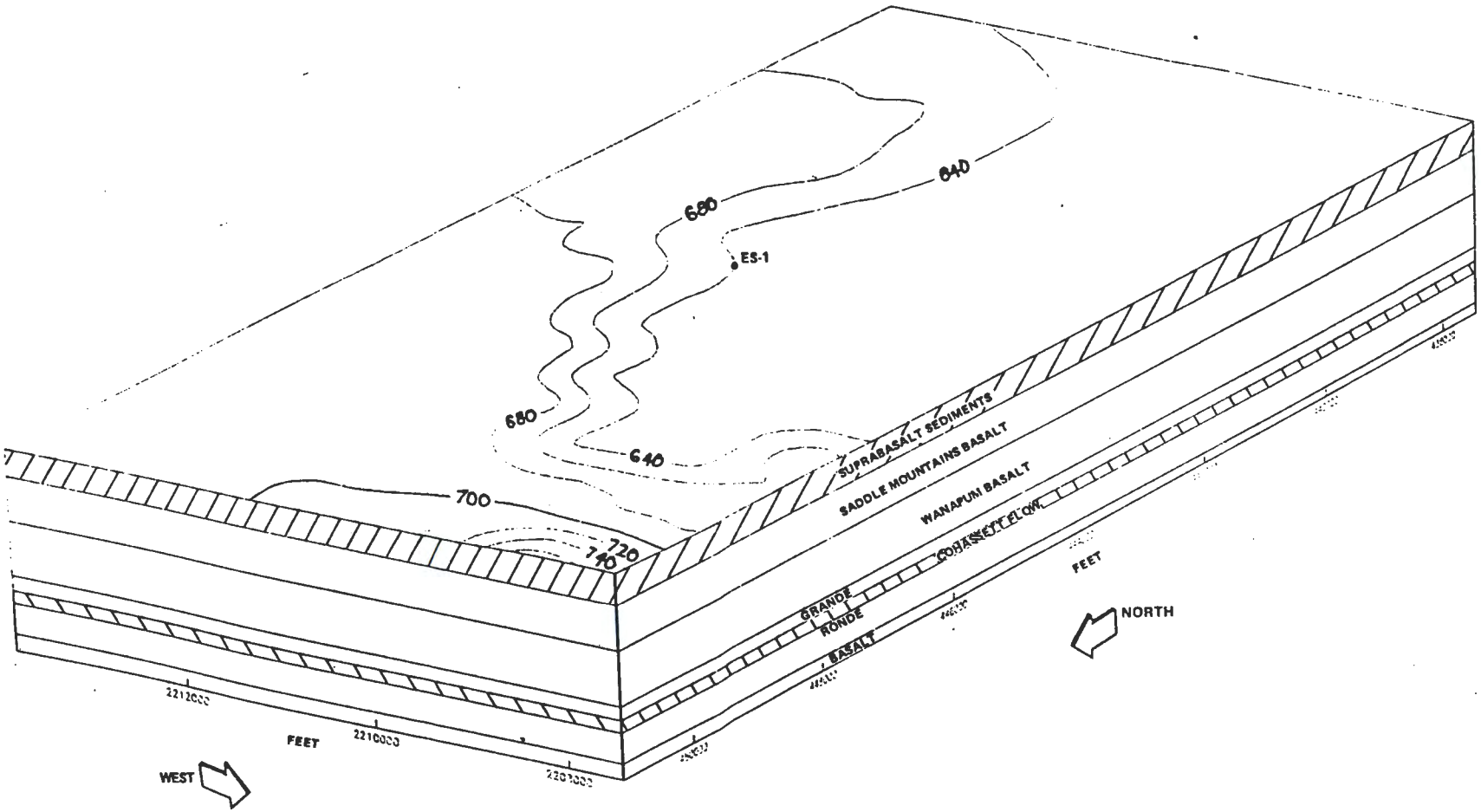

Figure 9. Perspective Block Diagram of Repository Layout Area, looking Southeast. Vertical exaggeration = 1X.

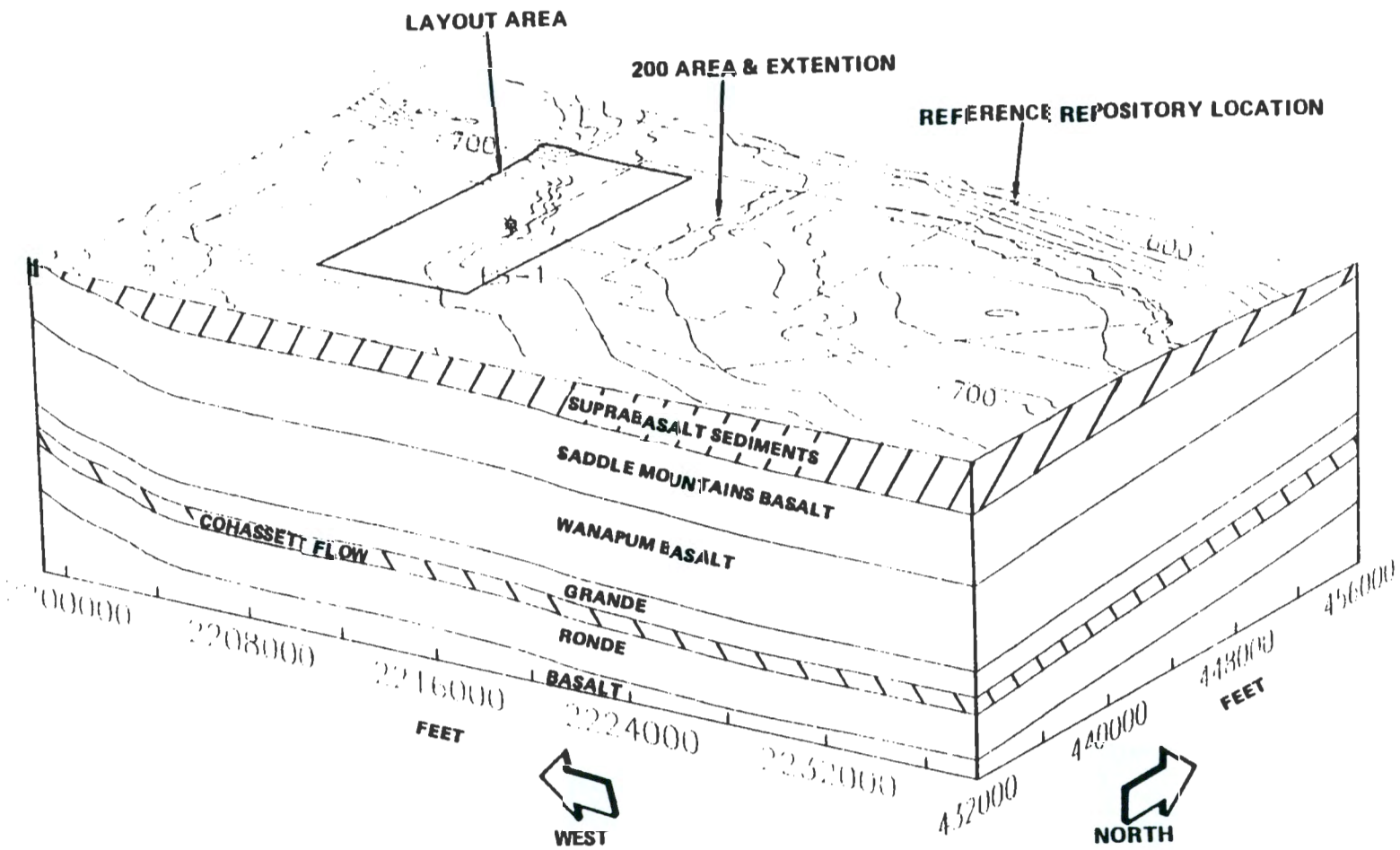

Figure 10. Perspective Block Diagram of the Model Area, looking Northwest.
Vertical exaggeration = 1X.

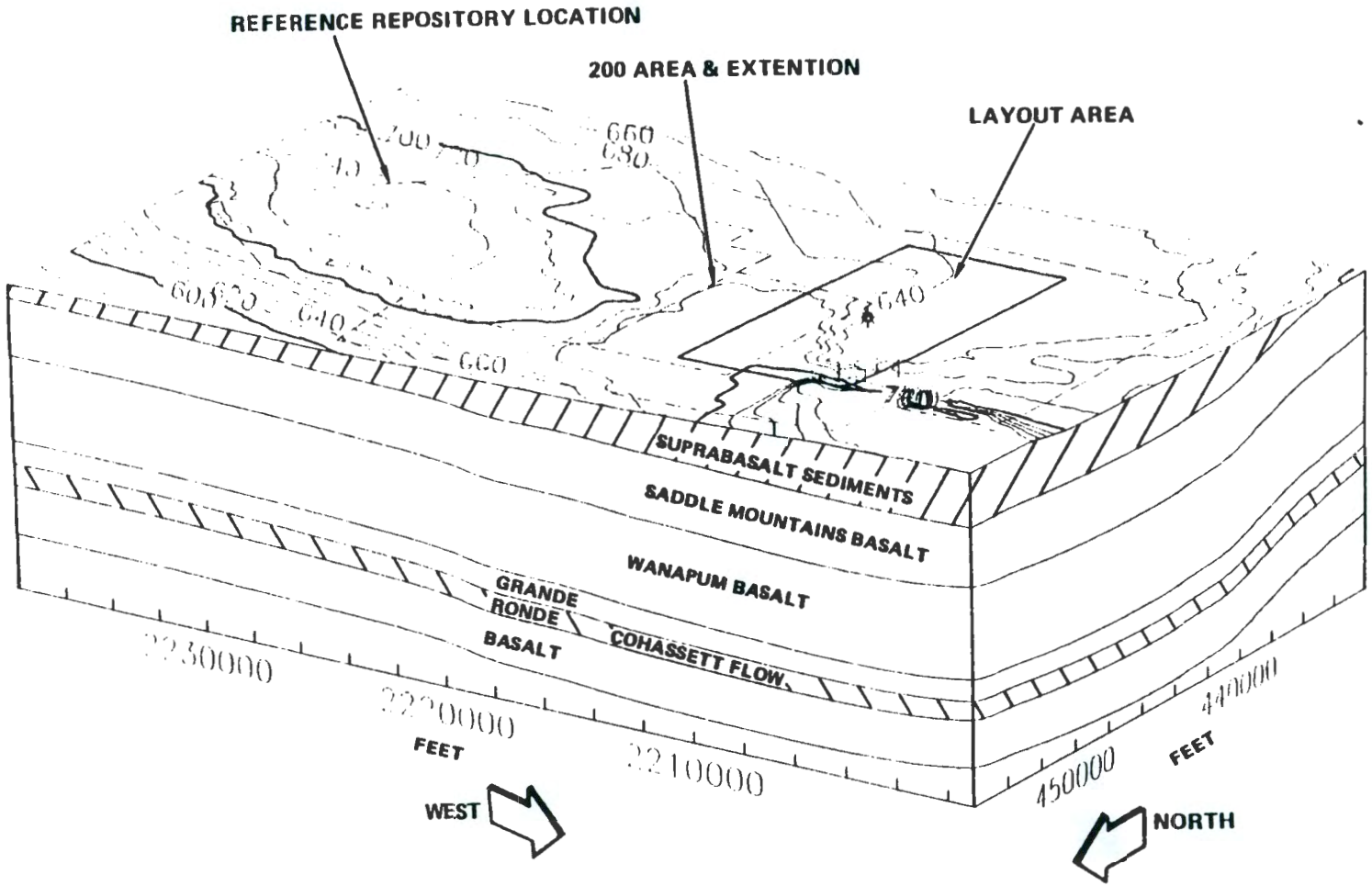

Figure 11. Perspective Block Diagram of the Model Area, looking Southeast. Vertical exaggeration = 1X.

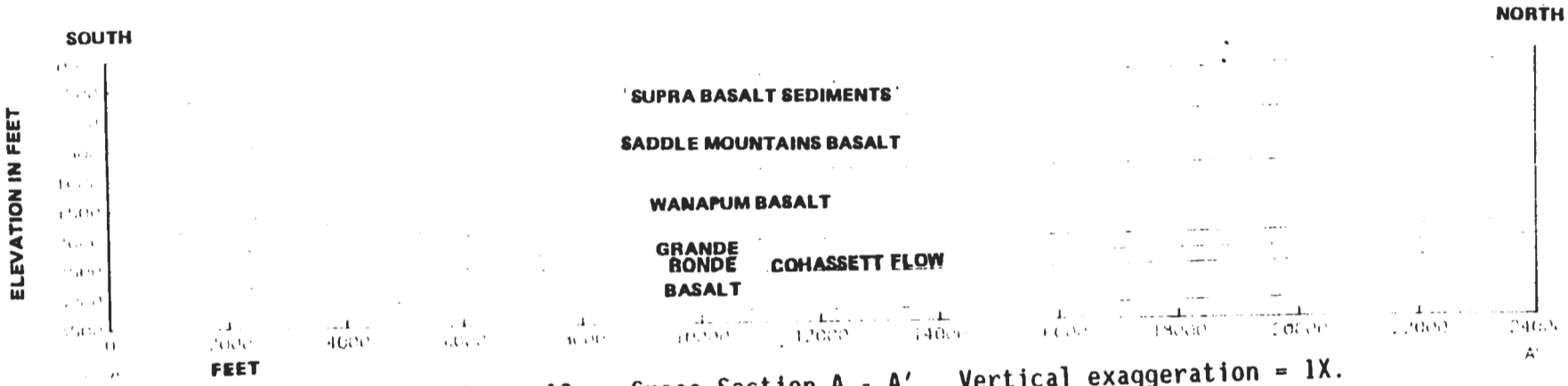

Figure 12a. Cross Section A - A'. Vertical exaggeration = 1X.

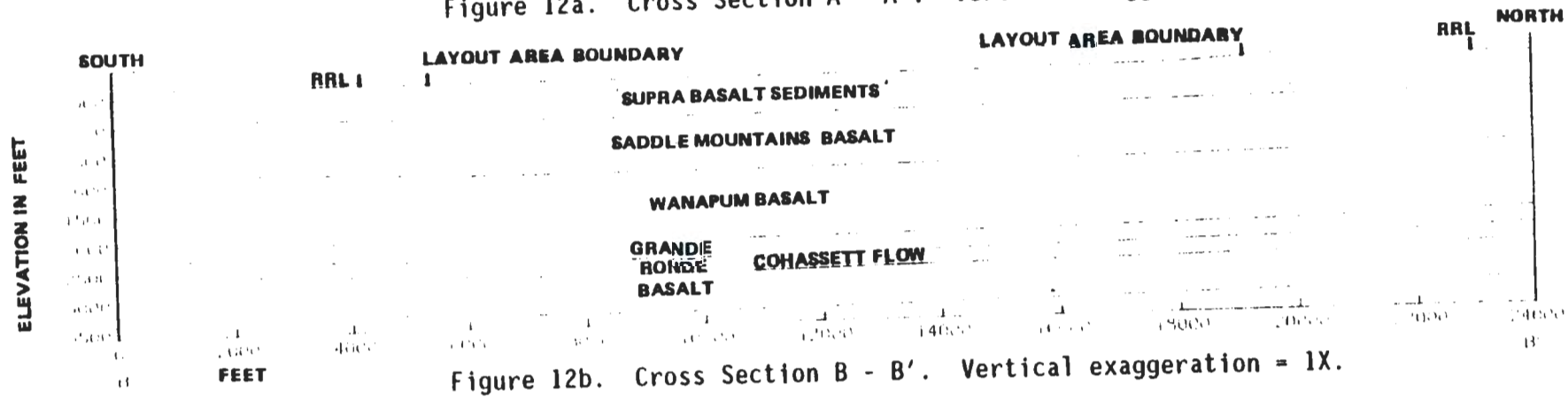

Figure 12b. Cross Section B - B'. Vertical exaggeration = 1X.

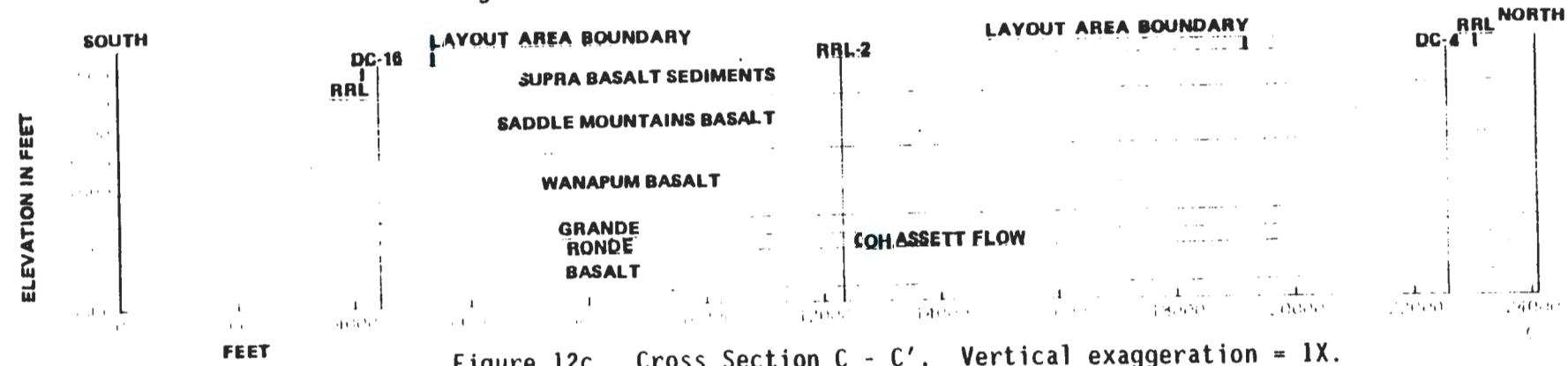

Figure 12c. Cross Section C - C'. Vertical exaggeration = 1X.

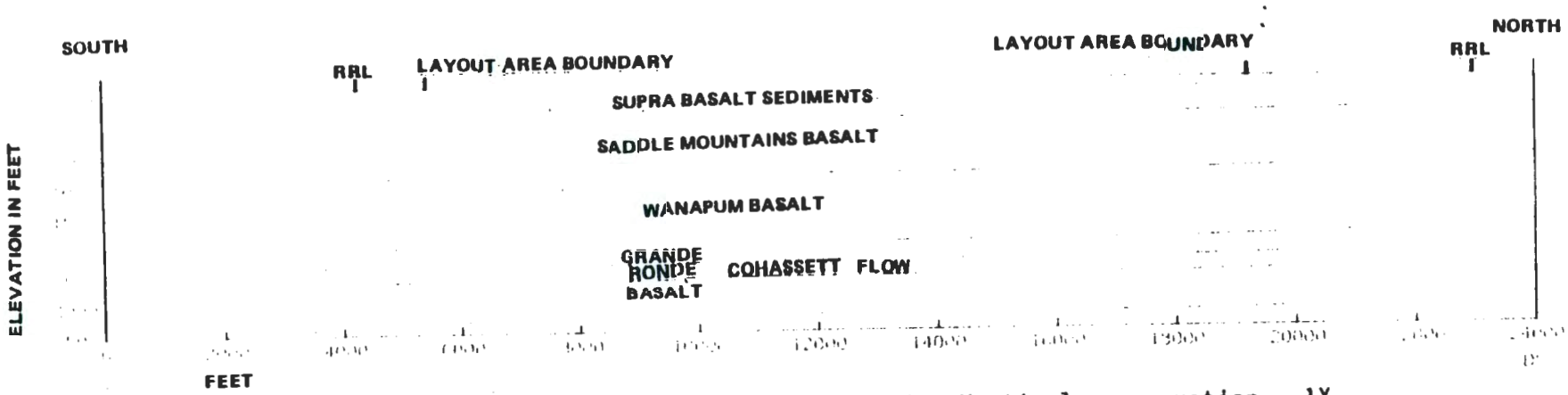

Figure 12d. Cross Section D - D'. Vertical exaggeration = 1X.

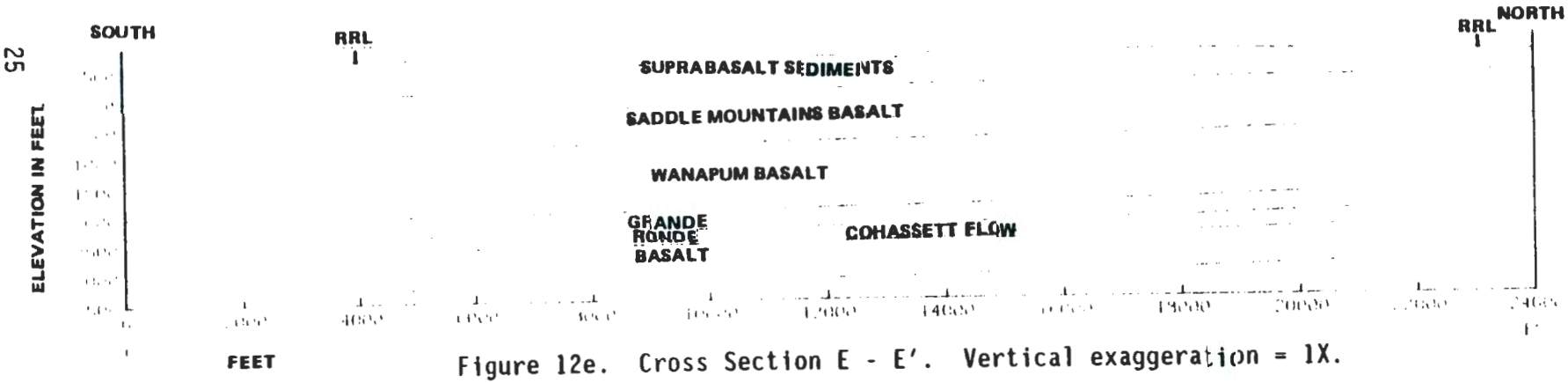

Figure 12e. Cross Section E - E'. Vertical exaggeration = 1X.

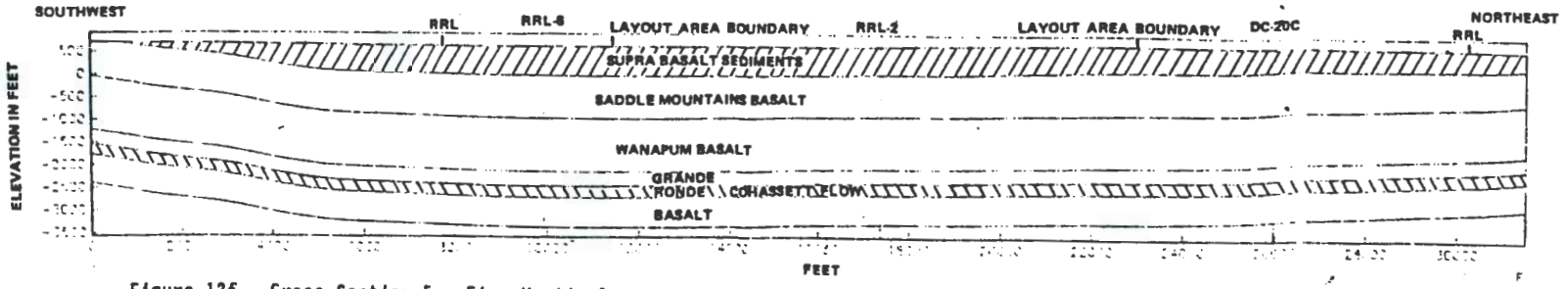

Figure 12f. Cross Section F - F'. Vertical exaggeration = 1X.

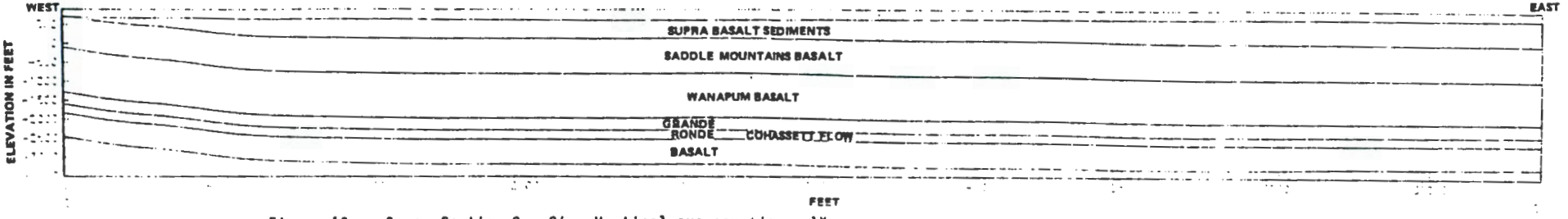

Figure 12g. Cross Section G - G'. Vertical exaggeration = 1X.

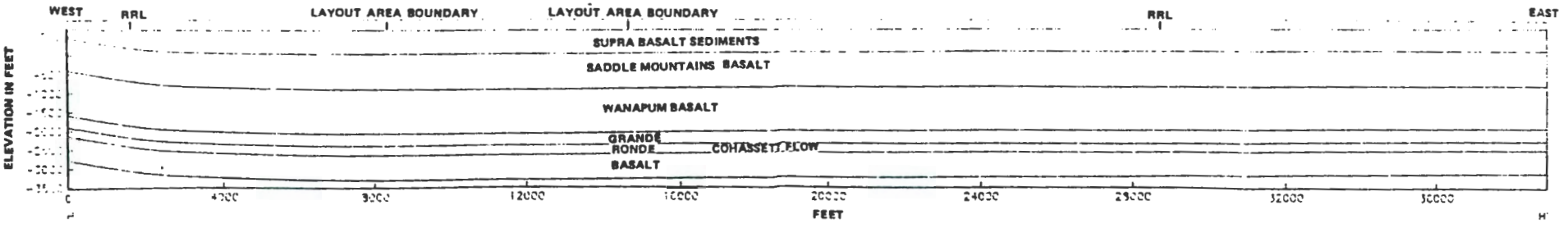

Figure 12h. Cross Section H - H'. Vertical exaggeration = 1X.

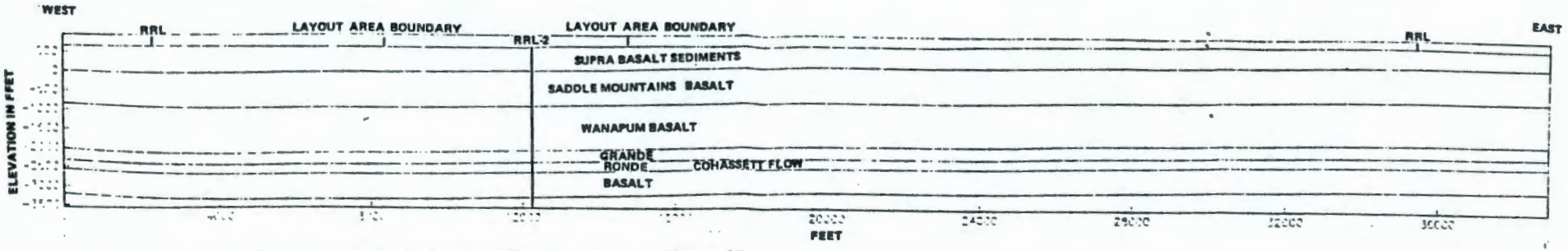

Figure 12i. Cross Section I - I'. Vertical exaggeration = 1X.

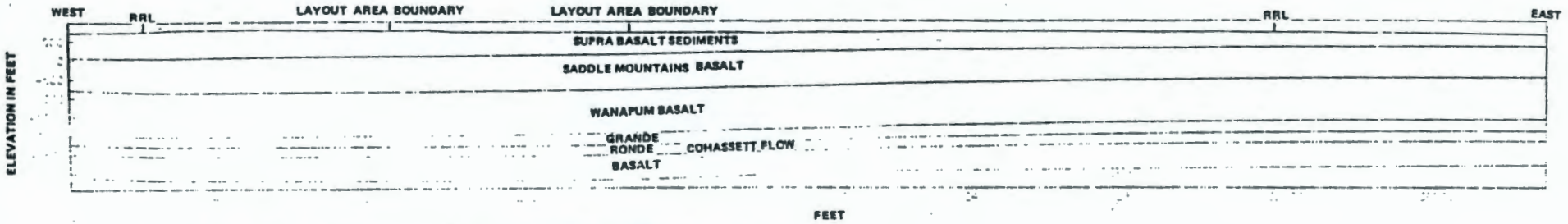

Figure 12j. Cross Section J - J'. Vertical exaggeration = 1X.

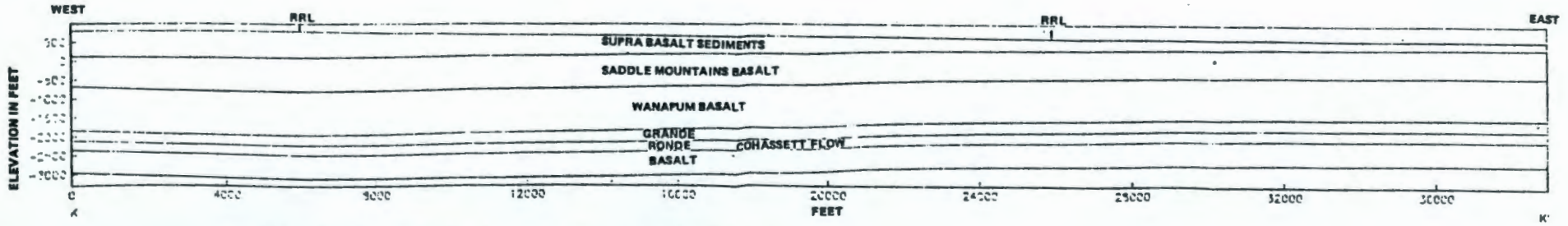

Figure 12k. Cross Section K - K'. Vertical exaggeration = 1X.

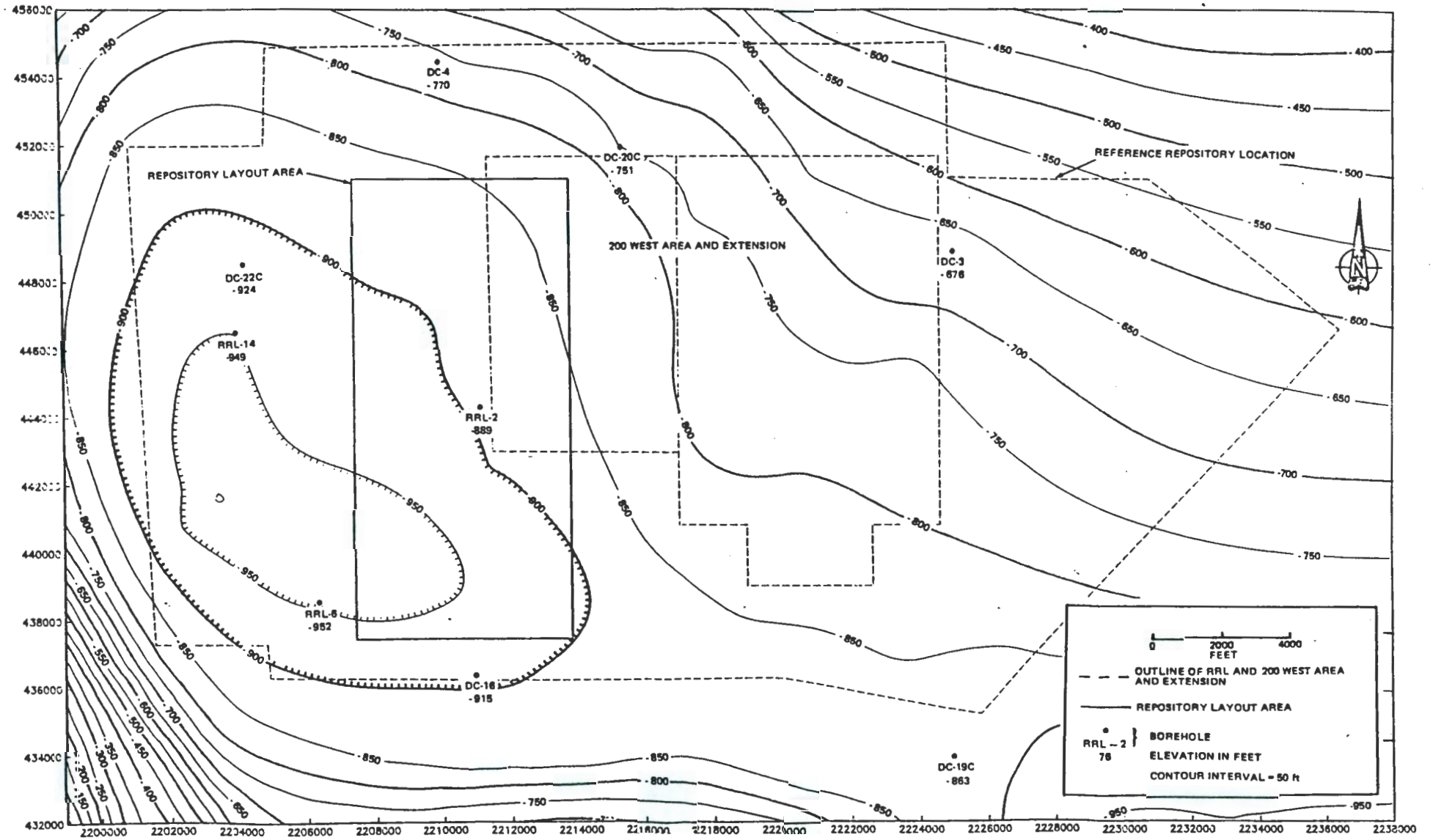

Figure 13. Top of Wanapum Basalt Structure Contour Map.

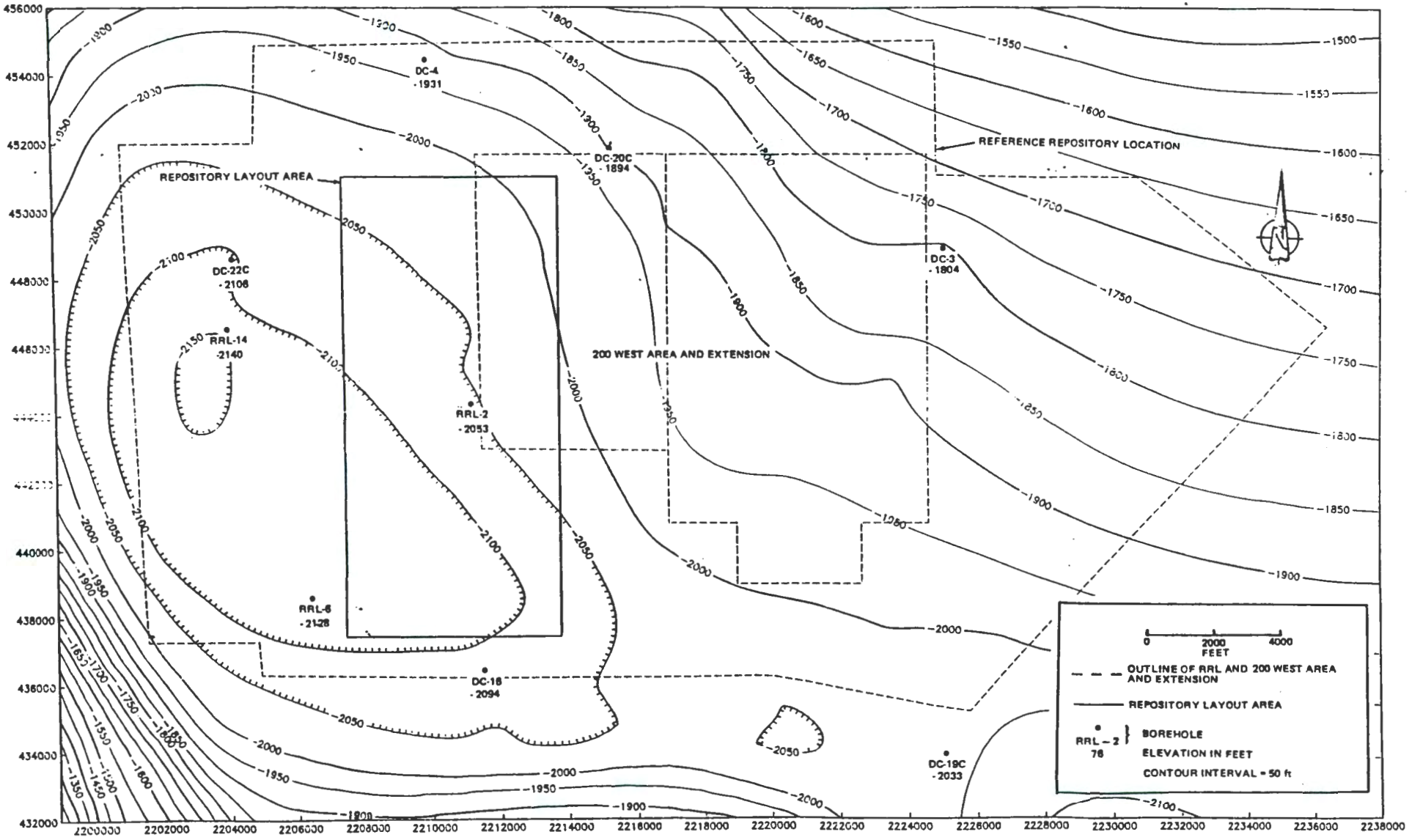

Figure 14. Top of Grande Ronde Basalt Structure Contour Map.

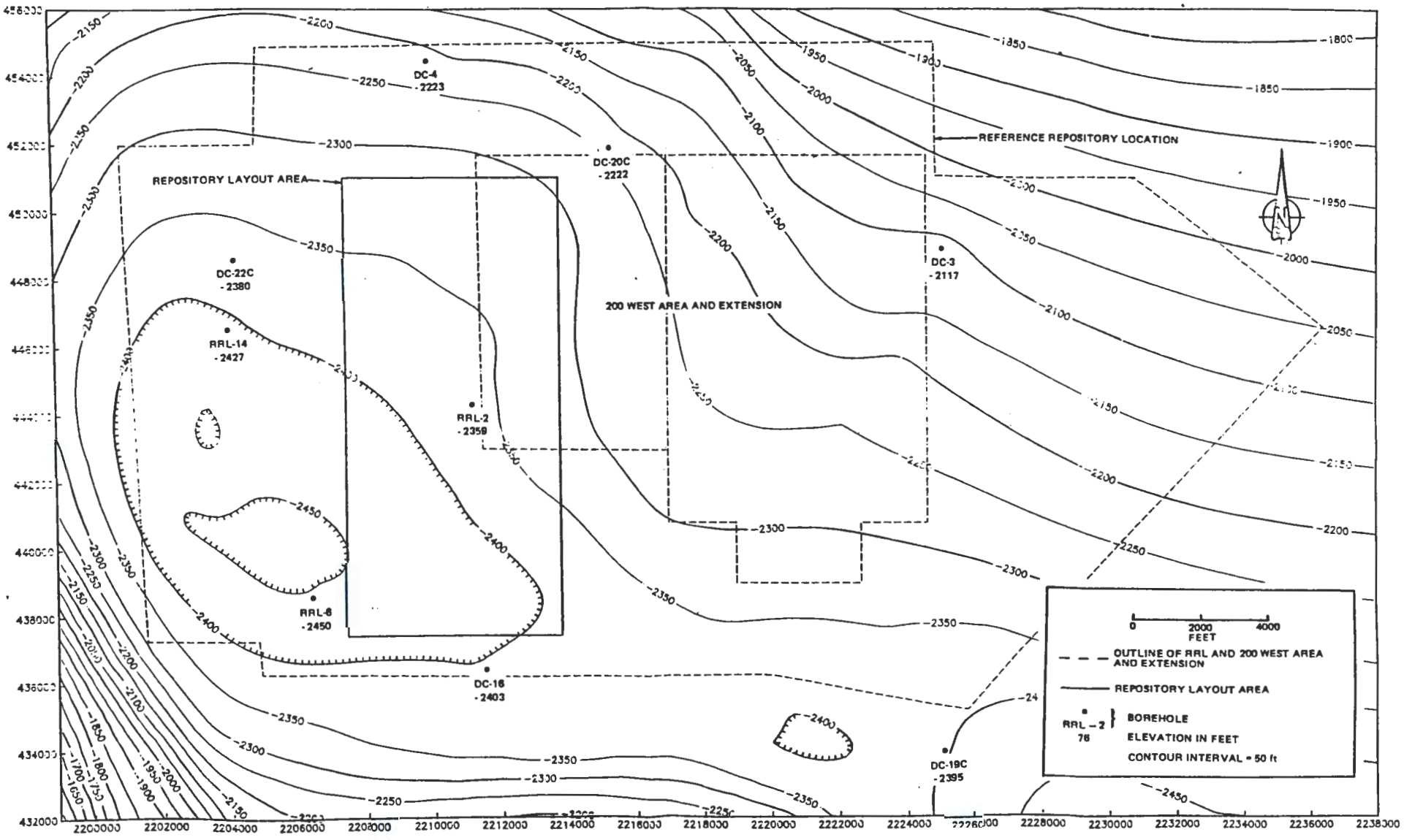

Figure 15. Top of Cohassett Flow Structure Contour Map.

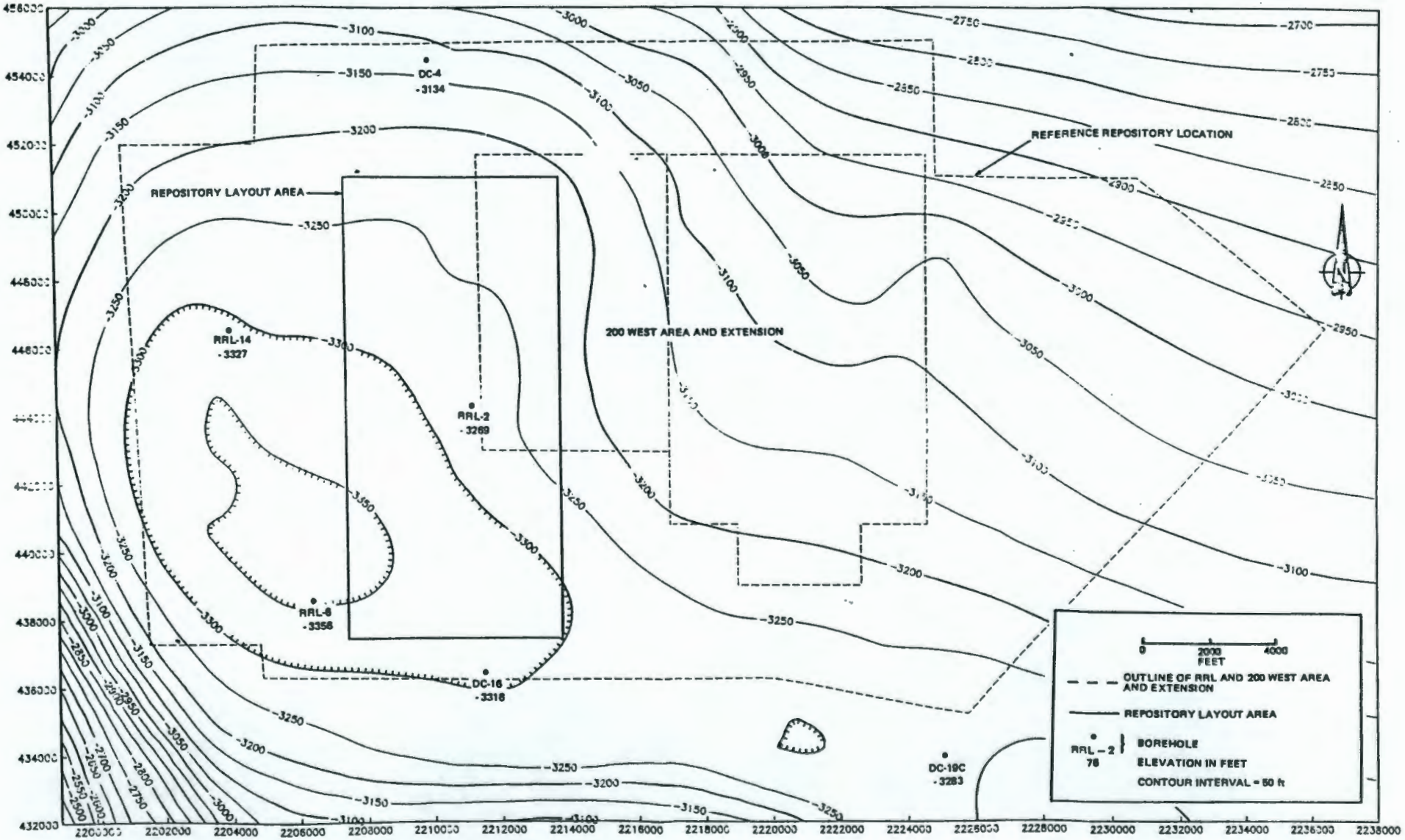

Figure 16. Top of Low Mg Flows Structure Contour Map.

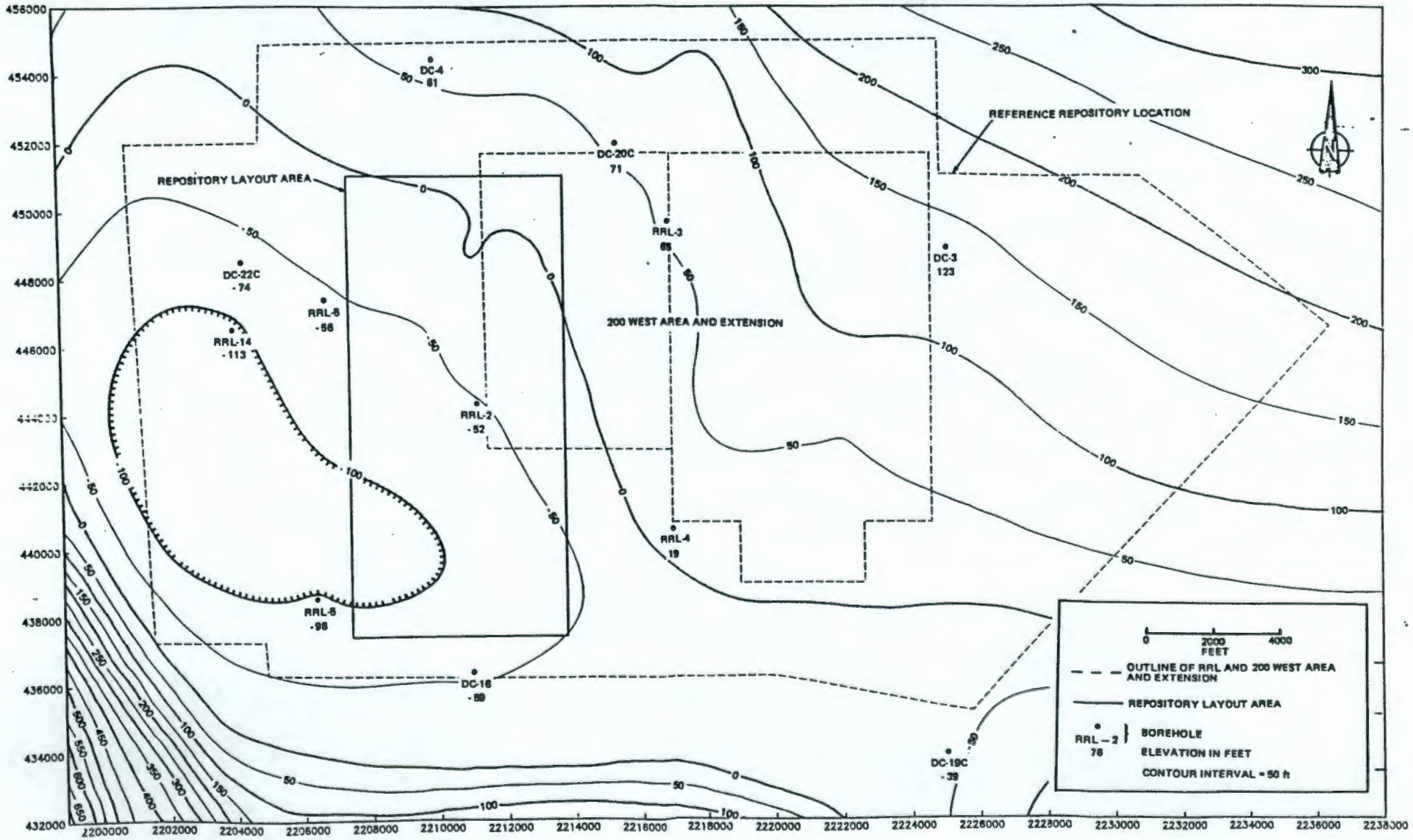

Figure 17. Top of Rattlesnake Ridge Interbed Structure Contour Map.

northerly direction than on the TOB. The latter trend remains fairly constant with depth until the upper flows of the Grande Ronde Basalt are encountered. Here the trend shifts to nearly north-south (see Figure 14). The shift between the TOB and the Rattlesnake Ridge interbed is due to thickening of the Elephant Mountain Member, at boreholes RRL-3 and DC-20, coupled with thinning at RRL-4 (Figure 5). Further down section, similar thinning or thickening of other flows results in the second change of trend. As seen on Figure 15 this feature appears on the Cohassett flow structure contour map and has the effect of flattening the dip of the flow at the eastern boundary of the current repository layout area.

In the eastern RRL, the structural dip gradually steepens with depth, down to the top of the Wanapum Basalt (Figure 13). Below the Wanapum Basalt, the dip remains nearly constant. This may be due to lack of data in the eastern RRL where the gridding routine may interpolate a thinning from distant boreholes to the northeast. This would cause less thickness to be subtracted from the overlying surfaces and result in a steeper dip.

A northeastern trending feature is apparent on the TOB map (Figure 4), between boreholes W19-10 and DC-3. This feature is shown on all surfaces near borehole DC-3 (Figures 4, 13 to 16, and Appendix A). This feature becomes more pronounced with depth. The significance or cause of this feature is unknown, but may be related to the linear placement of boreholes in this area. The linear placement could introduce a bias into the gridding and contouring routine.

CONCLUSIONS

This preliminary stratigraphic and structural model provides a systematic picture of the geologic framework of the RRL that is consistent with available data. The model depicts the stratigraphic and structural aspects of the RRL and the repository layout area. It provides a means of generating cross sections, block diagrams and structure contours at any desired scale. The model can predict stratigraphy in new boreholes and can be updated as new borehole information becomes available.

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APPENDIX A

Structure contour maps

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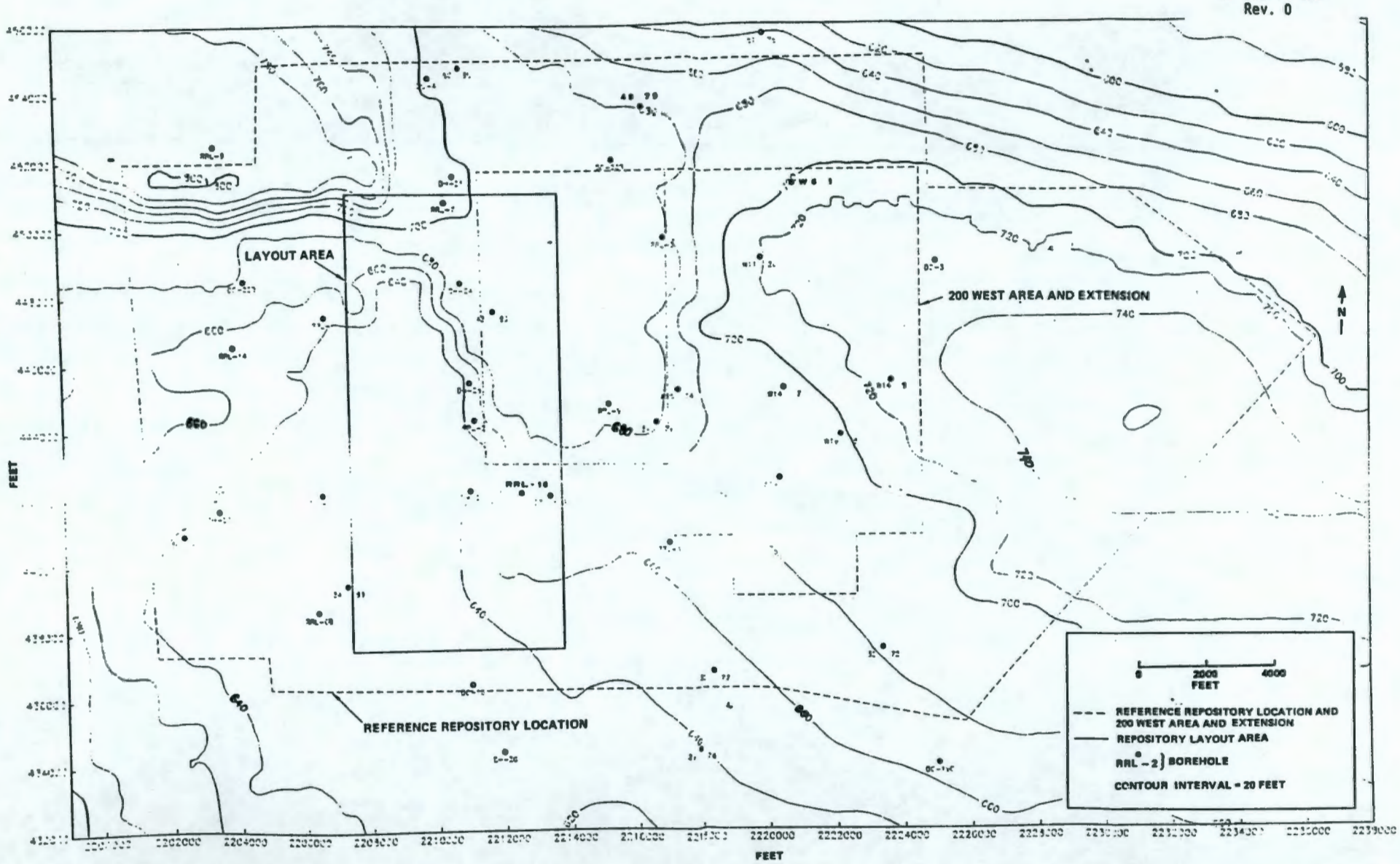


Figure A-1. Contour Map of the Ground Surface.

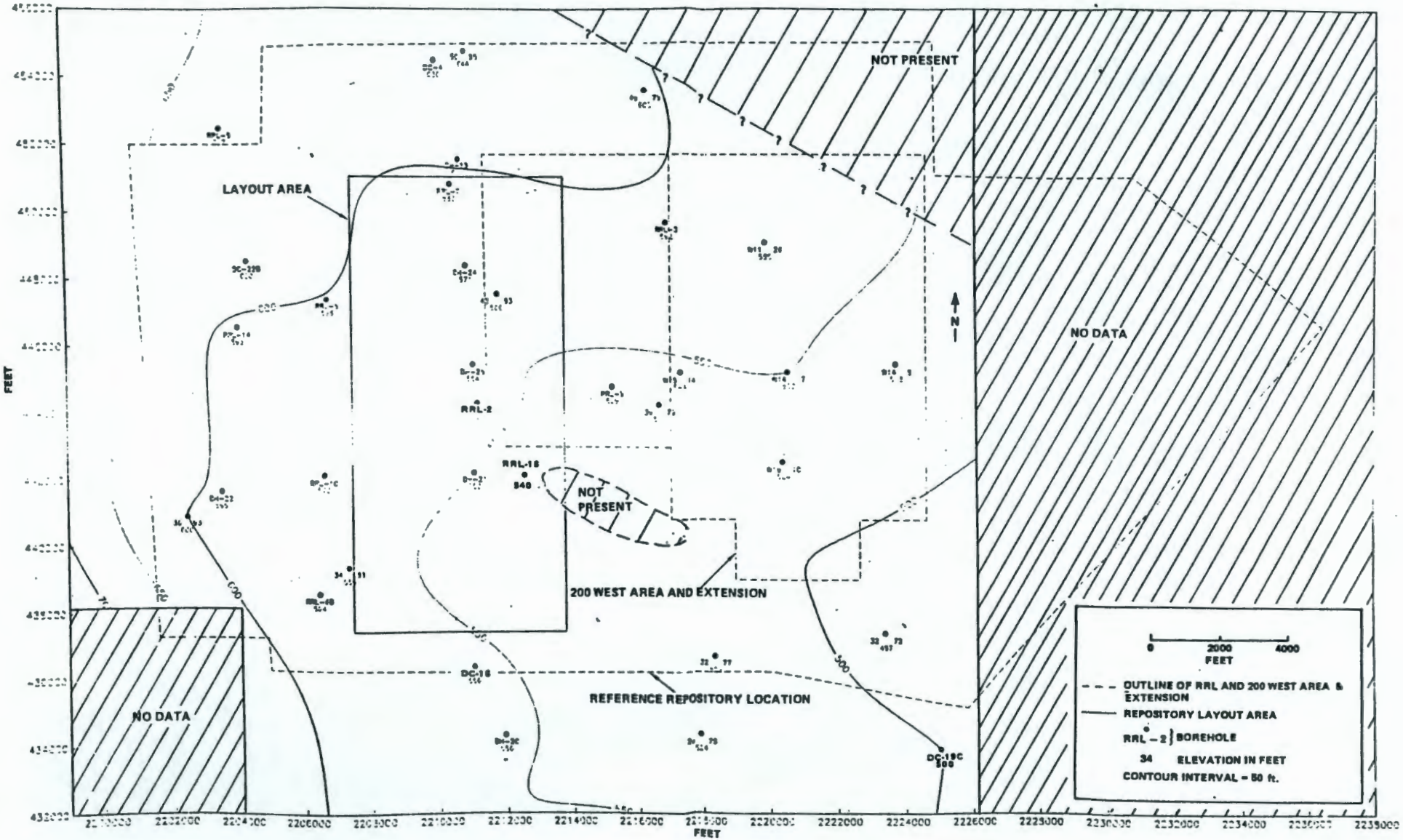
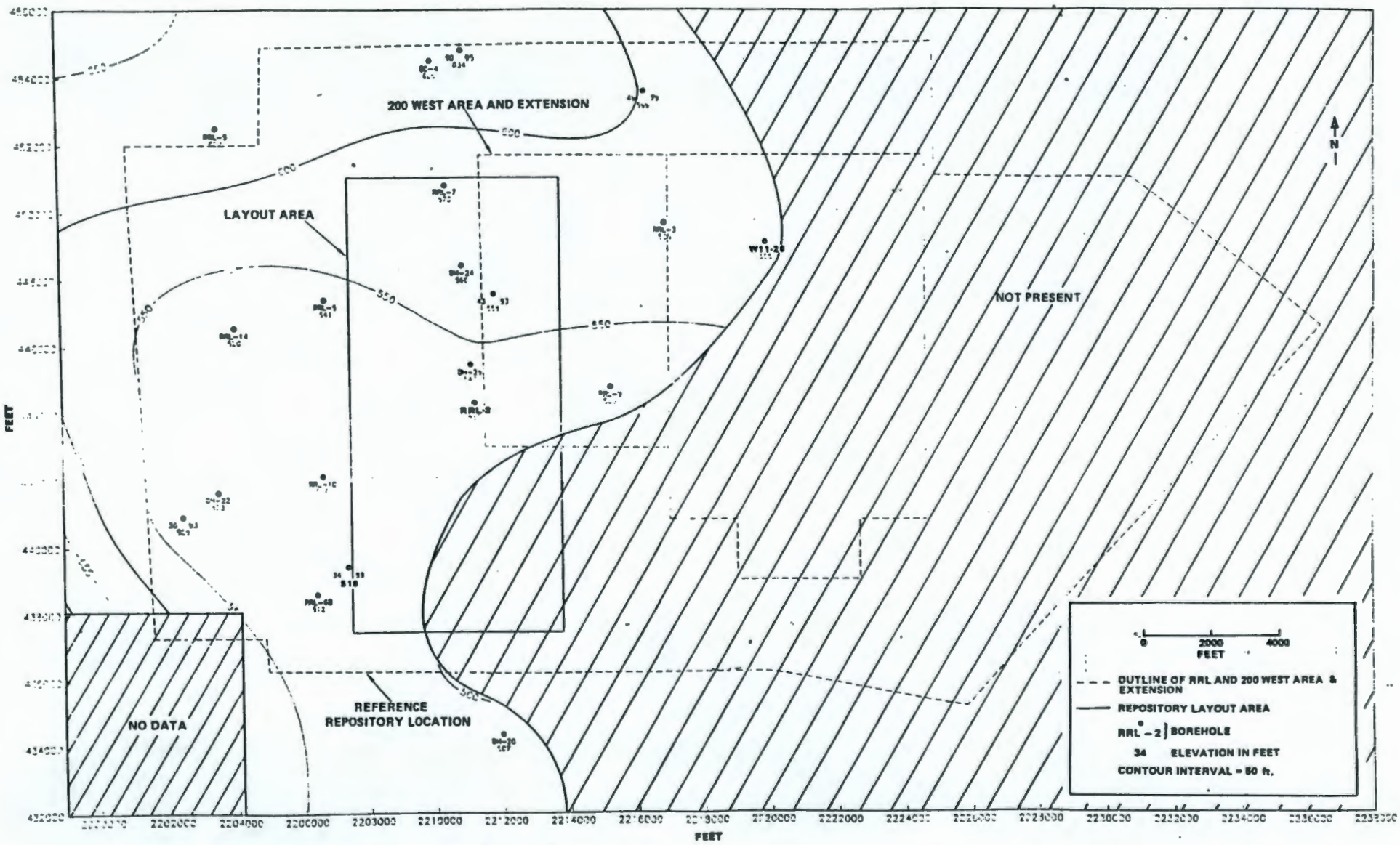


Figure A-2. Top of the Plio-Pleistocene Unit Structure Contour Map.



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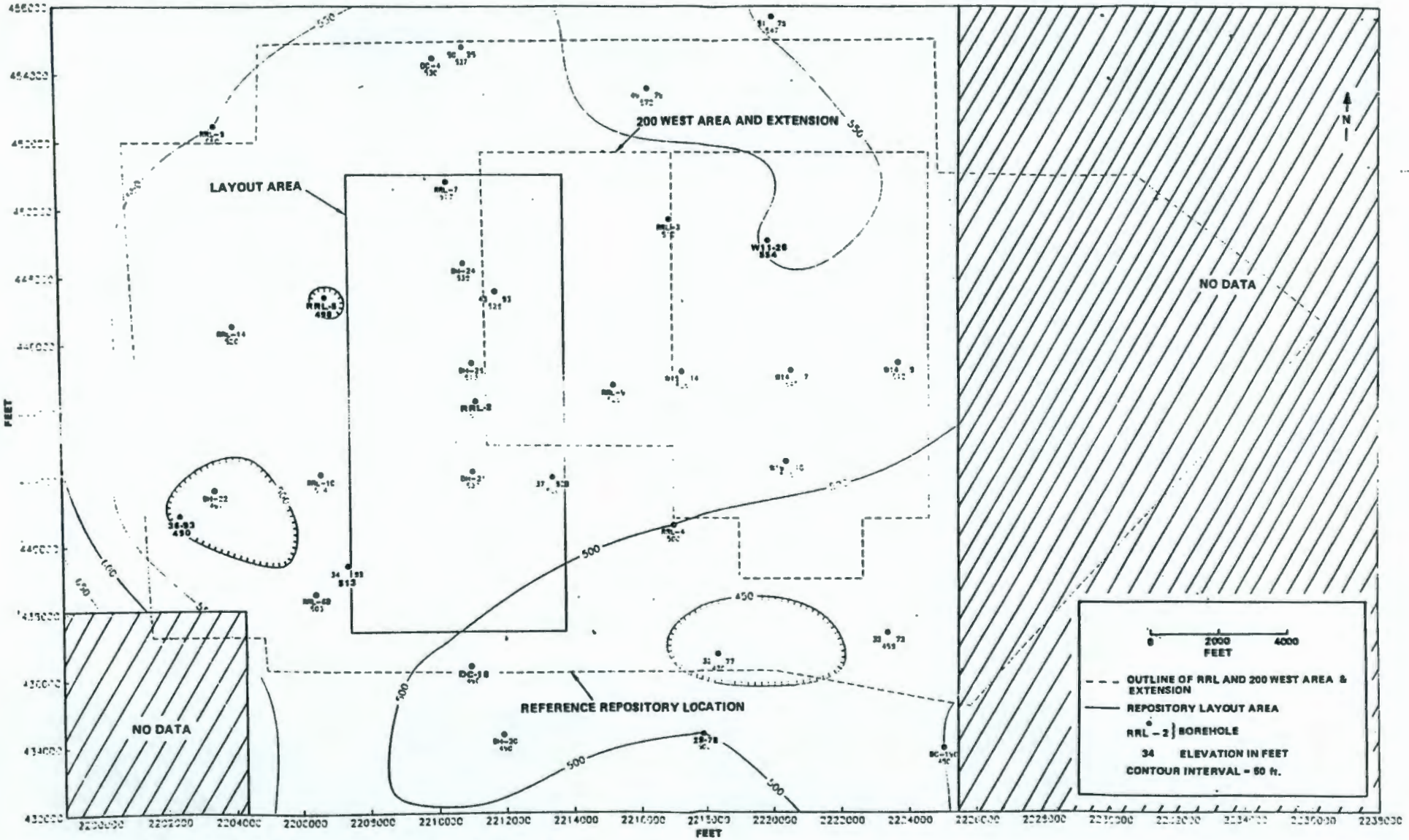

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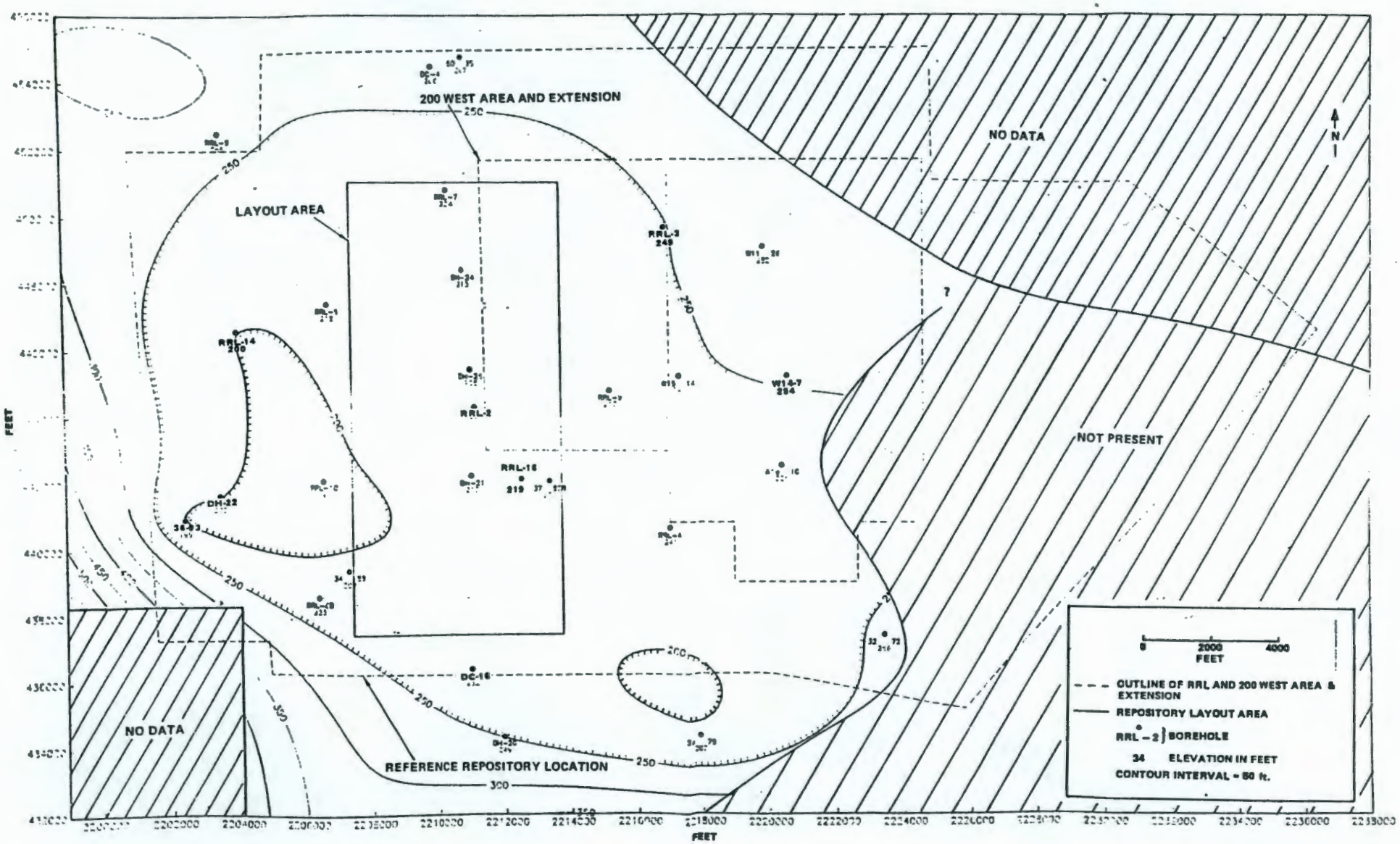

Figure A-5. Top of the Lower Ringold Unit Structure Contour Map.

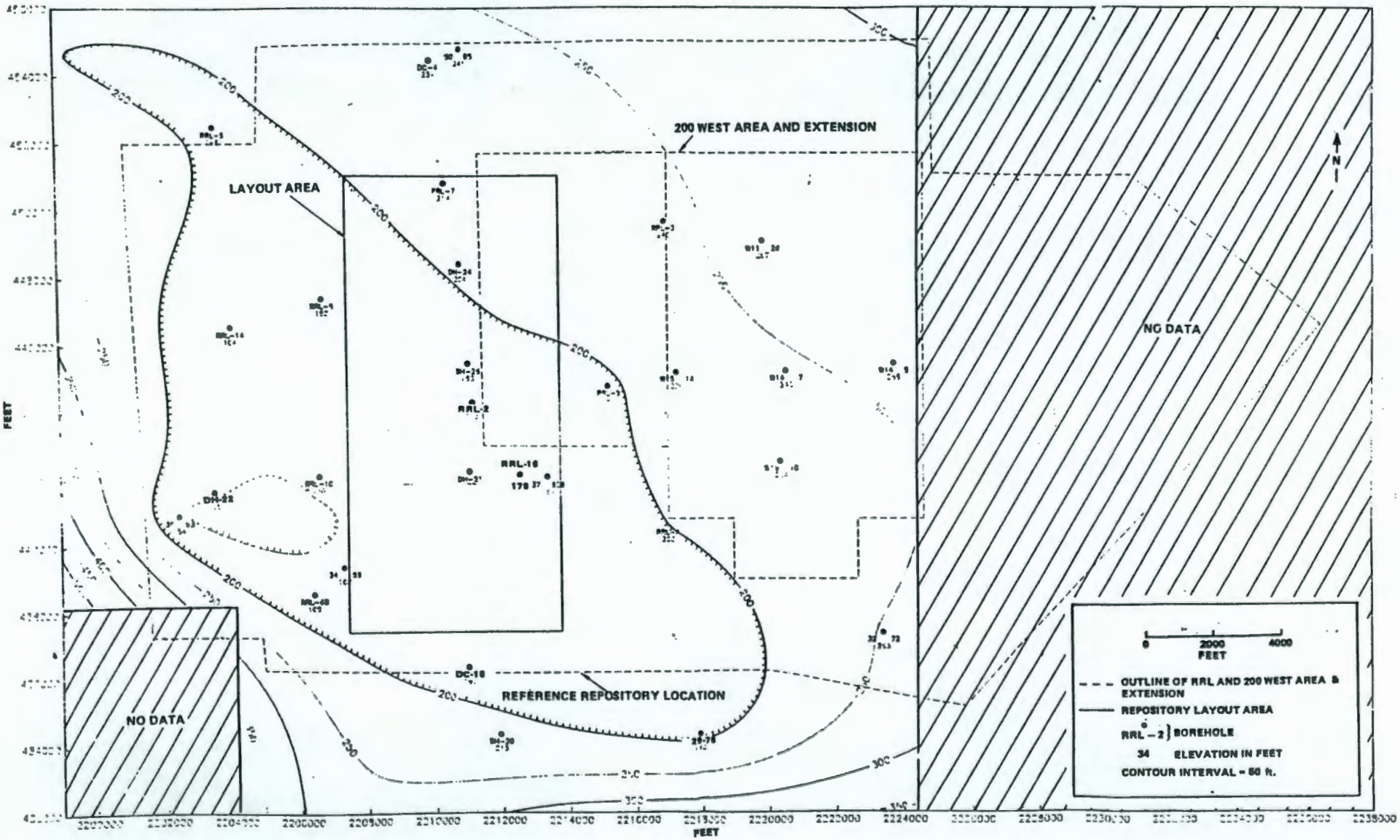

Figure A-6. Top of the Basal Ringold Unit Structure Contour Map.

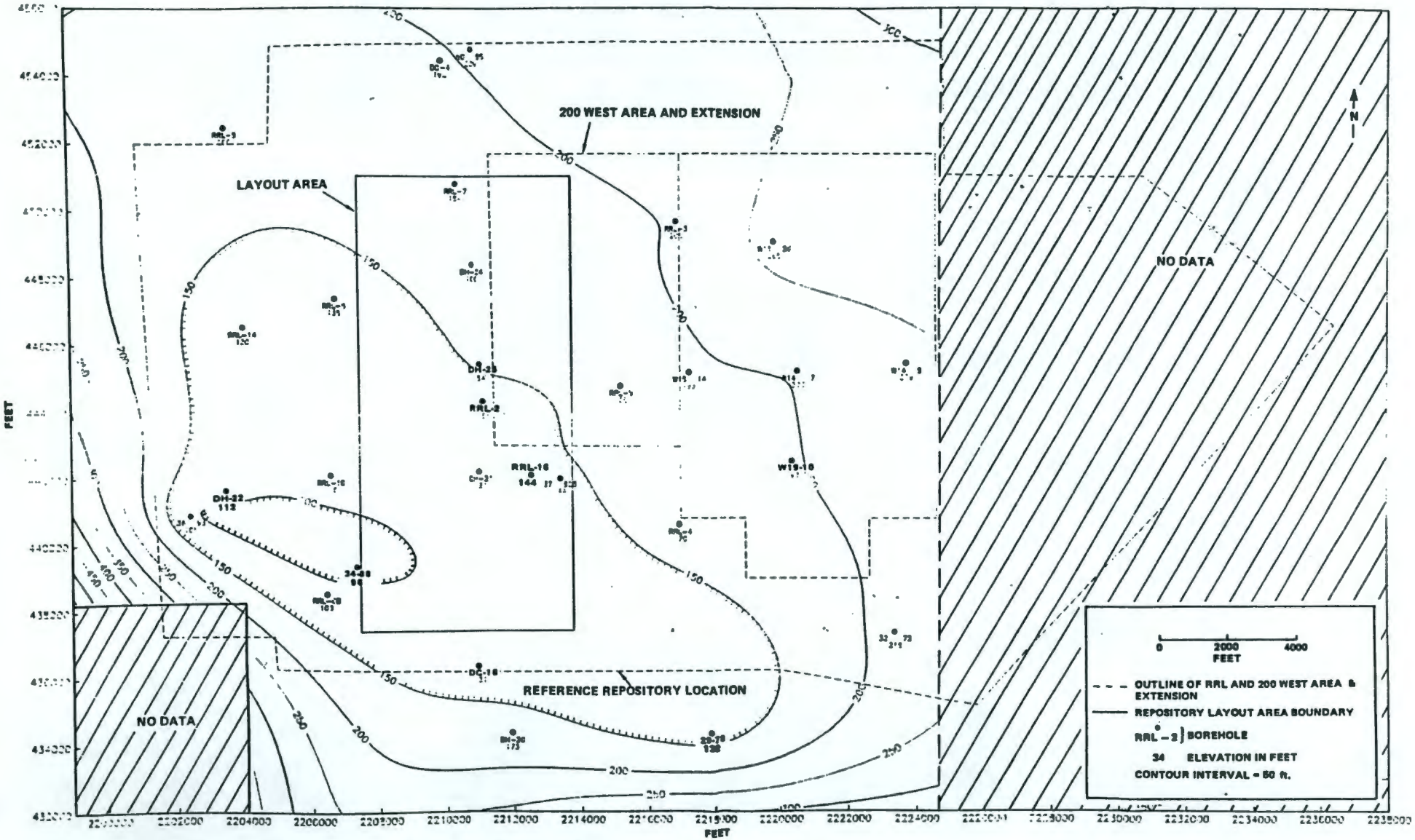

Figure A-7. Top of the Basal Ringold - Gravel Subunit Structure Contour Map.

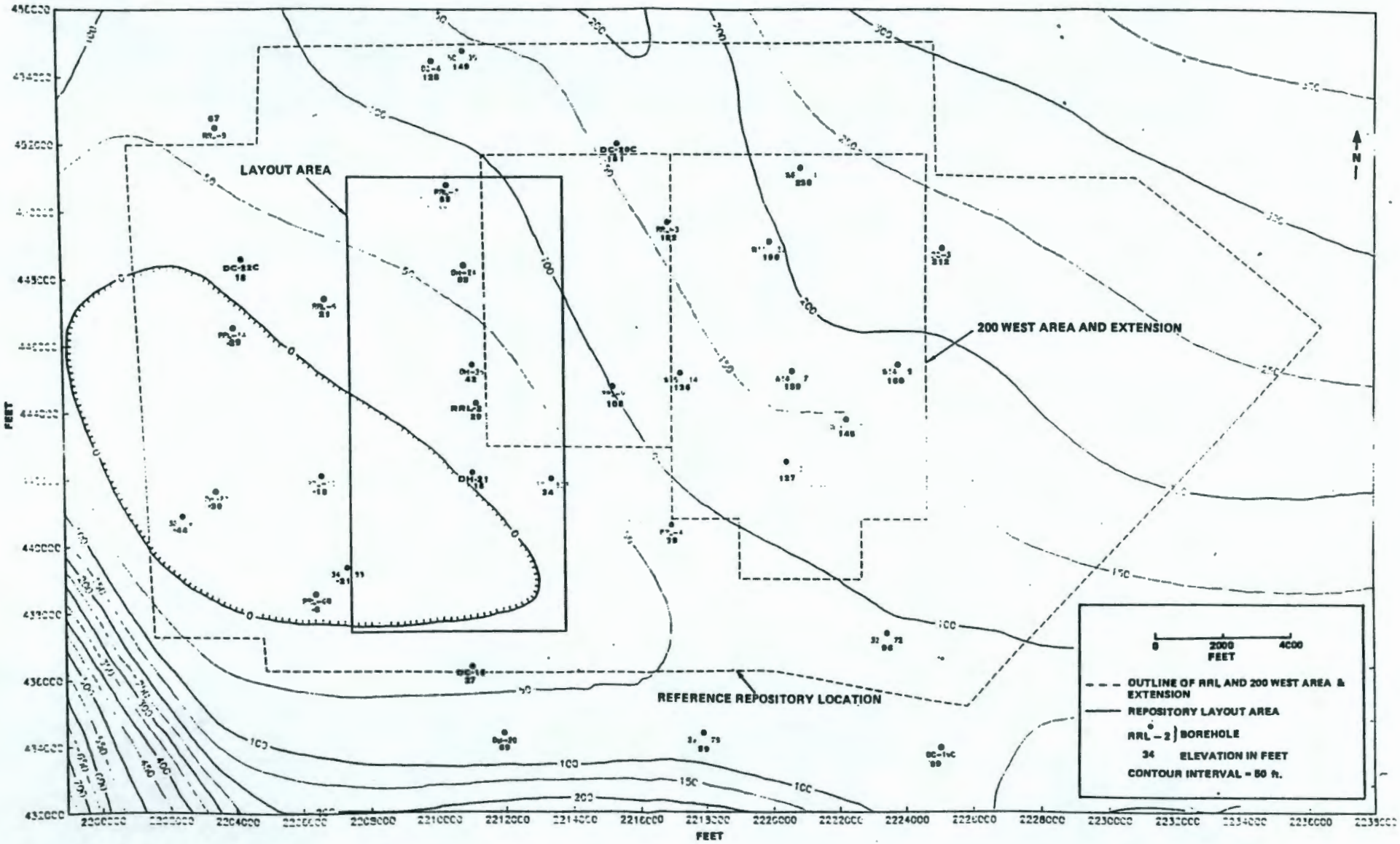

Figure A-8. Top of Basalt Structure Contour Map.

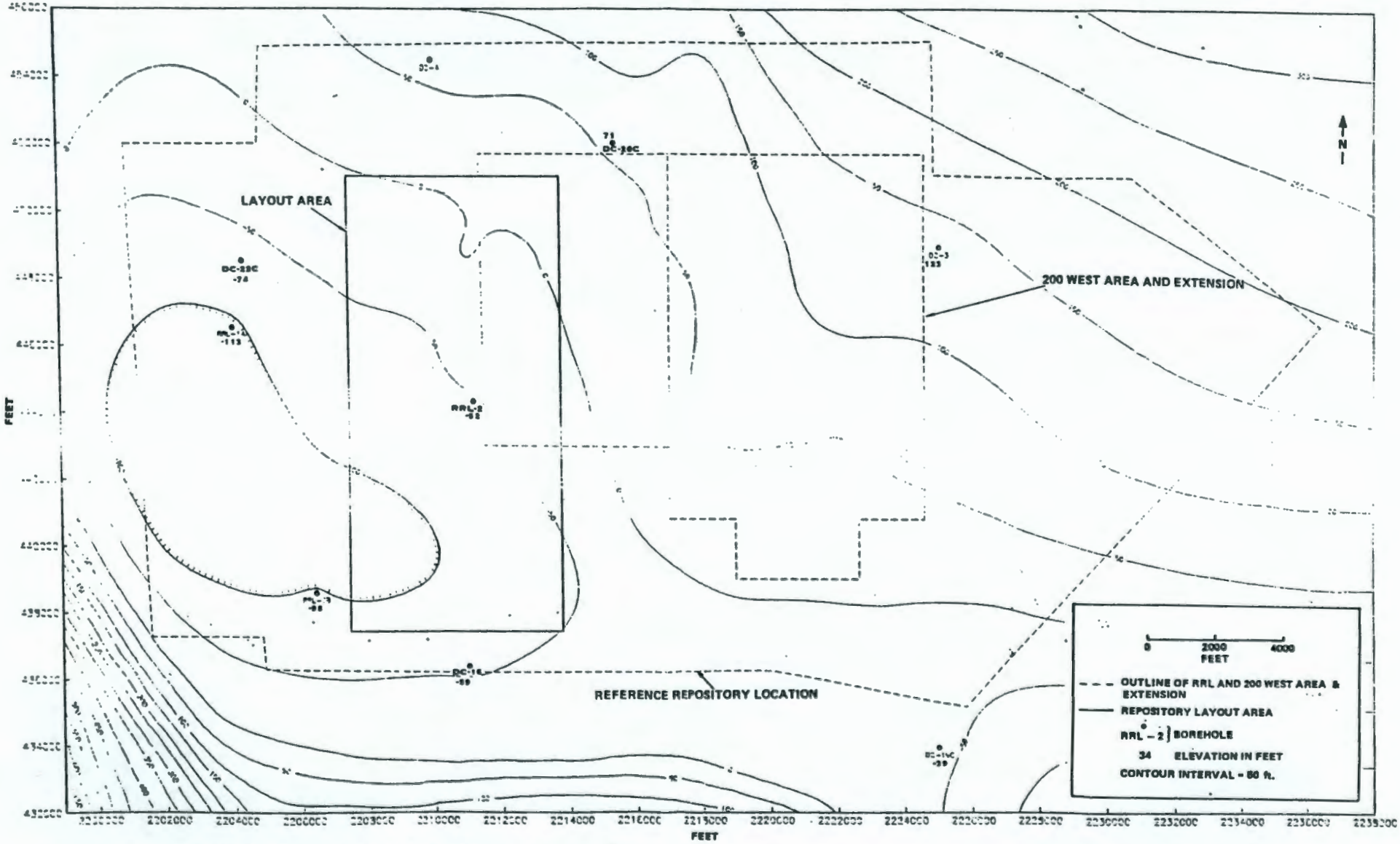

Figure A-9. Top of the Rattlesnake Ridge Interbed Structure Contour Map.

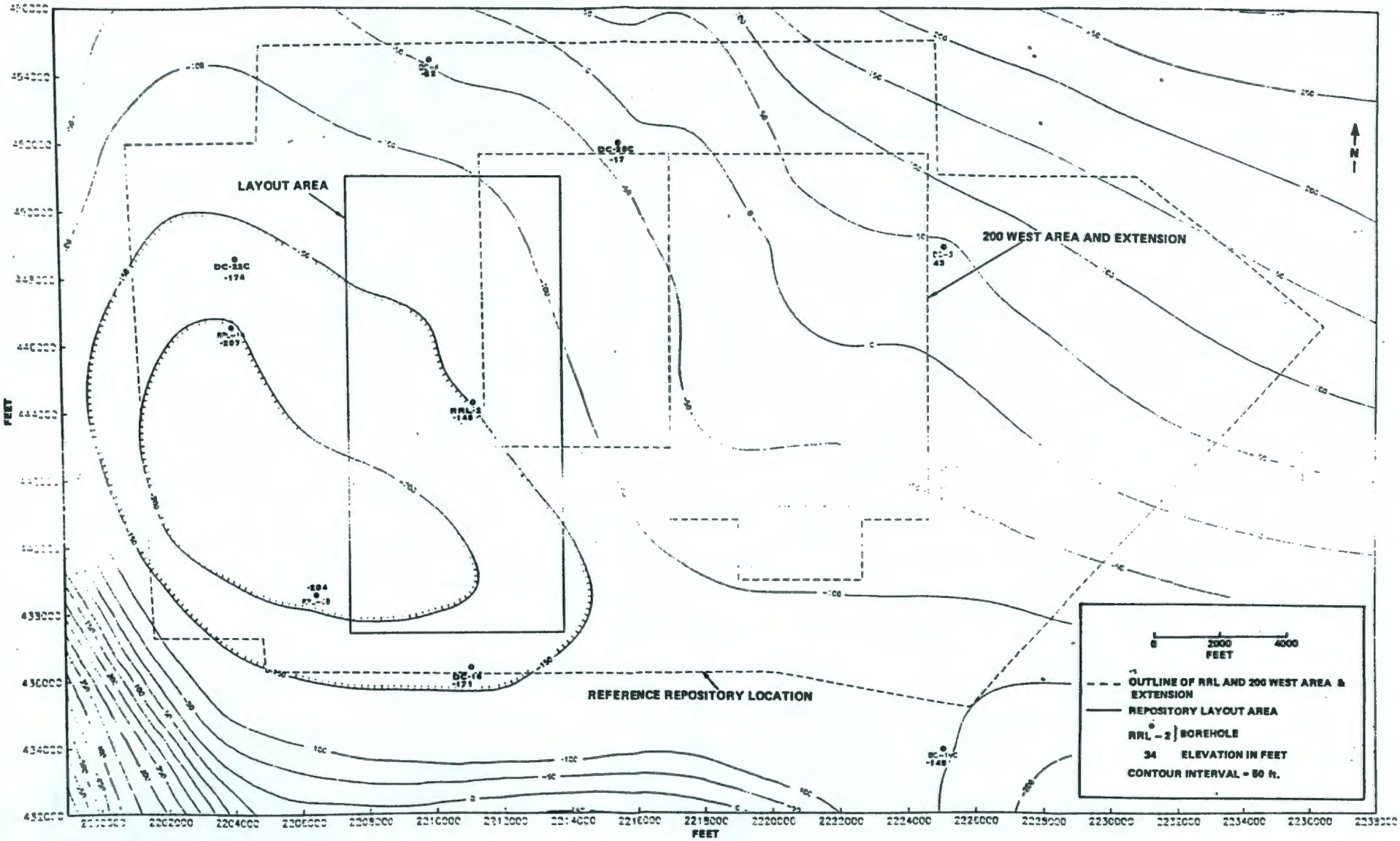

Figure A-10. Top of Pomona Member Structure Contour Map.

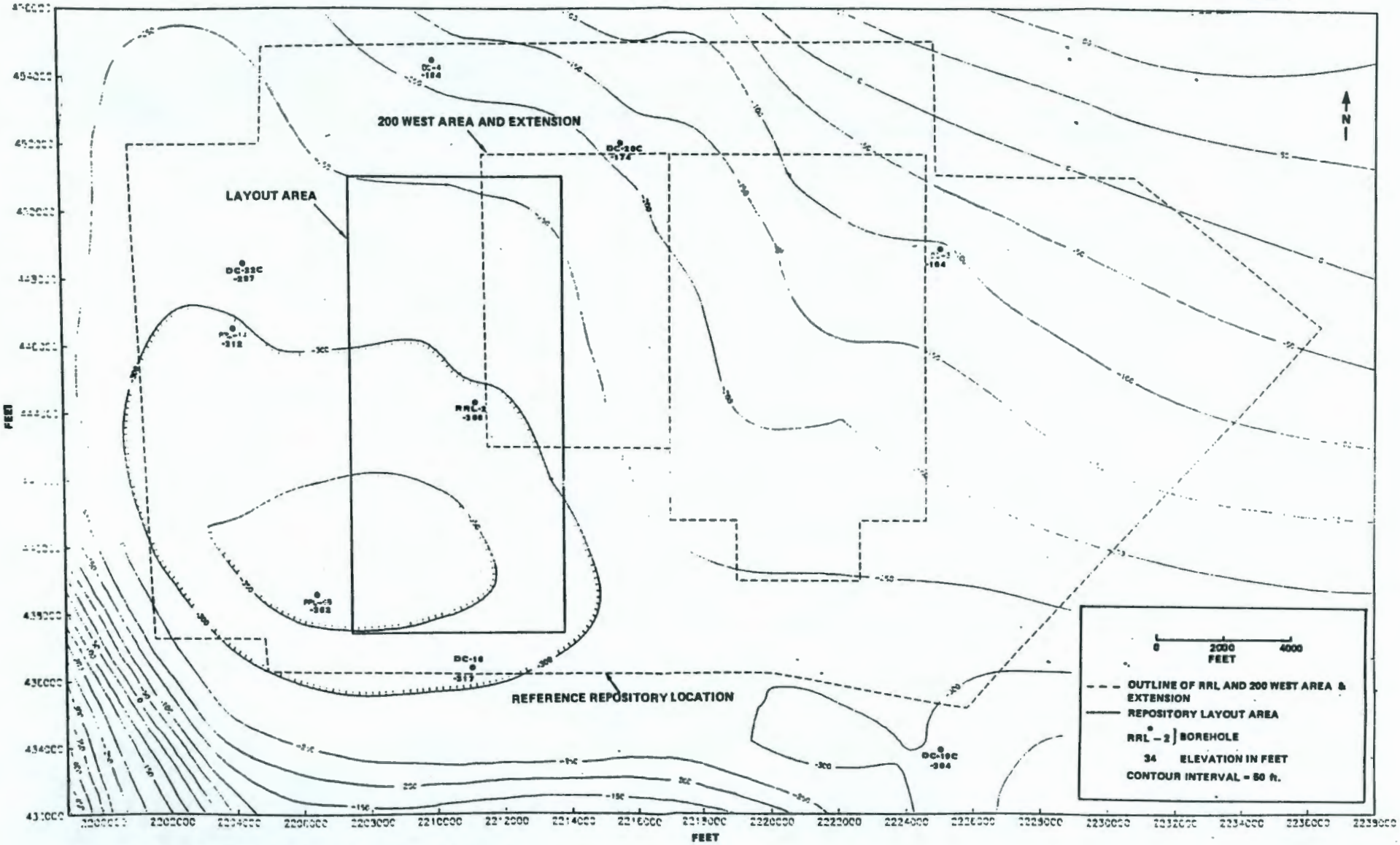

Figure A-11. Top of Selah Interbed Structure Contour Map.

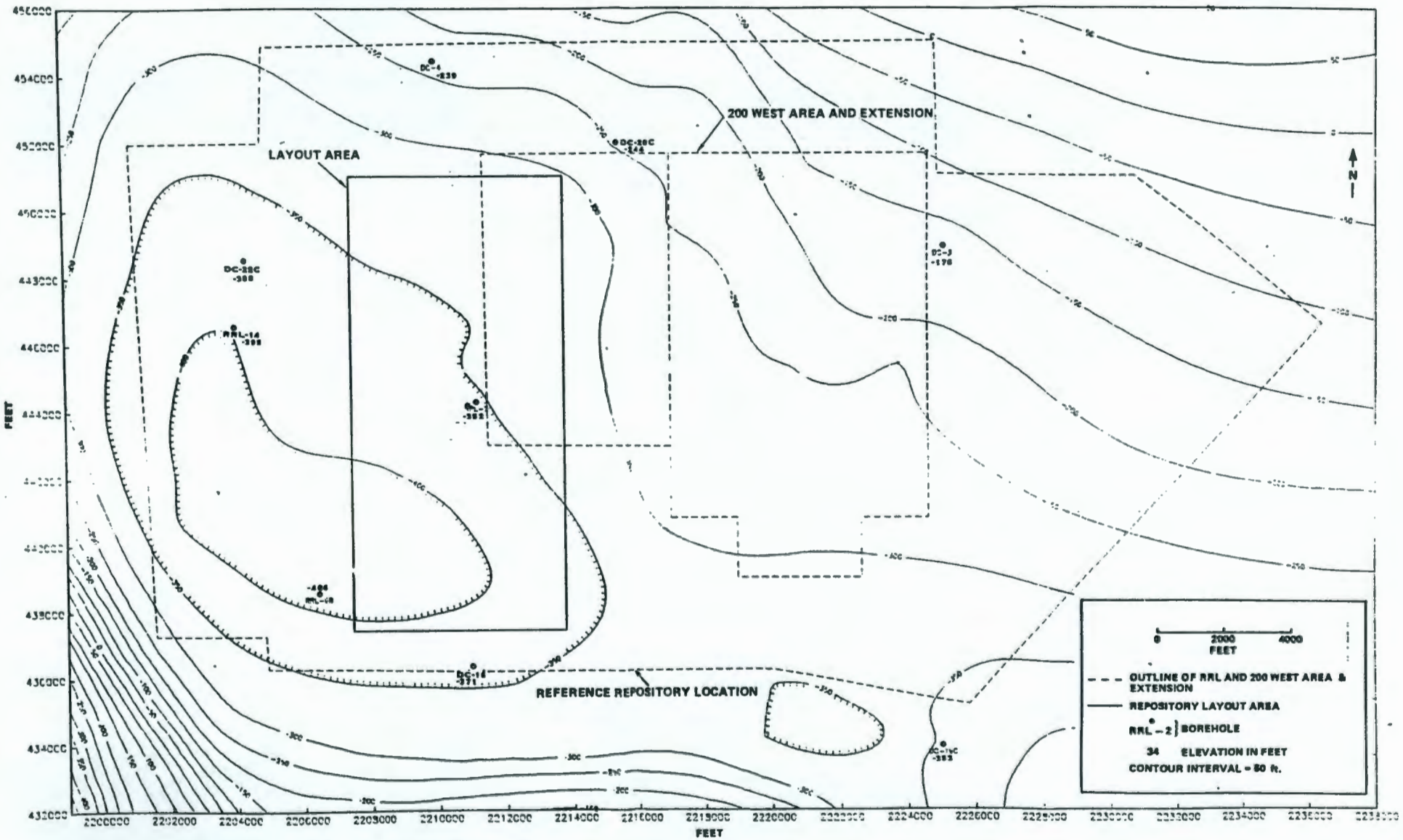

Figure A-12. Top of Esquatzel Member Structure Contour Map.

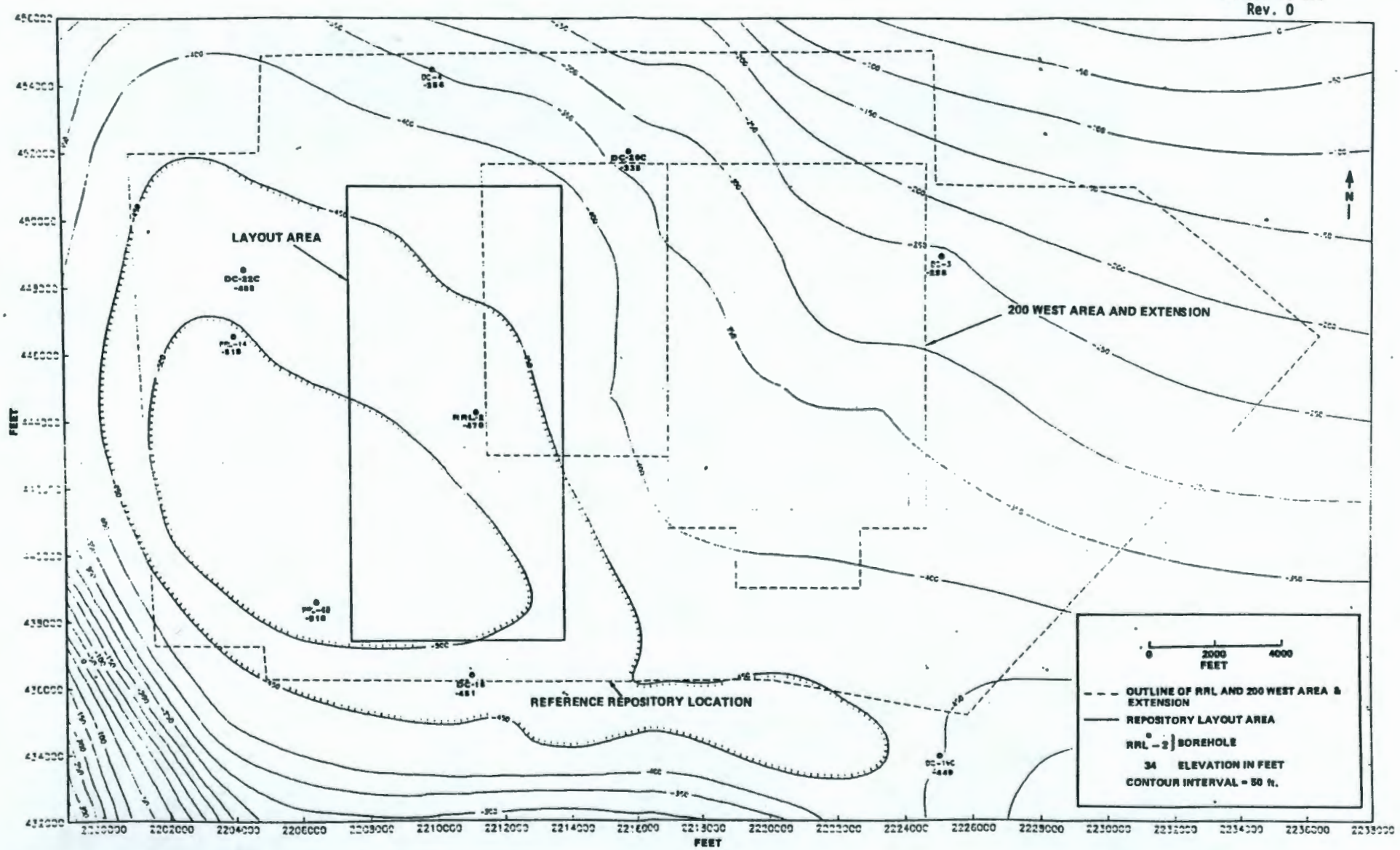

Figure A-13. Top of Cold Creek Interbed Structure Contour Map.

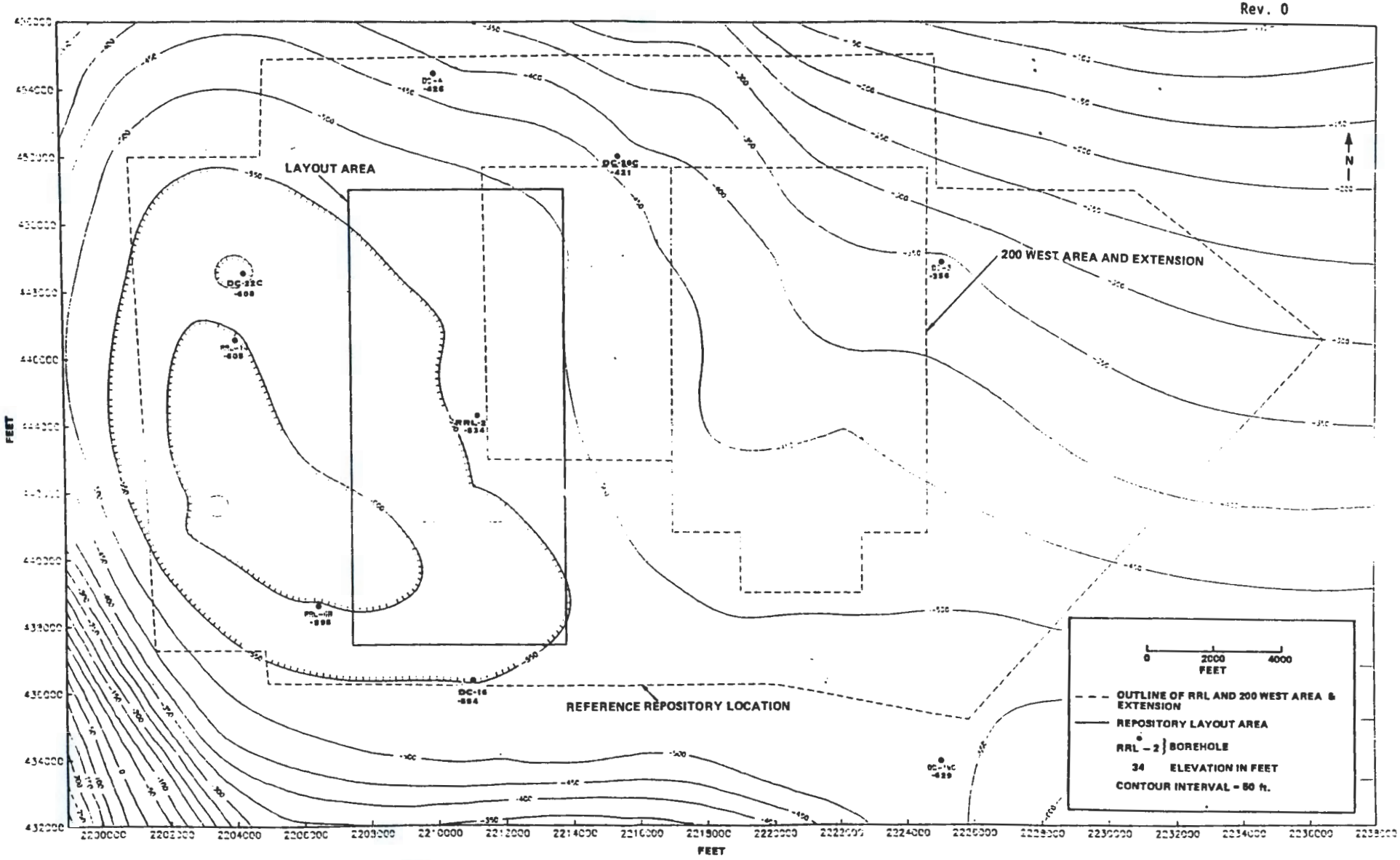

Figure A-14. Top of Umatilla Member Structure Contour Map.

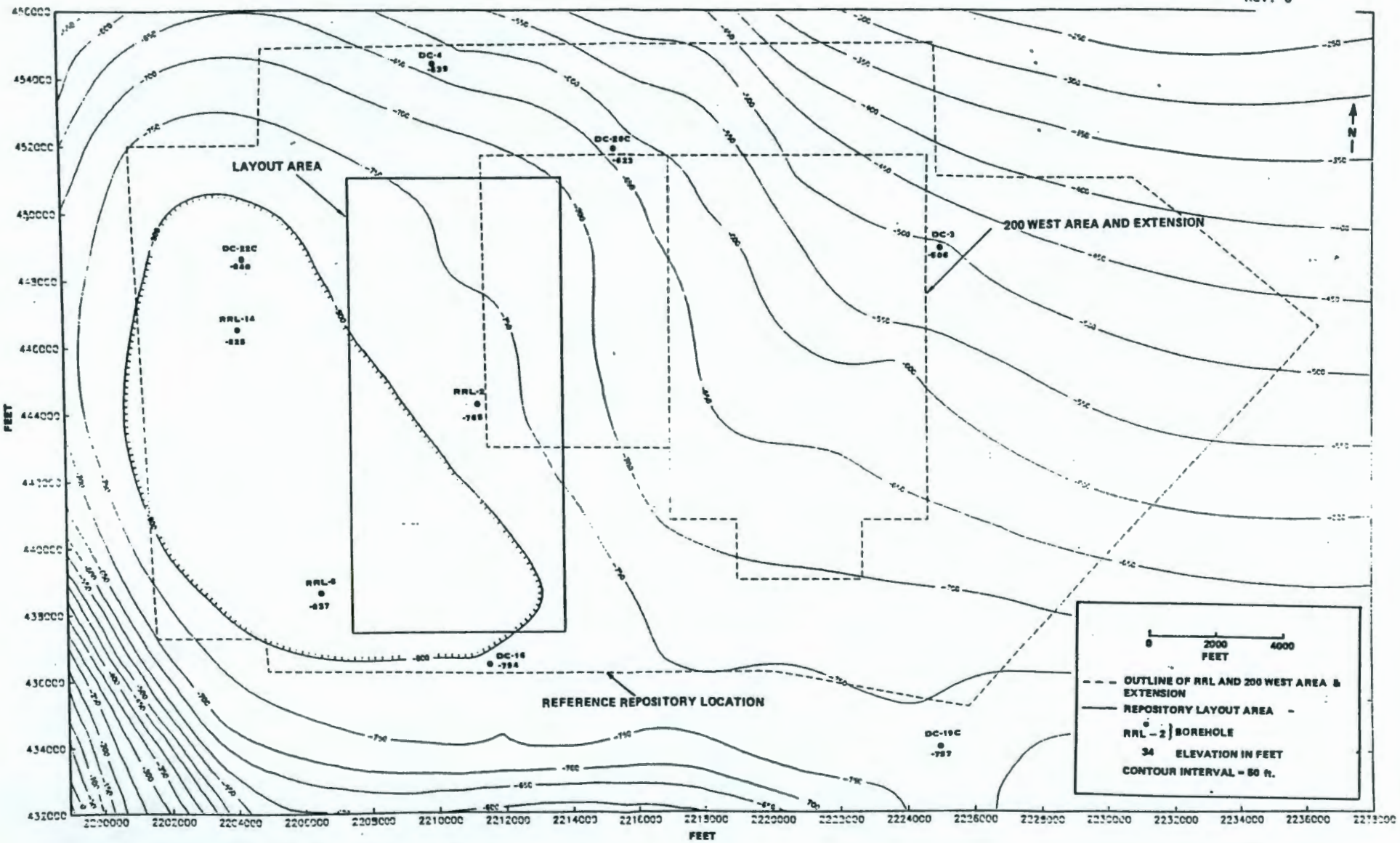

Figure A-15. Top of Mabton Interbed Structure Contour Map.

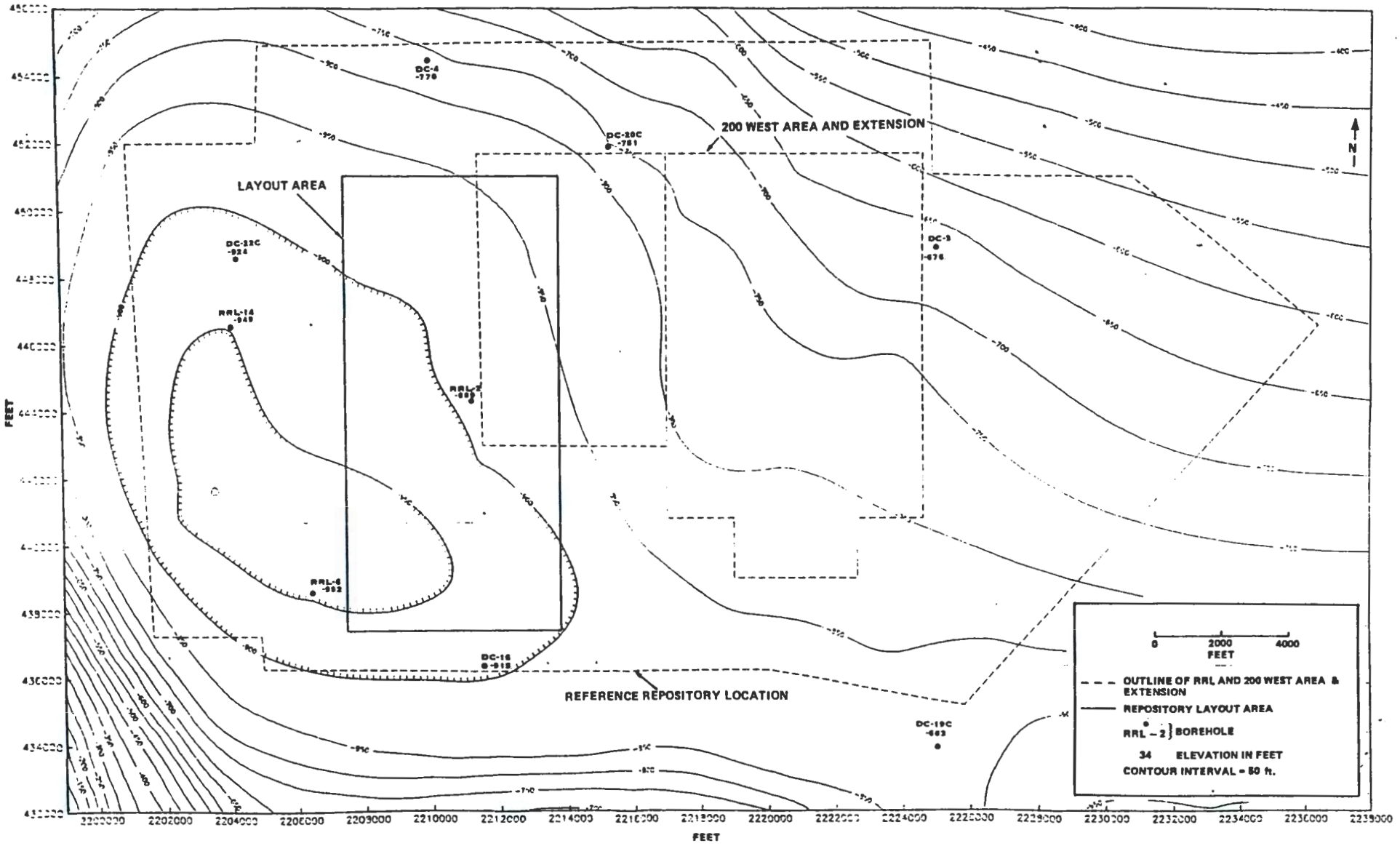

Figure A-16. Top of Wanapum Basalt Structure Contour Map.

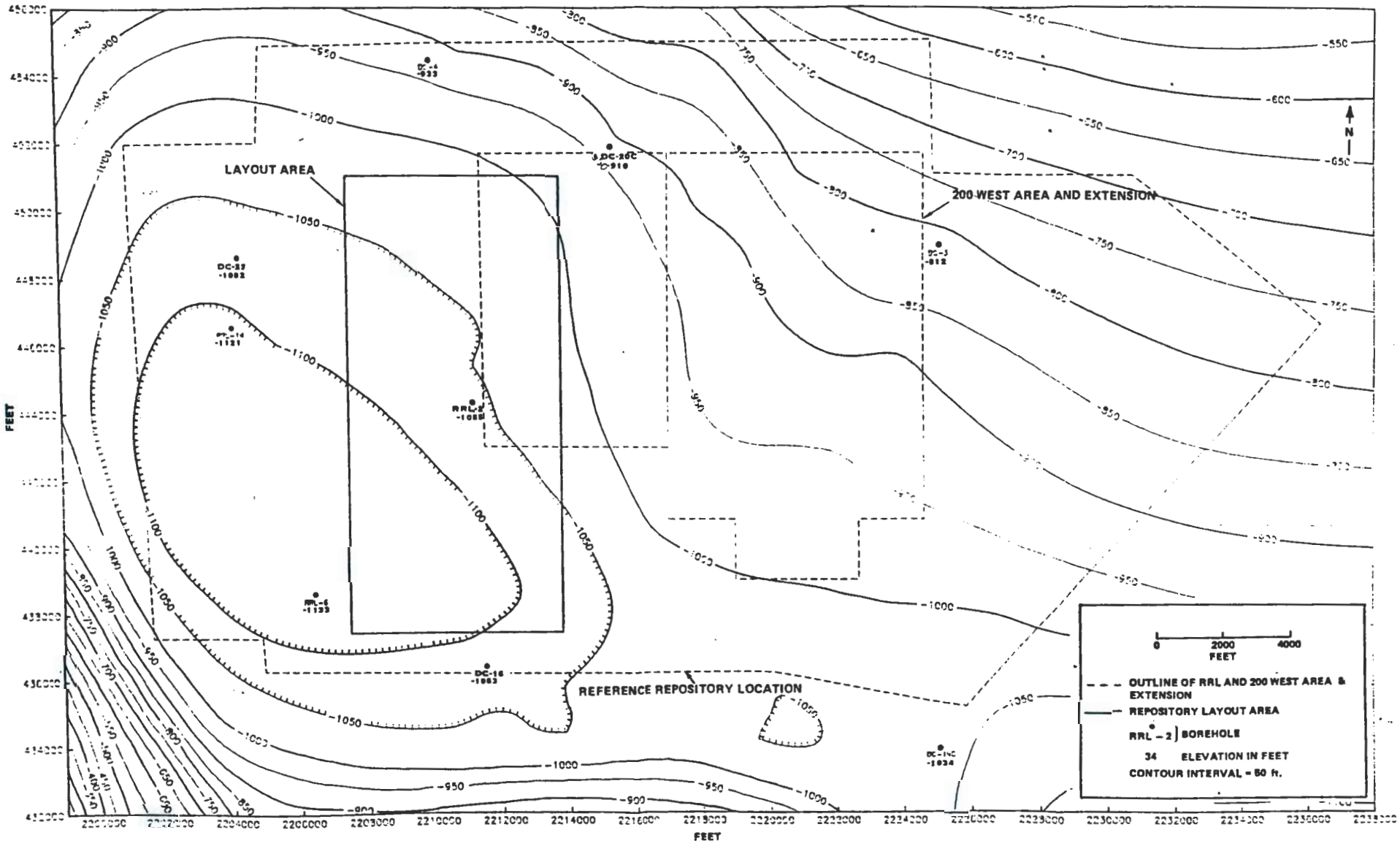

Figure A-17. Top of Rosalia Flow (Priest Rapids Member) Structure Contour Map.

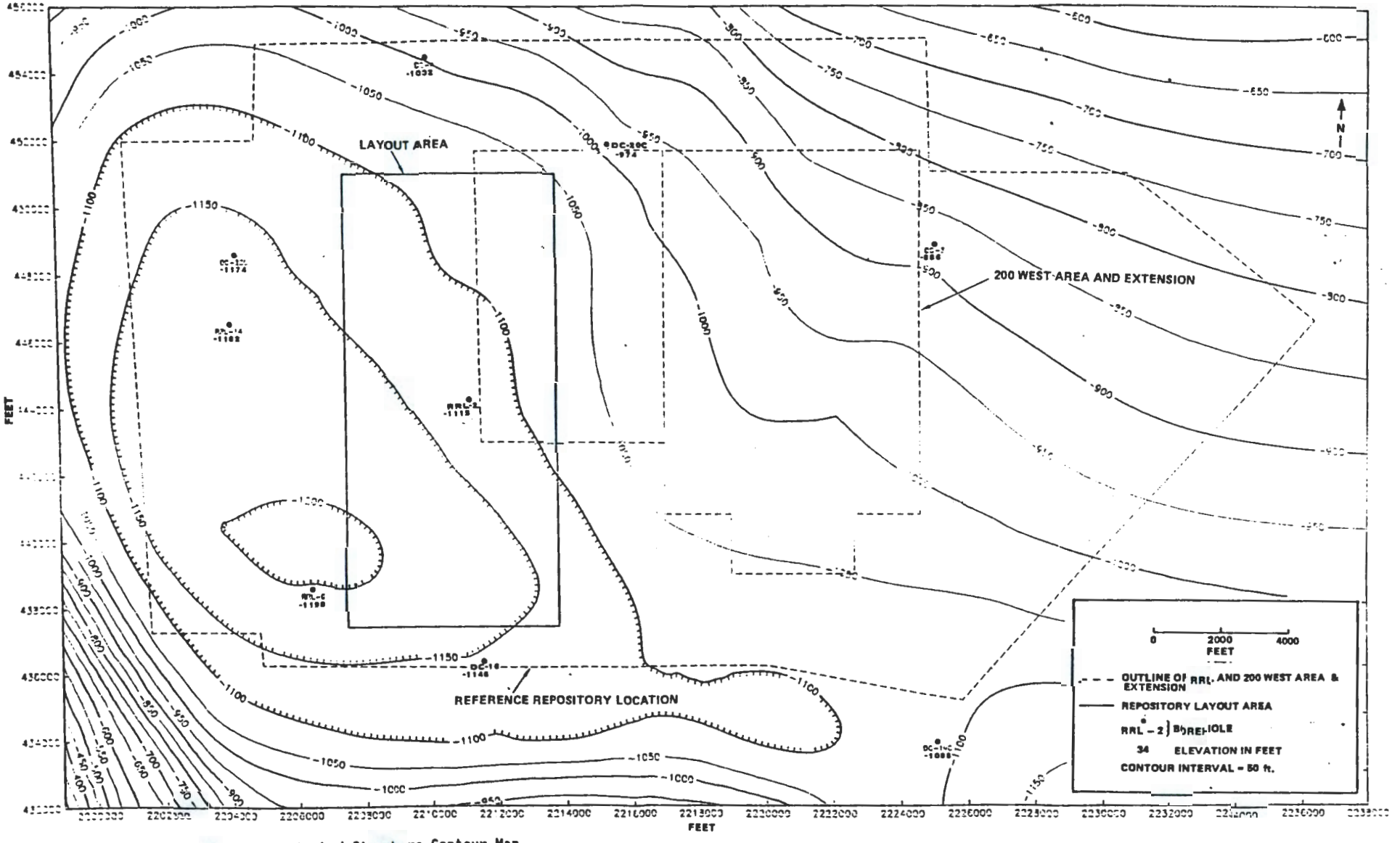

Figure A-18. Top of Quincy Interbed Structure Contour Map.

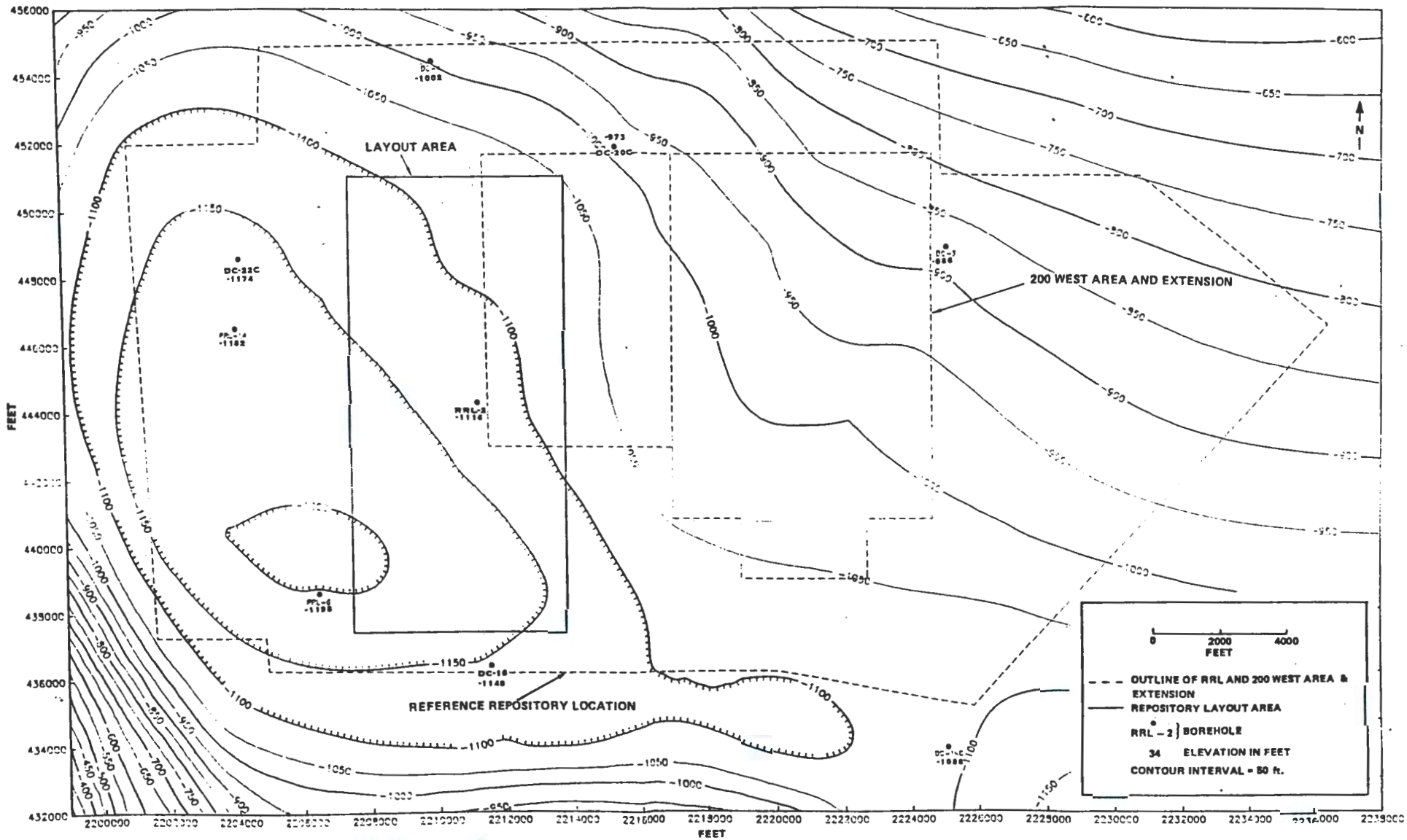

Figure A-19. Top of Roza Member Structure Contour Map.

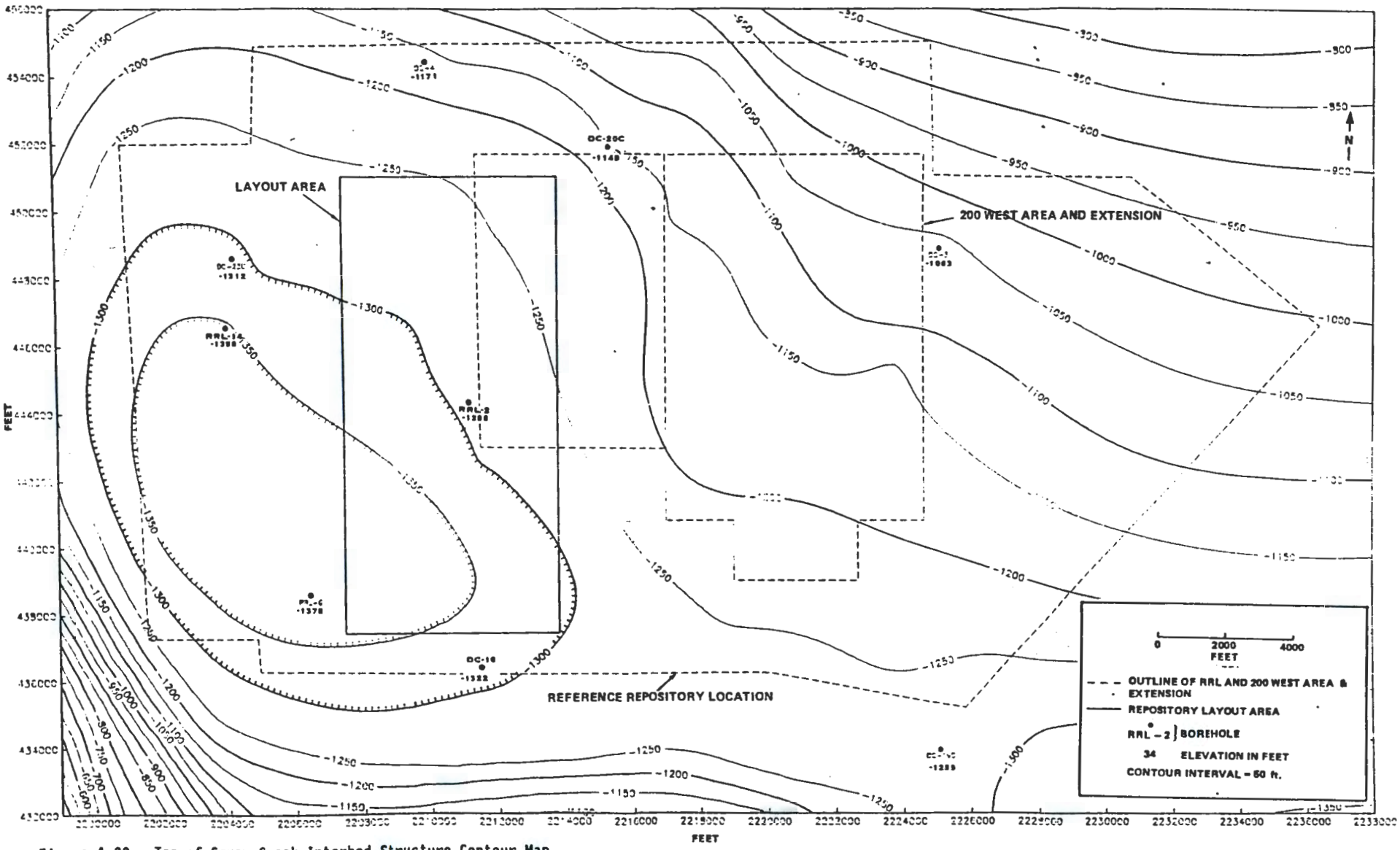

Figure A-20. Top of Squaw Creek Interbed Structure Contour Map.

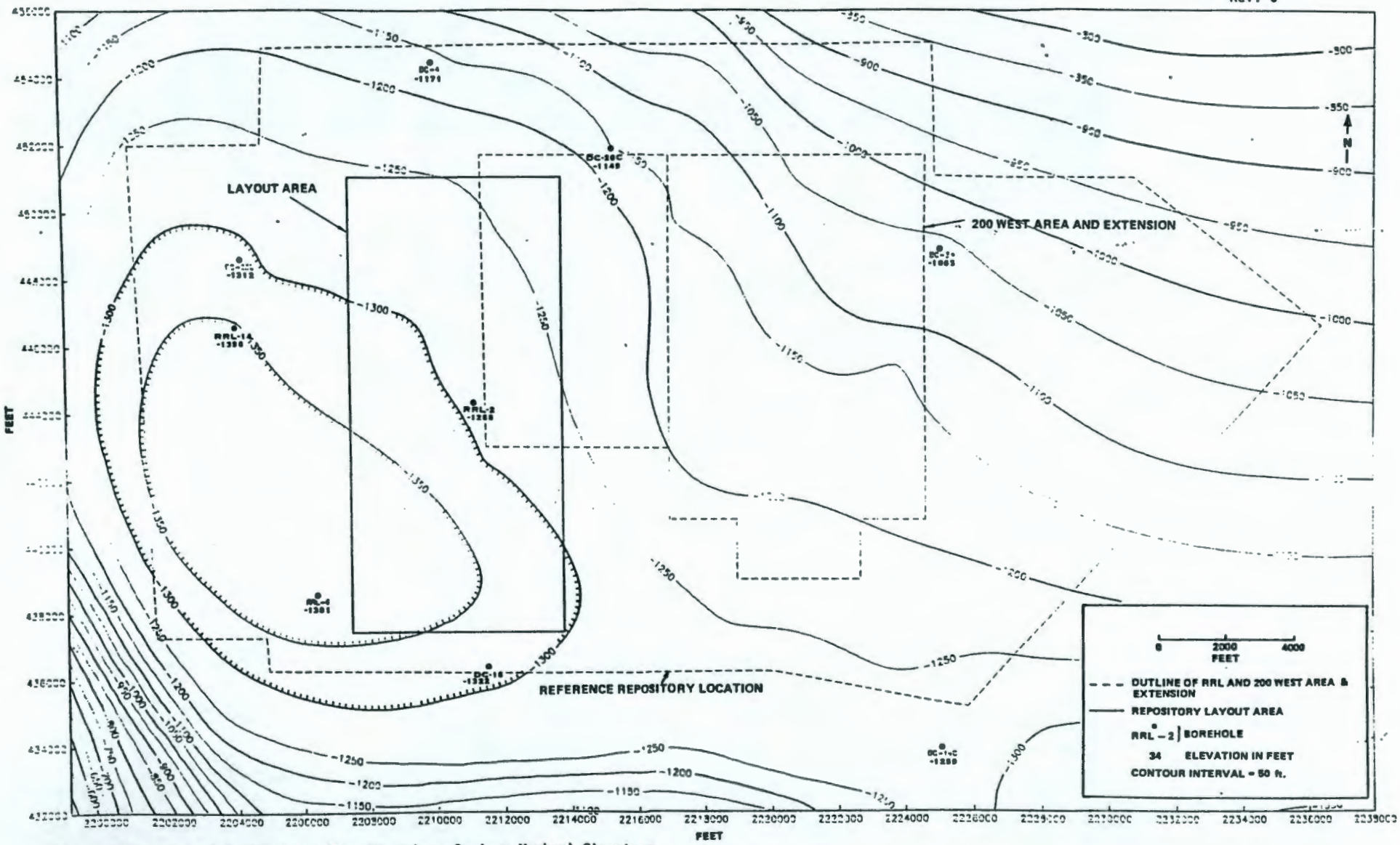

Figure A-21. Top of Sentinel Gap Flow (Frenchman Springs Member) Structure Contour Map.

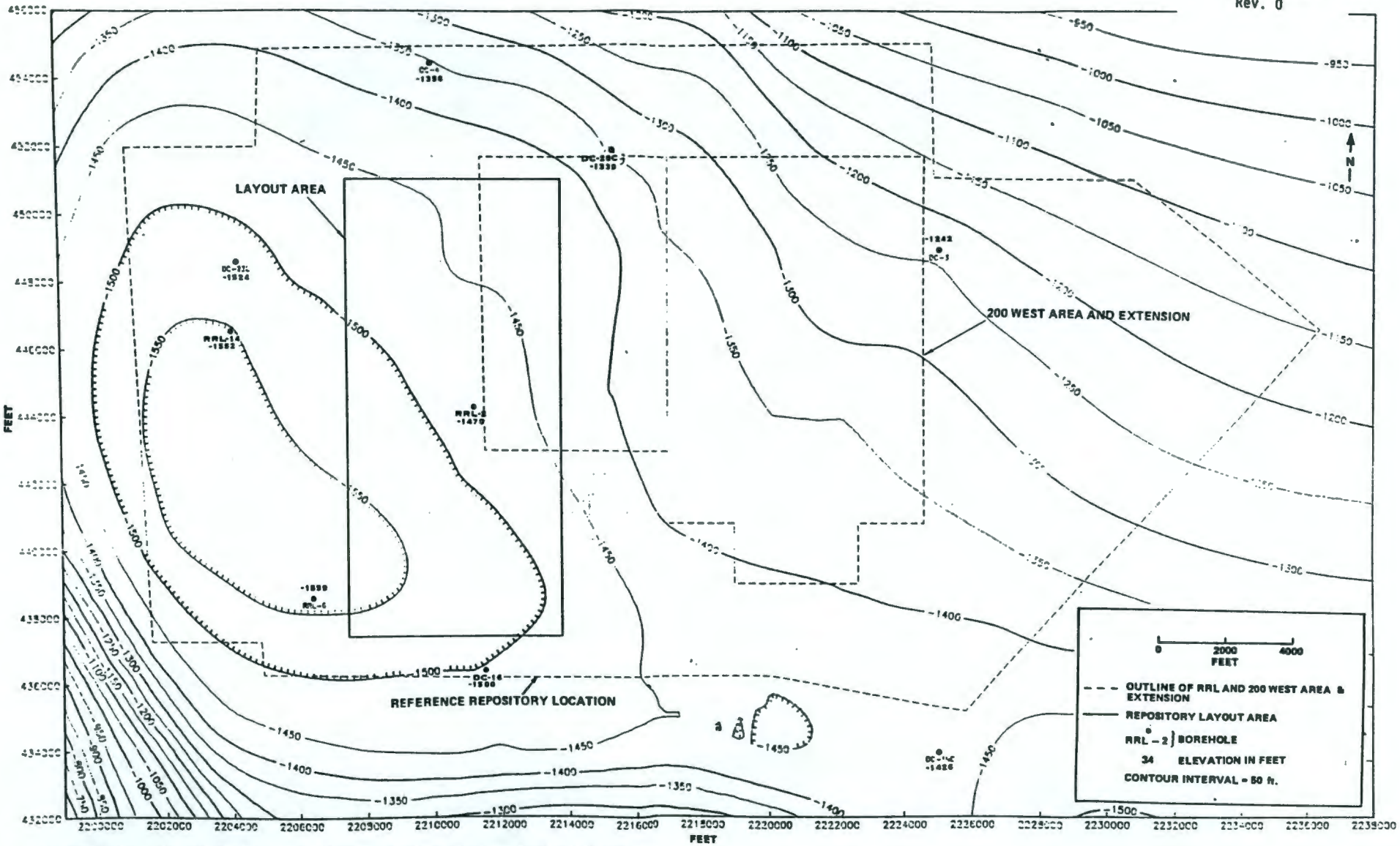

Figure A-22. Top of Sand Hollows Flows (Frenchman Springs Member) Structure Contour Map.

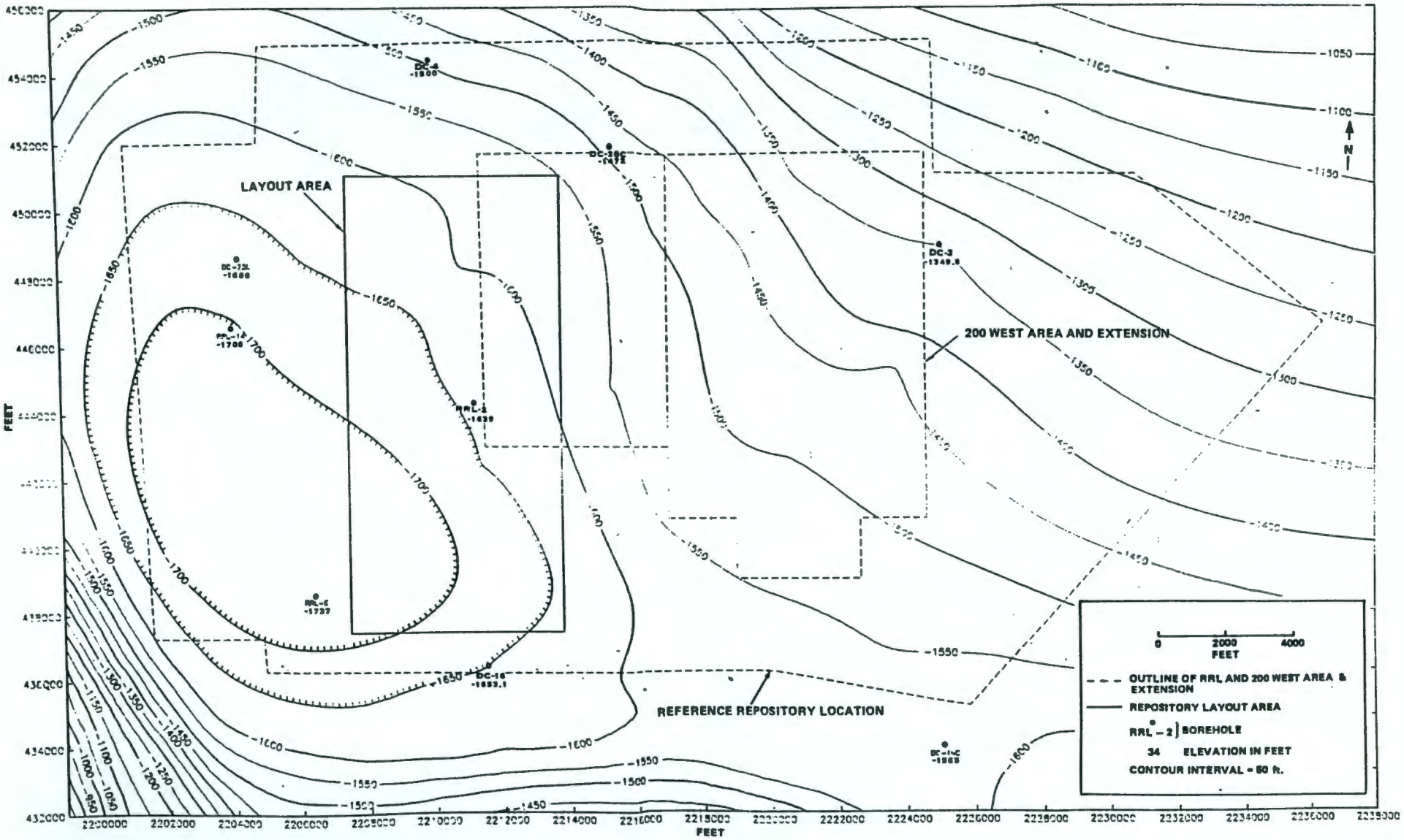

Figure A-23. Top of Silver Falls Flows (Frenchman Springs Member) Structure Contour Map.

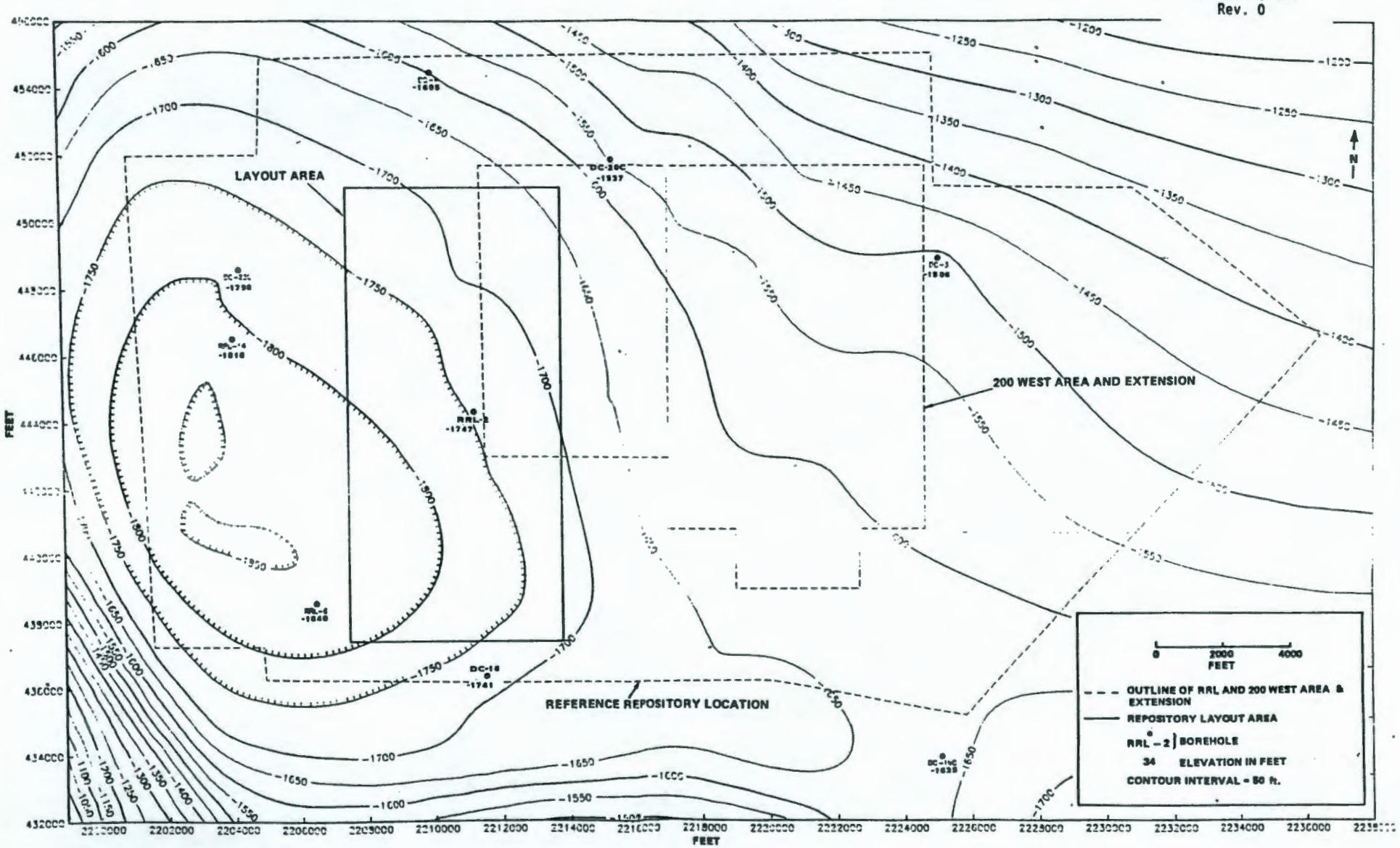

Figure A-24. Top of Ginkgo Flows (Frenchman Springs Member) Structure Contour Map.

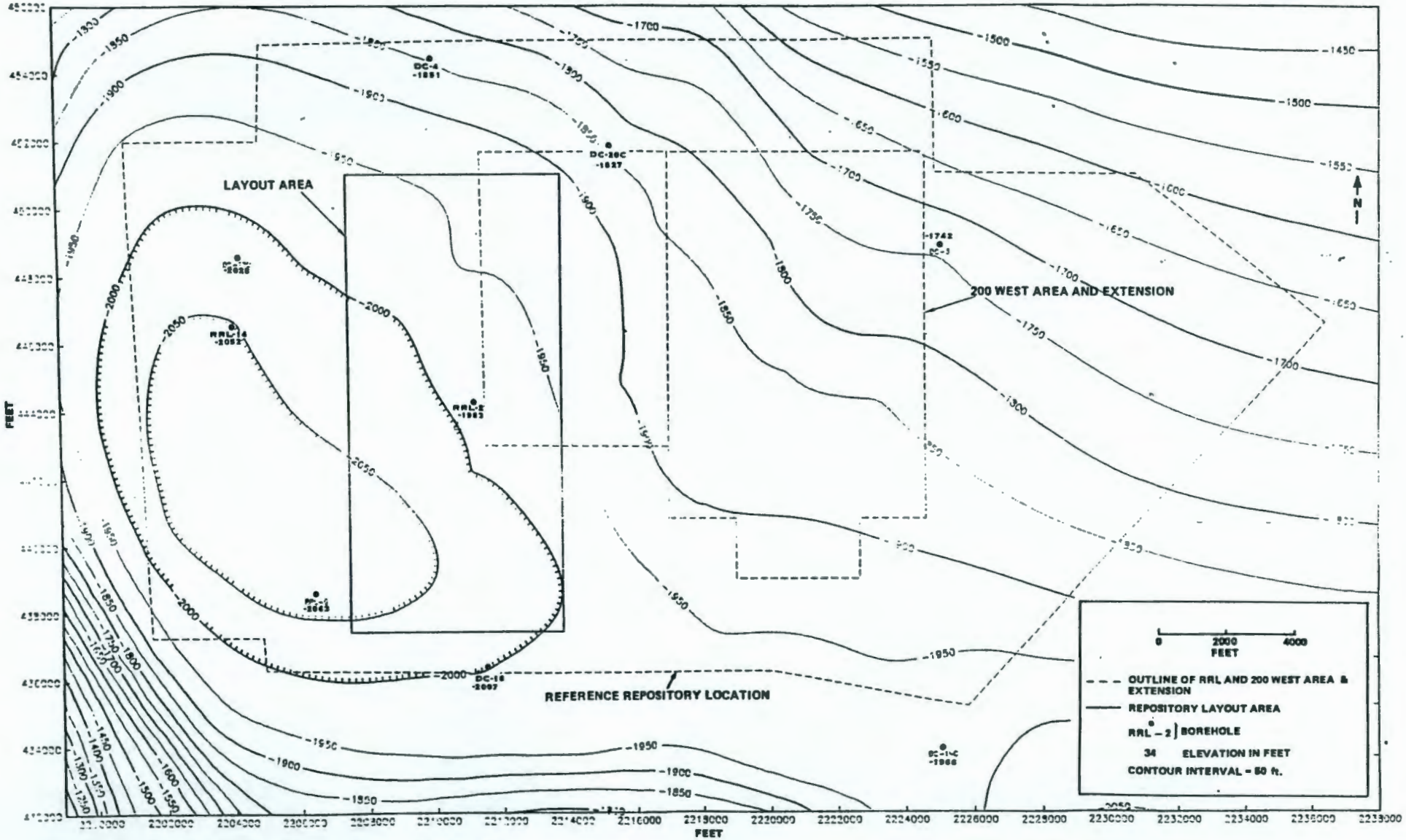

Figure A-25. Top of Unnamed Interbed Structure Contour Map.

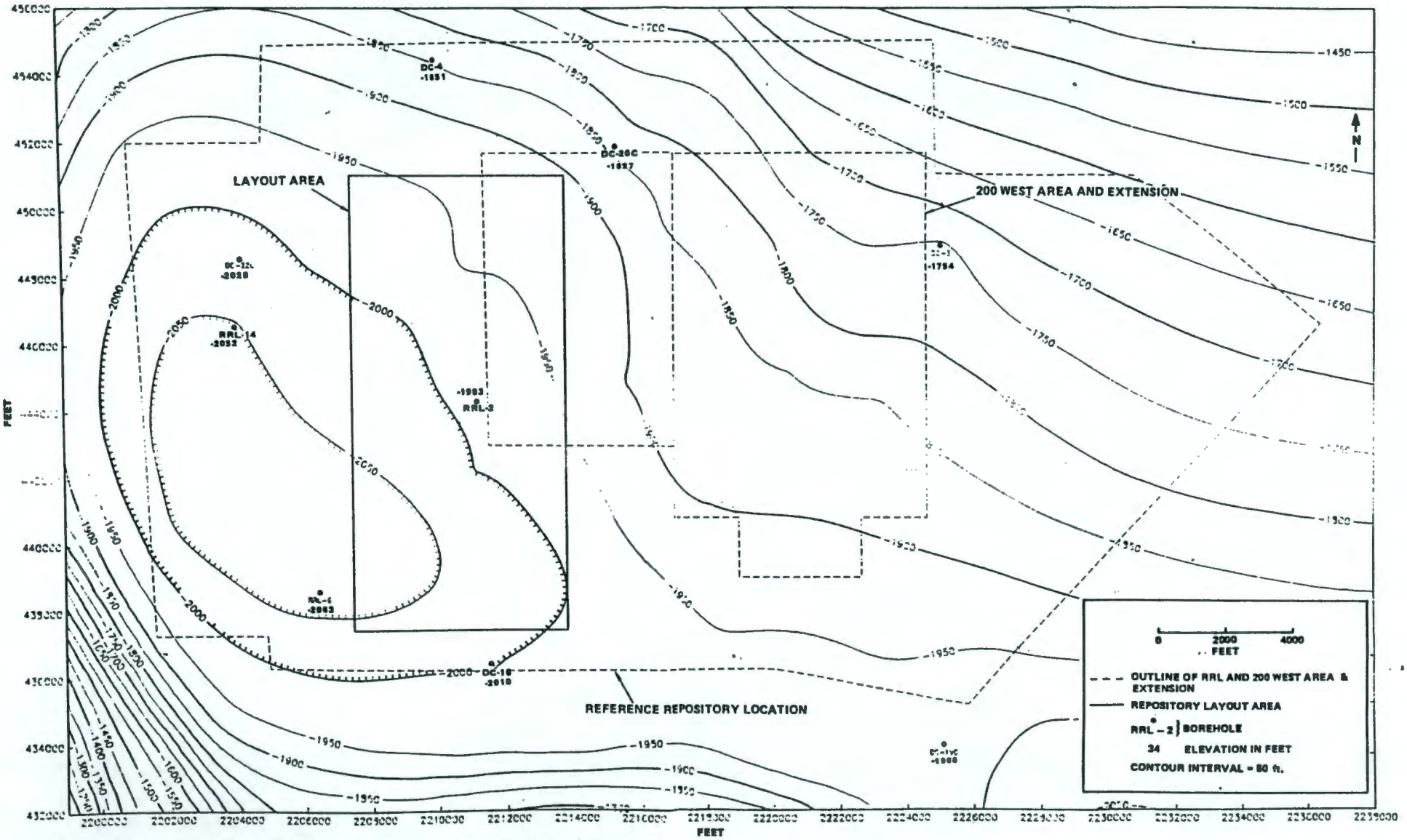

Figure A-26. Top of Palouse Falls Flow (Frenchman Springs Member) Structure Contour Map.

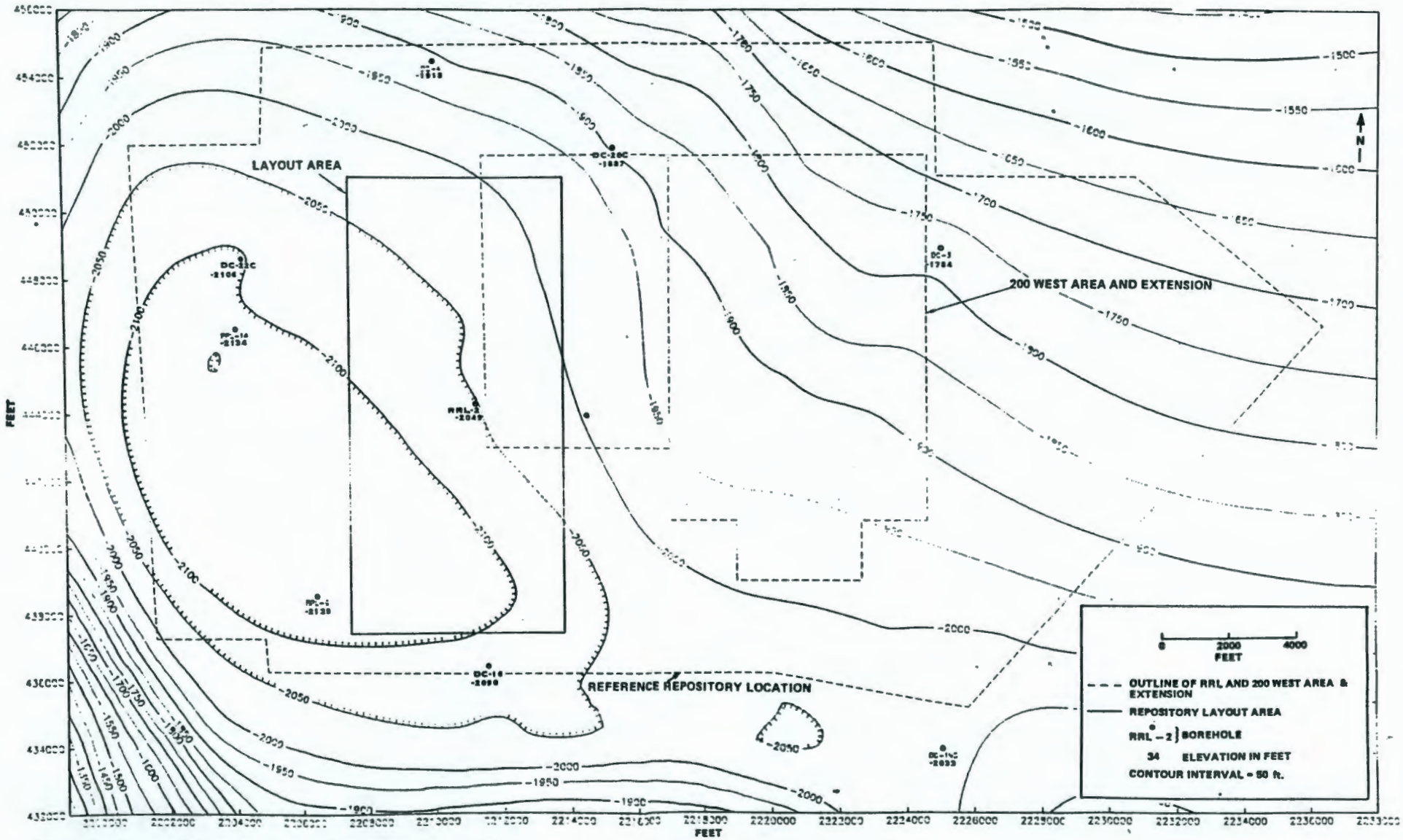

Figure A-27. Top of Vantage Interbed Structure Contour Map.

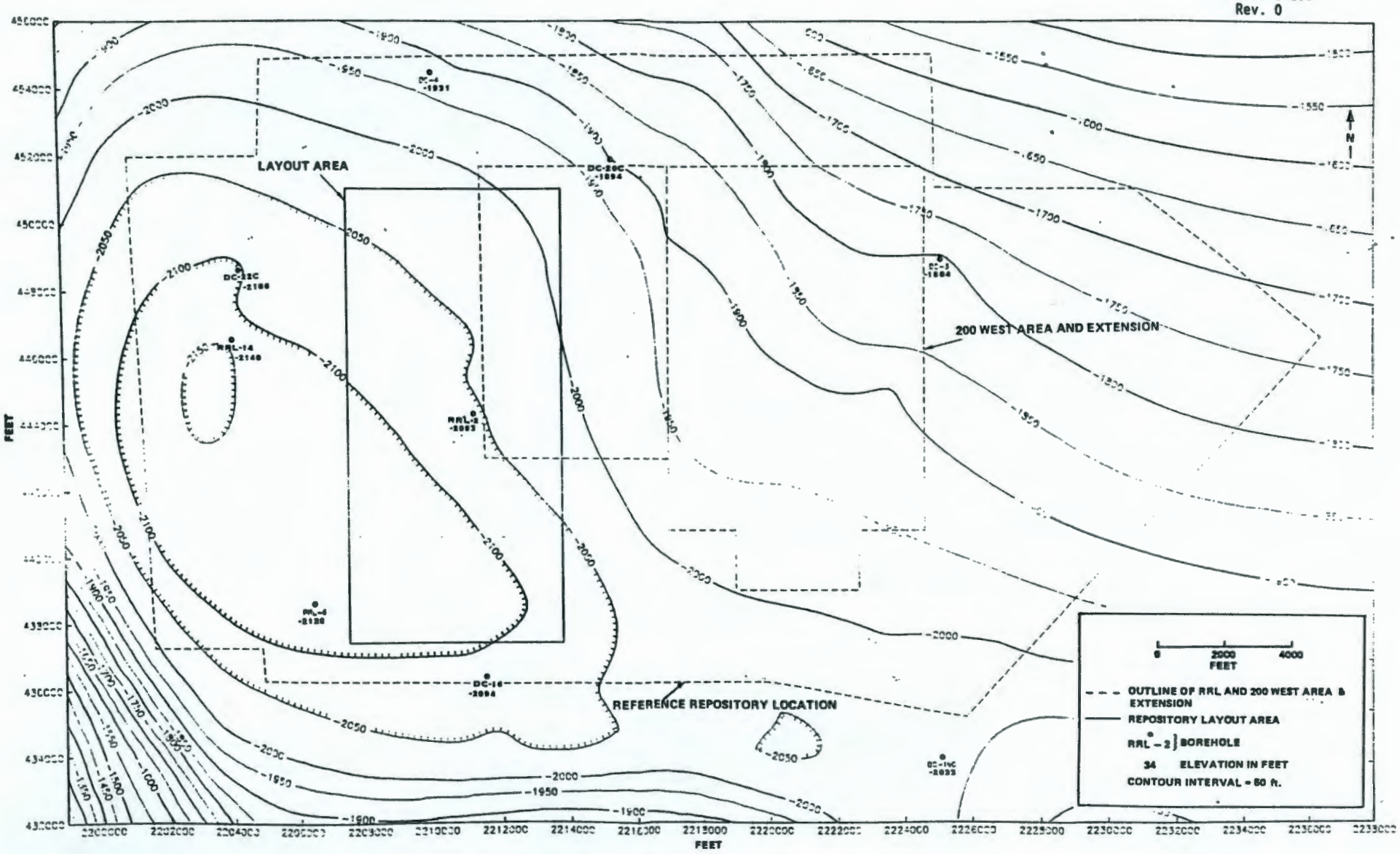

Figure A-28. Top of Grande Ronde Basalt Structure Contour Map.

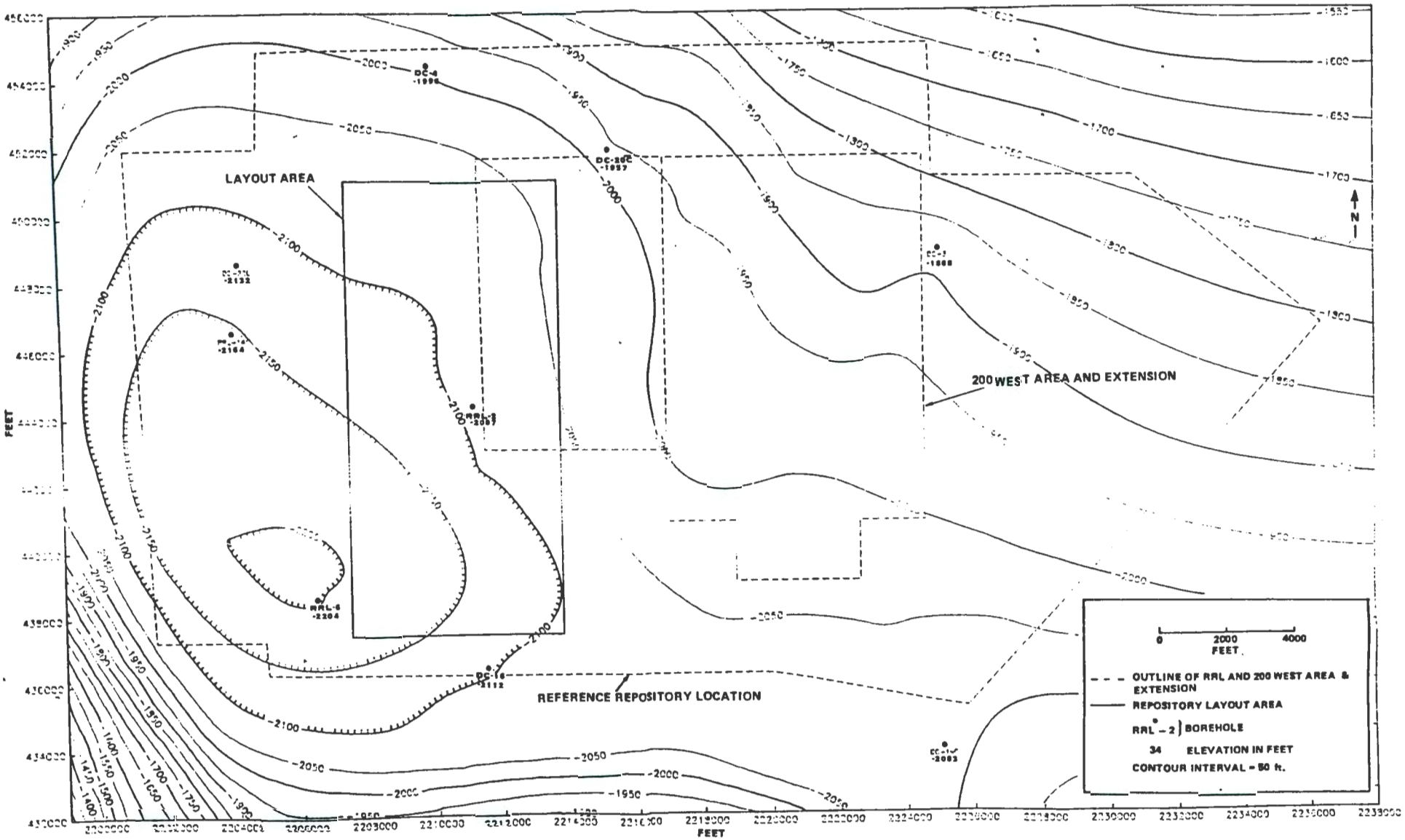

Figure A-29. Top of Grande Ronde Flow 3 Structure Contour Map.

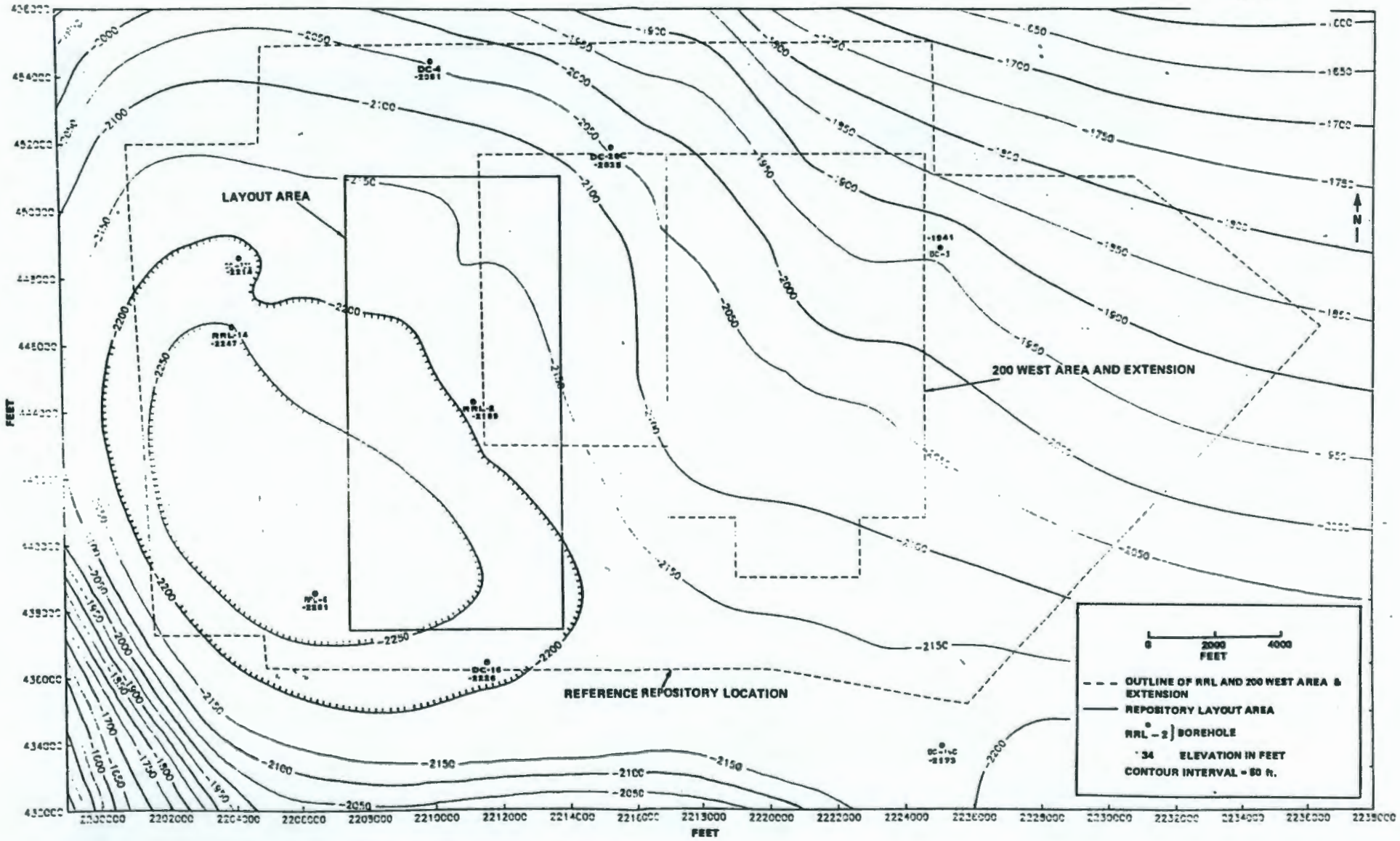

Figure A-30. Top of Rocky Coulee Flow (Grande Ronde Flow 4) Structure Contour Map.

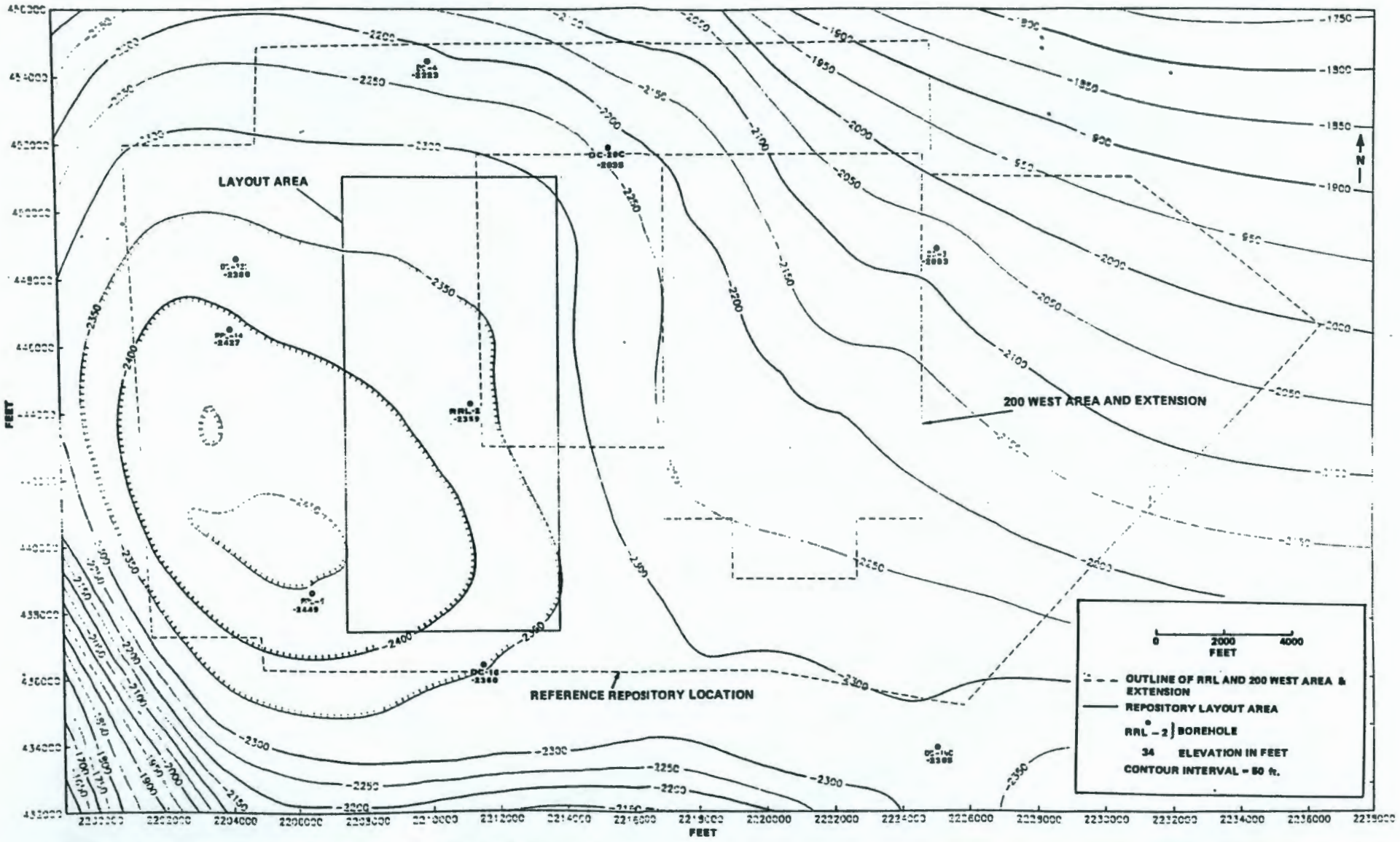

Figure A-31. Top of Levering Flow (Grande Ronde Flow 5) Structure Contour Map.

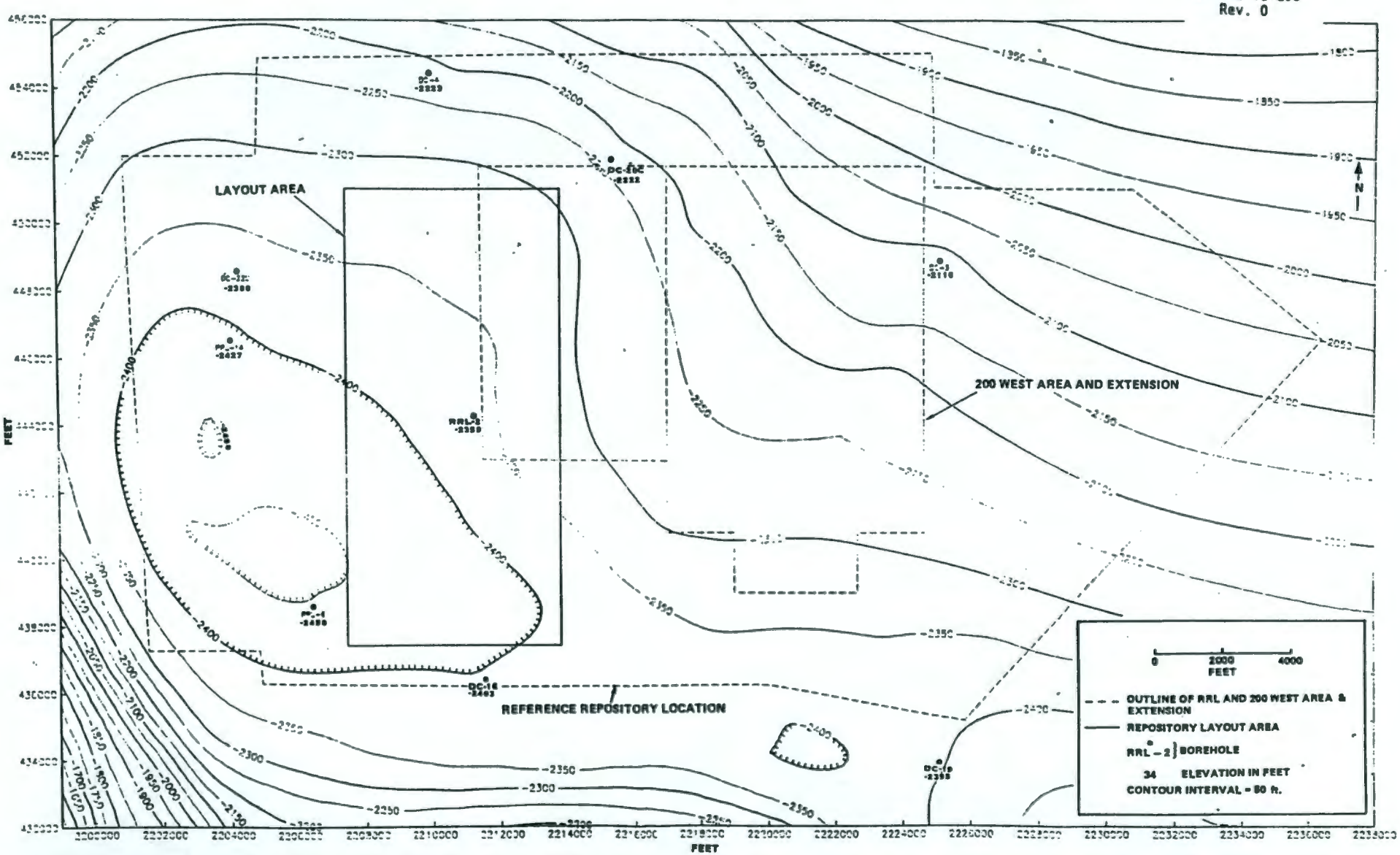

Figure A-32. Top of Cohassett Flow (Grande Ronde Flow 6) Structure Contour Map.

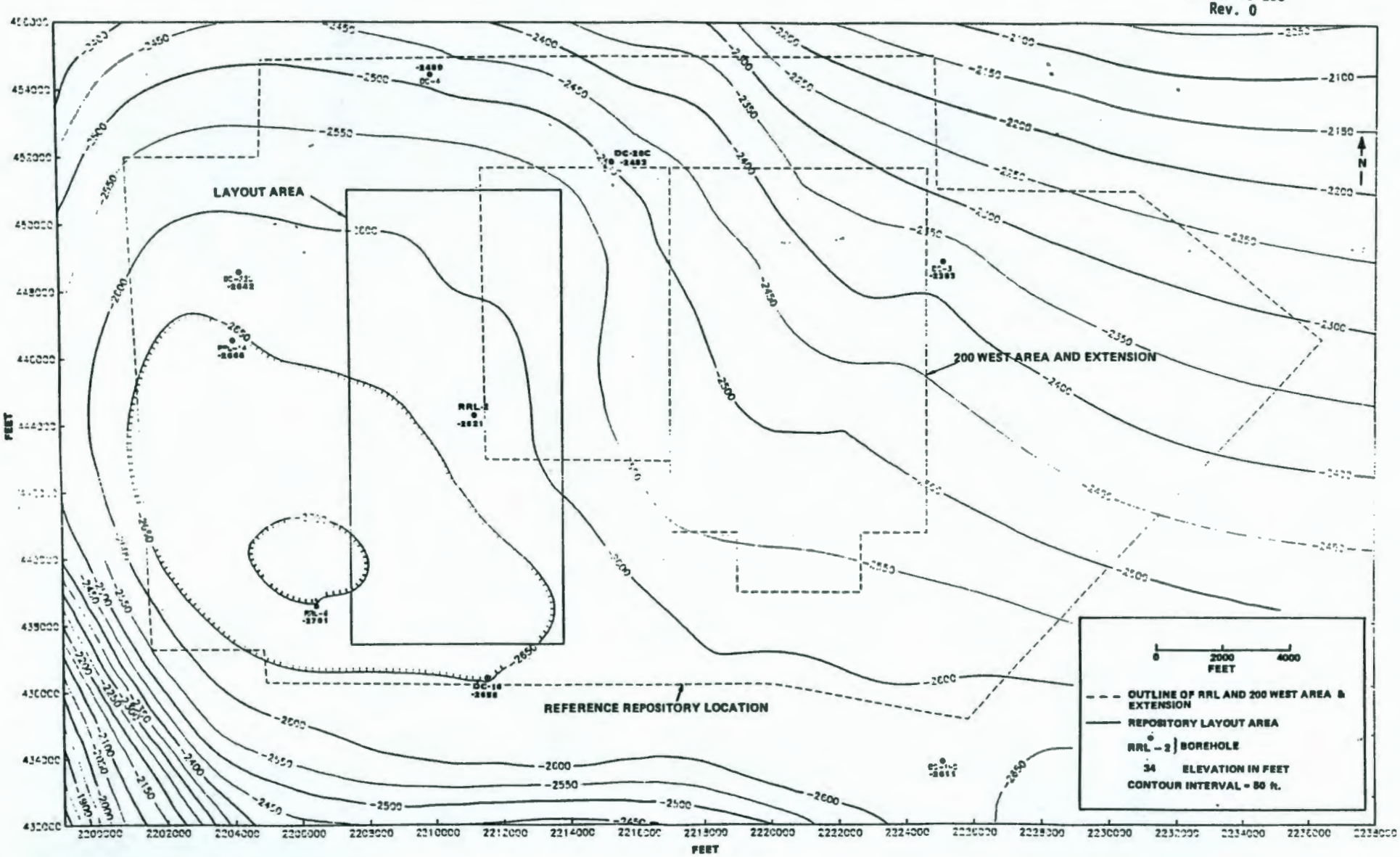

Figure A-33. Top of Birkett Flow (Grande Ronde Flow B) Structure Contour Map.

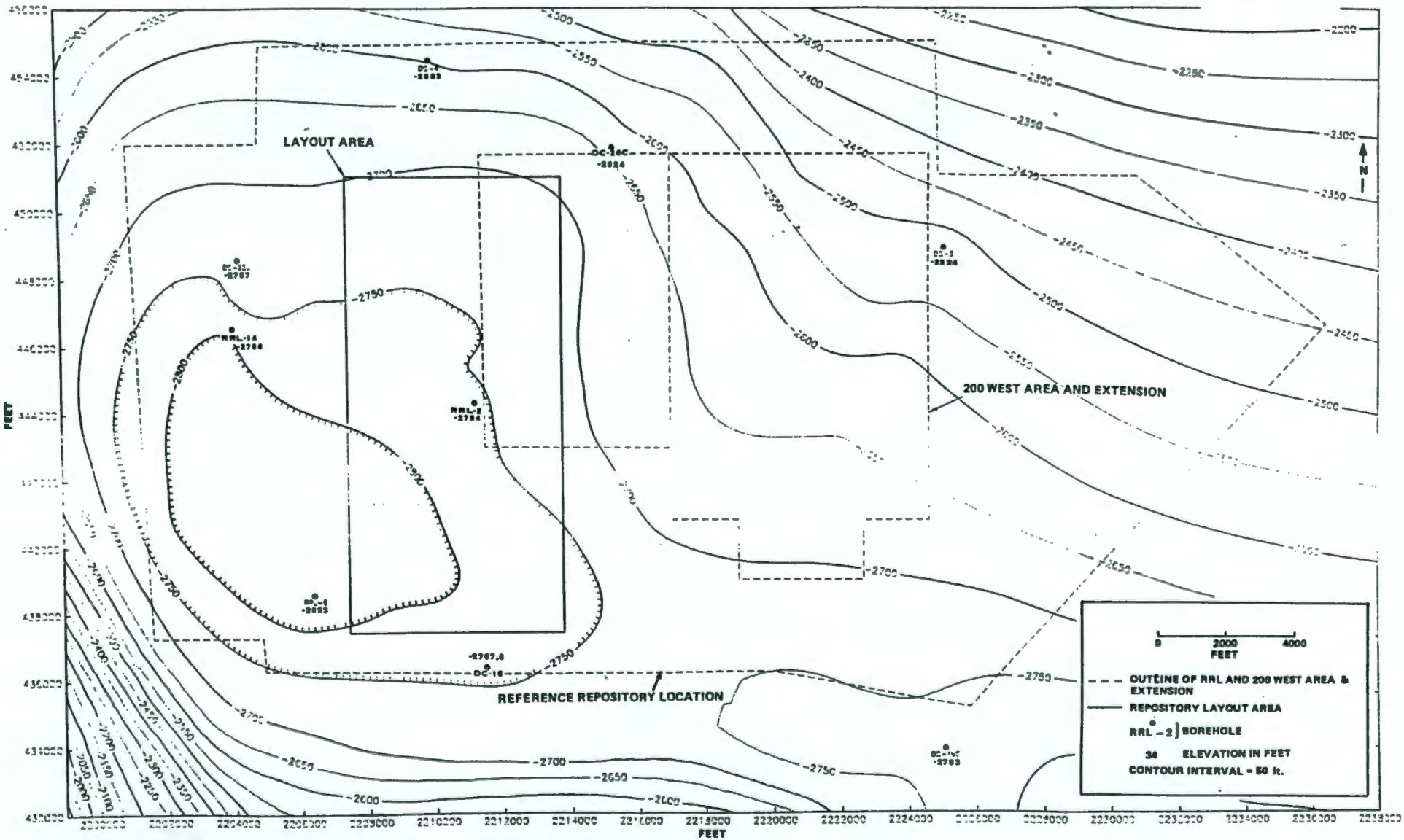

Figure A-34. Top of Grande Ronde Flow 9 Structure Contour Map.

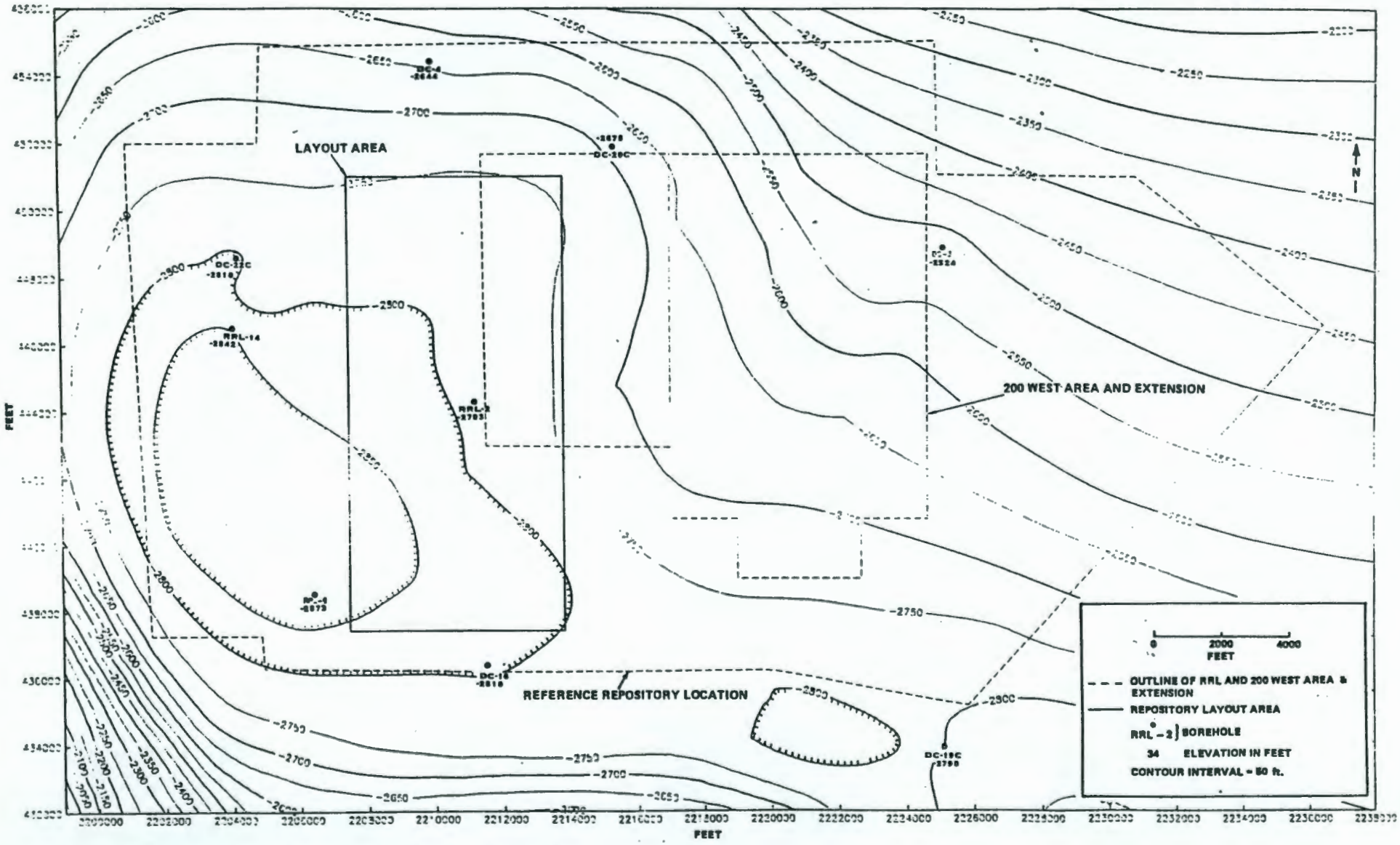

Figure A-35. Top of Grande Ronde Flow 10 Structure Contour Map.

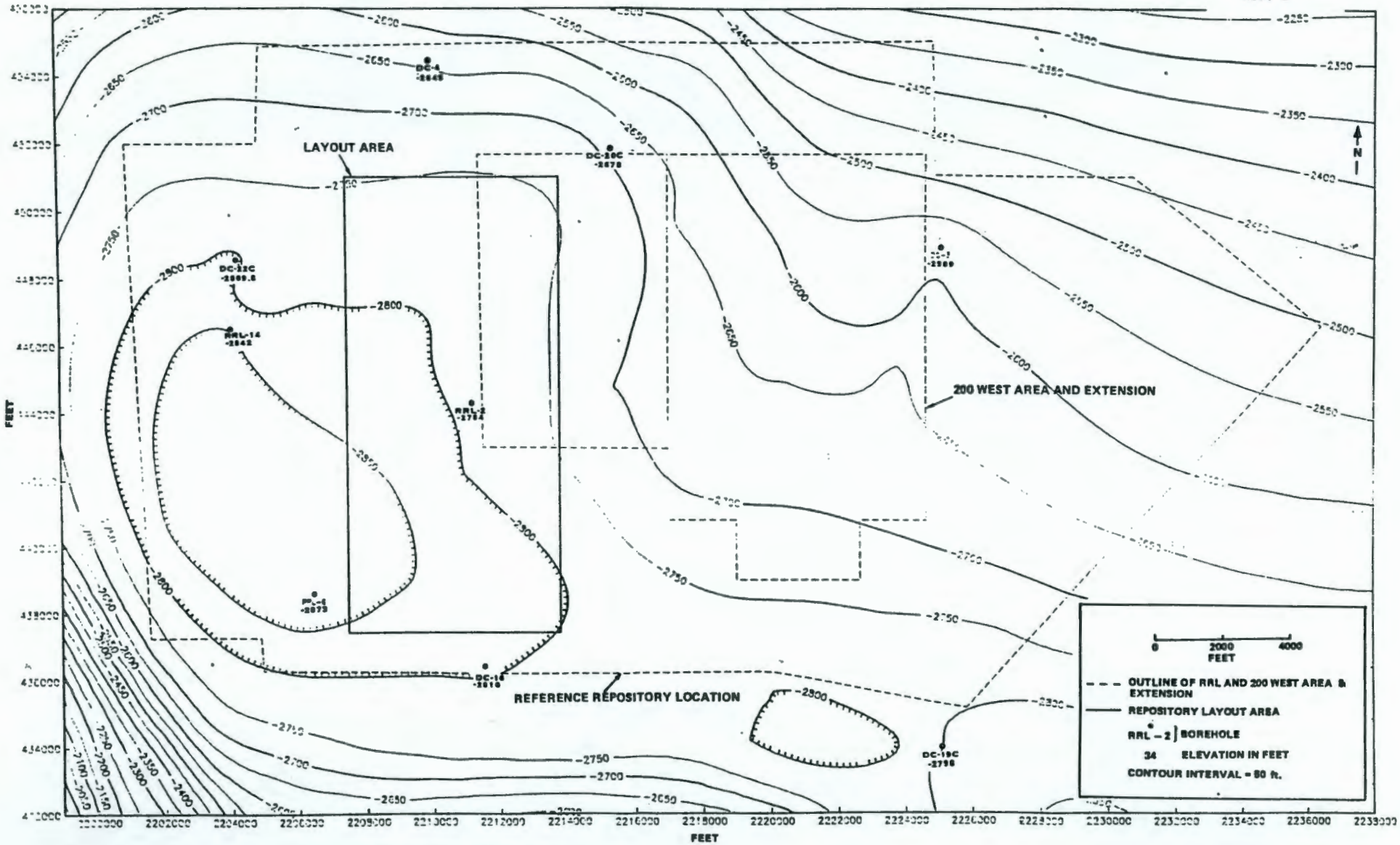

Figure A-36. Top of Grande Ronde Flow 11 Structure Contour Map.

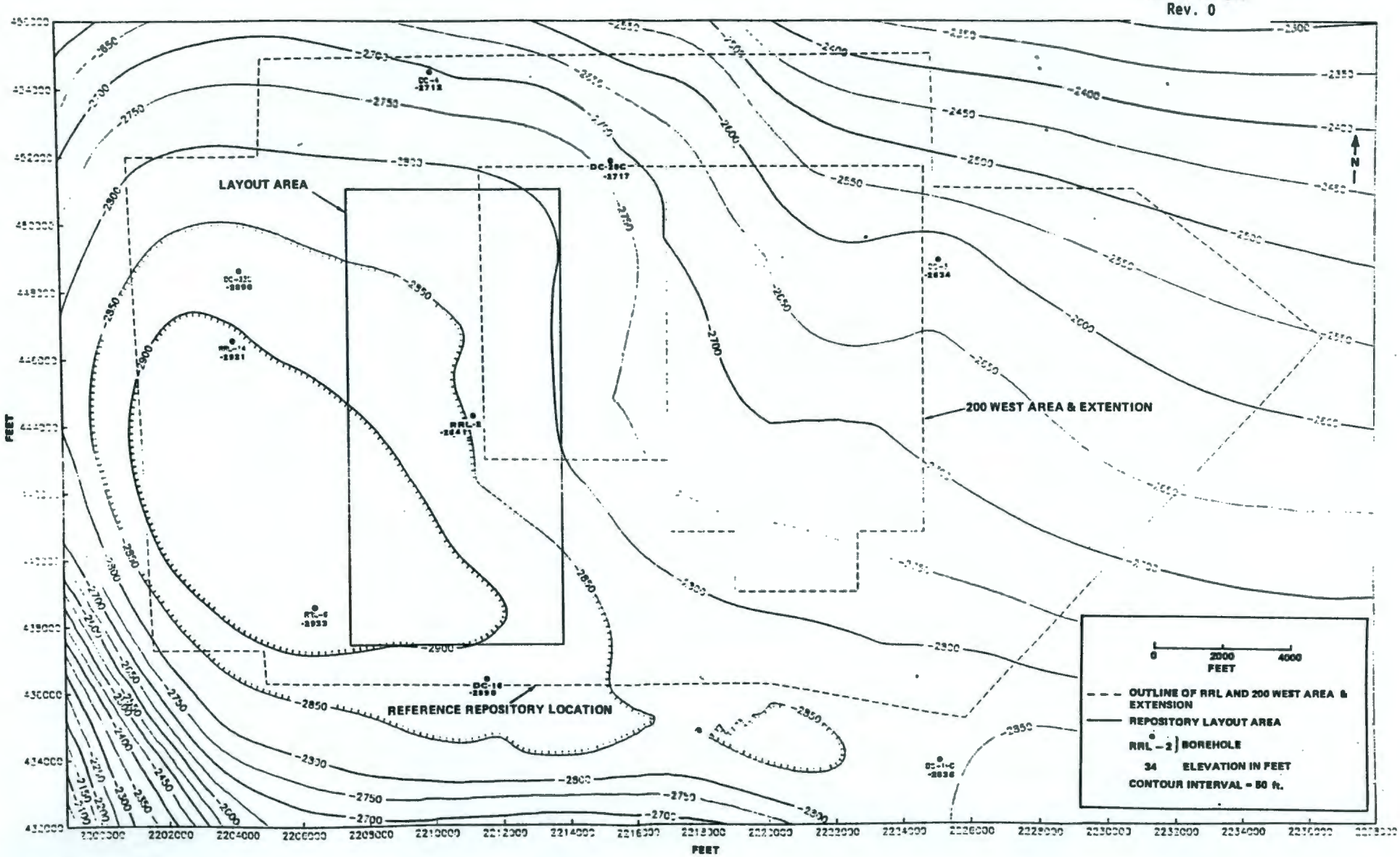

Figure A-37. Top of McCoy Canyon Flow (Grande Ronde Flow 13) Structure Contour Map.

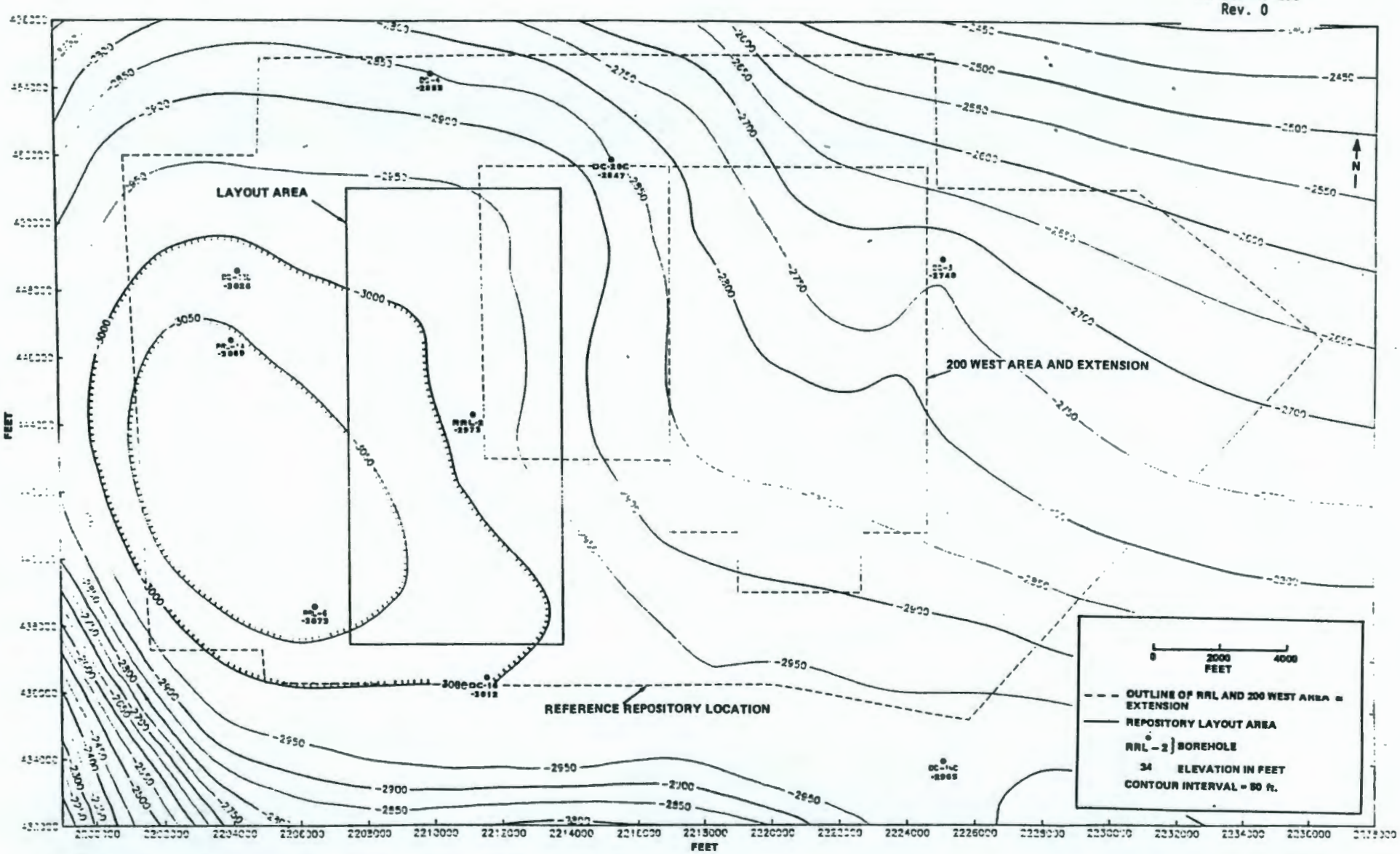

Figure A-38. Top of Umtanum Flow (Grande Ronde Flow 15) Structure Contour Map.

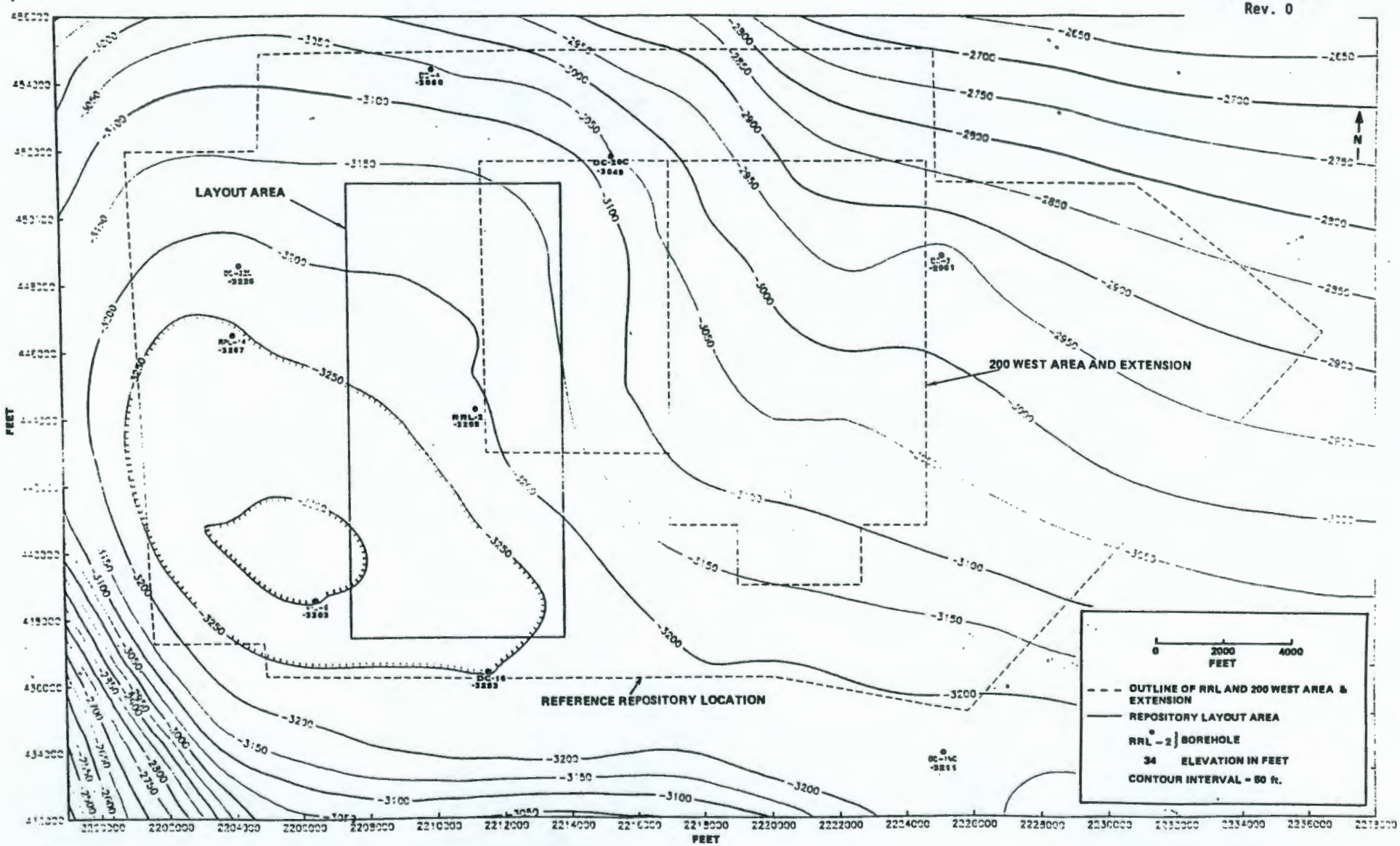

Figure A-39. Top of the Very-High Mg Flow (Grande Ronde Flow 19) Structure Contour Map.

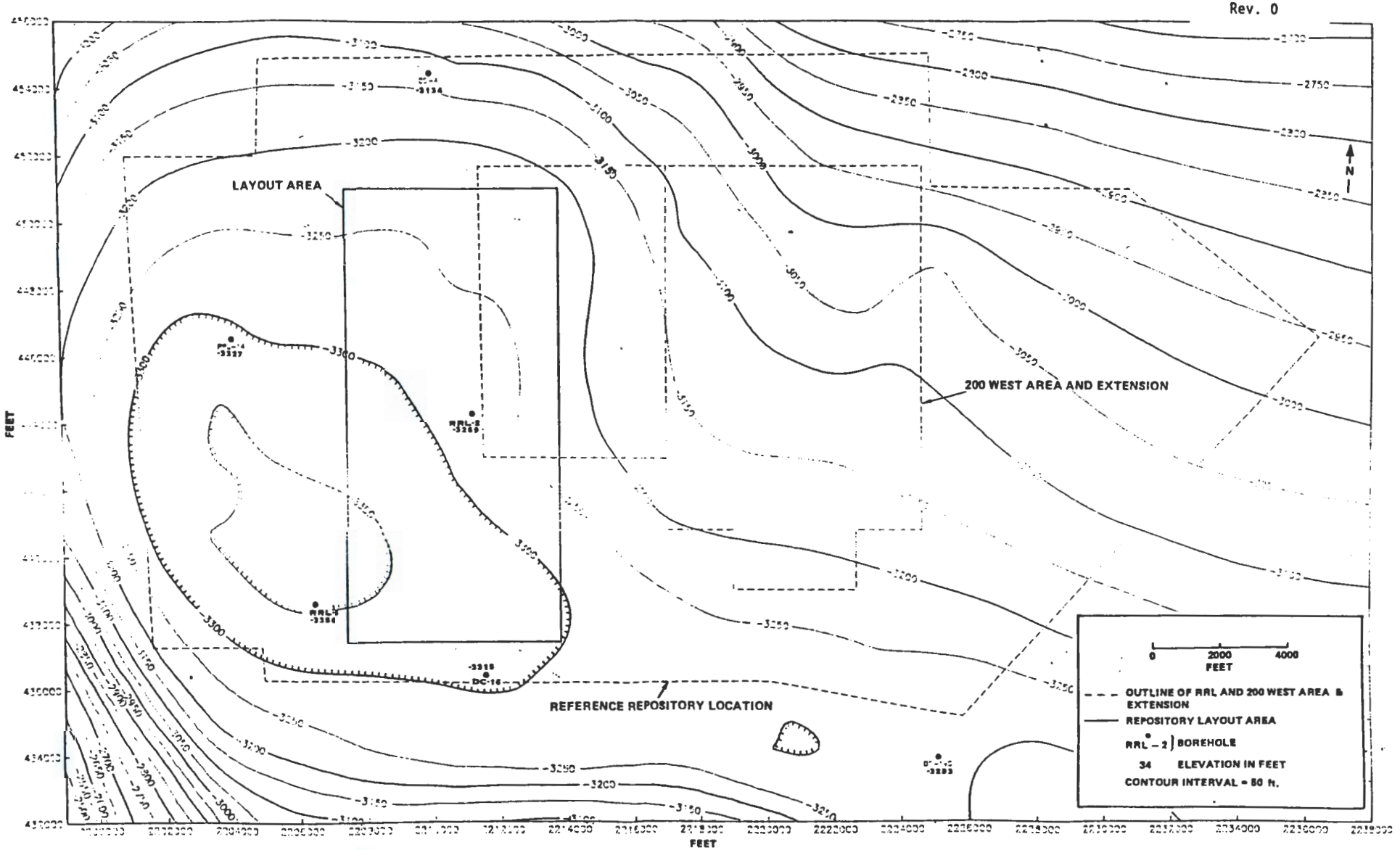

Figure A-40. Top of The Underlying Low Mg Flows Structure Contour Map.

APPENDIX B

Data tables used for structure contour maps of the suprabasalt sediments and isopach maps of the Saddle Mountains, Wanapum, and Grande Ronde Basalts and interbedded sediments.

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Table B-4 Thickness Data for Grande Ronde Basalt Isopach Maps . . . B-9

Table B-1. Contact Elevations used for the Construction of Suprabasalt Sediment Structure Contour Maps.

LOCATION	X[1]	Y	PLIO-PLEISTOCENE UNIT	UPPER RINGOLD UNIT	MIDDLE RINGOLD UNIT	LOWER RINGOLD UNIT	BASAL RINGOLD UNIT	BASAL RINGOLD (GRAVEL SUBUNIT)	TOP OF BASALT
surface	2212318.	429450.	640[2]	640	640	640	640	640	640
26 89	2206495.	431002.	605	544	518	351	302	276	170
DH-26	2212011.	430827.	565	540	533	437	392	358	299
*DH-20	2211939.	434344.	556	507	490	249	213	173	69
*29 78	2217899.	434356.	524	500	500	207	192	132	59
DB-14	2216034.	430151.	589	576	576	506[3]	506	506	506
*32 72	2223385.	437387.	487	473	458	256	253	215	96
*32 77	2218355.	436714.	529	444	430				
*DC-16	2211516	436403.	556	496	496	232	191	131	27
*RRL-4	2216983.	440599.	500	500	500	241	200	170	79
*RRL-6B	2206423.	438580.	564	512	503	223	168	108	-8
*36 93	2202420.	440913.	600	525	490	199	154	105	-44
*DH-21	2211077.	442206.	550	532	530	217	177	131	16
*RRL-2	2211185.	444298.	559	536	521	231	173	133	29
*37 82B	2213419.	442030.	542	526	526	233	184	144	34
*RRL-9	2215245.	444762.	539	529	525	217	195	165	108
*39 79	2216667.	444208.	533						
*W14 8	2223737.	445433.	518	512	512	258	258	239	160
*DH-25	2211075.	445430.	554	547	513	238	188	154	42
*RRL-5	2206742.	447389.	598	541	498	218	180	135	21
*RRL-14	2203991.	446541.	593	520	520	200	164	120	-29
DB-11	2195160.	454042.			583	387	387	383	383
*RRL-8	2203572.	452477.	637	632	550	255	198	166	67
*RRL-7	2210393.	450803.	580	570	517	224	214	184	85
*DC-4	2209991.	454469.	636	625	530	266	234	192	128
*49 79	2216296.	453576.	605	599	572				
*50 85	2210897.	454788.	644	634	527	267	241	209	149
*W11 26	2219908.	449079.	585	565	554	282	267	265	190
*W14 7	2220582.	445211.	550	546	546	254	245	203	159
*W15 14	2217287.	445177.	544	530	525	241	226	193	136
*DH-22	2203444.	441646.	595	523	491	202	155	112	-30
*DH-24	2210874.	448400.	571	566	538	213	204	166	85

[1] X and Y are location coordinates in feet east and north of the Washington State reference meridian and parallel respectively.

[2] All elevations are in feet. Values are from Bjornstad (1984).

[3] Underlined values are modified from Bjornstad (1984).

* Data points within modeled area.

Table B-1. Contact Elevations used for the Construction of Suprabasalt Sediment Structure Contour Maps - continued.

LOCATION	X[1]	Y[1]	PLIO-PLEISTOCENE UNIT	UPPER RINGOLD UNIT	MIDDLE RINGOLD UNIT	LOWER RINGOLD UNIT	BASAL RINGOLD UNIT	BASAL RINGOLD (GRAVEL SUBUNIT)	TOP OF BASALT
*RRL-3	2216917.	449676.	592[2]	585	510[3]	249	240	205	182
*34 88	2207328.	439378.	559	518	513	208	160	96	-21
*W19 10	2220418.	442509.	524	515	515	225	224	198	127
*DH-23	2210651.	451575.	611						
*W6 1	2220884.	451294.							238
*W19 8	2222216.	443783.							145
*43 83	2211789.	447553.	566	558	528				
surface	2216000.	429500.	623	623	623	623	623	623	623
25 70	2225495.	430316.	493	447	447				
43 104	2191046.	447575.	761	646	624	441	421	311	
51 75	2220052.	455691.	547	547	547				267
55 89	2206736.	459810.	602	602	602				
55 95	2200446.	459951.	674	674	640	384	349	327	265
55 76	2219120.	459955.							360
DH-27	2196455.	454768.			558	331	329	329	322
DH-28	2198773.	454772.			560	238	210	171	80
MCGEE	2191995.	457461.							356
YR1	2192200.	443500.	820	820	820	820	820	820	820
YR2	2193750.	441900.	800	800	800	800	800	800	800
YR3	2194350.	440350.	800	800	800	800	800	800	800
YR4	2195650.	439700.	800	800	800	800	800	800	800
YR5	2198000.	435450.	800	800	800	800	800	800	800
YR6	2199150.	431100.	800	800	800	800	800	800	800
YR7	2199200.	429000.	800	800	800	800	800	800	800
*RRL-10	2206591.	442103.	570	536	514	195	156	116	-18
*RRL-16	2212592.	442122.	540			219	178	144	20
*DC-19C	2225006.	433929.	500	450	450				89
*DC-20C	2215369.	452006.							181
*DC-22C	2204315.	448519.	630						18
*DC-3	2225056.	448924.							212

[1] X and Y are location coordinates in feet east and north of the Washington State reference meridian and parallel respectively.
[2] All elevations are in feet. Values are from Bjornstad (1984).
[3] Underlined values are modified from Bjornstad (1984).
* Data points within modeled area.

Table B-2. Thickness Data for Saddle Mountains Basalt and Ellensburg Formation Isopach Maps.

BOREHOLE	X[1]	Y	ELEPHANT MT. MEMBER	RATTLE-SNAKE INTERBED	POMONA MEMBER	SELAH INTERBED	ESQUAT-ZEL MEMBER	COLD CREEK INTERBED	UMATILLA MEMBER	MABTON INTERBED
DB-1[a]	2308700	407100	125[2]	9	157	5	107	7	244	44
DB-2[a]	2307800	421100	112	23	142	27	68	3	195	47
DB-4[a]	2267200	439800	138	52	194	15	114	94	141	
DB-5[a]	2243750	457250	74	55	185	20	112	20	141	
DB-7[a]	2271500	388650	100	50	196	7	97	65	263	
DB-8[a]	2254050	447200	68	60	184	22	97	95	145	108
DB-9[a]	2238573	467091	0	0	121	29	99	7	166	
DB-10[a]	2259800	457000	62	49	188	16				
DB-11[a]	2195160	454042	0	0	114	0	89	41	219	141
DB-12[a]	2220000	468300	0	0	93	18	0	0	186	138
DB-13[a]	2247962	422513	121	73	184	19	118	85	247	101
DB-14[a]	2216034	430151	100	77	166	37	129	46	253	117
DB-15[a]	2253431	452505	99	50	184	26	92	94	80	94
DDH-1[b]	2246750	454650	78	46	196	18	148	0	128	110
DDH-3[c]	2310420	375043	158	30.5	183.5	2	95.5	76.5	273	40
DC-15[c]	2309775	389809	127.5	21.5	141.4	2.1	117.5	48	247	32
DC-8[c]	2280425	420220	143	73	166	14	109	75	223	64
DC-12[c]	2241612	415290	109	91	172	36	80	83	223	138
DC-6[c]	2277482	459429	132	27	176	14	74	0	114	79
DC-2[c]	2246947	453146	39	20	192	93	98	98	140	
*DC-3[c]	2225057	448924	90	80	148	72	82	98	150	170
*DC-4[c]	2209991	454469	61	113	132	55	117	70	213	131
DH-4[c]	2284368	520797	44	1	123	0	0	0	0	23
DH-5[c]	2173000	518750	99	23	136	62	0	0	0	77
DC-14[c]	2261245	489704	137	137	191	191	0	0	0	102
*RRL-2[c]	2211185	444298	81	96	159.5	44.5	118	64	231	124
*RRL-3[d]	2216917	449676	117							

[1] X and Y are location coordinates in feet east and north of the Washington State reference meridian and parallel respectively.
[2] All elevations are in feet.
[a] Fecht and Lillie, 1982
[b] ARCHO, 1976
[c] Landon, 1985
[d] Deju, 1981
[e] Skurla, 1985
[f] S/HNP-PSAR, 1981
[g] USGS, 13/24-27K1, drillers logs
[h] USGS, 13/24-26G1, drillers logs
[i] USGS, 13/24-25E1, drillers logs
* Data points within modeled area.

Table B-2. Thickness Data for Saddle Mountains Basalt and Ellensburg Formation Isopach Maps - continued.

BOREHOLE	X[1]	Y	ELEPHANT MT. MEMBER	RATTLE-SNAKE INTERBED	POMONA MEMBER	SELAH INTERBED	ESQUAT-ZEL MEMBER	COLD CREEK INTERBED	UMATILLA MEMBER	MABTON INTERBED
*RRL-4[d]	2216983	440599	60[2]							
*RRL-5[d]	2206742	447389	77							
*RRL-6[c]	2206423	438580	90	106	158	43.5	112.5	80	239	115
*RRL-14[c]	2203991	446541	86	94	105	83	119	90	220	124
RSH-1[c]	2180000	401750	46	0	124	0	0	0	222	83
*DC-16[c]	2211516	436403	86	112	146	54	110	73	240	121
*DC-19[c]	2225066	433929	128	106	159	49	96	80	228	106
*DC-20[c]	2215285	451882	110	88	157	70	91	87	201	128
*DC-22[c]	2204190	448600	86	100	113	101	100	120	232	84
DH-27[e]	2196455	454701	0	0	117.1	.4	95.2	20.2		
DH-28[e]	2198772	454771	74.1	74	193.6	1.7				
DH-92[f]	2262027	453750	128		58					
DH-93[f]	2264528	453847	145	35						
DH-96[f]	2260433	453701	55							
DH-97[f]	2263334	453790	110	45						
DH-125[f]	2288370	444382	200	68						
S-5[f]	2272289	424503	150	50						
S-6[f]	2264275	430424	130	65						
S-7[f]	2265443	433100	130	60						
S-22[f]	2275531	429837	145	60						
S-24[f]	2264836	415133	130	80						
MJ-1[f]	2264631	451449	120	35						
MJ-2[f]	2263630	451413	135							
MJ-3[f]	2262629	451378	125							
ENYEART[g]	2183800	455301	0	0	79	0	0	0	284	
OBRIAN[h]	2181137	457656	0	0	0	0	0	0	288	
FORD[i]	2183786	458009	0	0	0	0	0	0	322	
MCGEE[c]	2191784	457783	0	0	0	0	0	0	68	

[1] X and Y are location coordinates in feet east and north of the Washington State reference meridian and parallel respectively.
[2] All elevations are in feet.
[a] Fecht and Lillie, 1982
[b] ARCHO, 1976
[c] Landon, 1985
[d] Deju, 1981
[e] Skurla, 1985
[f] S/HNP-PSAR, 1981
[g] USGS, 13/24-27K1, drillers logs
[h] USGS, 13/24-26G1, drillers logs
[i] USGS, 13/24-25E1, drillers logs
* Data points within modeled area.

Table B-3. Thickness Data for Wanapum Basalt and Ellensburg Formation Isopach Maps (Lolo to Squaw Creek Interbed).

LOCATION	X[1]	Y	LOLO FLOW	ROSALIA FLOW	QUINCY INTERBED	ROZA MEMBER	SQUAW CREEK INTERBED
DDH-3	2310420	375043	134.[2]	0.	27.	144.	0.
DC-15	2309775	389809	104.5	87.5	0.	167.5	.5
DC-8	2280425	420220	128.	93.	0.	211.	2.
DC-12	2241612	415290	96.	107.	2.	178.	0.
DC-6	2277482	459429	88.	122.	0.	172.	3.5
DC-2	2246947	453146	162.	50.	0.	202.	0.
*DC-3	2225057	448924	145.	65.	0.	177.	0.
*DC-4	2209991	454469	163.	69.	0.	169.	0.
DH-4	2284368	520797	83.	114.	2.	191.	2.
DH-5	2173000	518750	42.	184.	1.	137.	5.
DC-14	2261245	489704	126.	95.	0.	197.	1.
*RRL-2	2211185	444298	166.	60.4	.6	172.	0.
*RRL-6	2206423	438580	181.	65.	0.	179.5	3.
*RRL-14	2203991	446541	172.	61.	0.	176.	0.
RSH-1	2180000	401750	183.	60.	0.	150.	34.
*DC-16	2211516	436403	168.	63.	1.5	174.5	0.3
*DC-19C	2225066	433929	171.	54.	0.	171.	0.
*DC-20C	2215285	451882	159.	64.	0.	175.	0.
*DC-22C	2204190	448600	158.	92.	0.	138.	0.
MCGEE	2191784	457783	129.	110.	0.	195.	0.
DB-15[3]	2253431	452505				196	4.0

[1] X and Y are location coordinates in feet east and north of the Washington State reference meridian and parallel respectively.
[2] All elevations are in feet. All data from Landon, 1985, except where noted.
[3] Diediker and Ledgerwood, 1980
* Data points within modeled area.

Table B-3. Thickness Data for Wanapum Basalt and Ellensburg Formation Isopach Maps (Sentinel Gap flow to Vantage Interbed) - continued.

LOCATION	X[1]	Y	SENTINEL GAP FLOW	WALLULA GAP FLOW	SAND HOLLOW FLOWS	SILVER FALLS FLOWS	GINKGO FLOWS	UNNAMED INTERBED	PALOUSE FALLS FLOW	VANTAGE INTERBED
DDH-3	2310420	375043	96.5[2]	48.5	298.	0.	254.	0.	37.	0.
*DC-15	2309775	389809	77.	38.	216.	41.	279.	1.	57.5	0.5
DC-8	2280425	420220	31.	0.	244.	60.	265.5	0.	80.5	2.
DC-12	2241612	415290	117.	0.	181.	105.	300.	6.	15.5	0.
DC-6	2277482	459429	122.	0.	125.	126.	222.	0.	102.	1.
DC-2	2246947	453146	108.	0.	107.	148.	258.	0.	78.	4.
*DC-3	2225057	448924	179.	0.	107.	157.	236.	12.	30.	20.
*DC-4	2209991	454469	187.	0.	142.	105.	246.	0.	67.	13.
DH-4	2284368	520797	170	0.	0.	103.	232.	0.	158.	10.
DH-5	2173000	518750	199.	0.	164.	0.	270.	0.	0.	28.
DC-14	2261245	489704	104.	0.	135.	103.	261.	0.	53.	0.
*RRL-2	2211185	444298	182.	0.	169.	108.	236.	0.	66.	4.
*RRL-6	2206423	438580	178.	0.	178.5	103	223.	0.	64.8	0.4
*RRL-14	2203991	446541	194.	0.	156.	118.	226.	0.	82.	6.
RSH-1	2180000	401750	173.	0.	171.	170.	160.	0.	75.	0.
*DC-16	2211516	436403	177.7	0.	153.	71.	282.5	3.	80.	4
*DC-19C	2225066	433929	167.	0.	139.	70.	331.	0.	67.	0.
*DC-20C	2215285	451882	190.	0.	133.	65.	290.	0.	60.	7.
*DC-22C	2204190	448600	212.	0.	156.	118.	230.	0.	78.	0.
MCGEE	2191784	457783	207.	0.	121.	96.	224.	6.4	47.6	30.
JERICO	2170000	540000	62.	0.	162.	0.	191.	0.	0.	
SGAP	2145000	535100	70.	0.	150.	0.	145.	0.	0.	

[1] X and Y are location coordinates in feet east and north of the Washington State reference meridian and parallel respectively.

[2] All elevations are in feet. All data from Landon, 1985.

* Data points within modeled area.

Table B-4. Thickness Data for Grande Ronde Basalt Isopach Maps (GR-1 to GR-8).

LOCATION	X[1]	Y	GR-1 Flow	GR-2 Flow	GR-3 Flow	ROCKY COULEE	GR-5 Flow	Cohassett Flow	GR-7 Flow	GR-8 Flow
DDH-3	2310420	375043	57.[2]	117.	0.	203.	22.	164.	0.	46.
DC-15	2309775	389809	83.	31.	38.	172.	63.	154.	0.	68.
DC-8	2280425	420220	18.	48.5	59.5	154.	68.	191.	0.	72.
DC-12	2241612	415290	35.5	84.	52.	158.	32.5	222.5	17.	89.5
DC-6	2277482	459429	0.	0.	107.	142.	53.	237.	0.	115.
DC-2	2246947	453146	0.	60.	55.	153.	31.	277.	0.	122.
*DC-3	2225057	448924	0.	84.	53.	142.	33.	267.	0.	141.
*DC-4	2209991	454469	0.	65.	55.	172.	0.	266.	0.	114.
DH-4	2284368	520797	0.	18.	83.	52.	29.	257.	0.	161.
DH-5	2173000	518750	0.	0.	95.	156.	47.	234.	0.	108.
DC-14	2261245	489704	0.	0.	35.	185.	59.	259.	46.	93.
*RRL-2	2211185	444298	0.	34.	102.	170.	0.	262.	0.	133.
*RRL-6	2206423	438580	0.	75.8	77.	168.5	0.	251.5	0.	122.
*RRL-14	2203991	446541	0.	24.	83.	180.	0.	239	0.	120.
RSH-1	2180000	401750	0.	44.	101.	170.	0.	222.	0.	82.
EMNIP	2166500	470000	0.	53.	58.	157.	23.	251.	0.	128.
SGAP	2145000	535100	0.	46.	27.	170.	62	244.	90.	121.
*DC-16	2211516	436403	0.	17.5	114.5	133.4	43.6	255.	0.	114.
*DC-19C	2225066	433929	0.	50.	90.	132.	92	216.	0.	142.
*DC-20C	2215285	451882	0.	63.	78.	187.	0.	261.	0.	141.
*DC-22C	2204190	448600	0.	26.	82.	166.	0.	262.	0.	112.
MCGEE	2191784	457783	0.	38.8	52.2	164.4	40.7	220.7	0.	120.2

[1] X and Y are location coordinates in feet east and north of the Washington State reference meridian and parallel respectively.

[2] All elevations are in feet. All data from Landon, 1985.

* Data points within modeled area.

Table B-4. Thickness Data for Grande Ronde Basalt Isopach Maps (GR-9 to GR-19) - continued.

LOCATION	GR-9 Flow	GR-10 Flow	GR-11 Flow	GR-12 Flow	McCoy Canyon Flow	GR-14 Flow	Umtanum Flow	GR-16 Flow	GR-17 Flow	GR-18 Flow	Very-H Mg Flo
DDH-3	45.[1]	35.	38.	60.	85.	0.	285.	0.	0.	114.	66.
DC-15	30.	20.	54.	47.	118.	0.	257.	0.	0.	81.	115.
DC-8	0.	37.5	87.5	0.	137.5	0.	241.5	22.	0.	84.5	51.
DC-12	0.	59.5	97.	0.	120.5	0.	235.9	0.	27.6	55.5	0.
DC-6	0.	0.	93.	0.	133.	0.	222.	0.	0.	0.	71.
DC-2	0.	50.	64.	0.	96.	0.	220.	0.	0.	0.	66.
*DC-3	0.	65.	45.	0.	106.	0.	221.	0.	0.	0.	
*DC-4	41.5	0.	67.5	0.	143.	0.	205.	0.	0.	0.	74.
DH-4	0.	0.	28.	0.	102.	83.	133.	0.	0.	0.	0.
DH-5	0.	0.	78.	0.	182.	0.	210.	0.	0.	0.	0.
DC-14	0.	0.	73.	0.	174.	0.	129.2	29.8	0.	0.	50.
*RRL-2	29.5	0.	57.5	0.	132.	0.	232.	0.	0.	0.	64.
*RRL-6	50.	0.	60.	0.	139.5	0.	230.5	0.	0.	0.	53.
*RRL-14	56.	0.	79.	0.	147.5	0.	198.5	0.	0.	0.	60.
RSH-1	0.	134.	119.	0.	105.	0.	212.	0.	0.	91.	0.
EMNIP	88.5	0.	71.5	0.	200.	0.	262.	0.	0.	0.	0.
SGAP	0.	0.	0.	0.	240.	0.	262.	0.	0.	0.	0.
*DC-16	43.	0.	80.	0.	116.5	0.	246.5	0.	0.	0.	62.0
*DC-19C	45.	0.	38.	0.	129.	0.	246.	0.	0.	0.	72.
*DC-20C	54.	0.	39.	0.	130.	0.	202.	0.	0.	0.	
*DC-22C	53.	0.	80.	0.	136.	0.	200	0.	0.	0.	
MCGEE	59.8	0.	44.3	0.	143.7	0.	234.5	0.	0.	0.	0.

[1] All elevations are in feet. All data from Landon, 1985.

* Data points within modeled area.

APPENDIX C

Isopach maps of the Saddle Mountains, Wanapum, and Grande Ronde Basalts and interbedded sediments.

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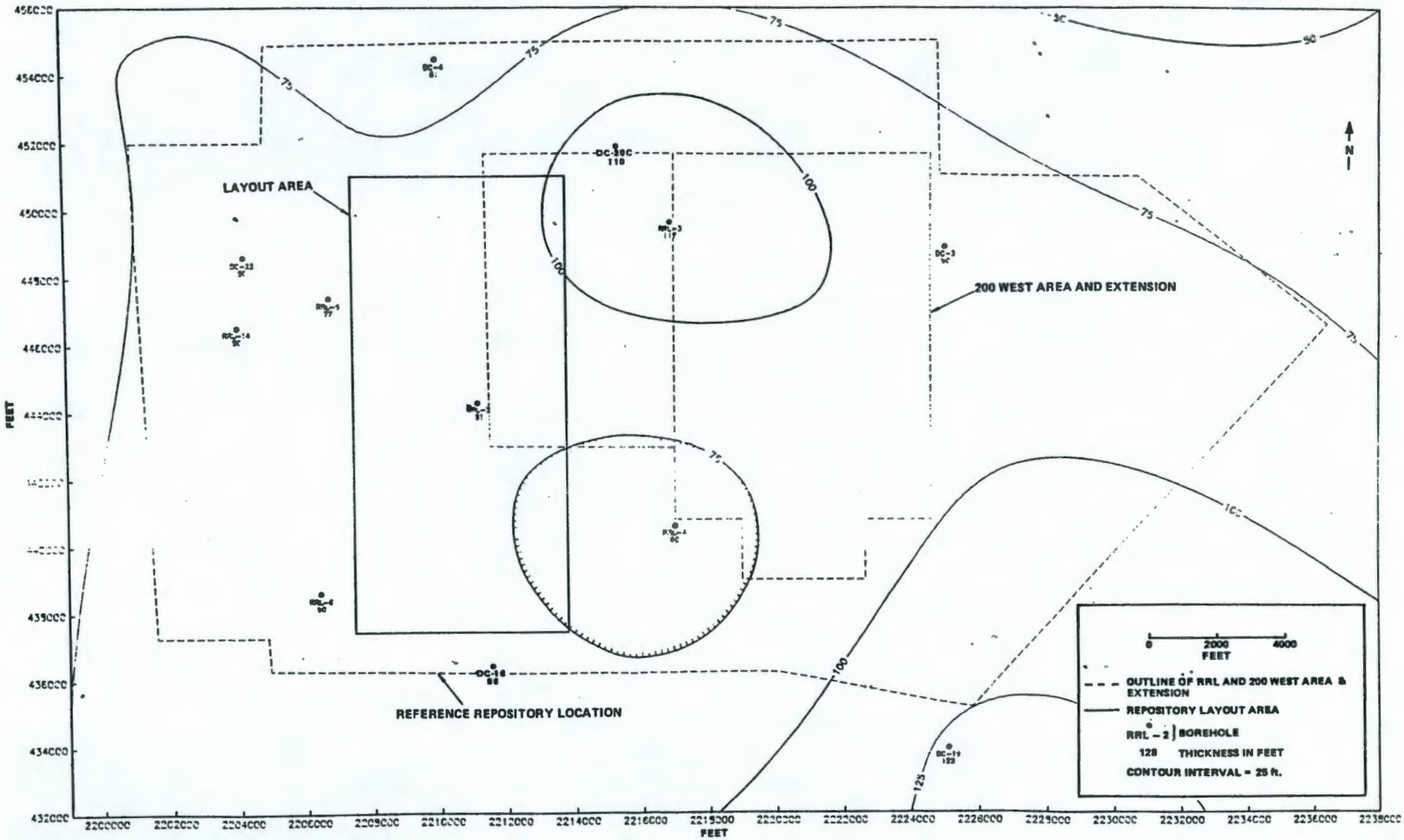
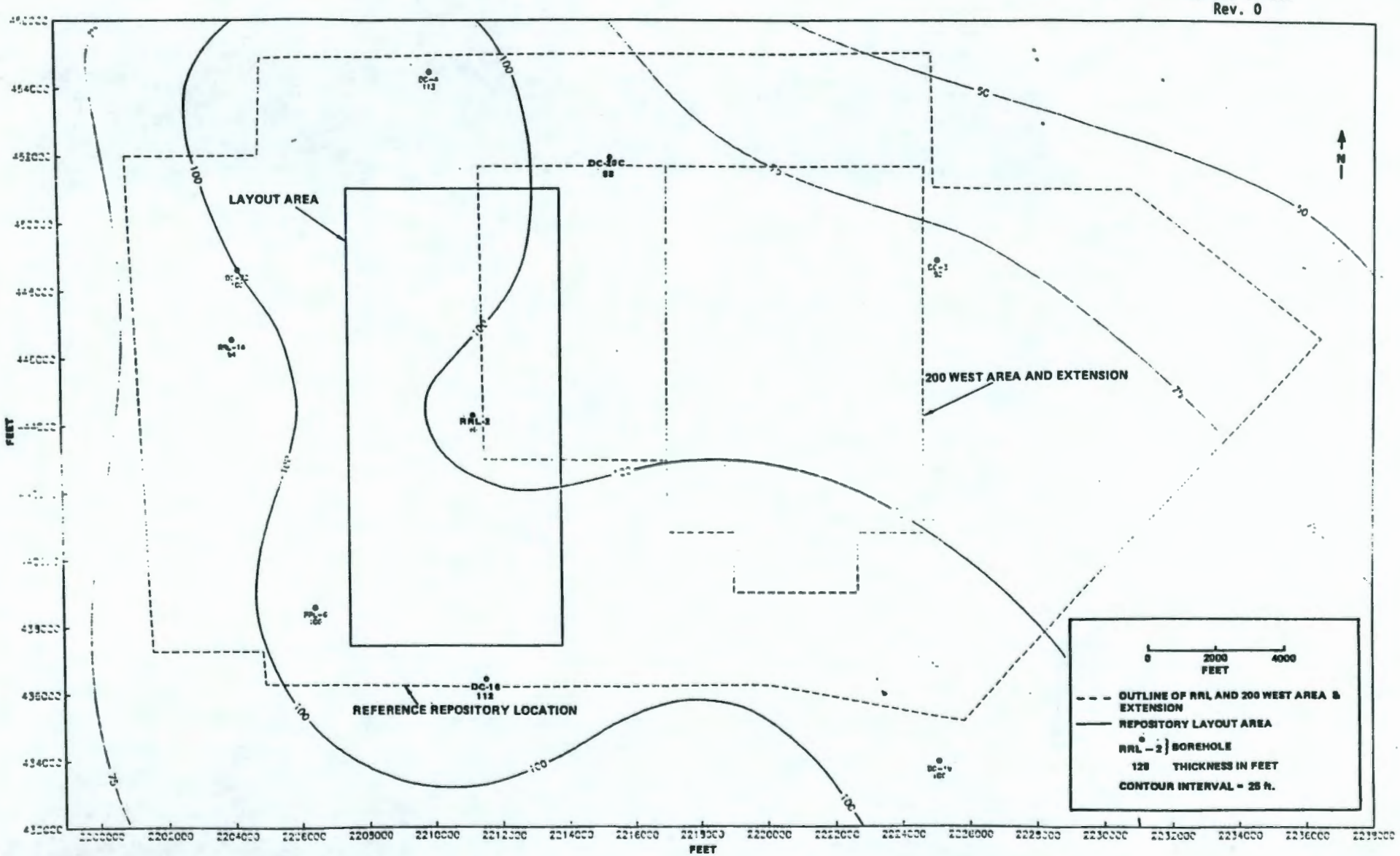


Figure C-1. Isopach Map of the Elephant Mountain Member.



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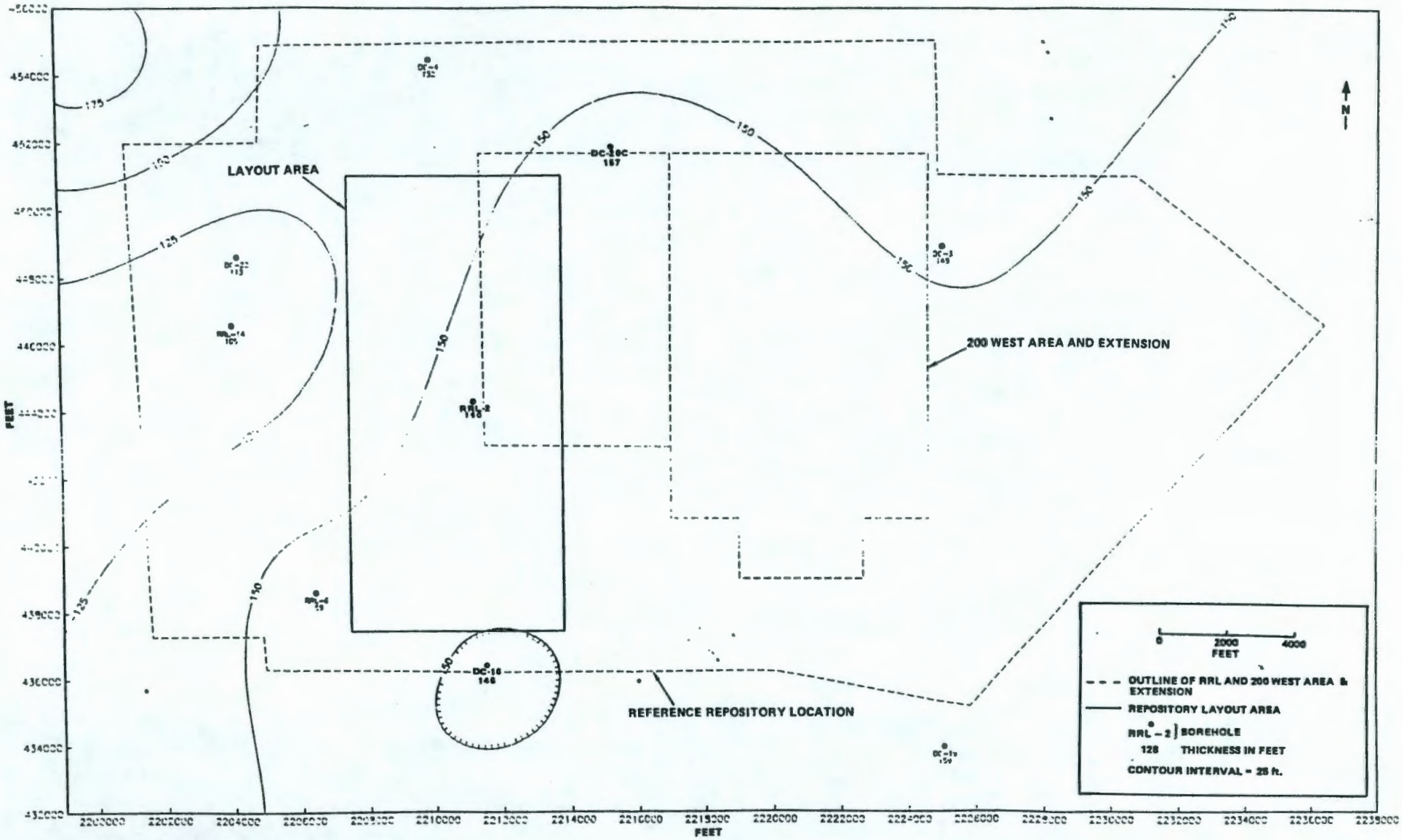
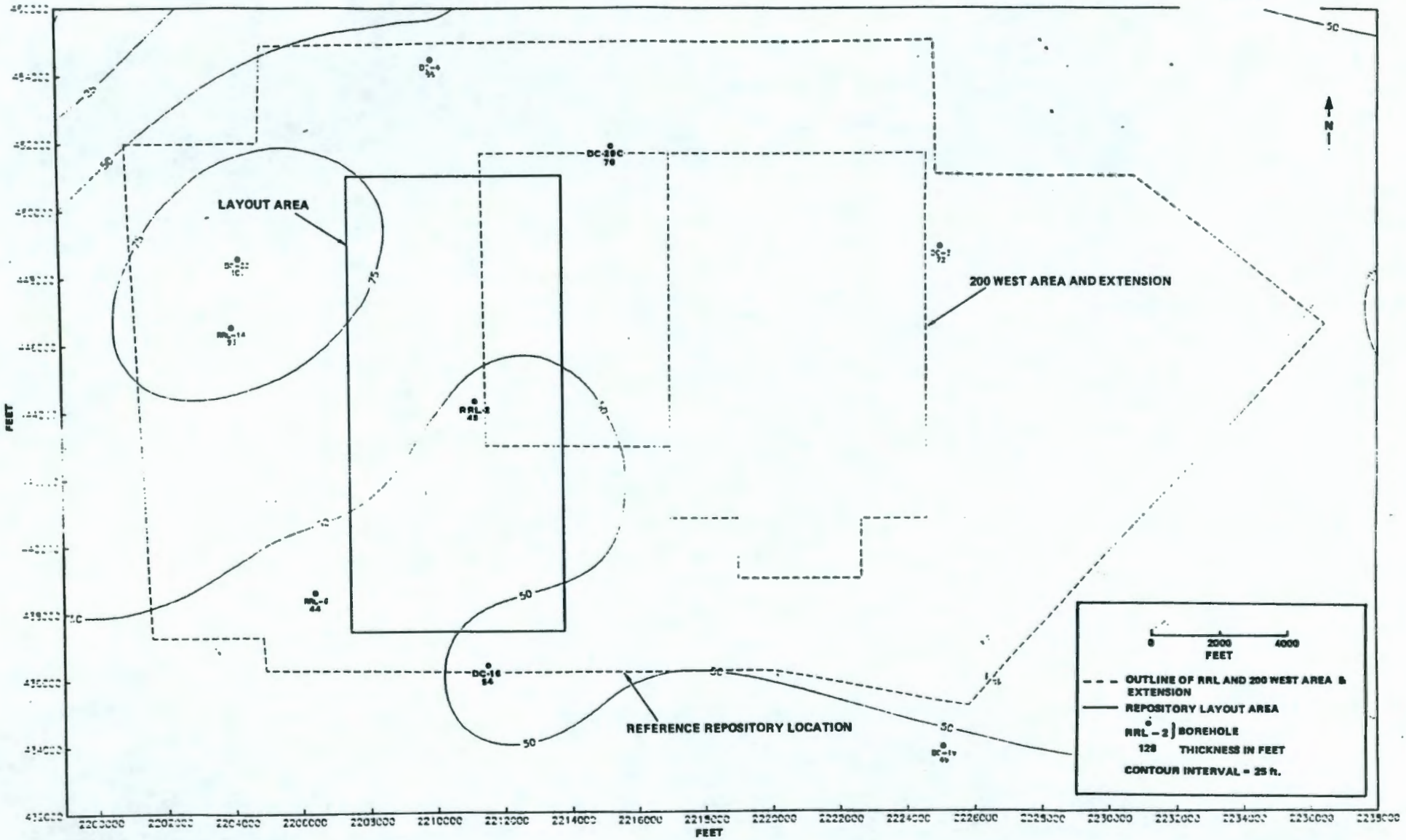


Figure C-3. Isopach Map of the Pomona Member.



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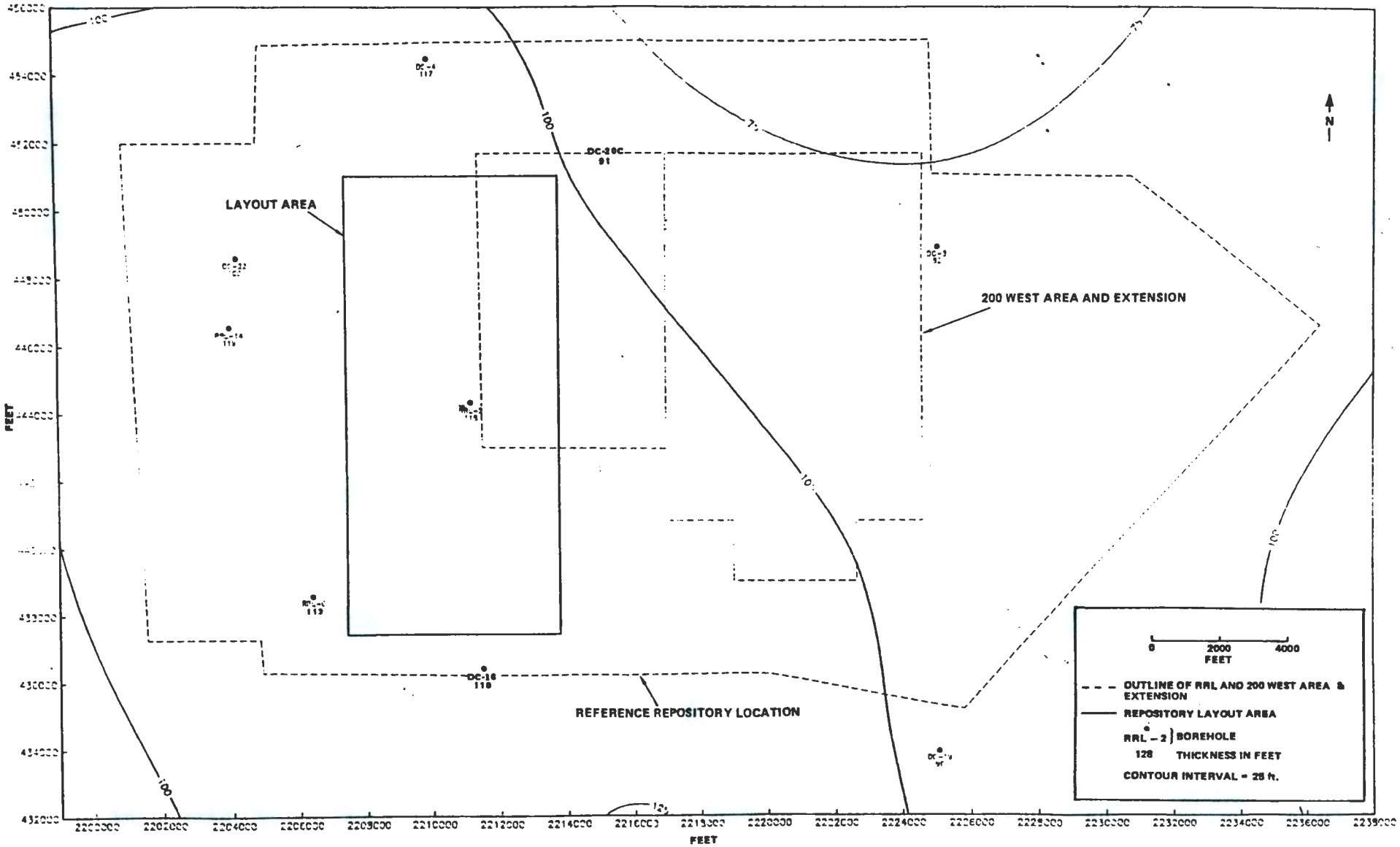

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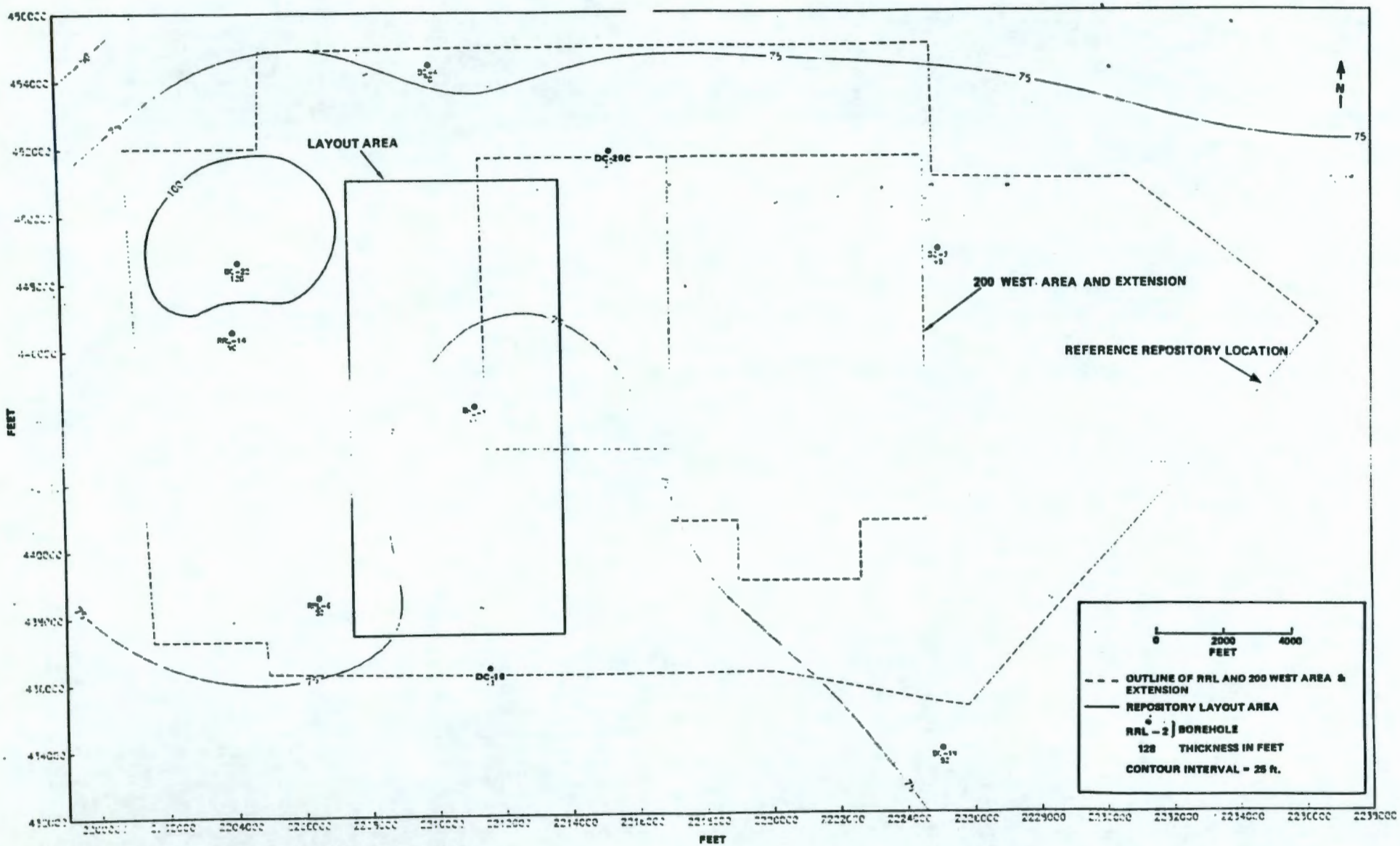

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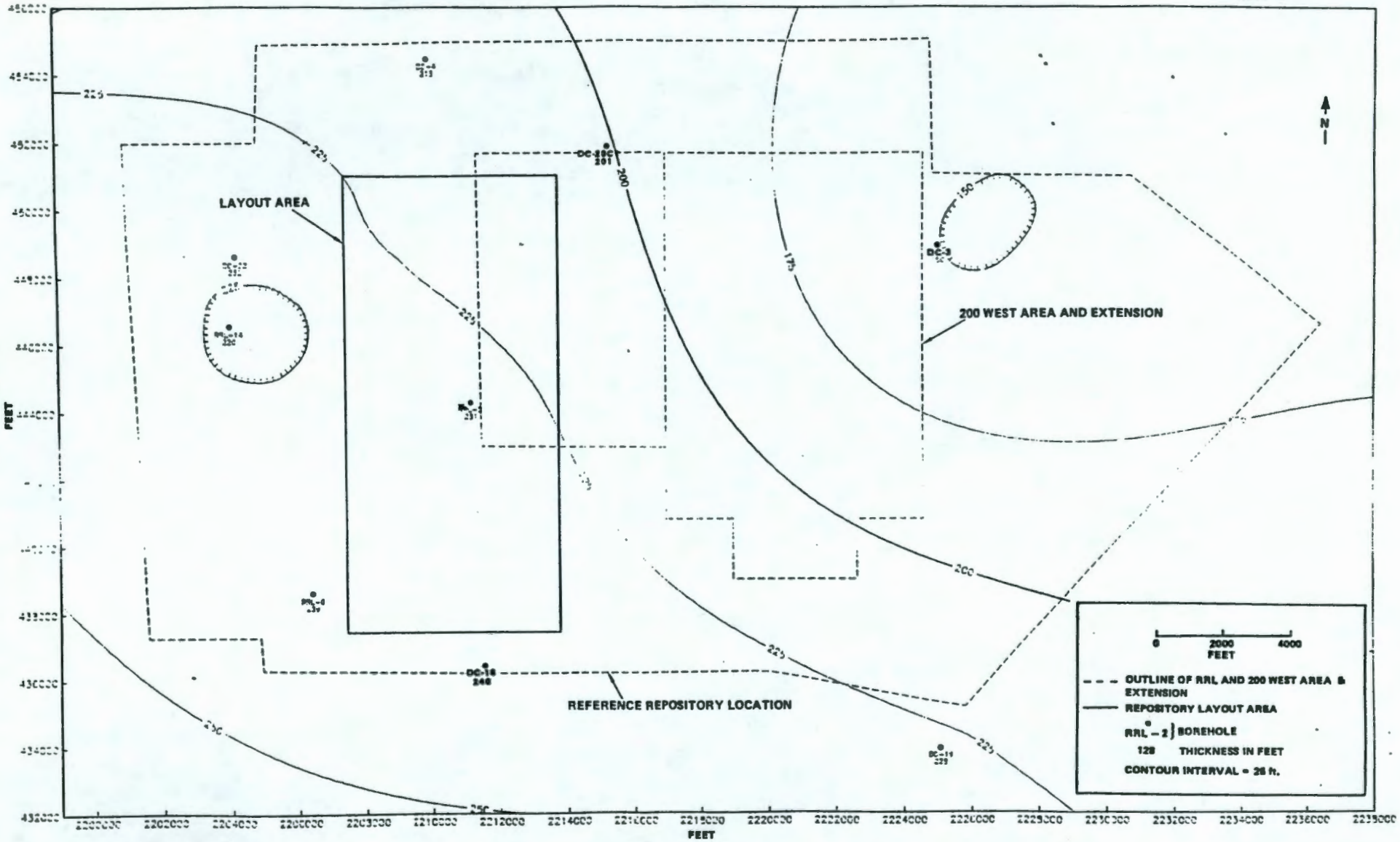

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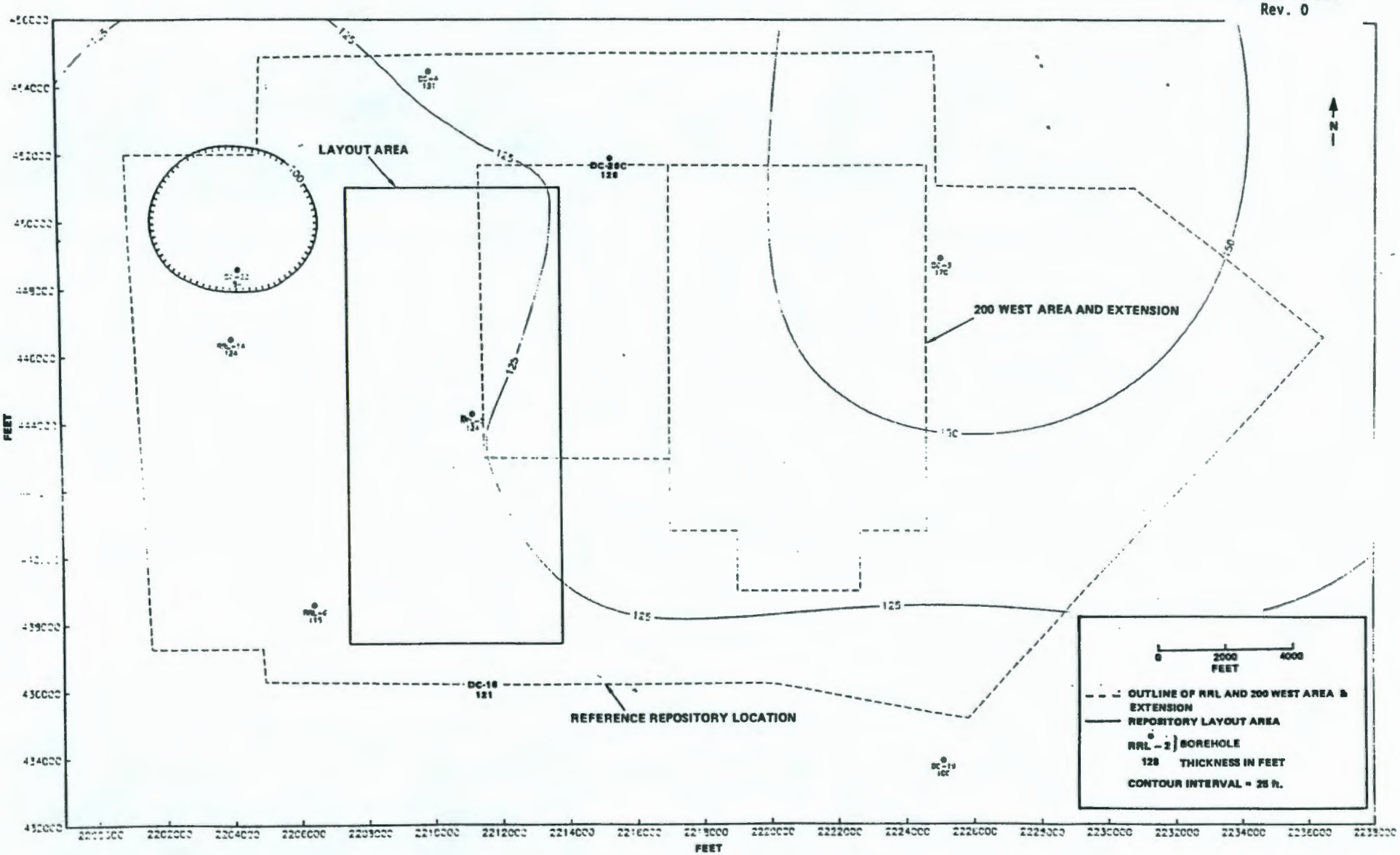

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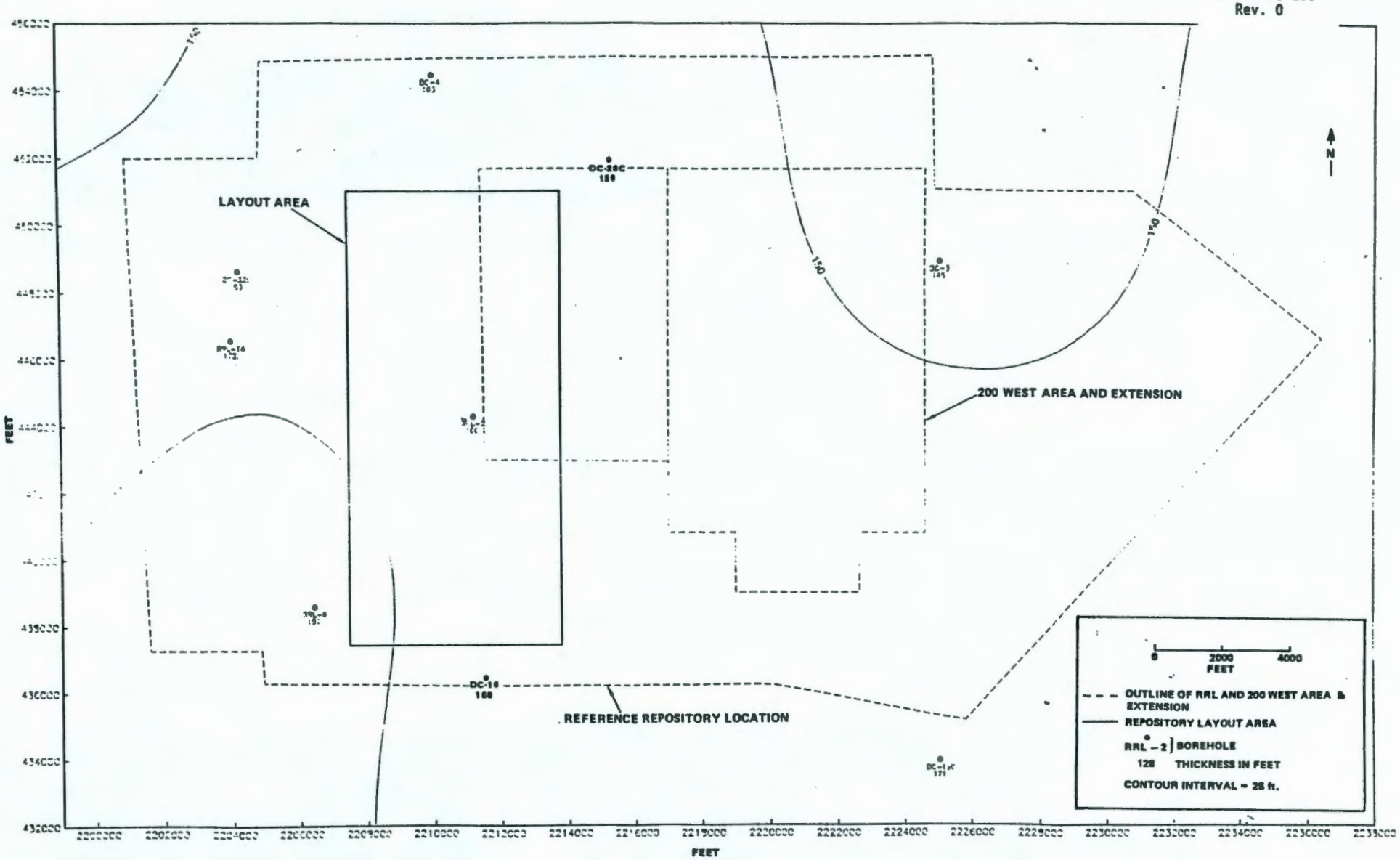

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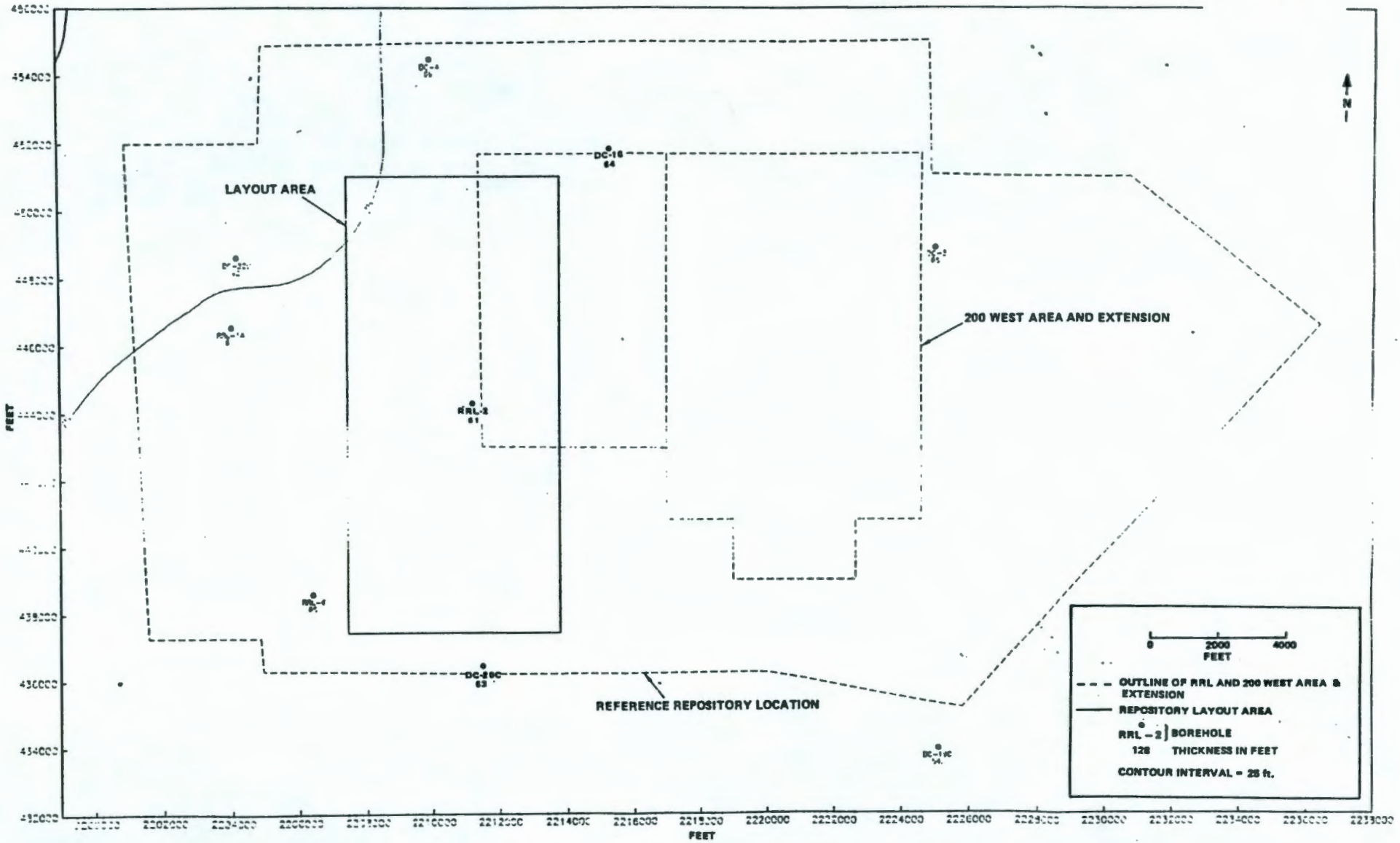

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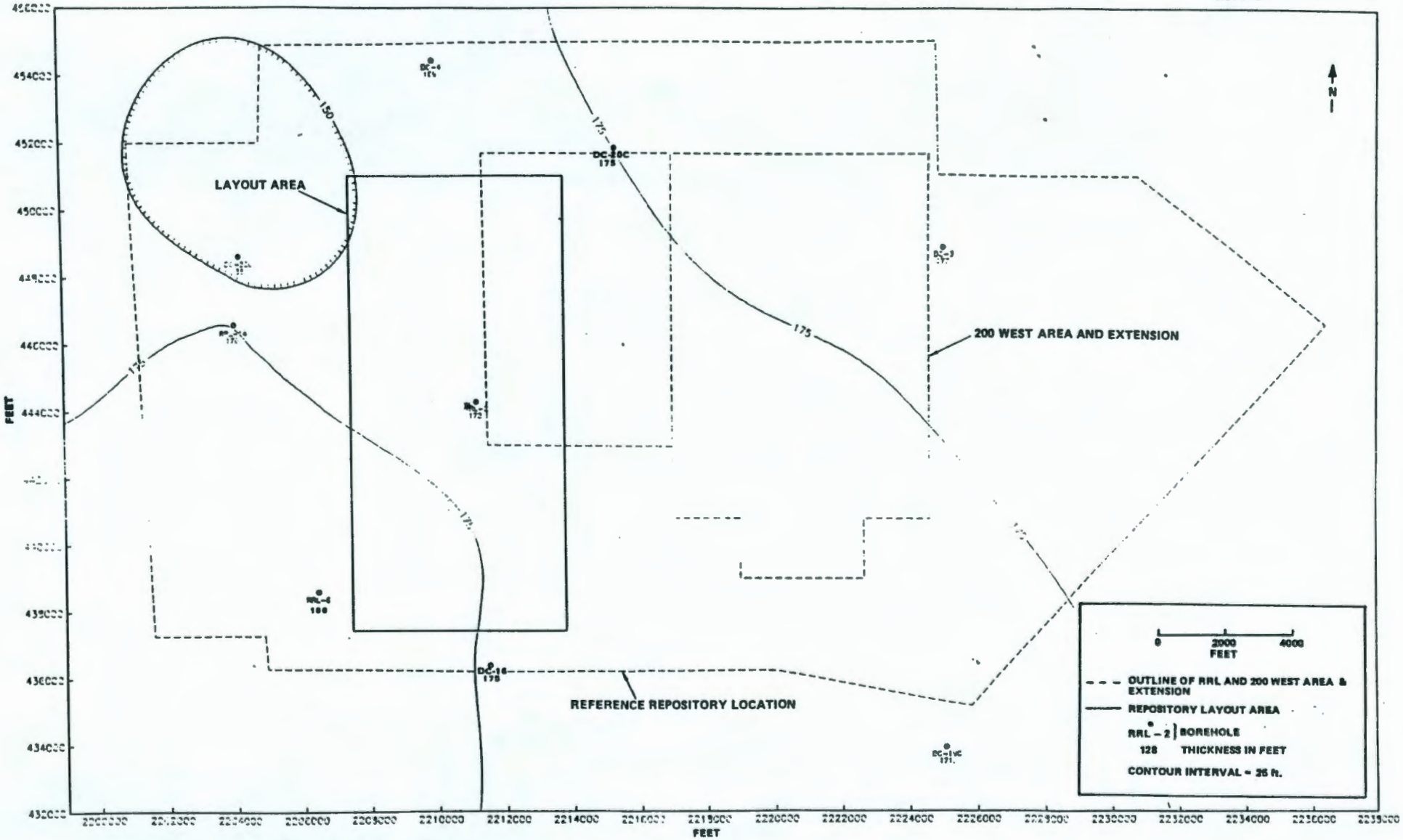

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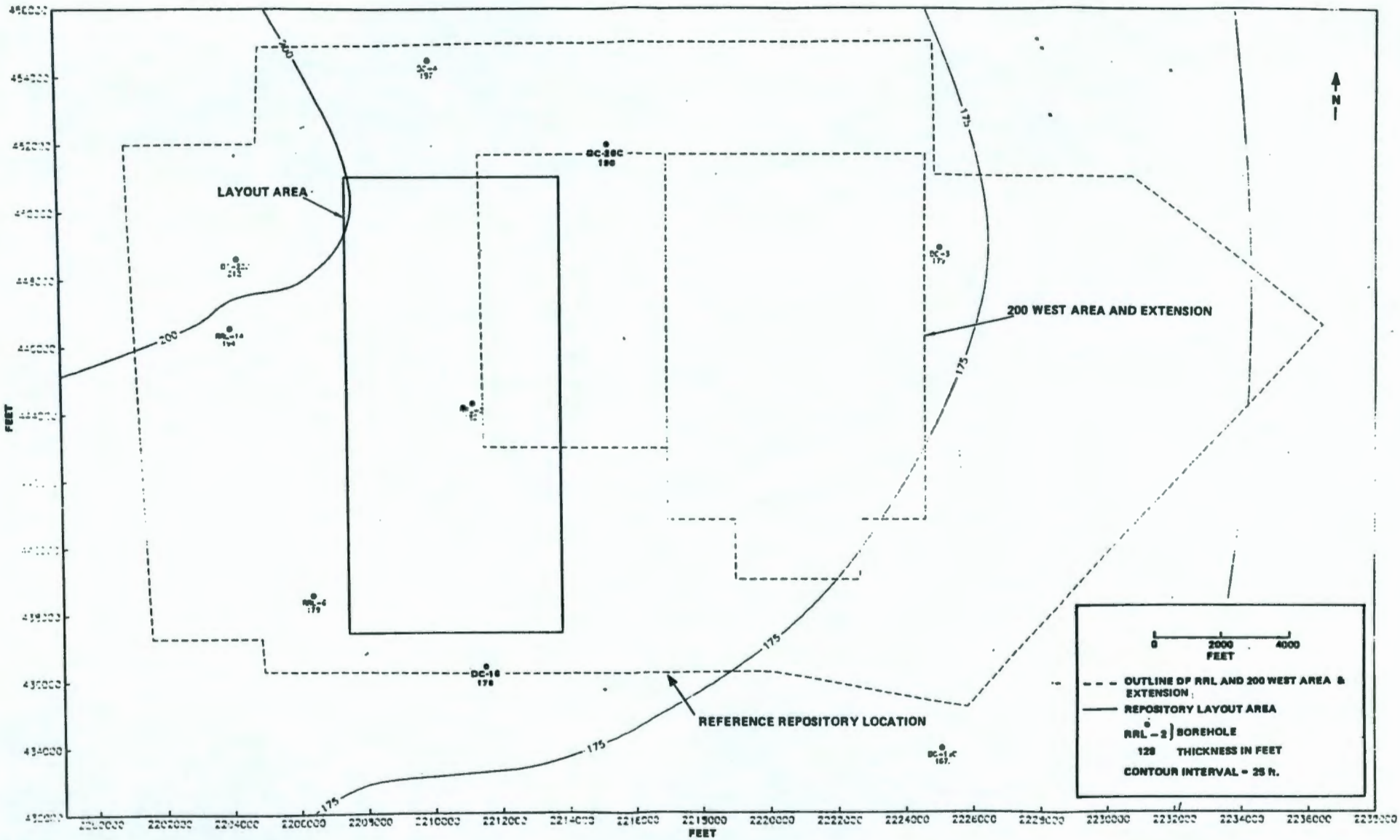

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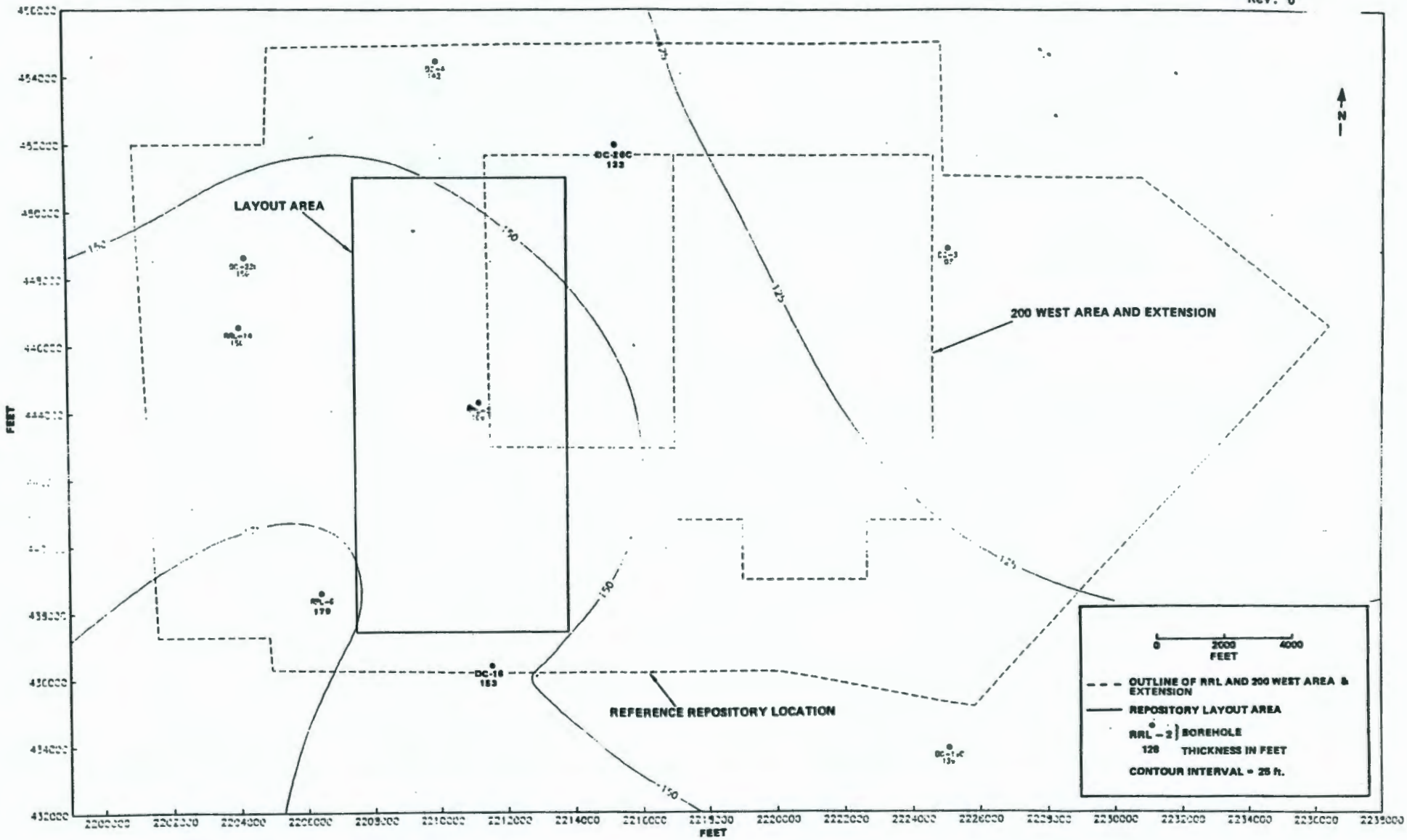


Figure C-13. Isopach Map of the Sand Hollow Flows.

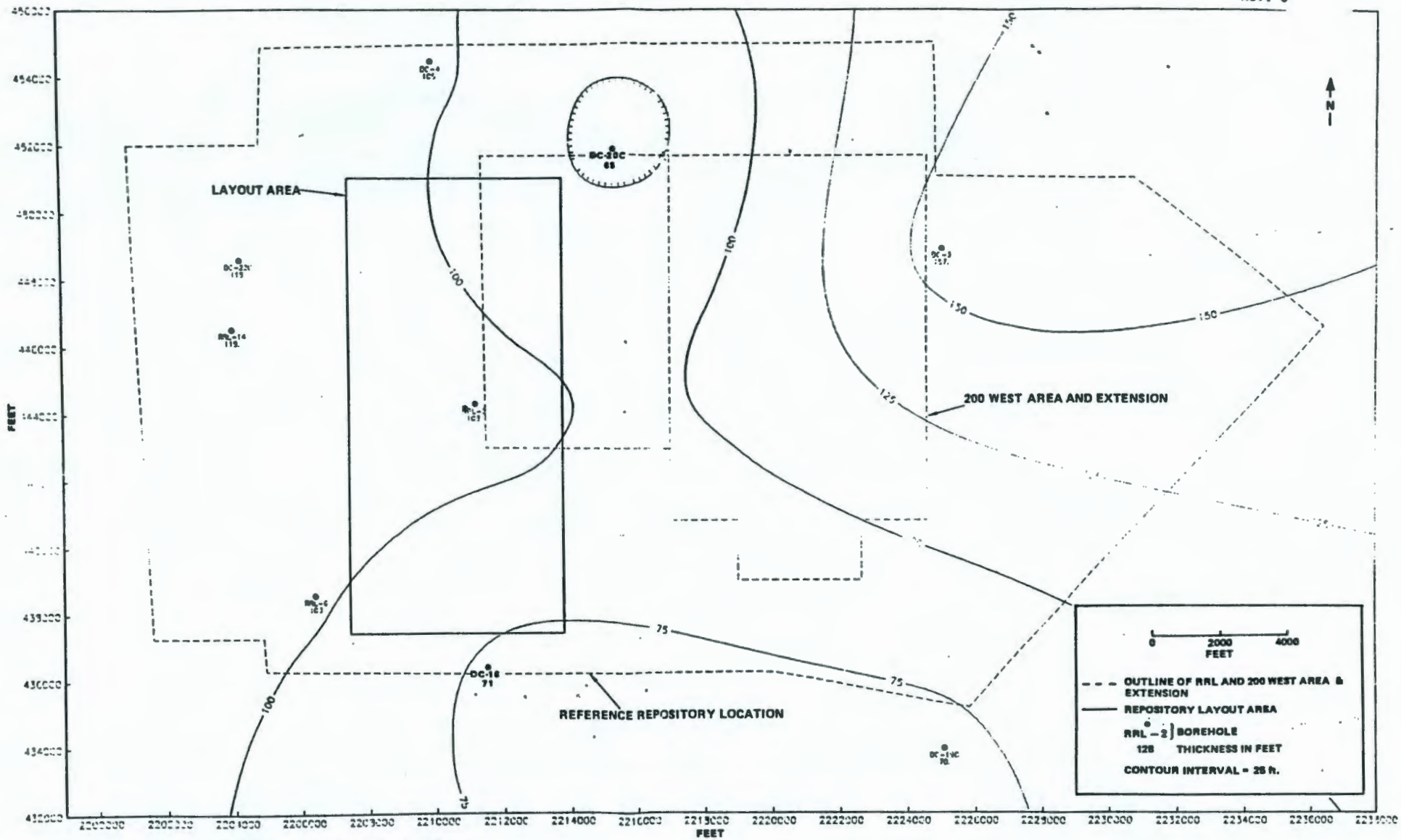
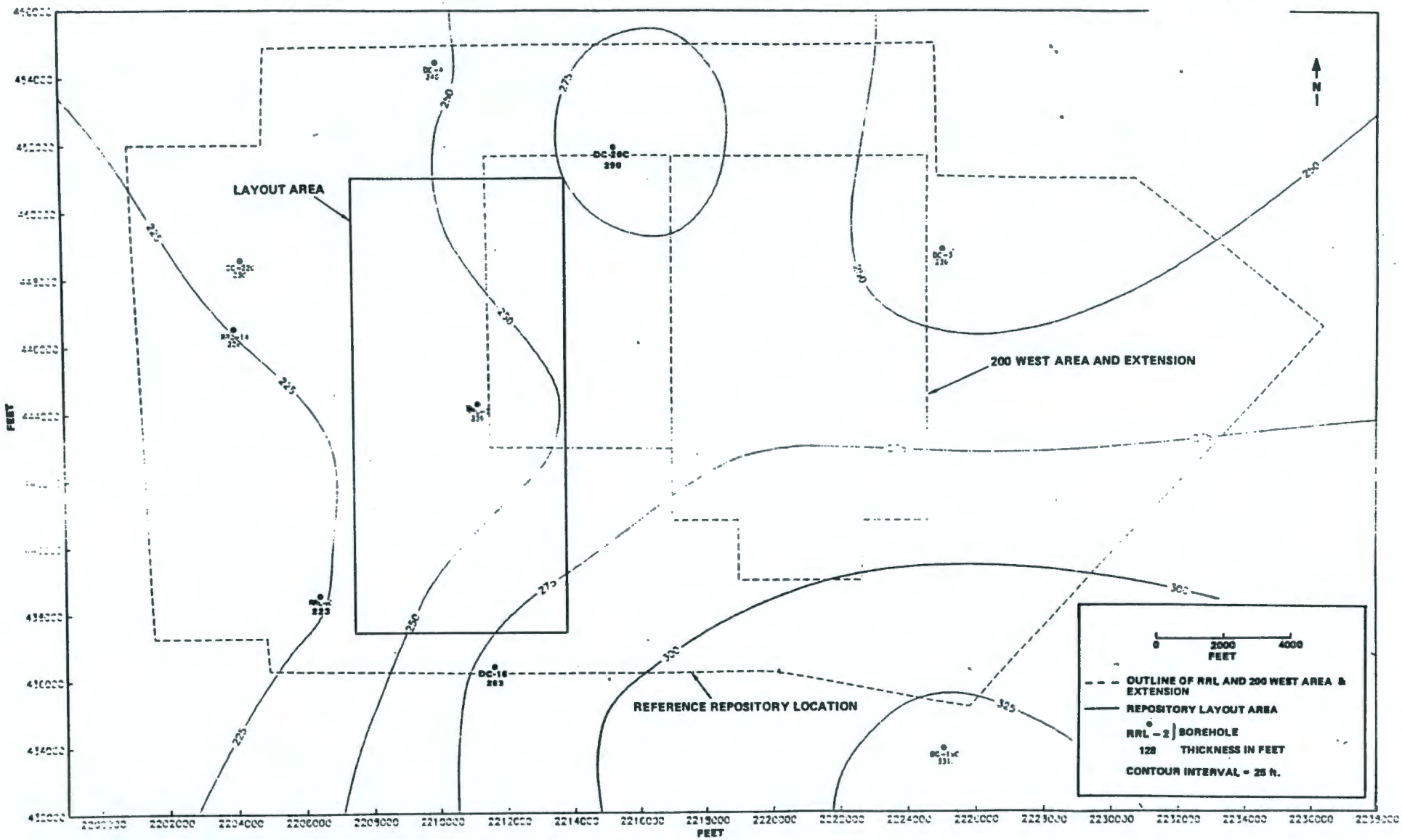


Figure C-14. Isopach Map of the Silver Falls Flows.



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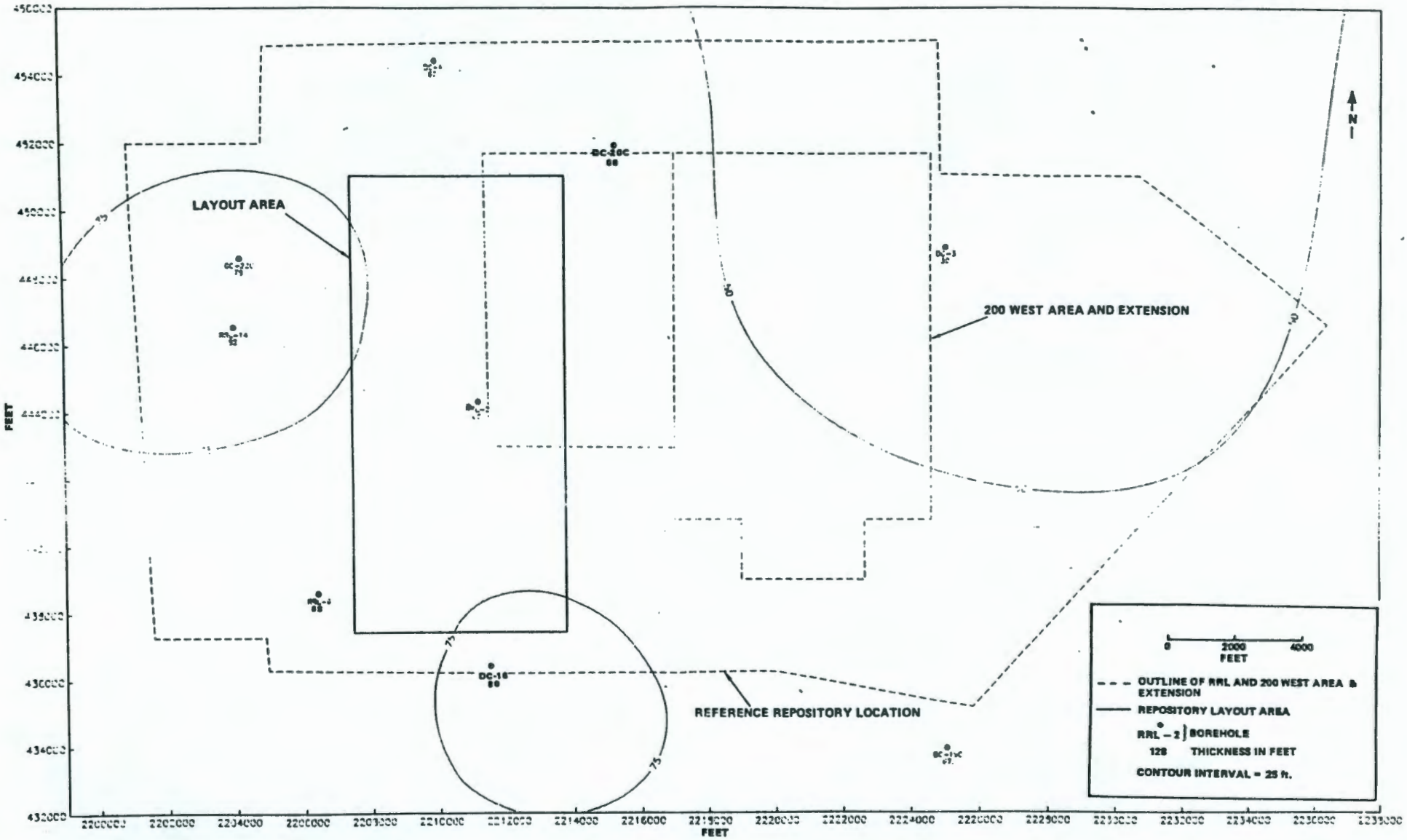

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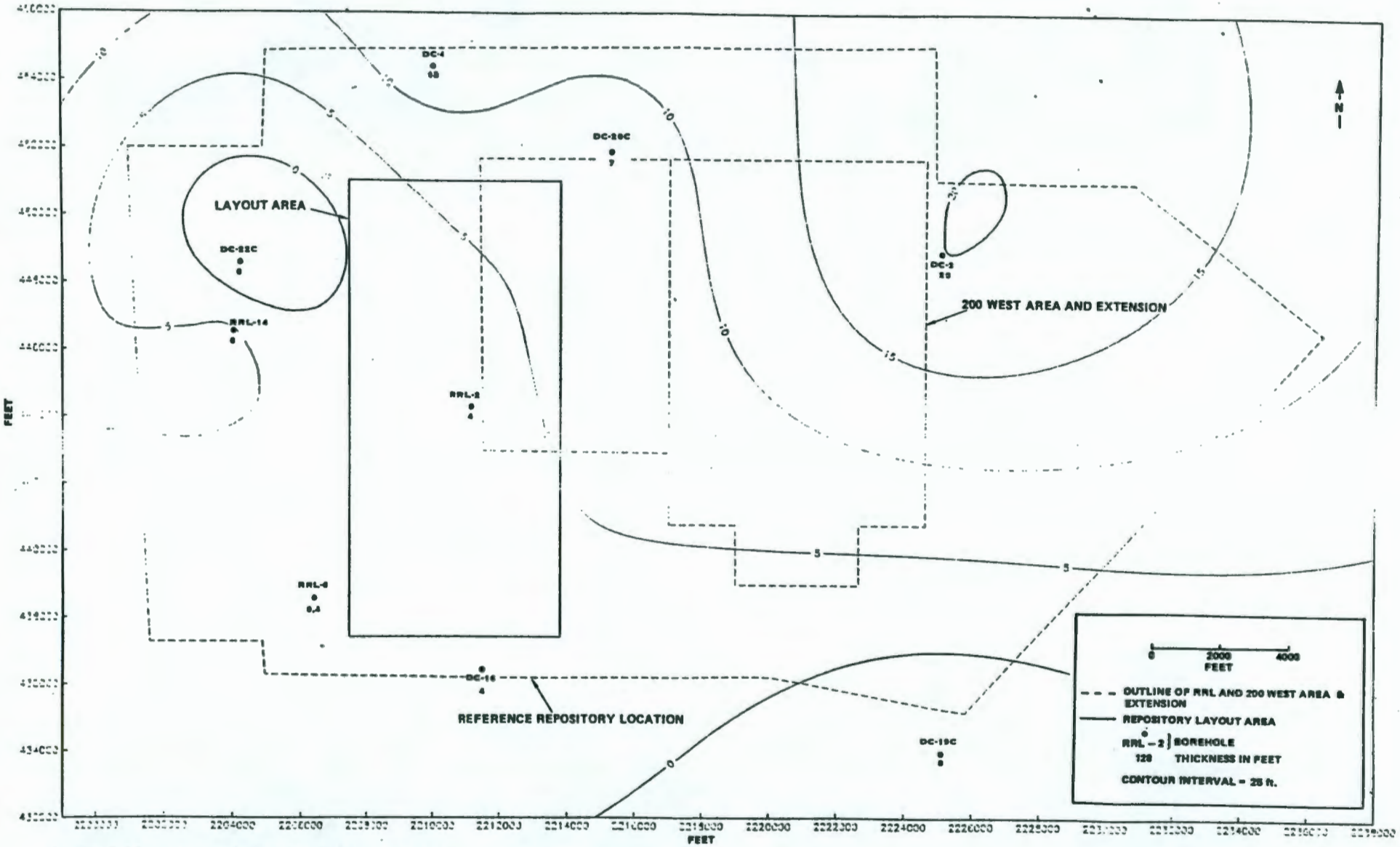
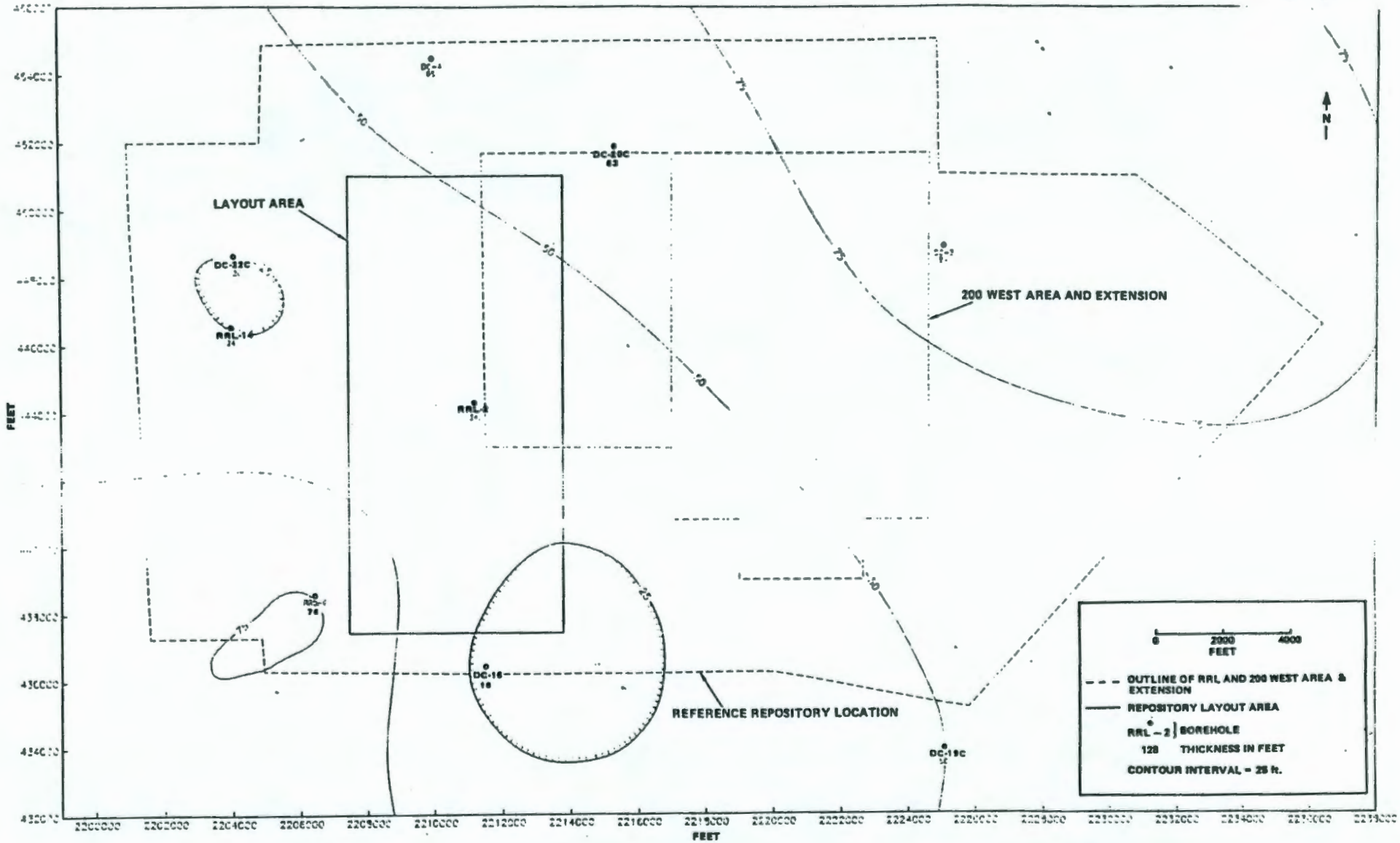


Figure C-17. Isopach Map of the Vantage Interbed.



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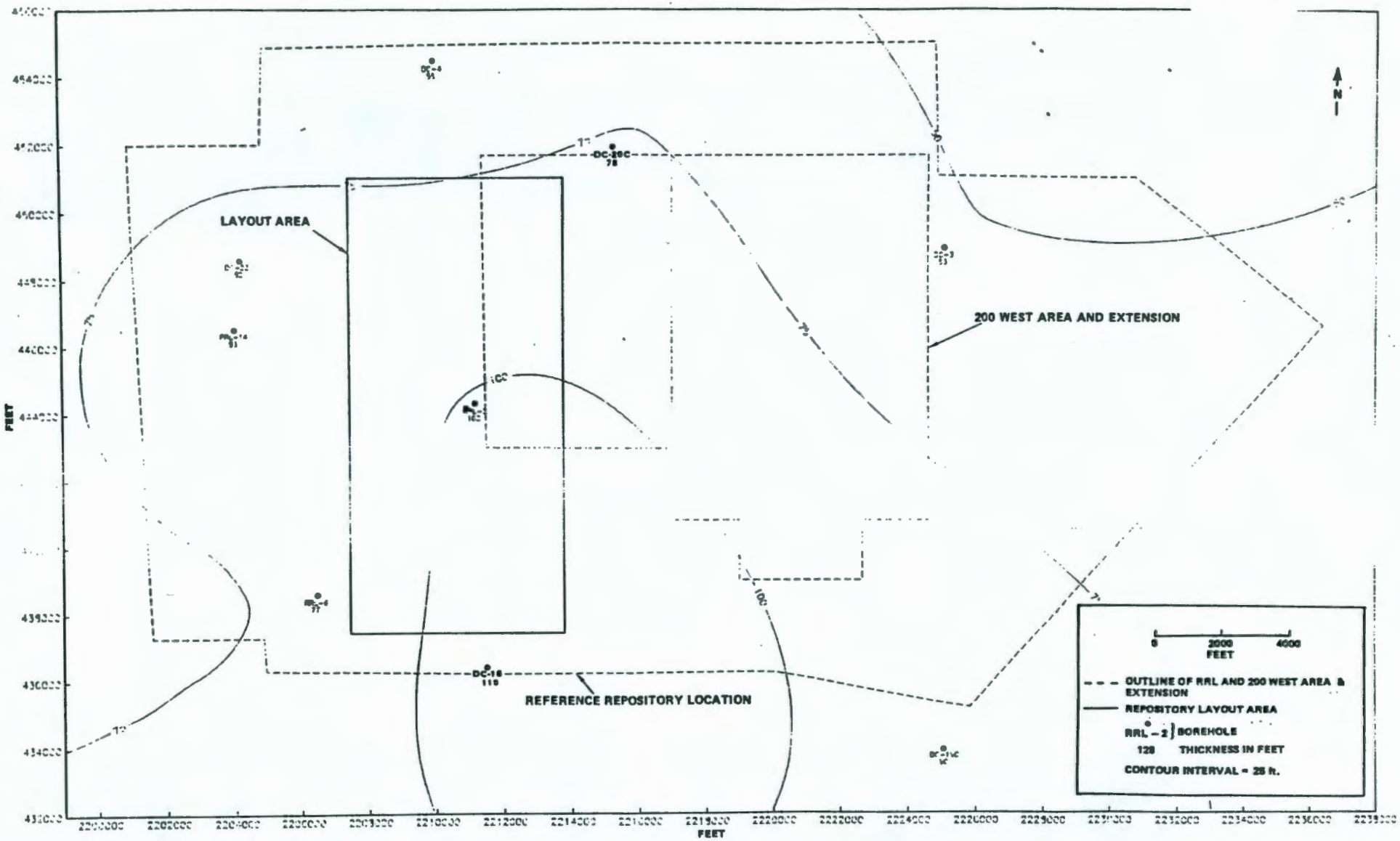

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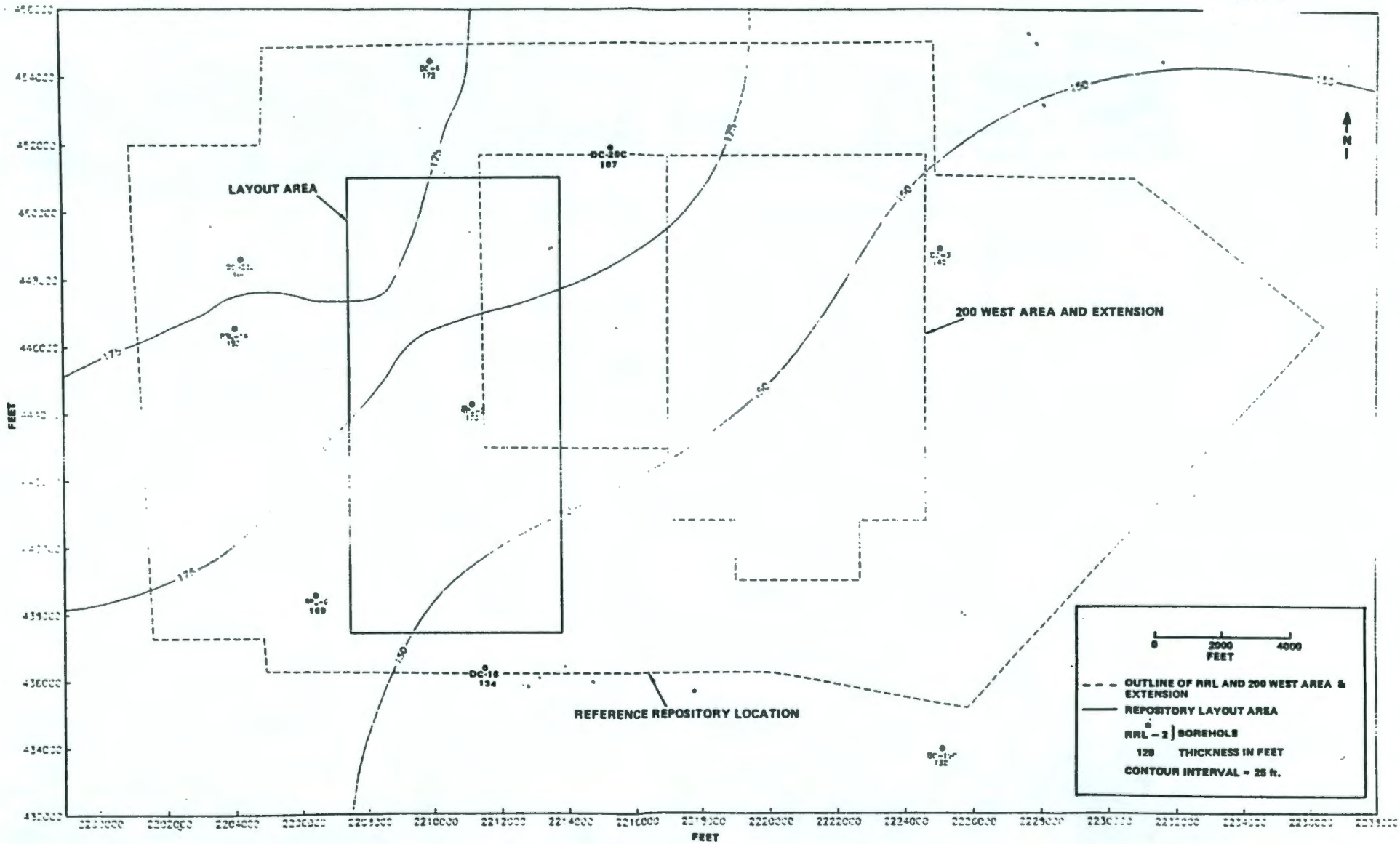

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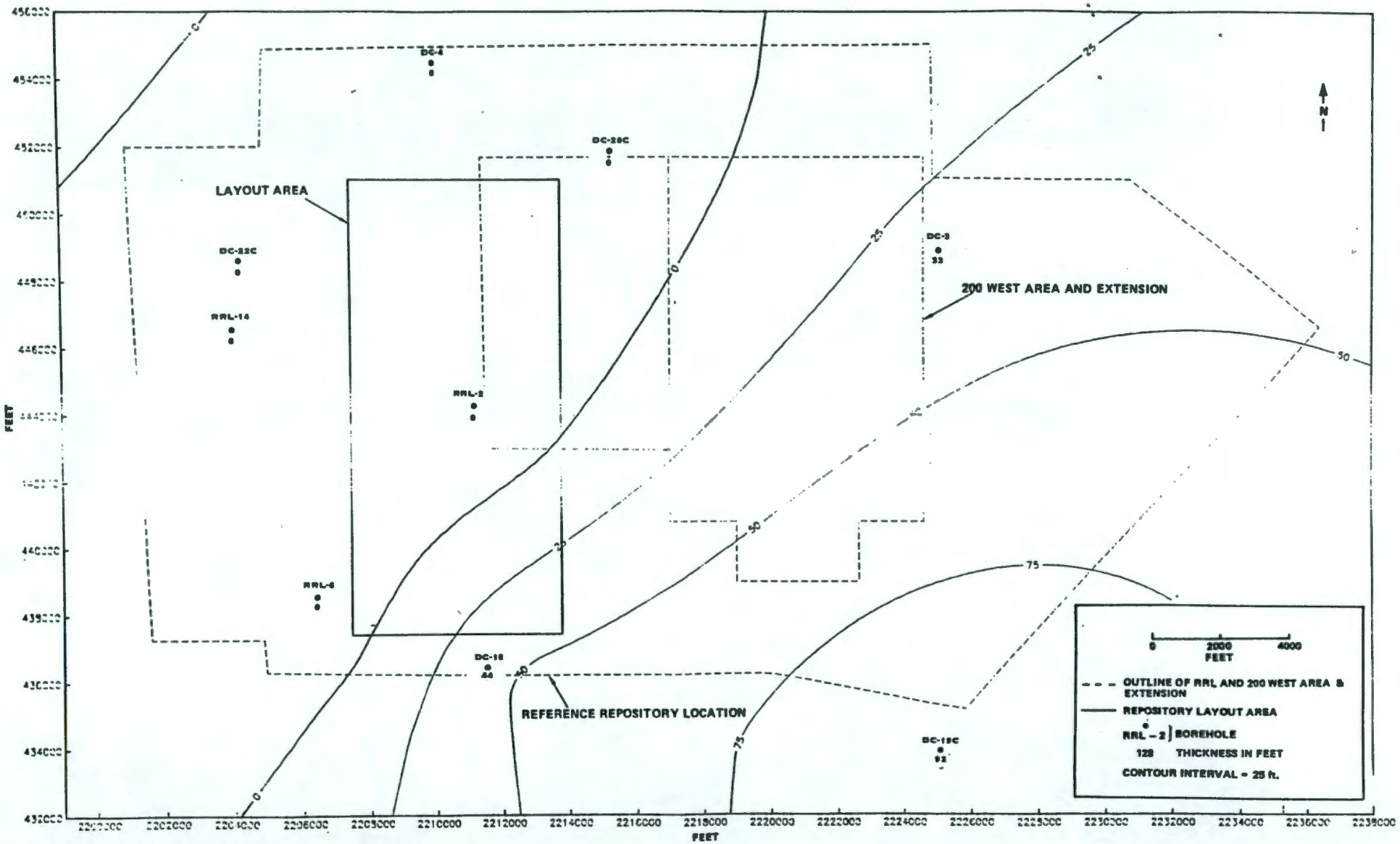

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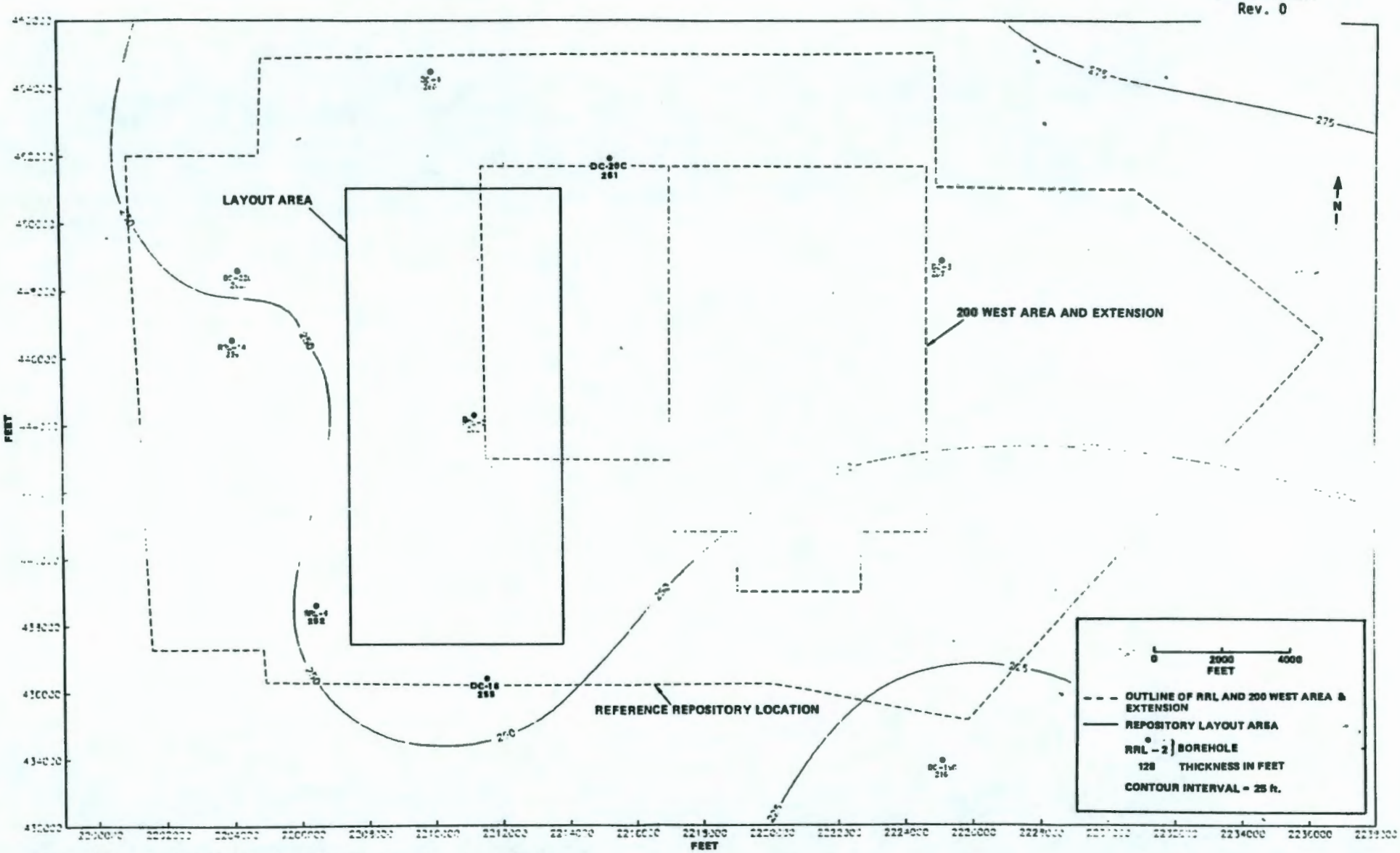

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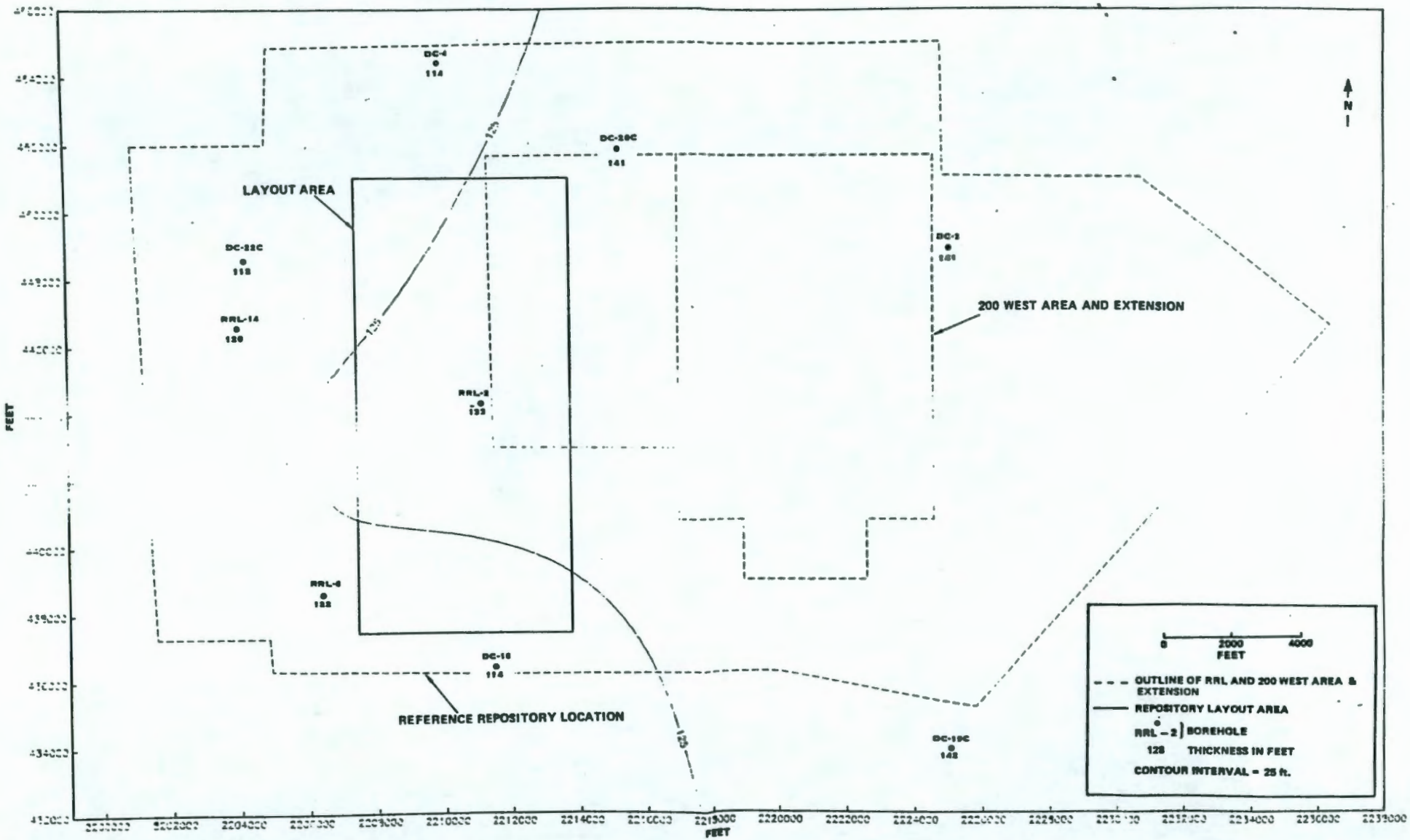

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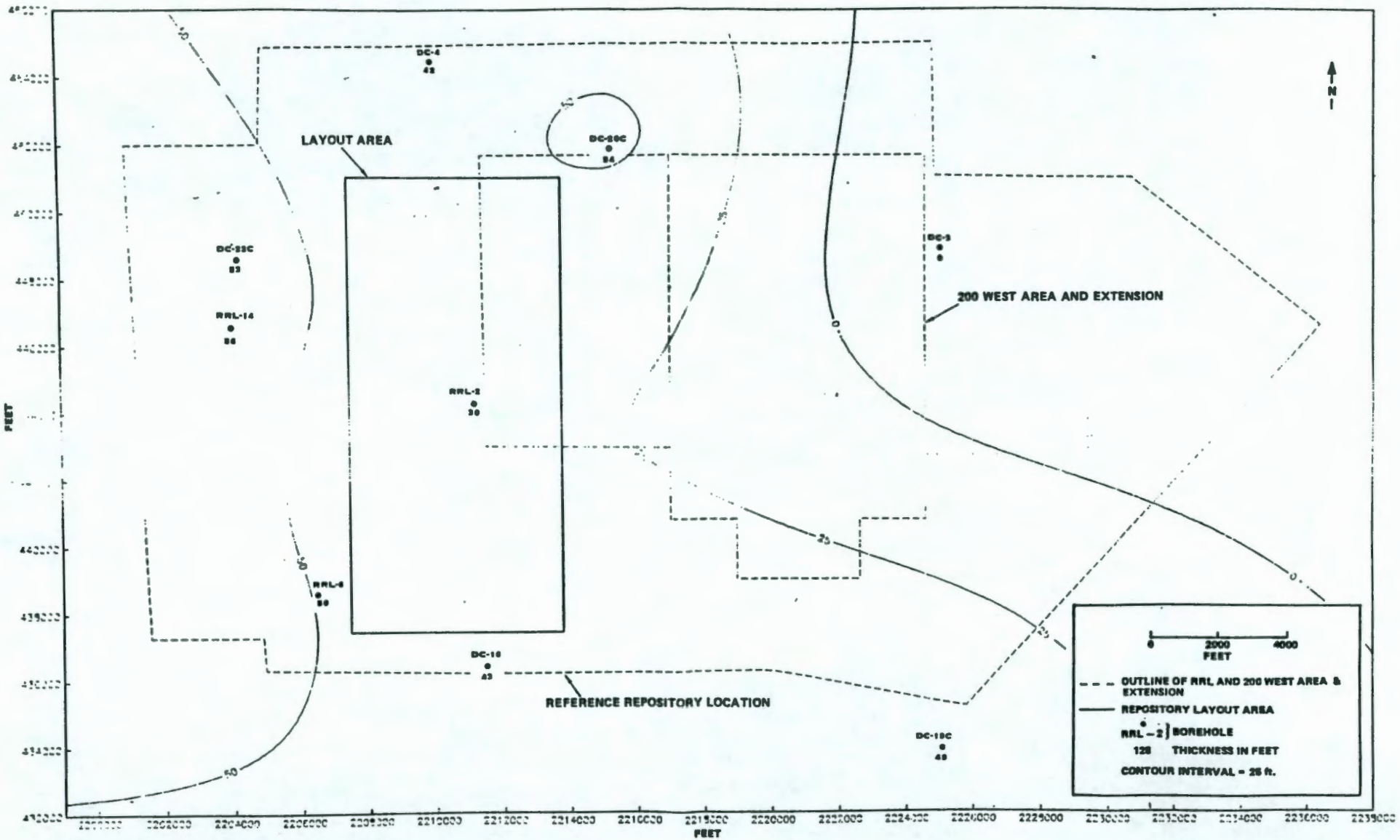

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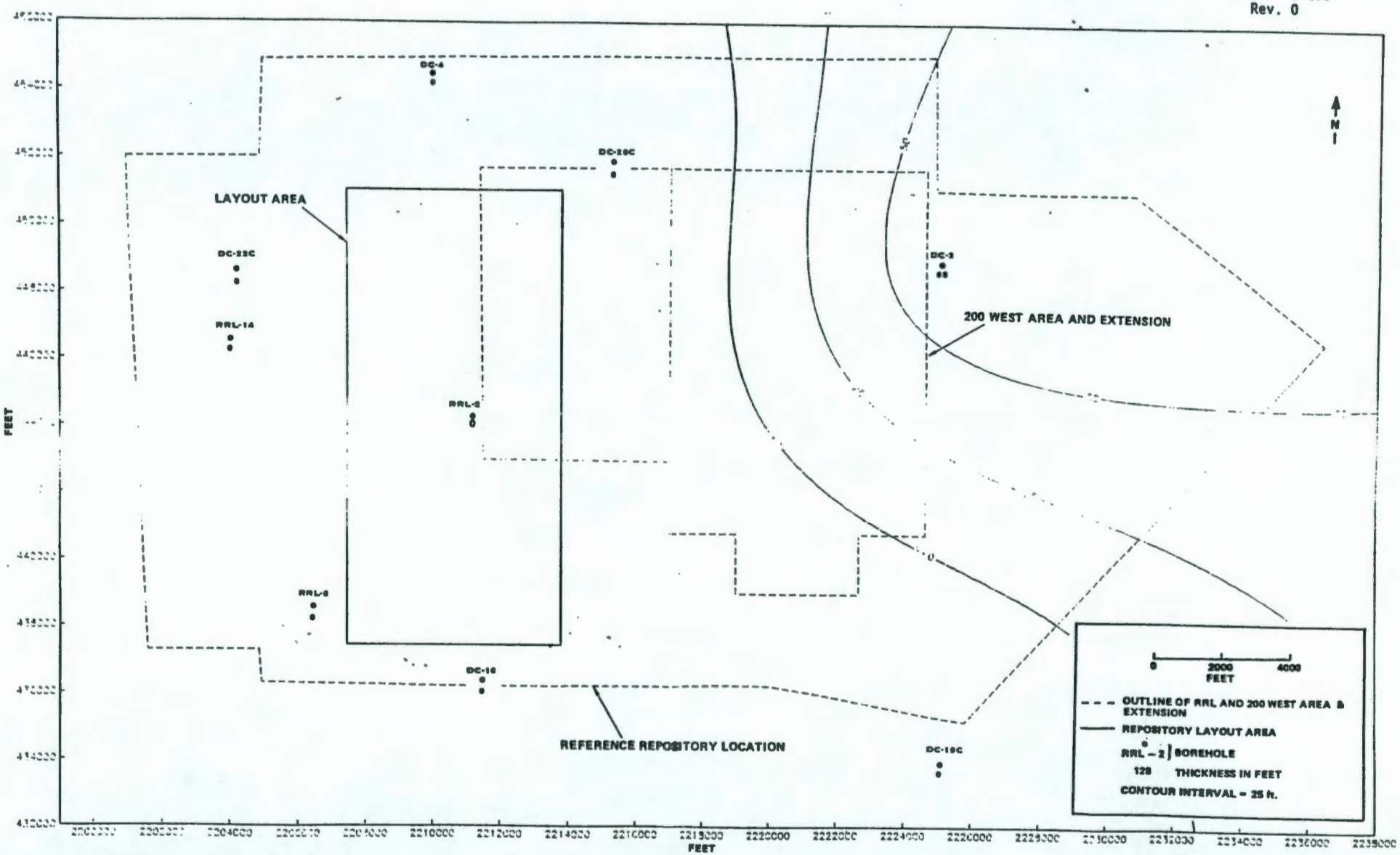

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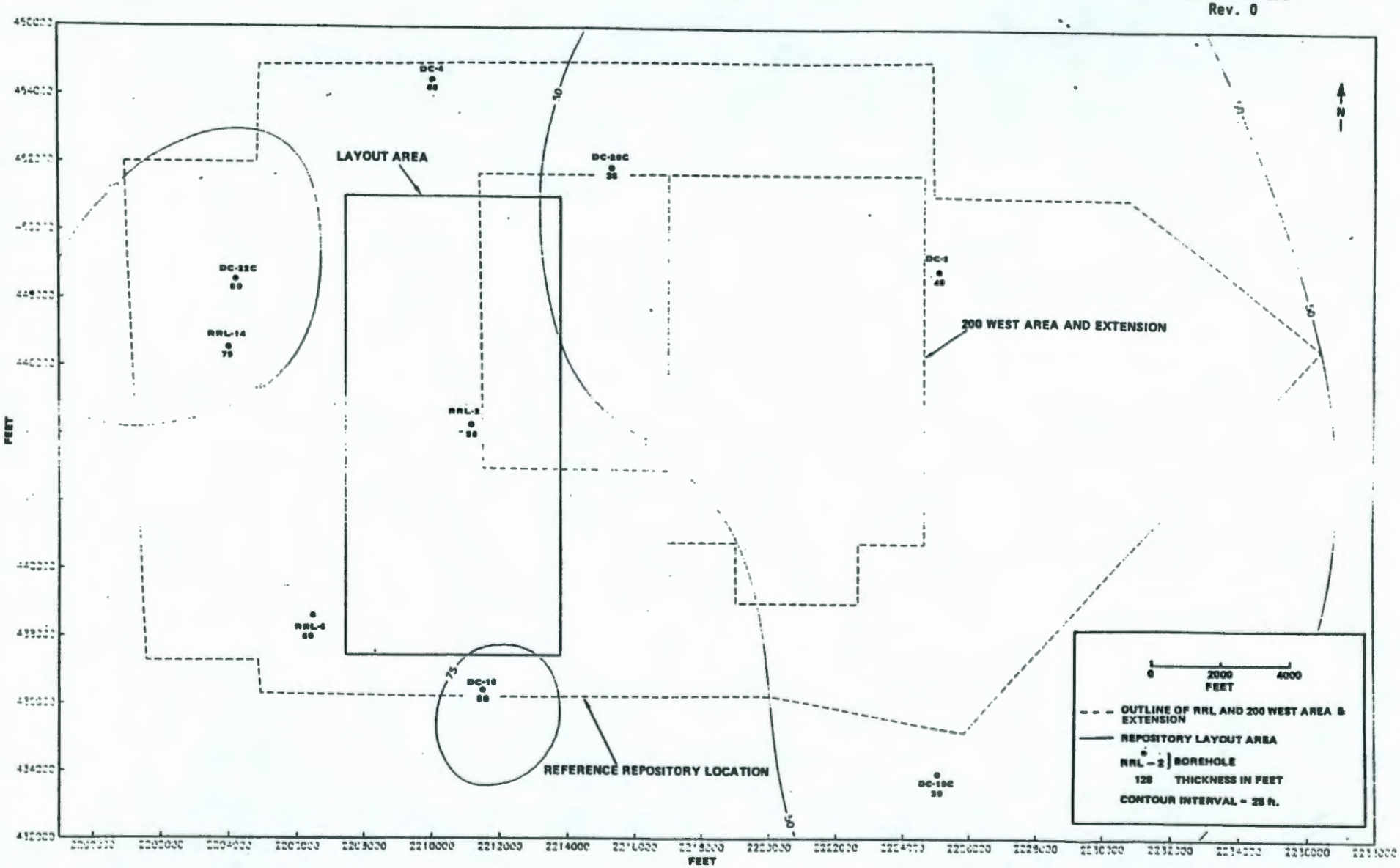

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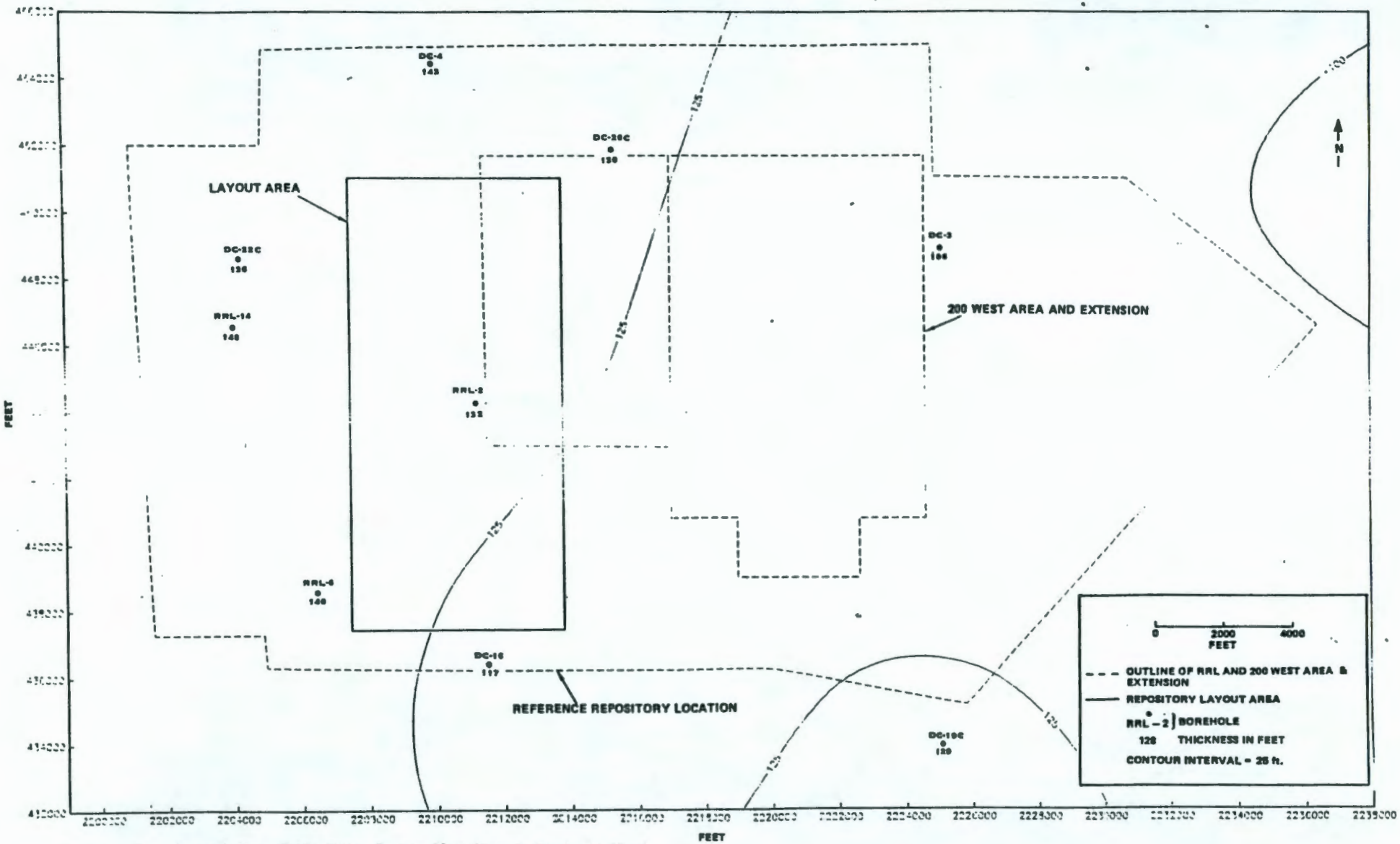

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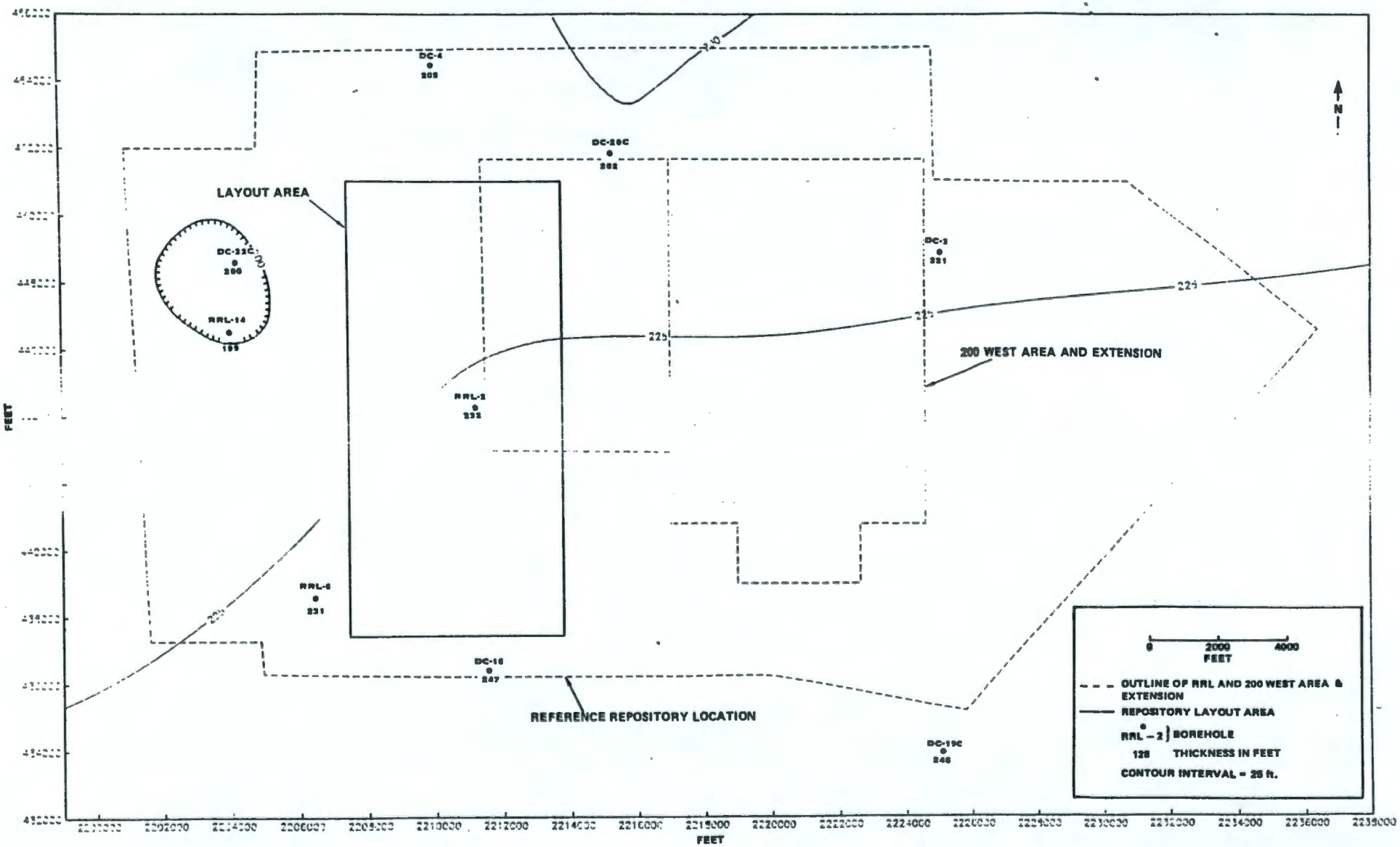

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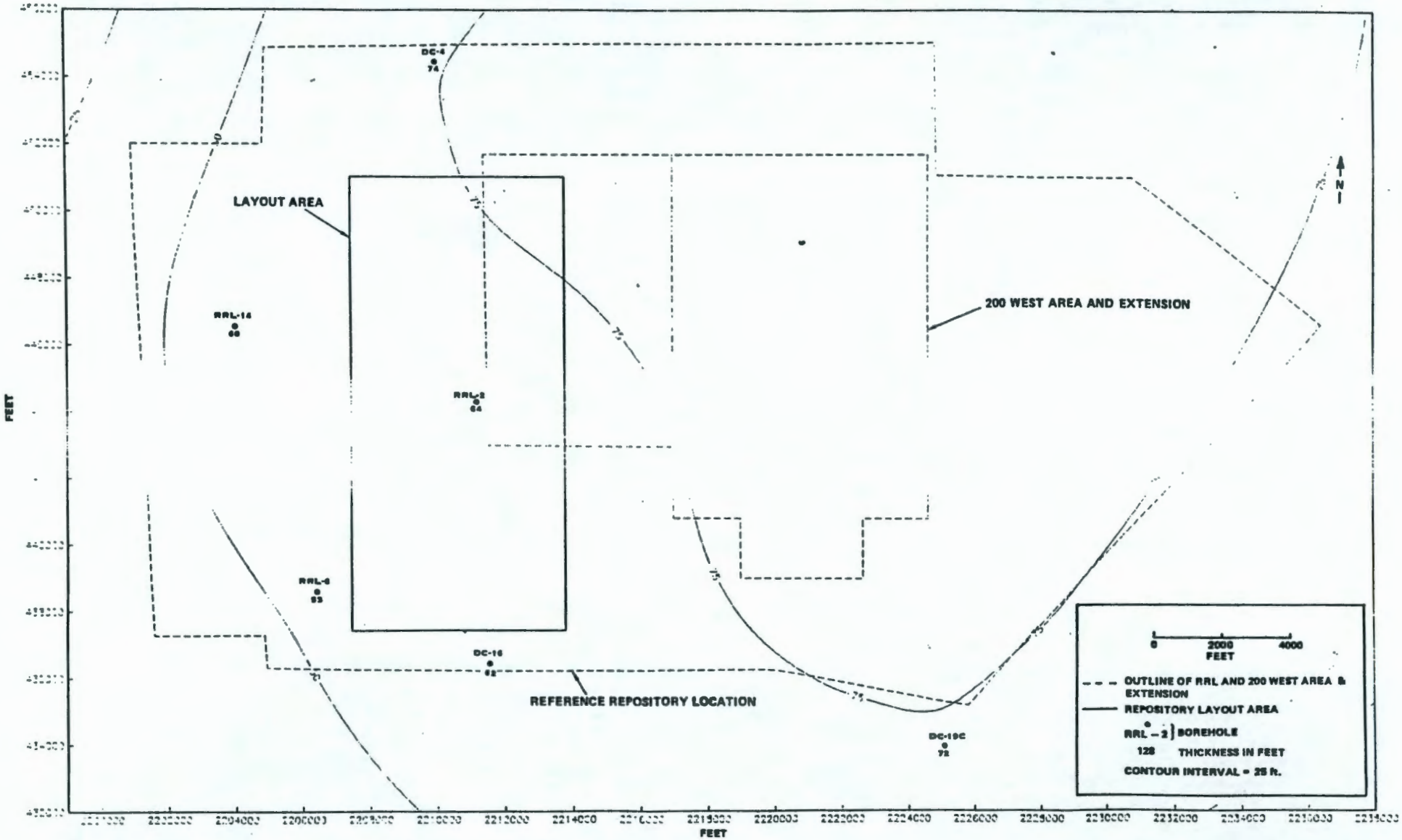

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APPENDIX D

Structure cross sections.

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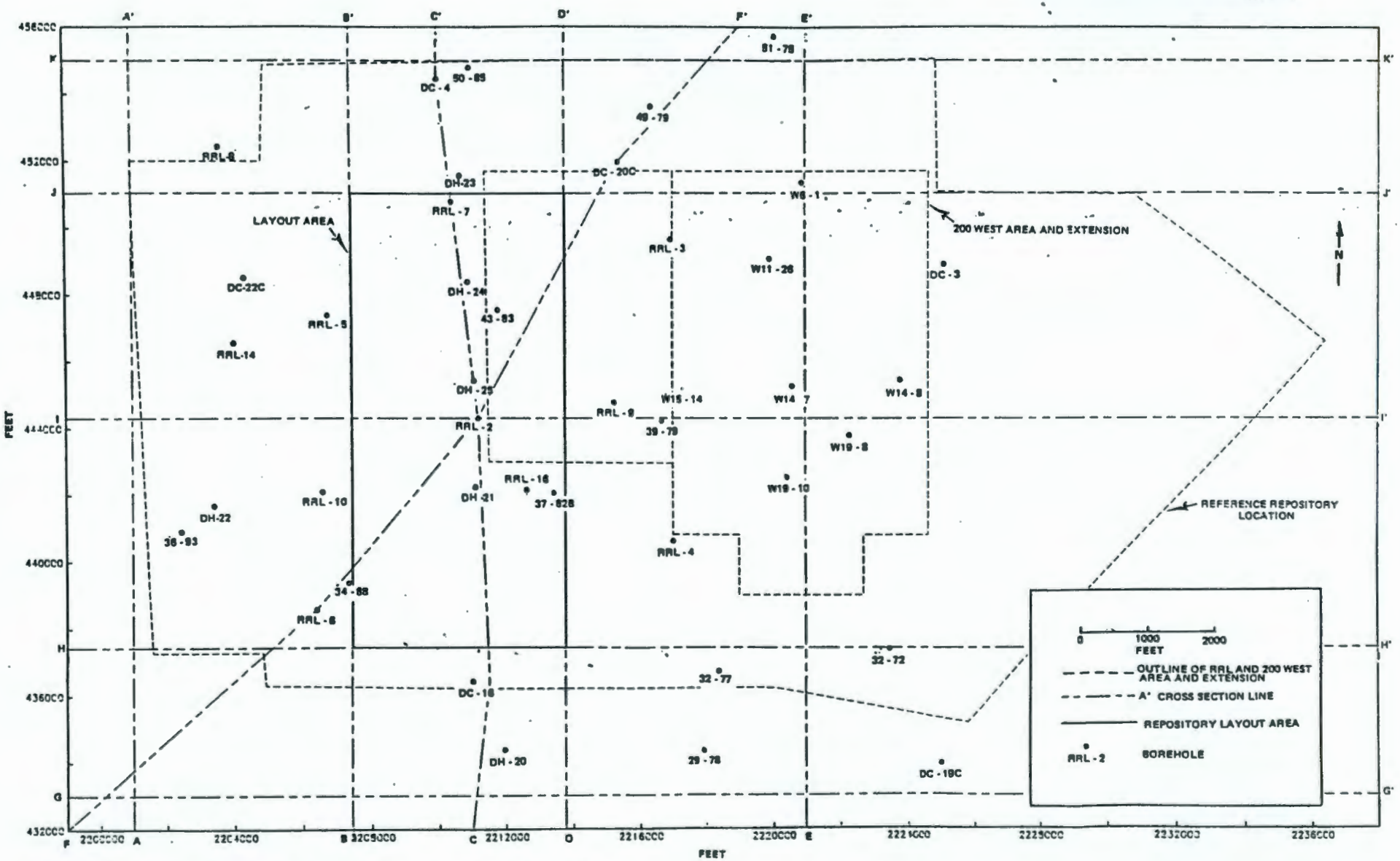

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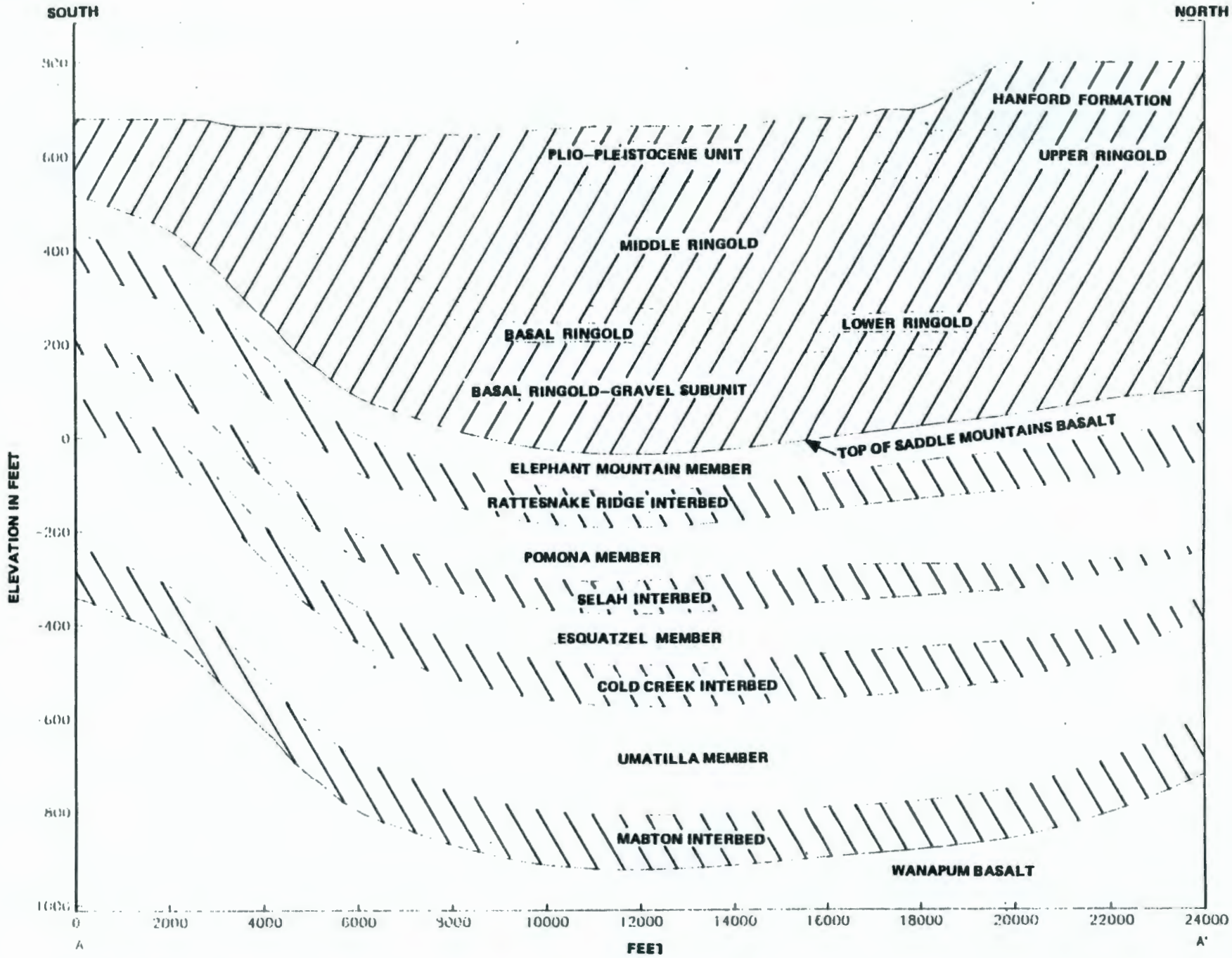

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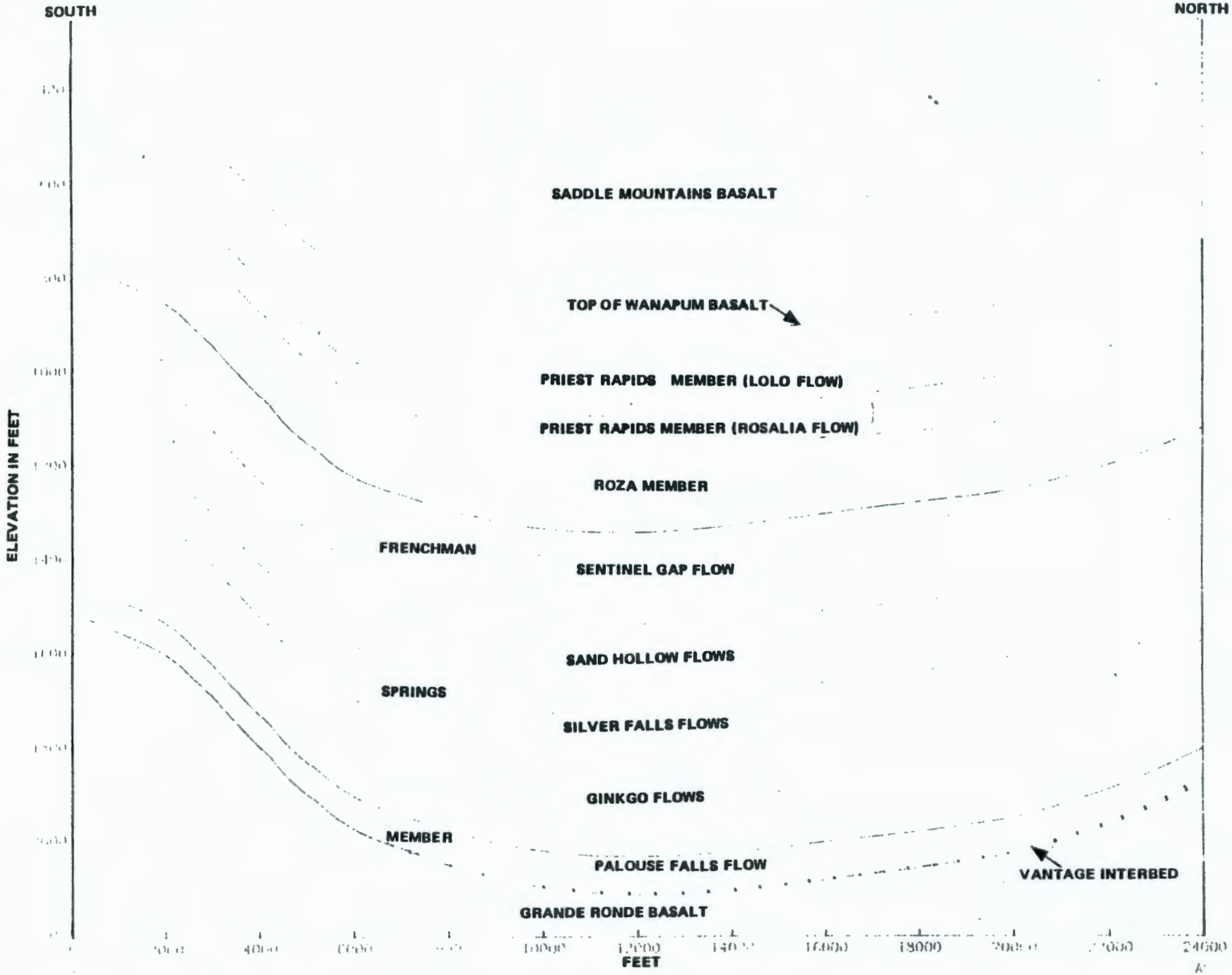

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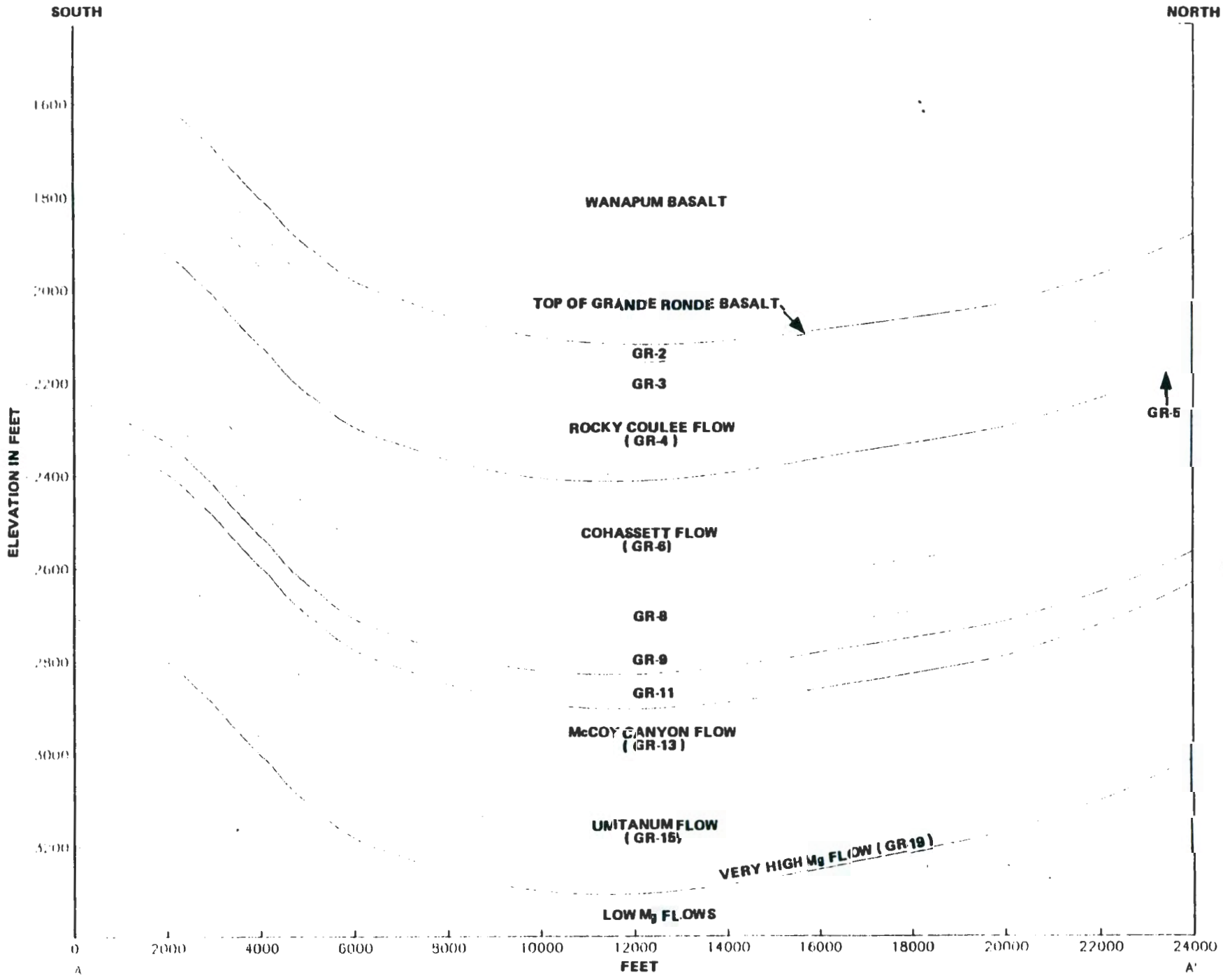

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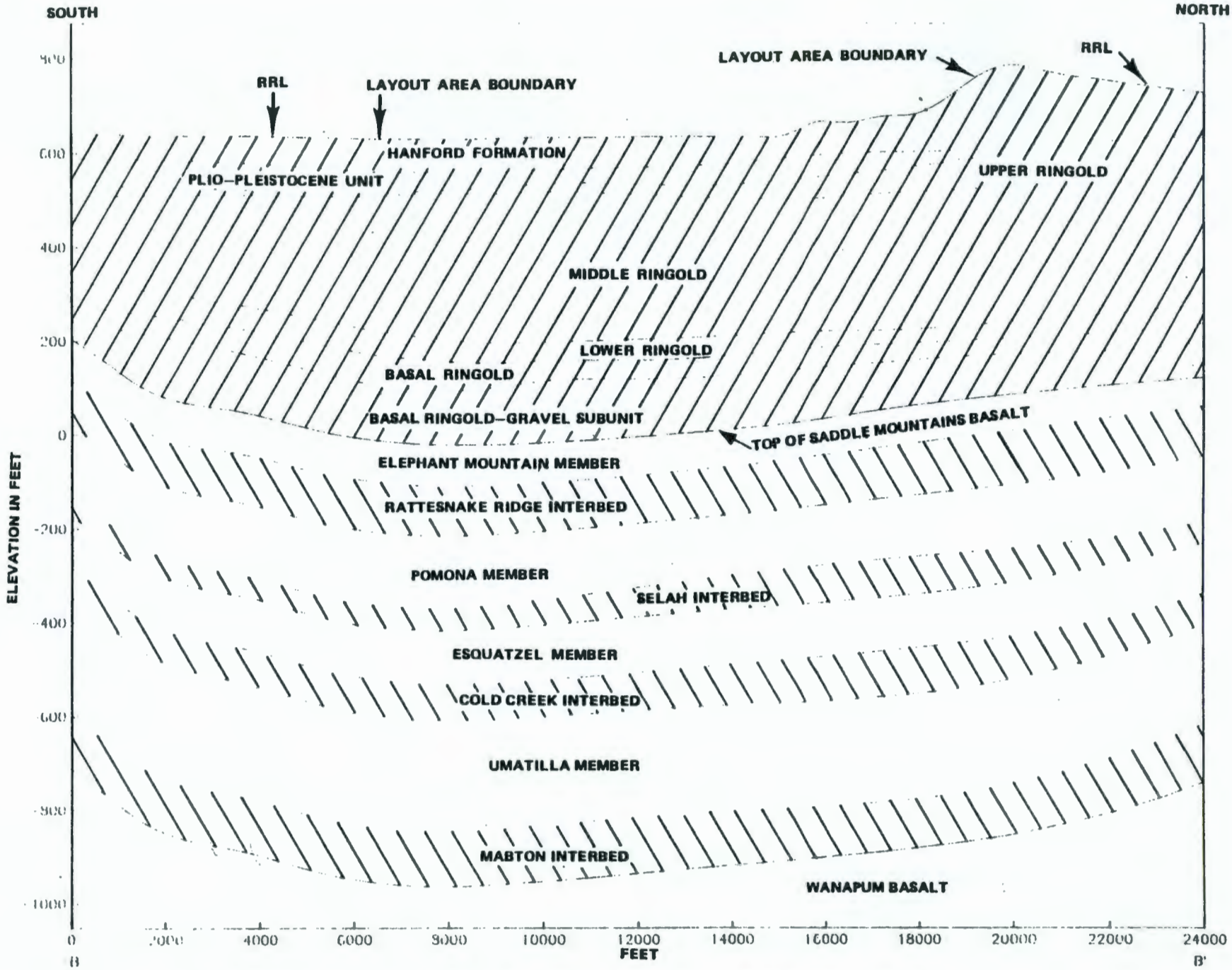

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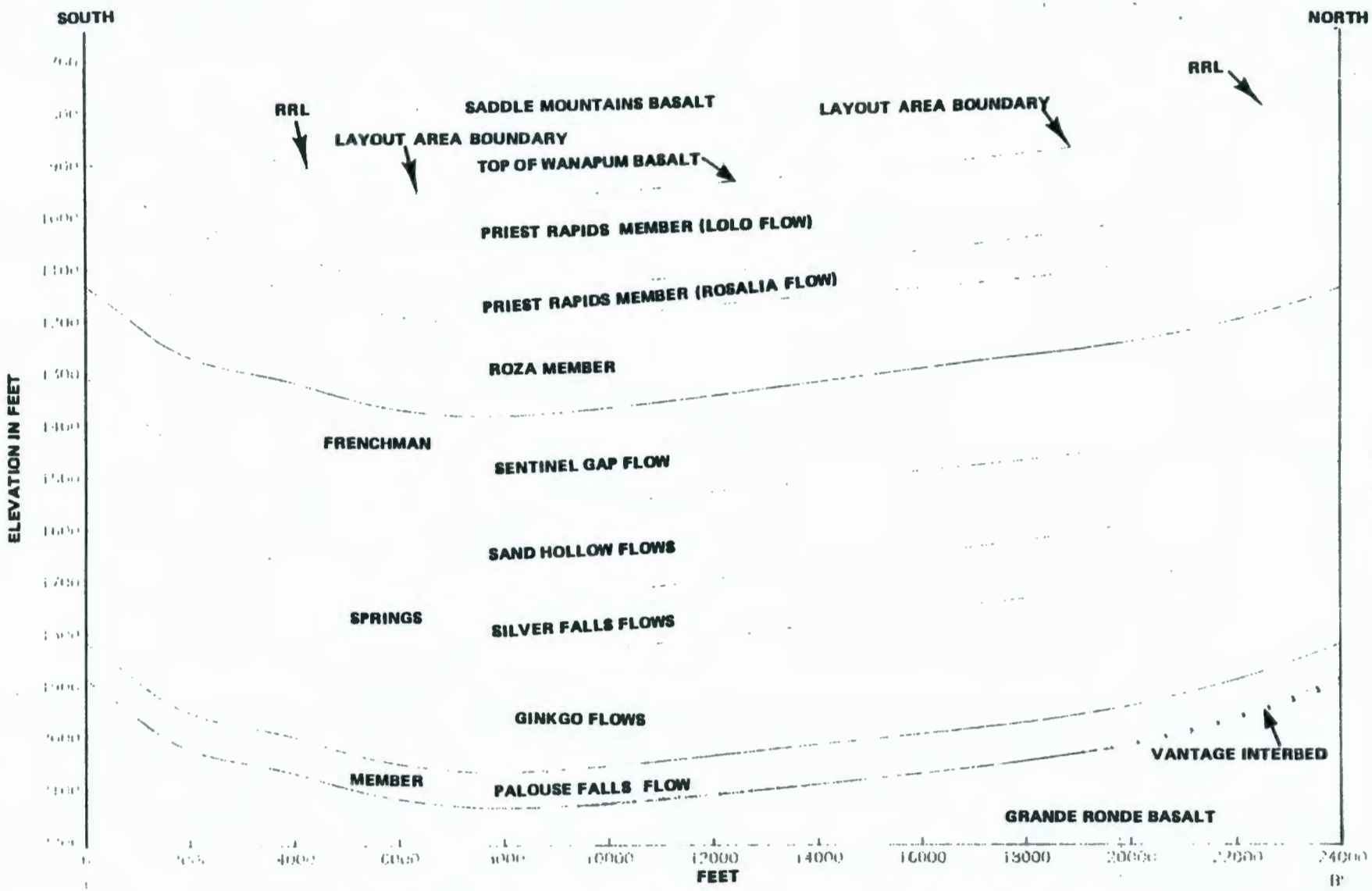

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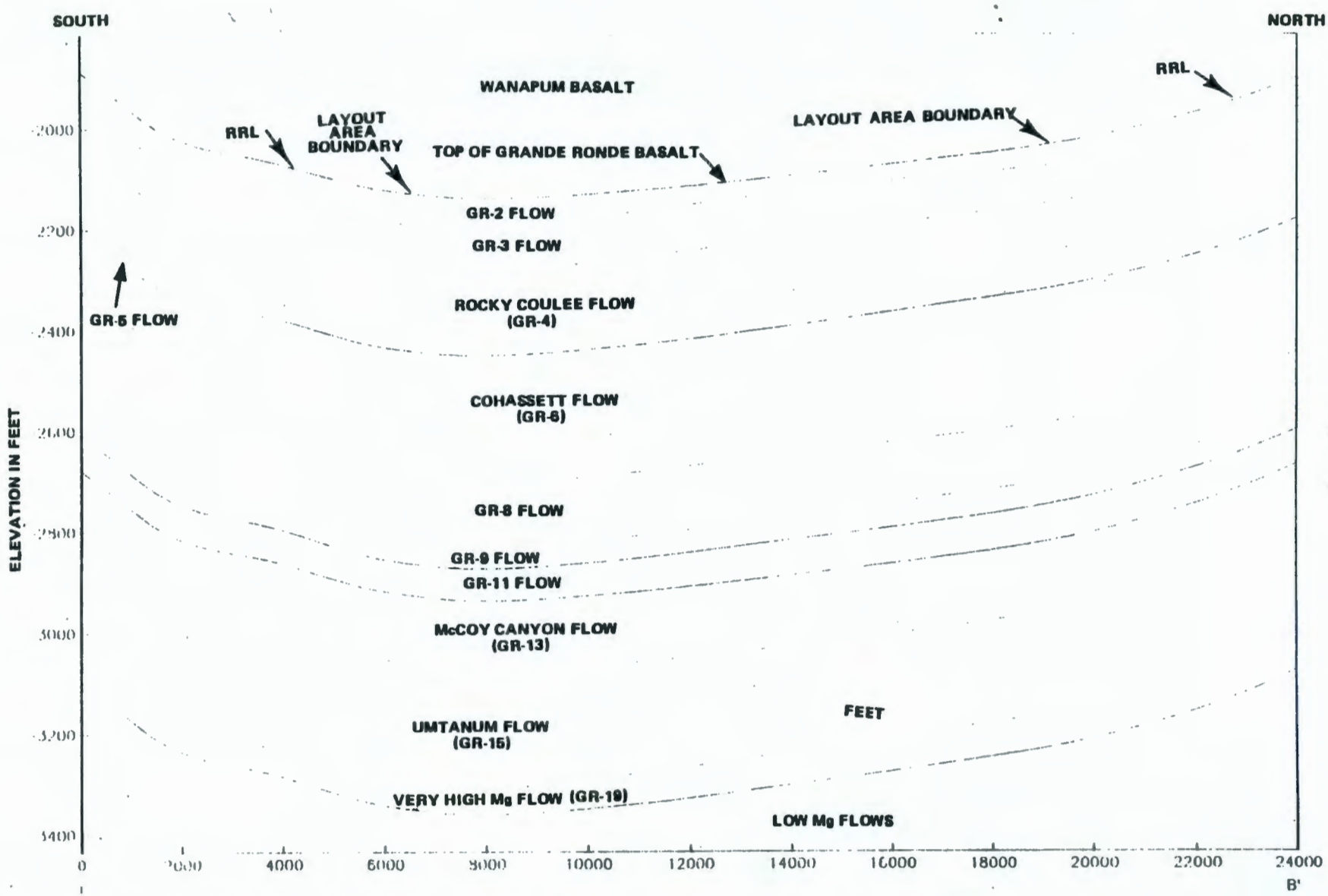

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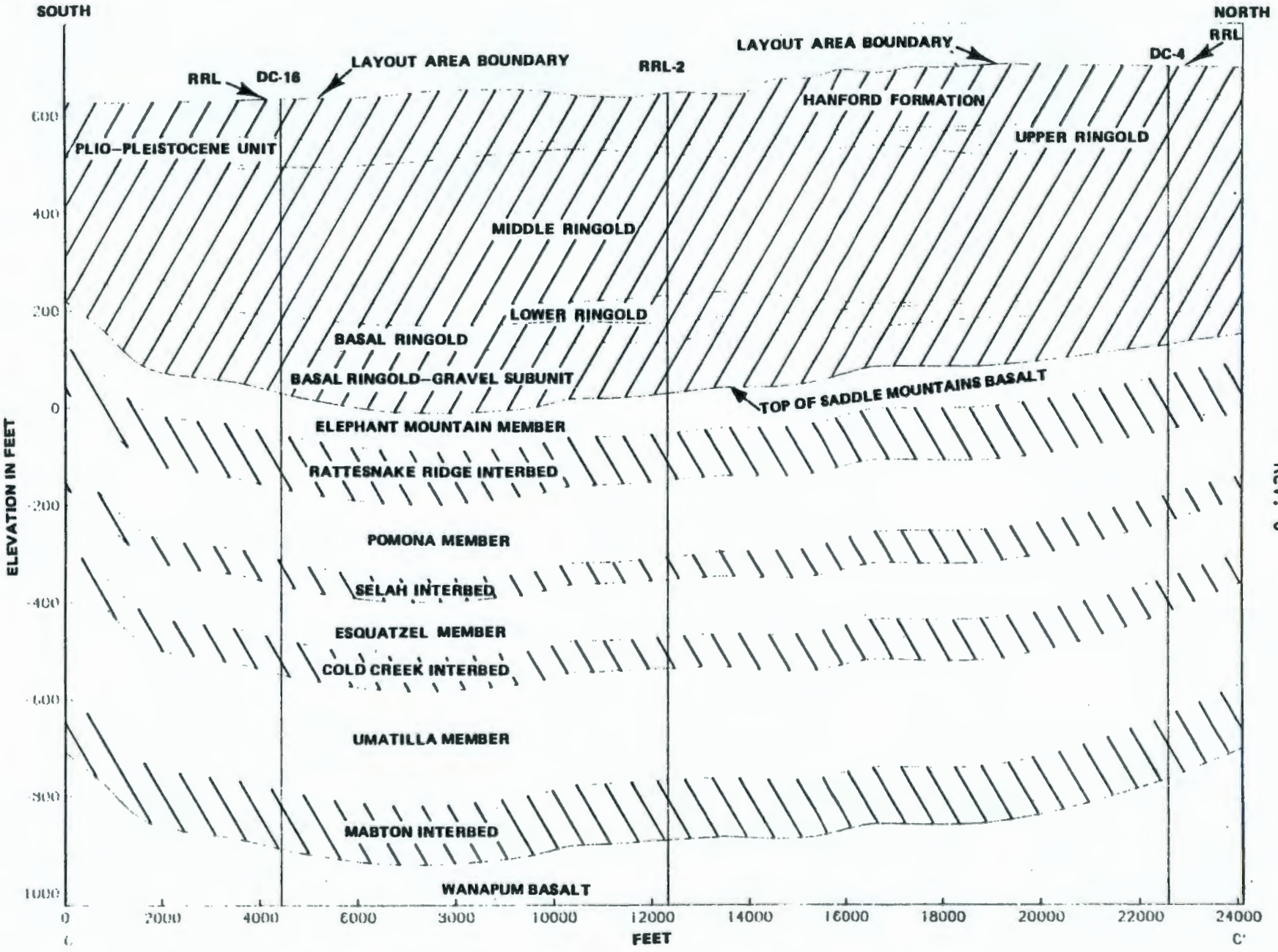

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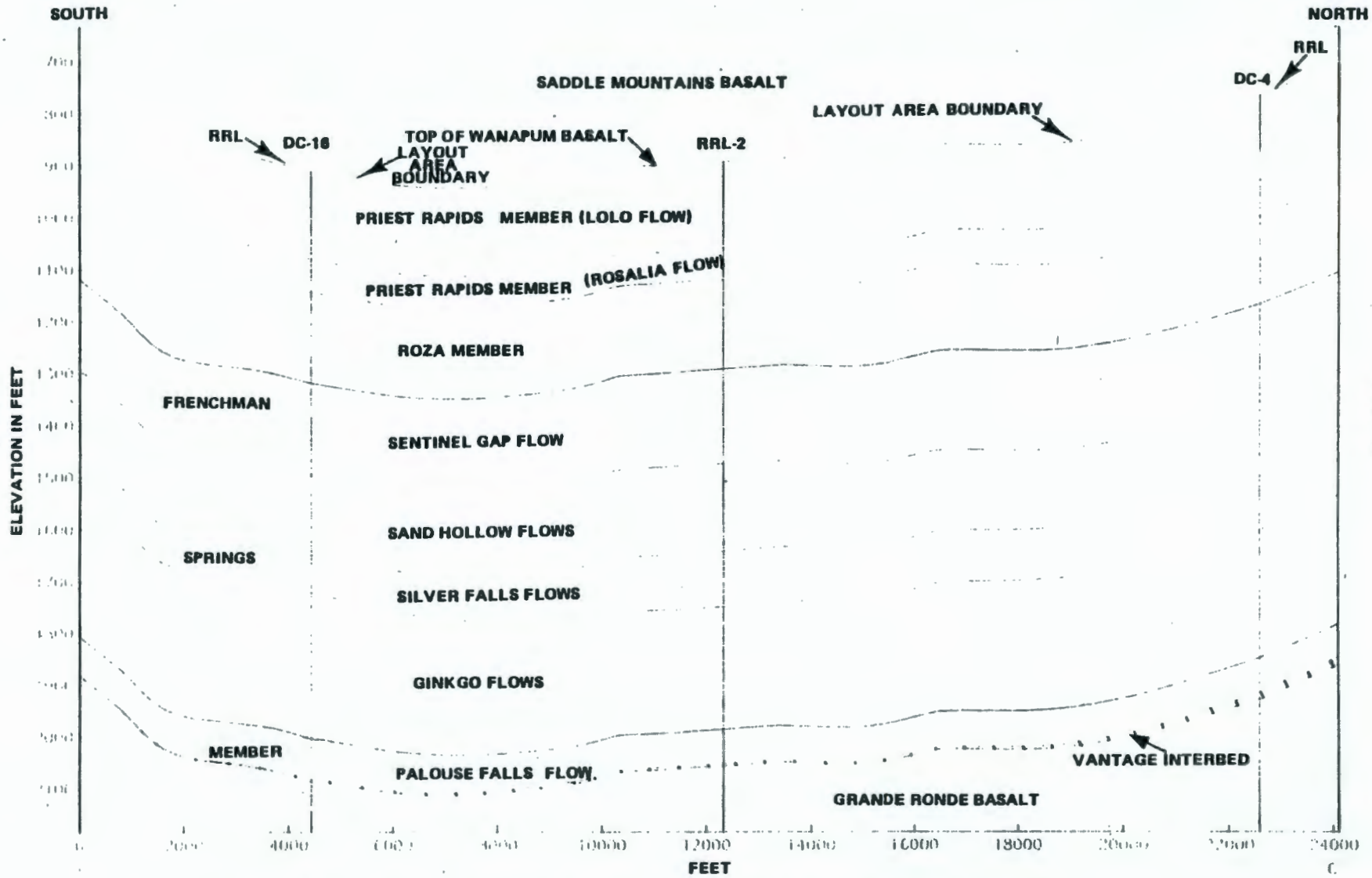

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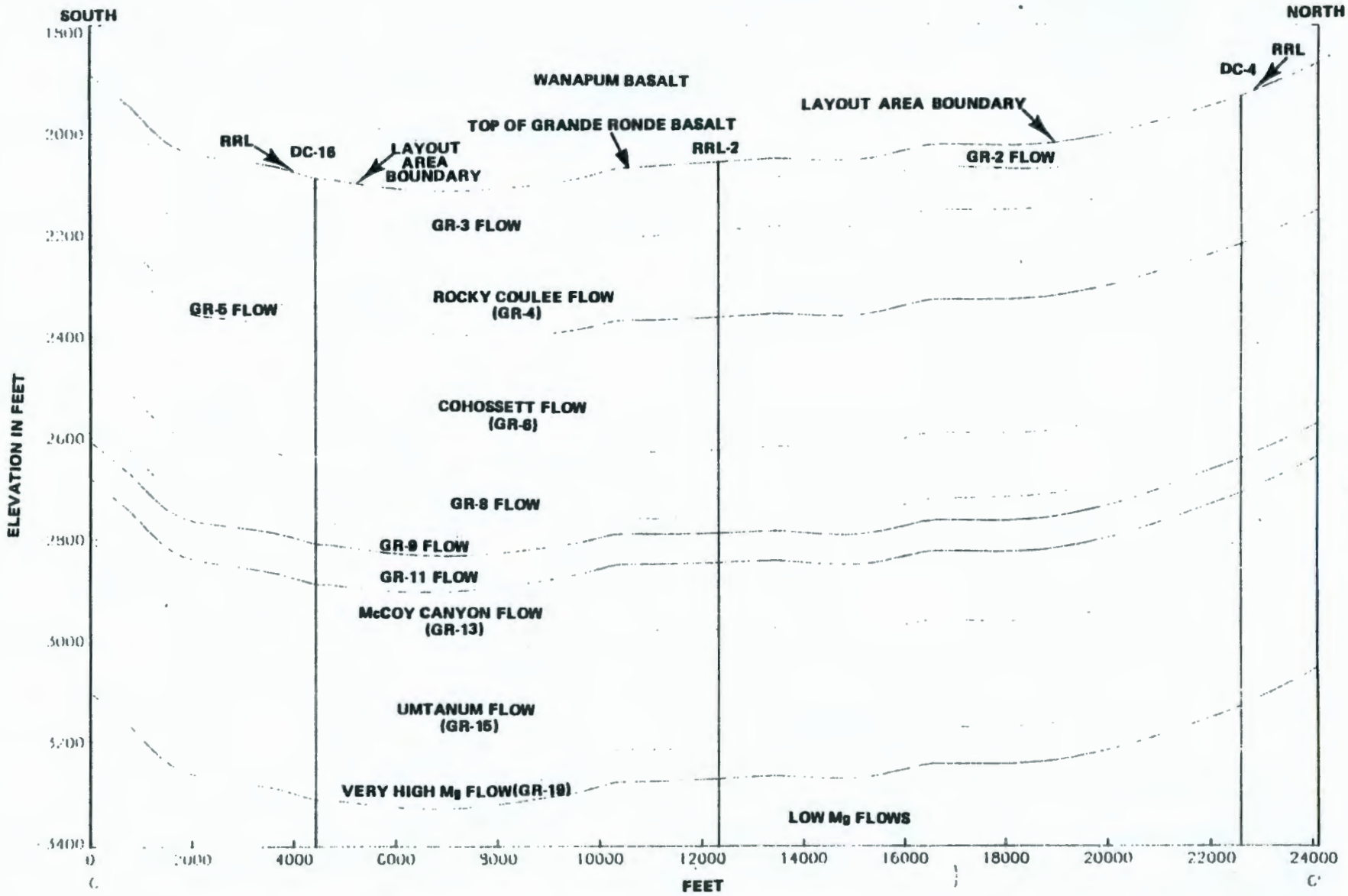

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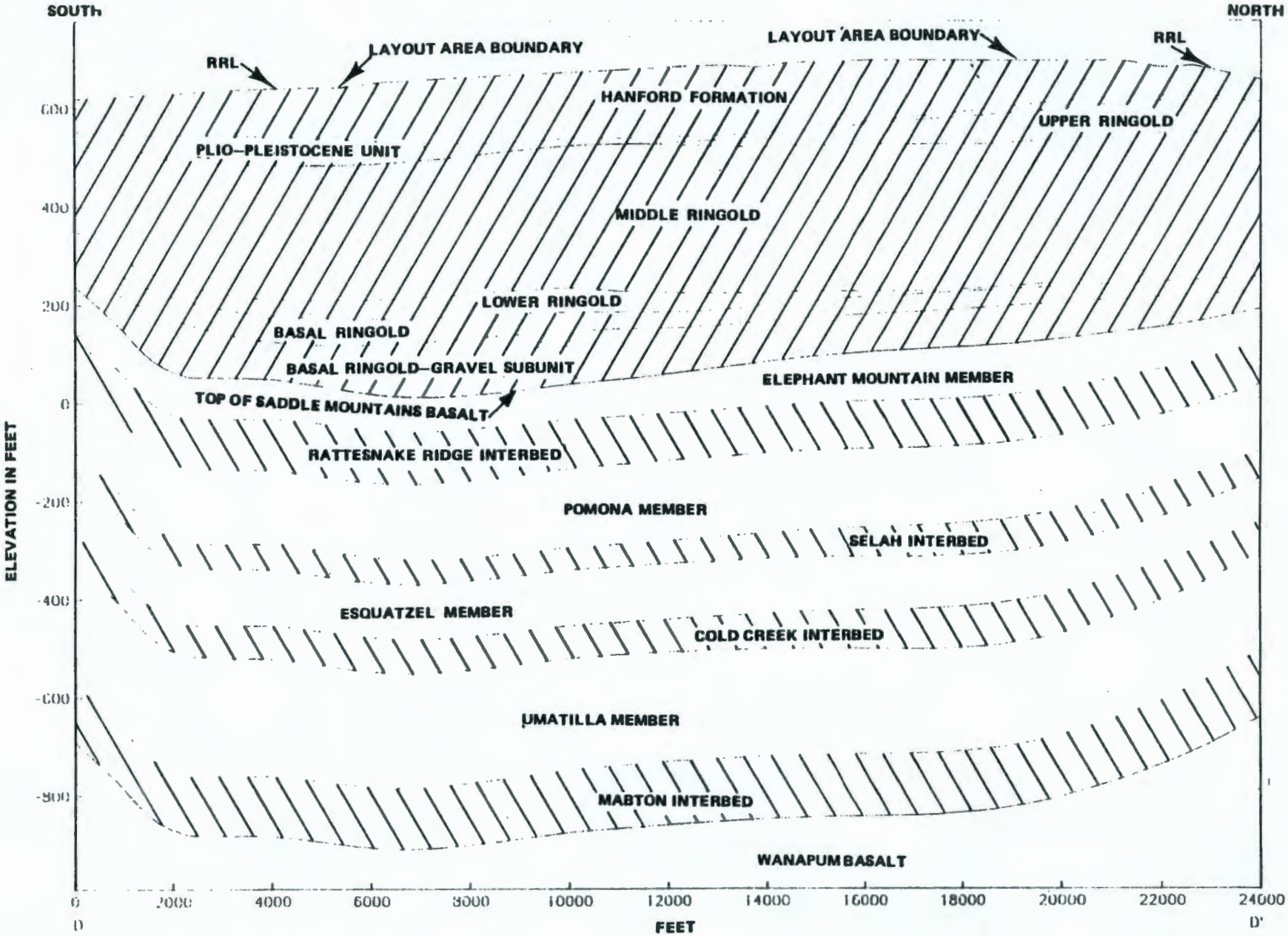

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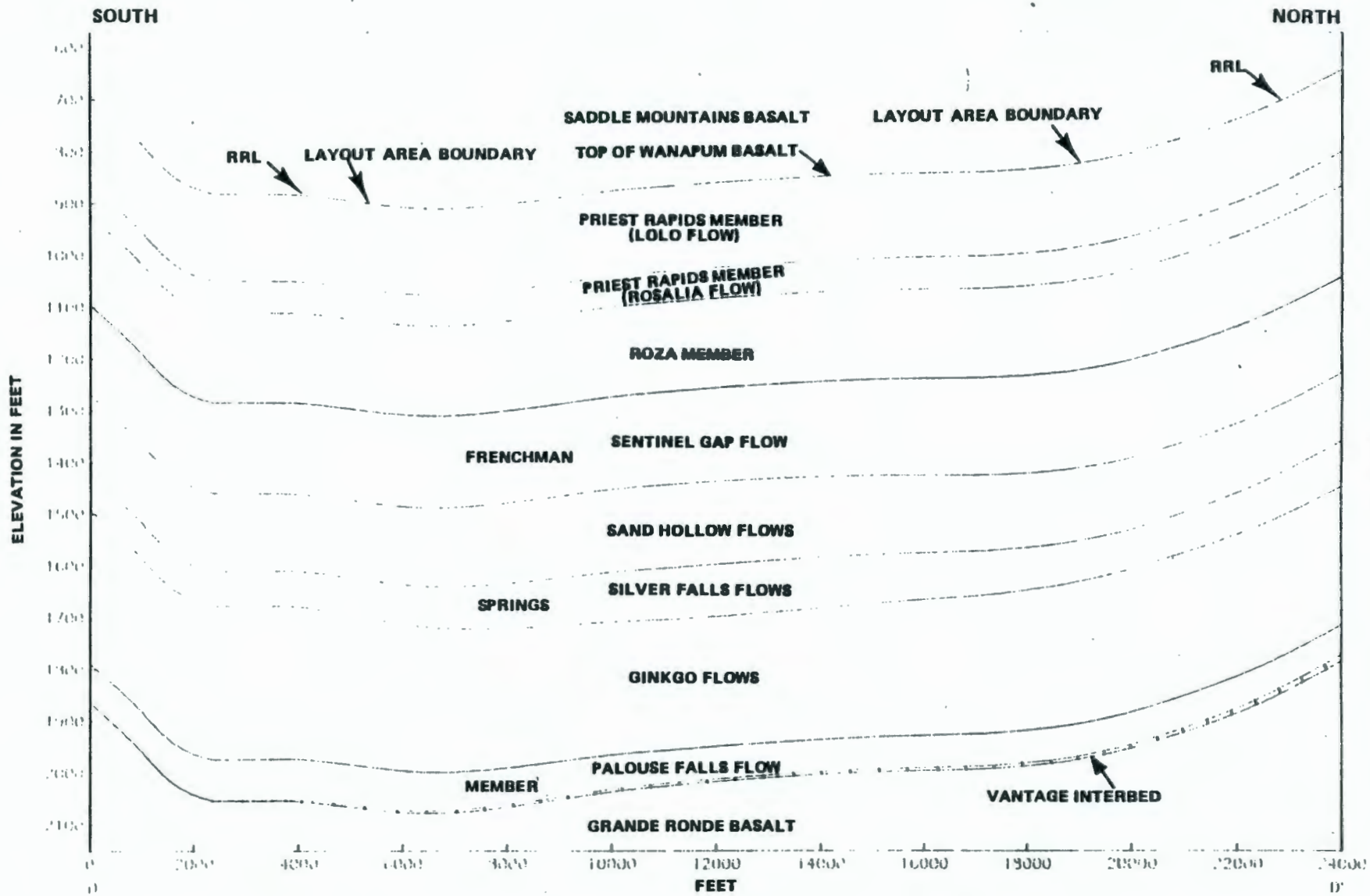

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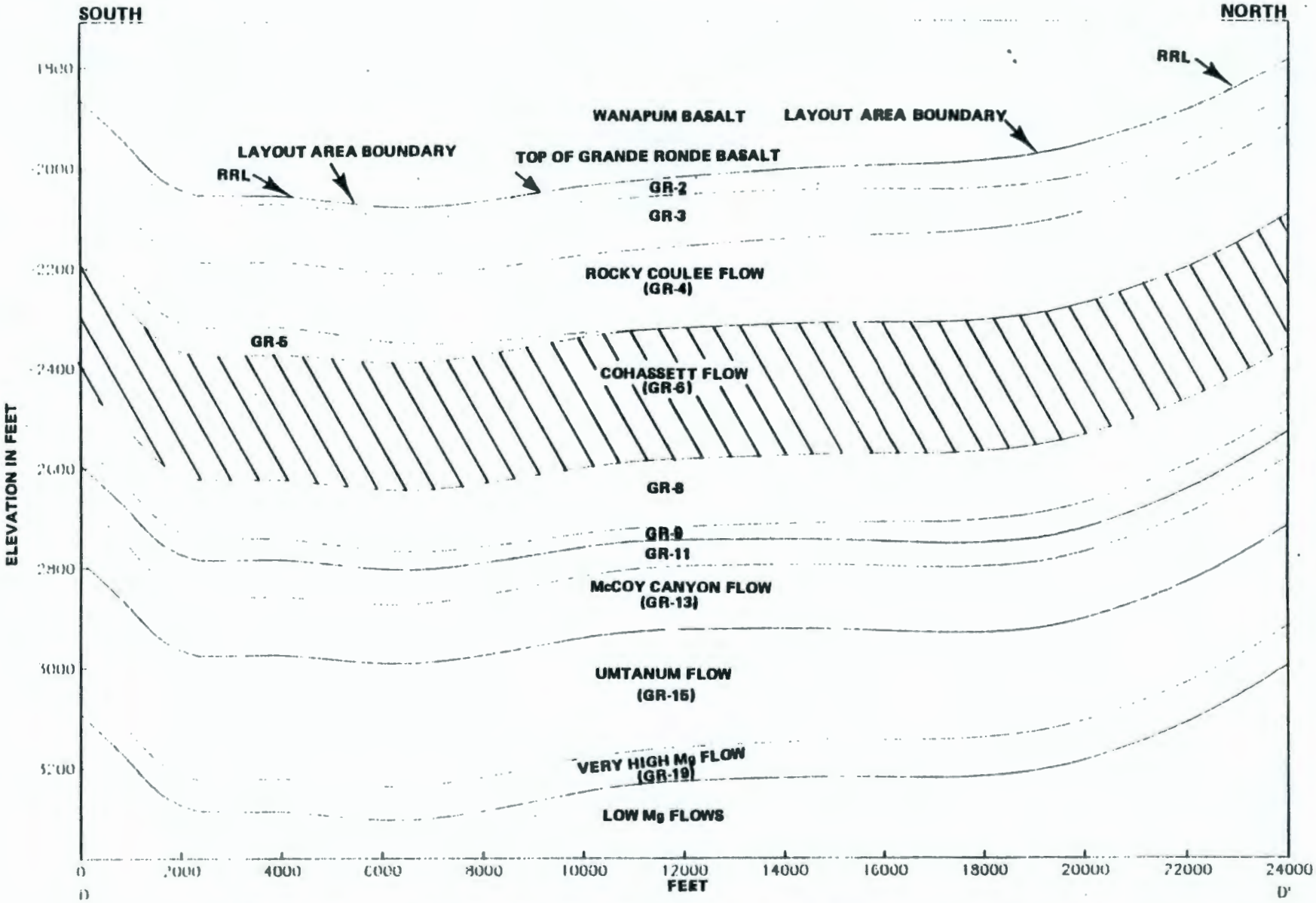

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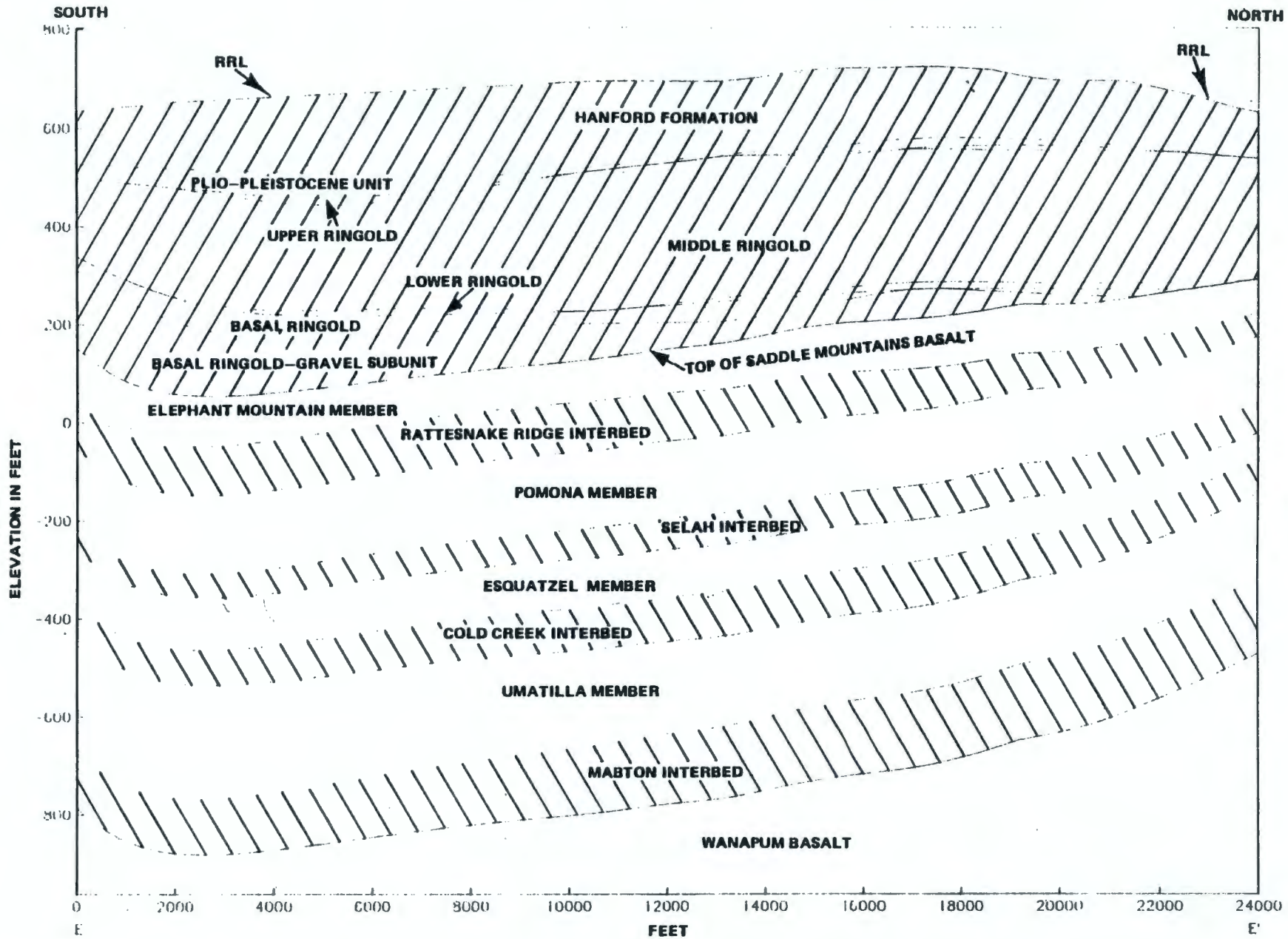

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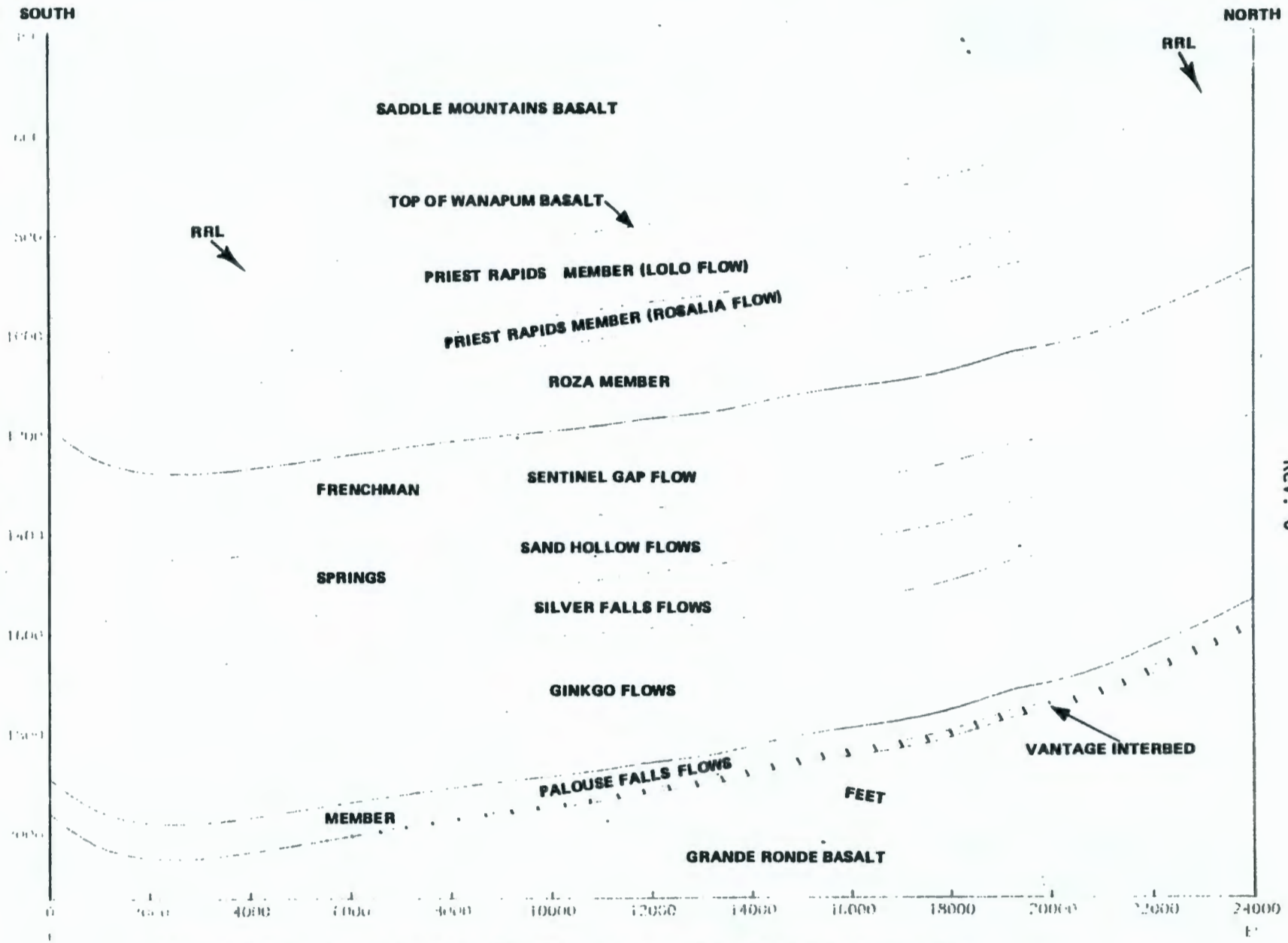

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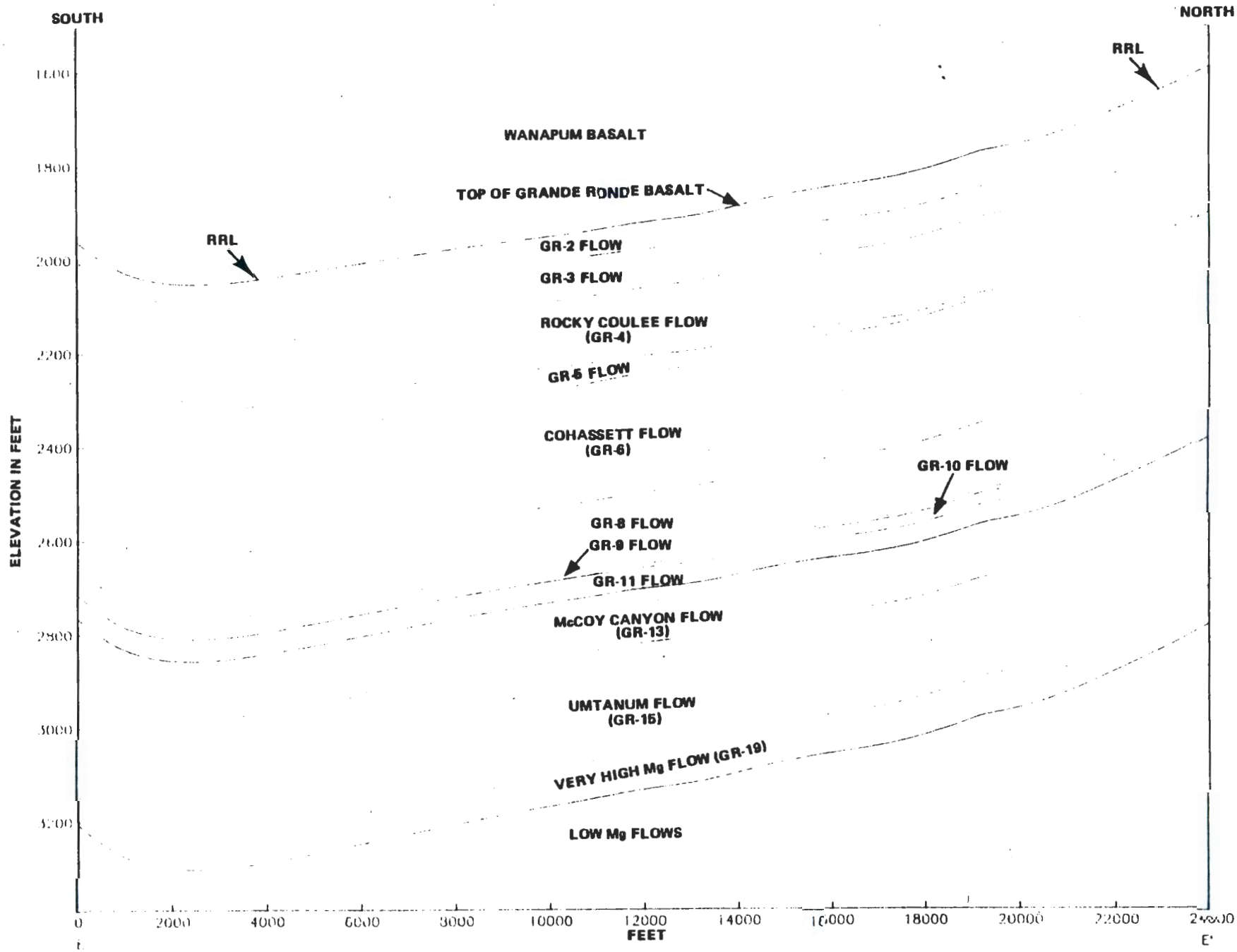

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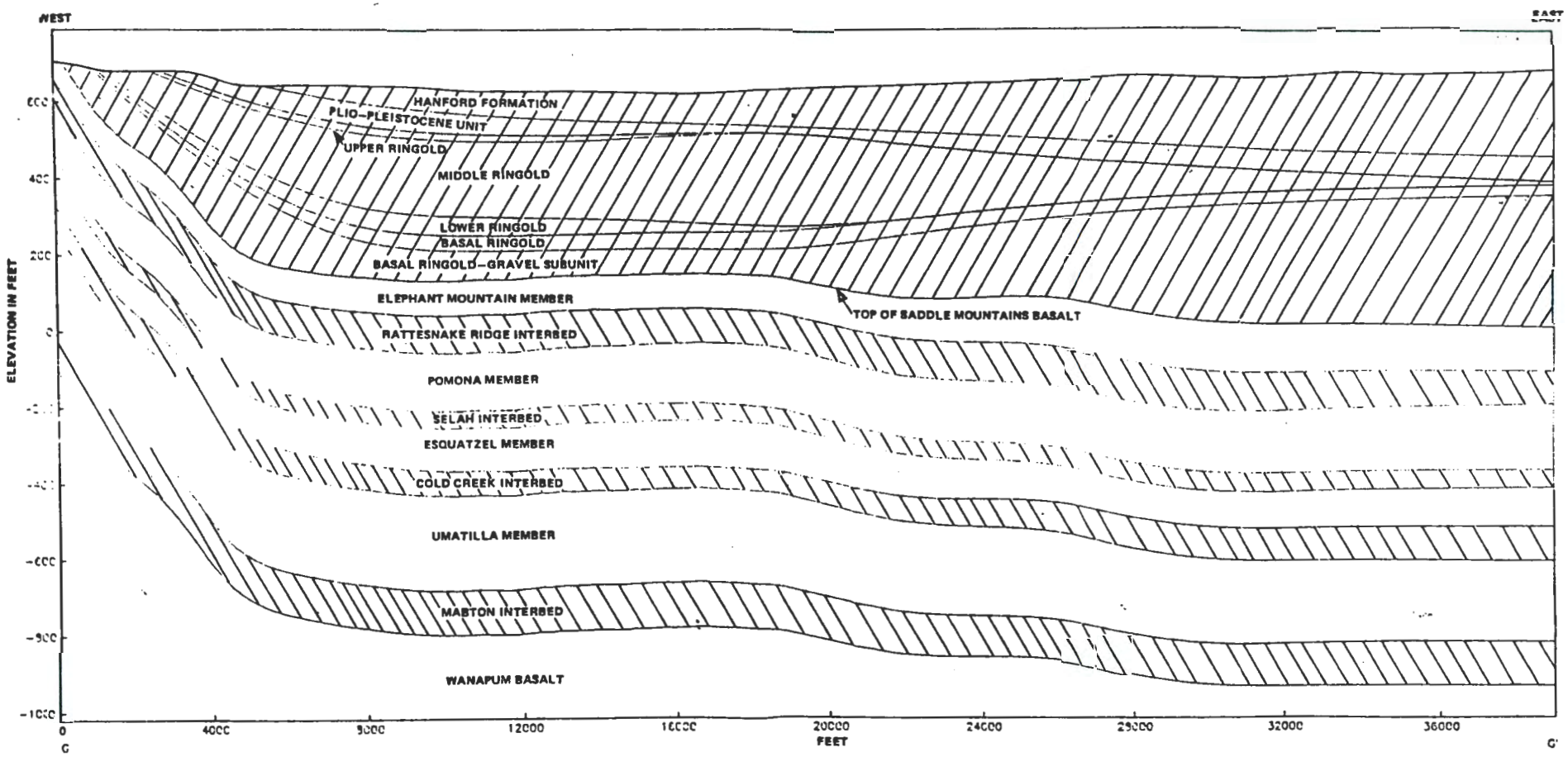

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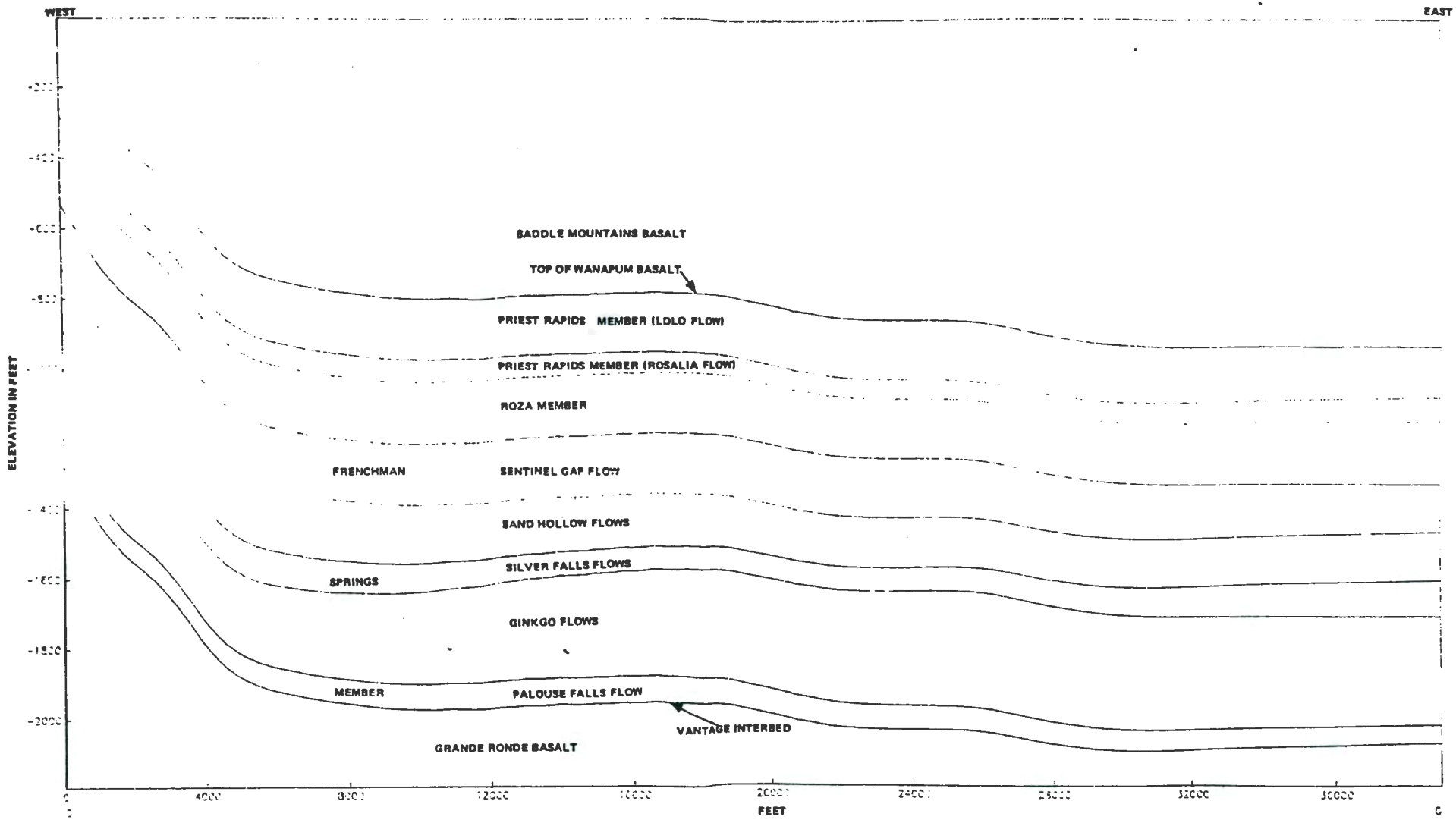

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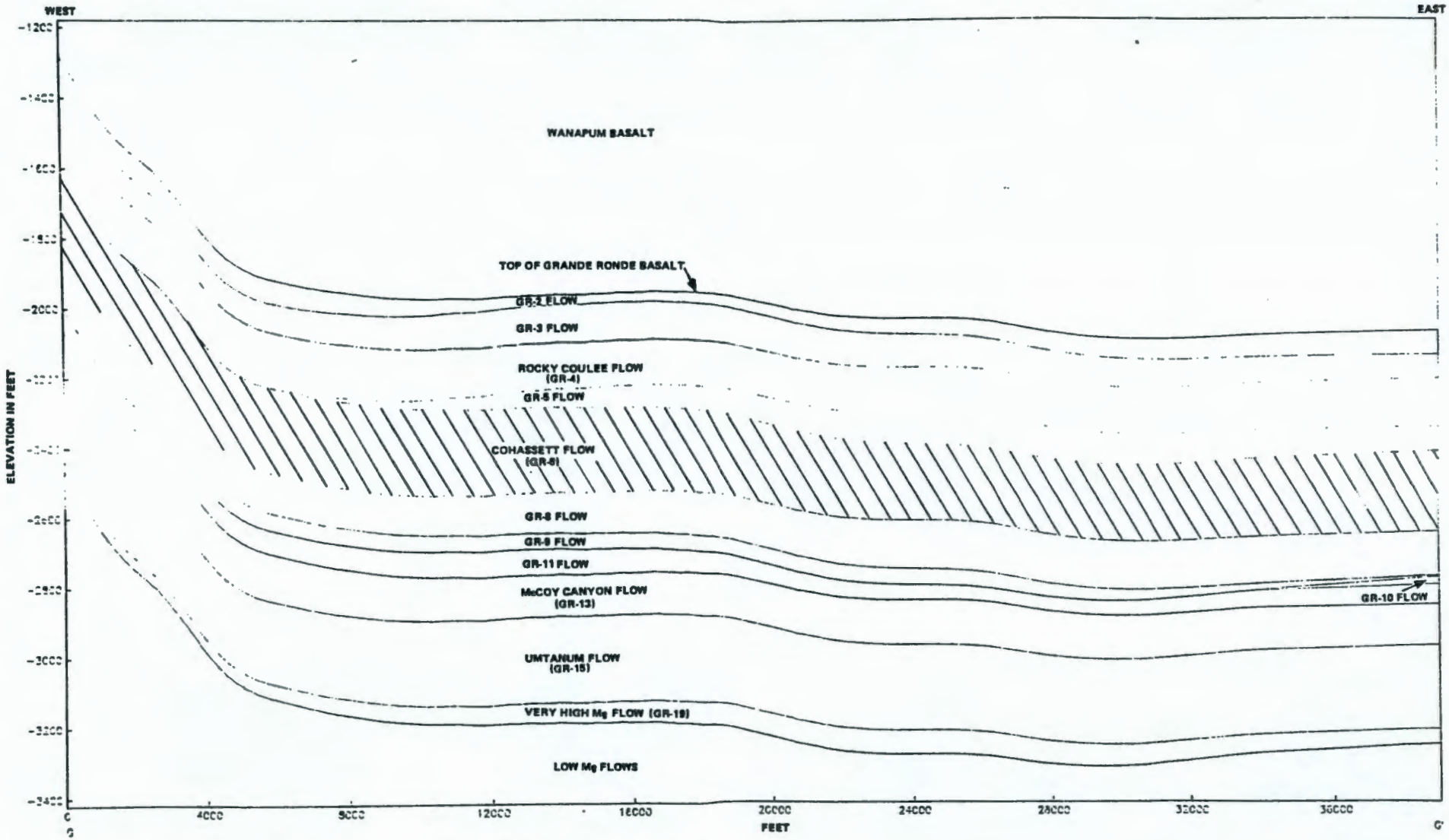

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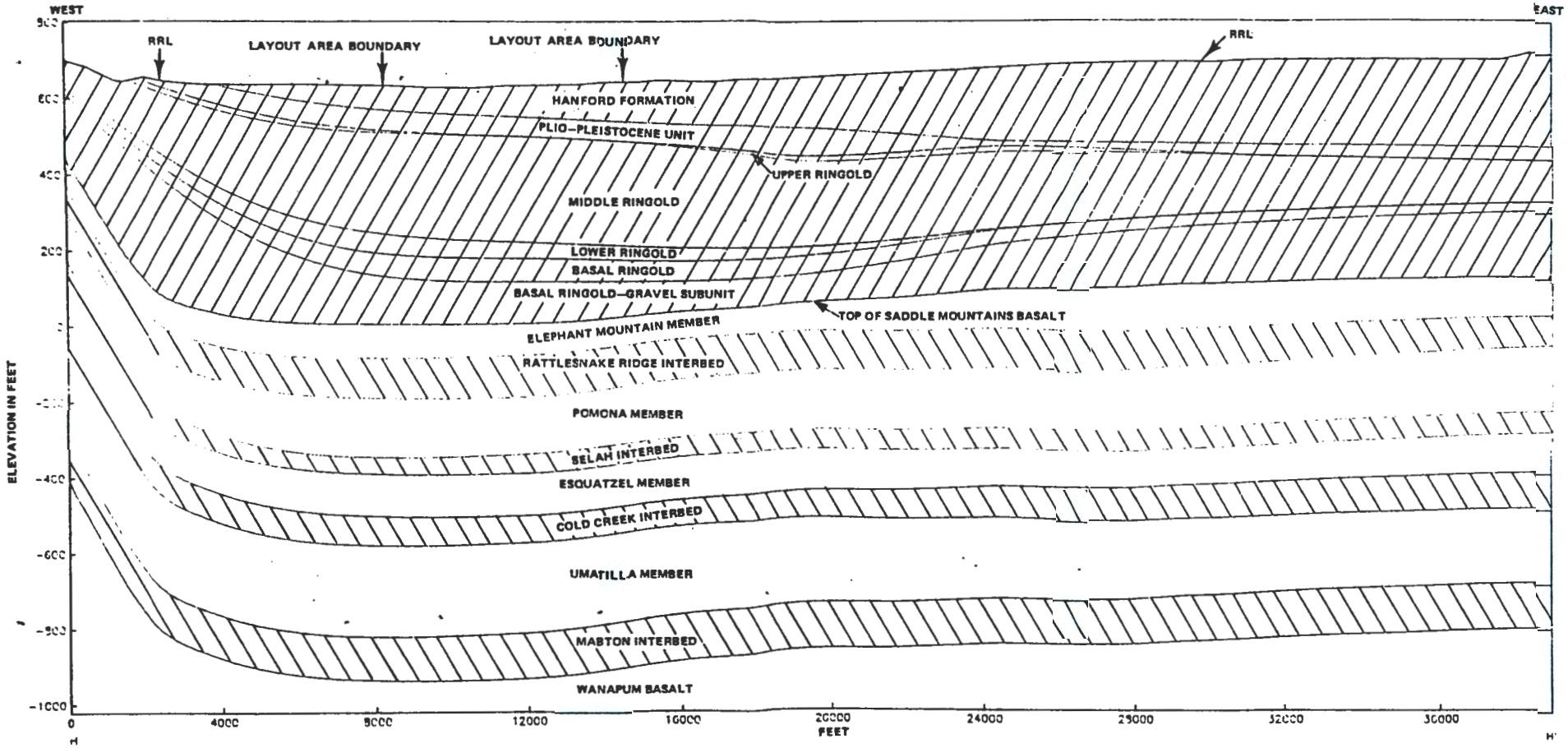

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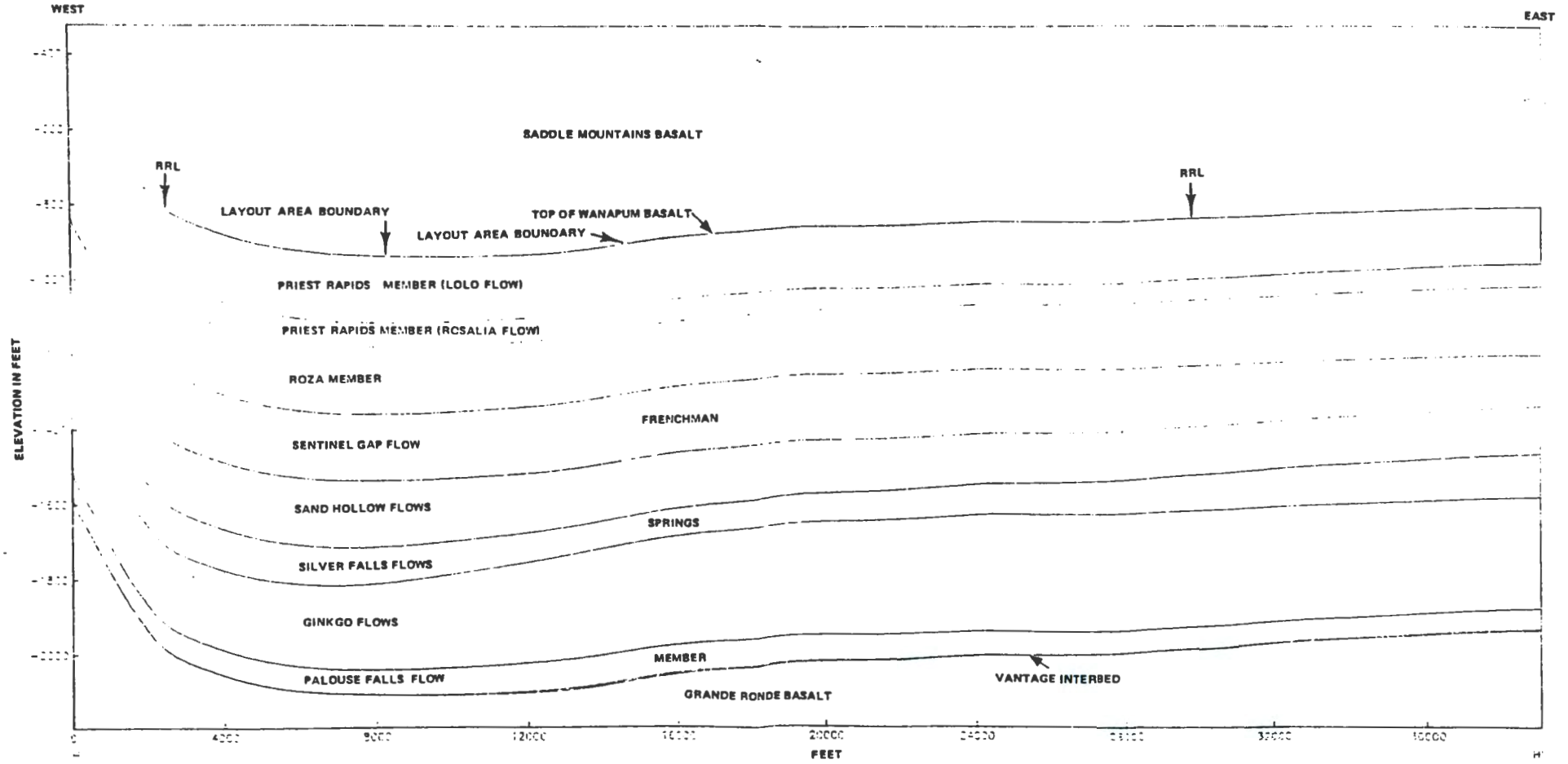

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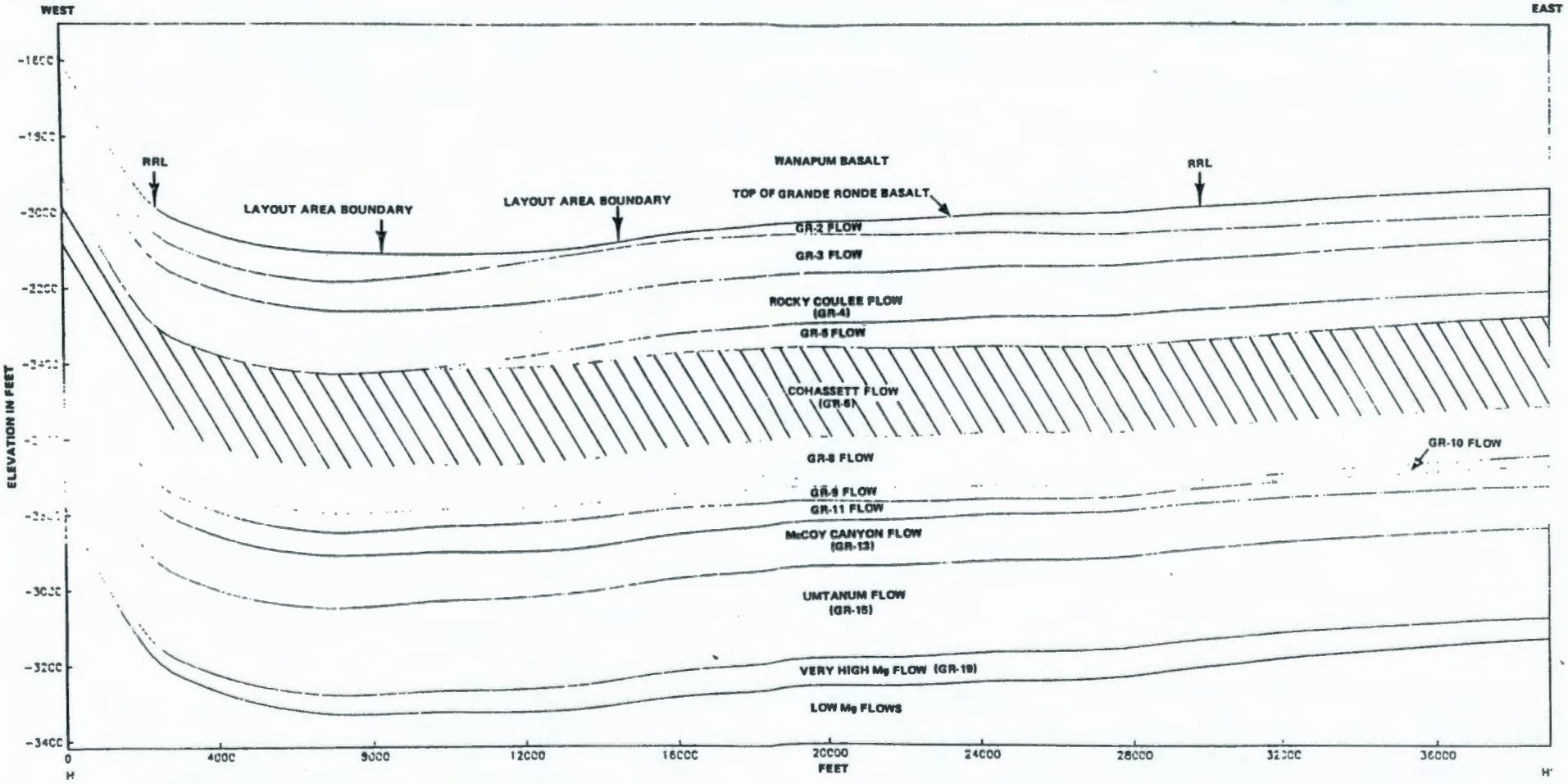

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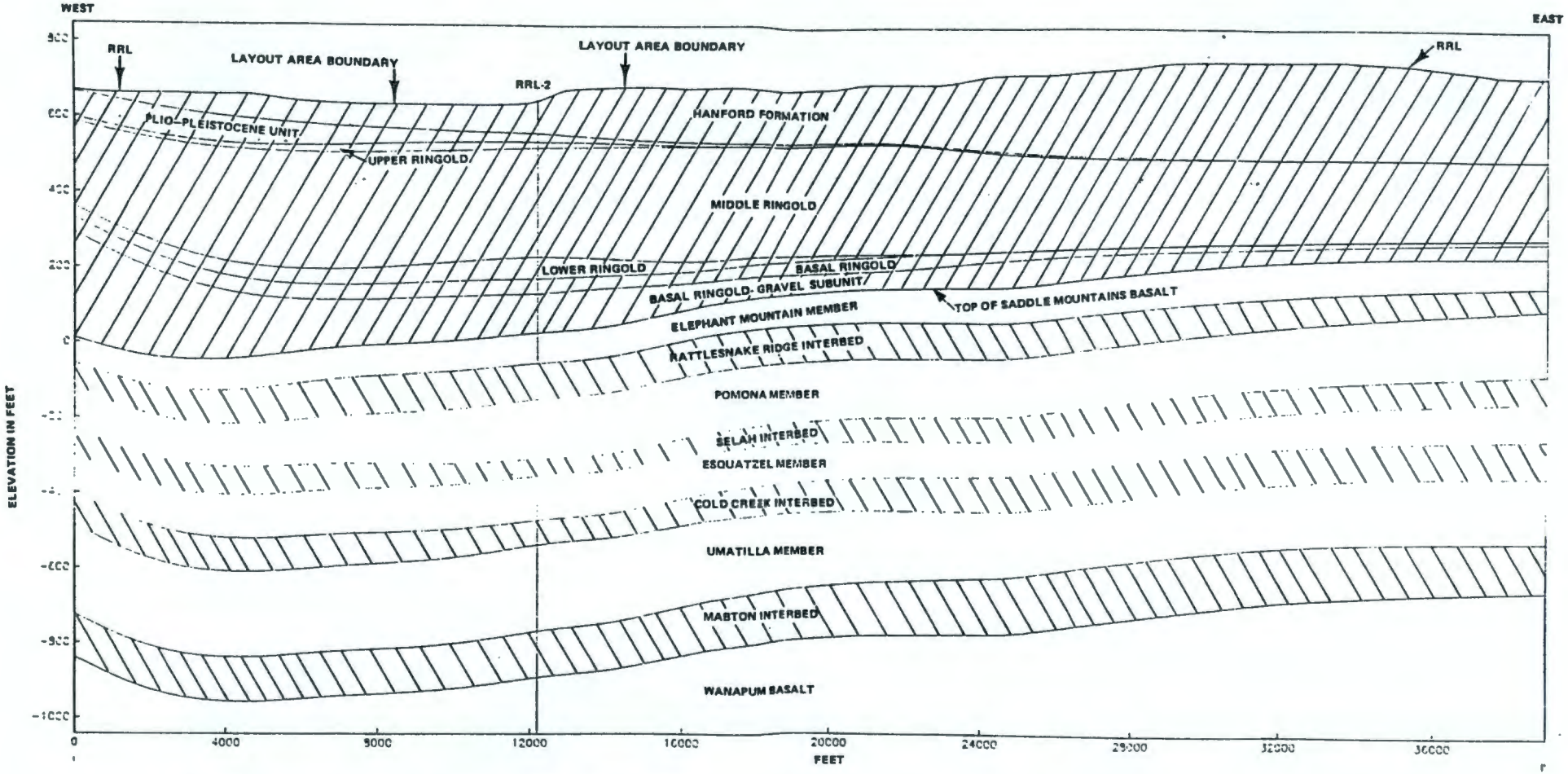

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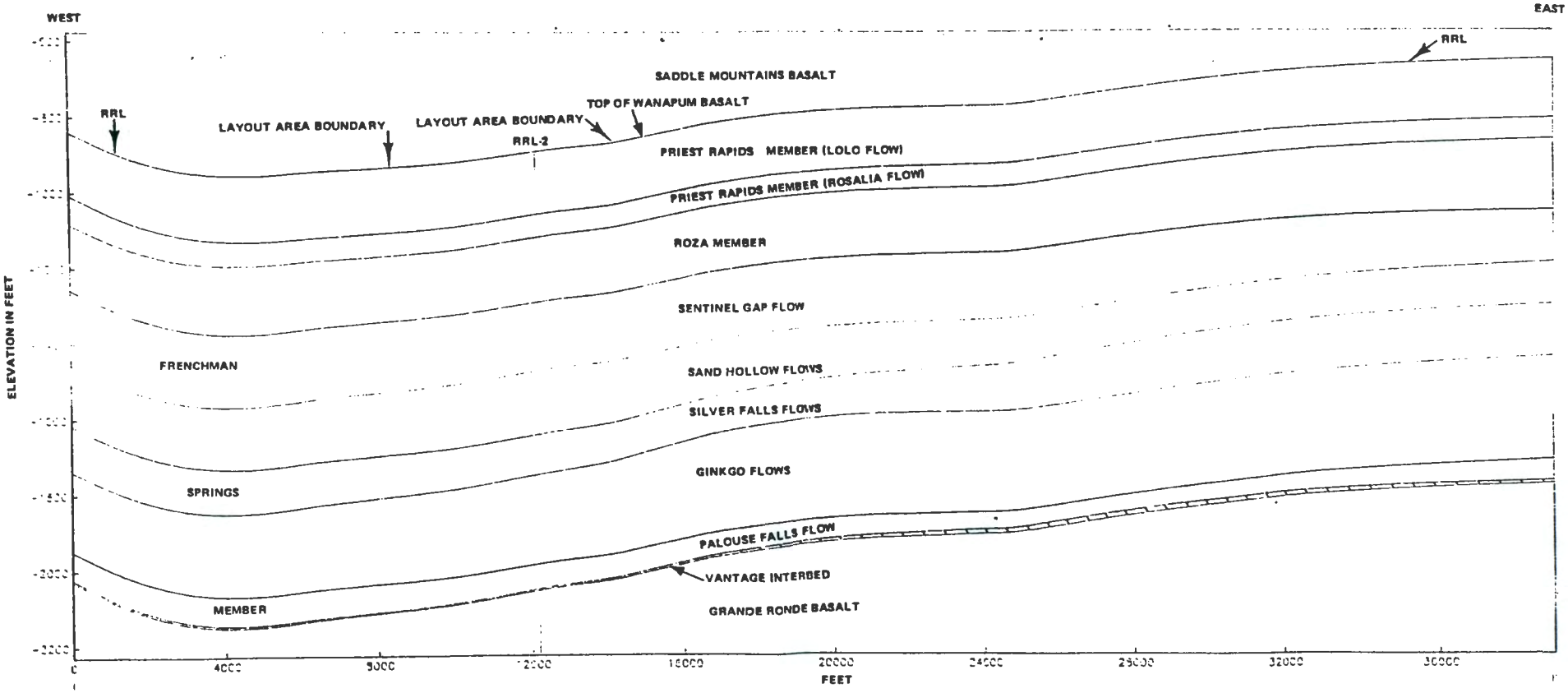

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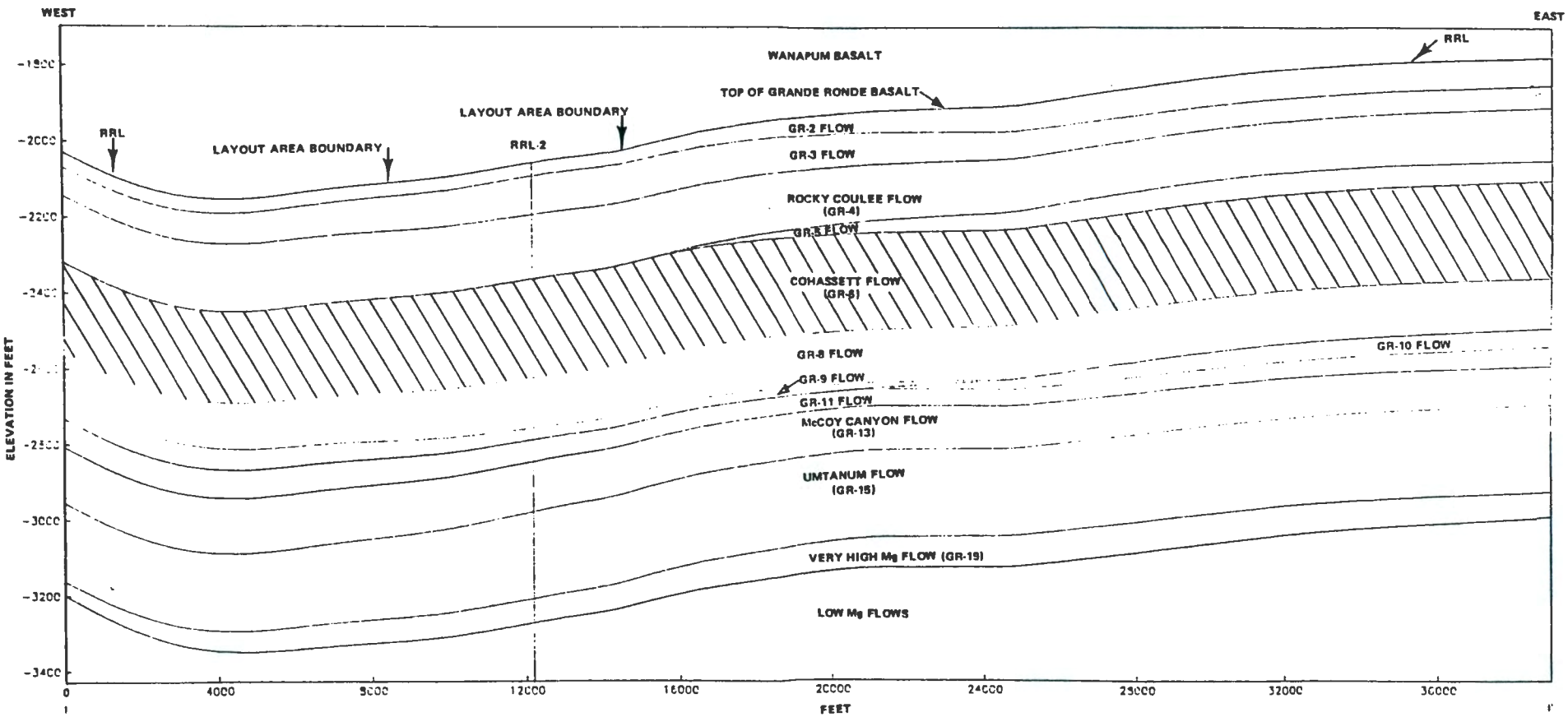

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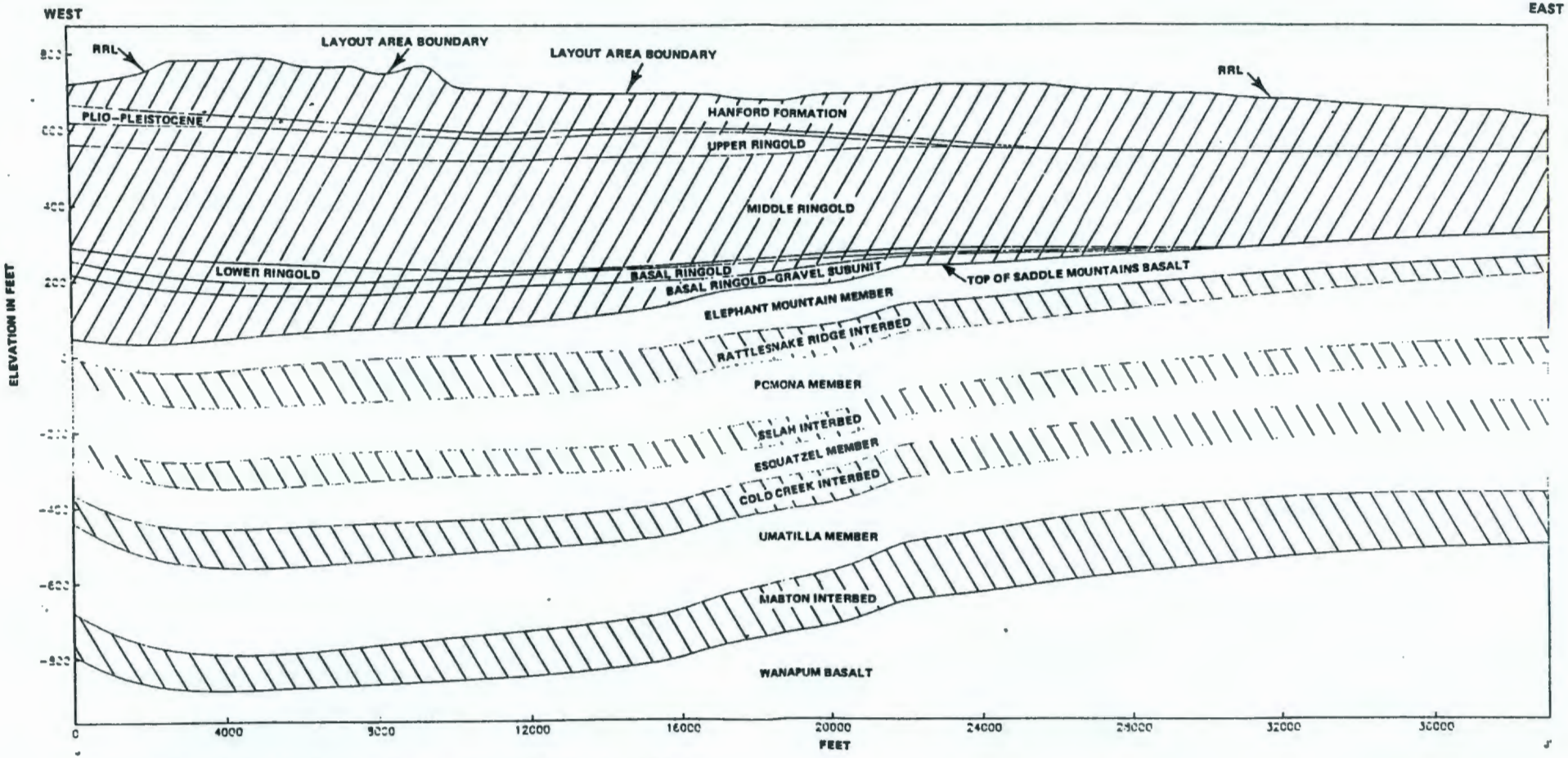

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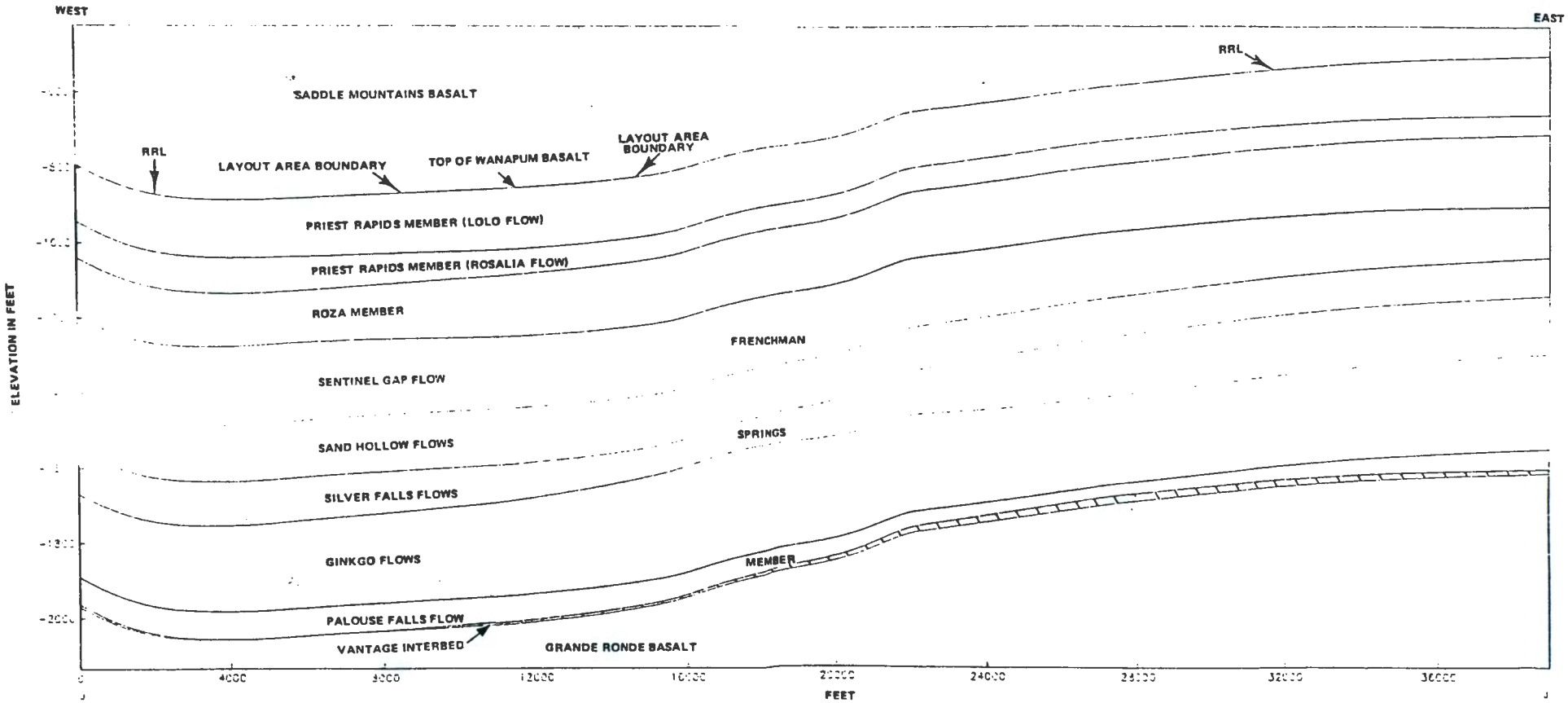

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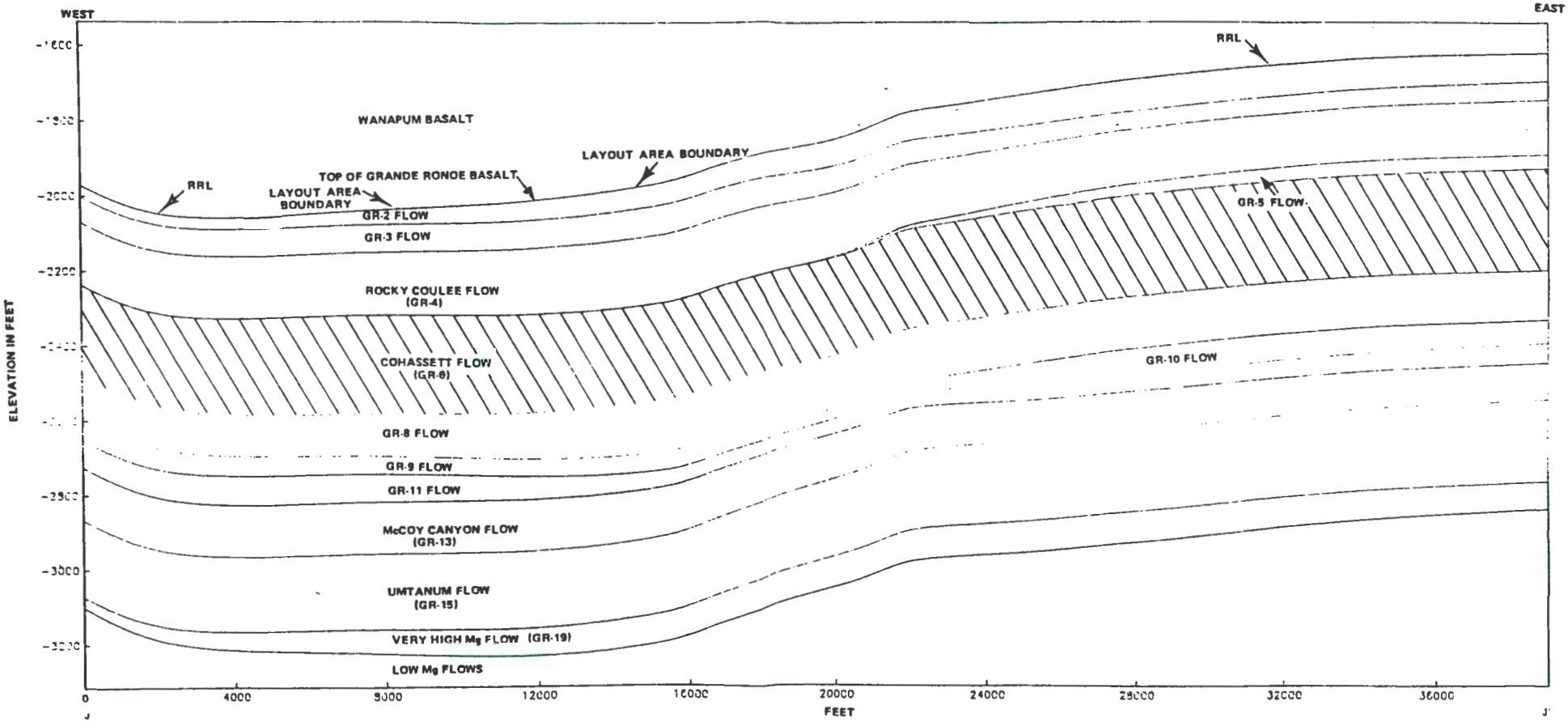

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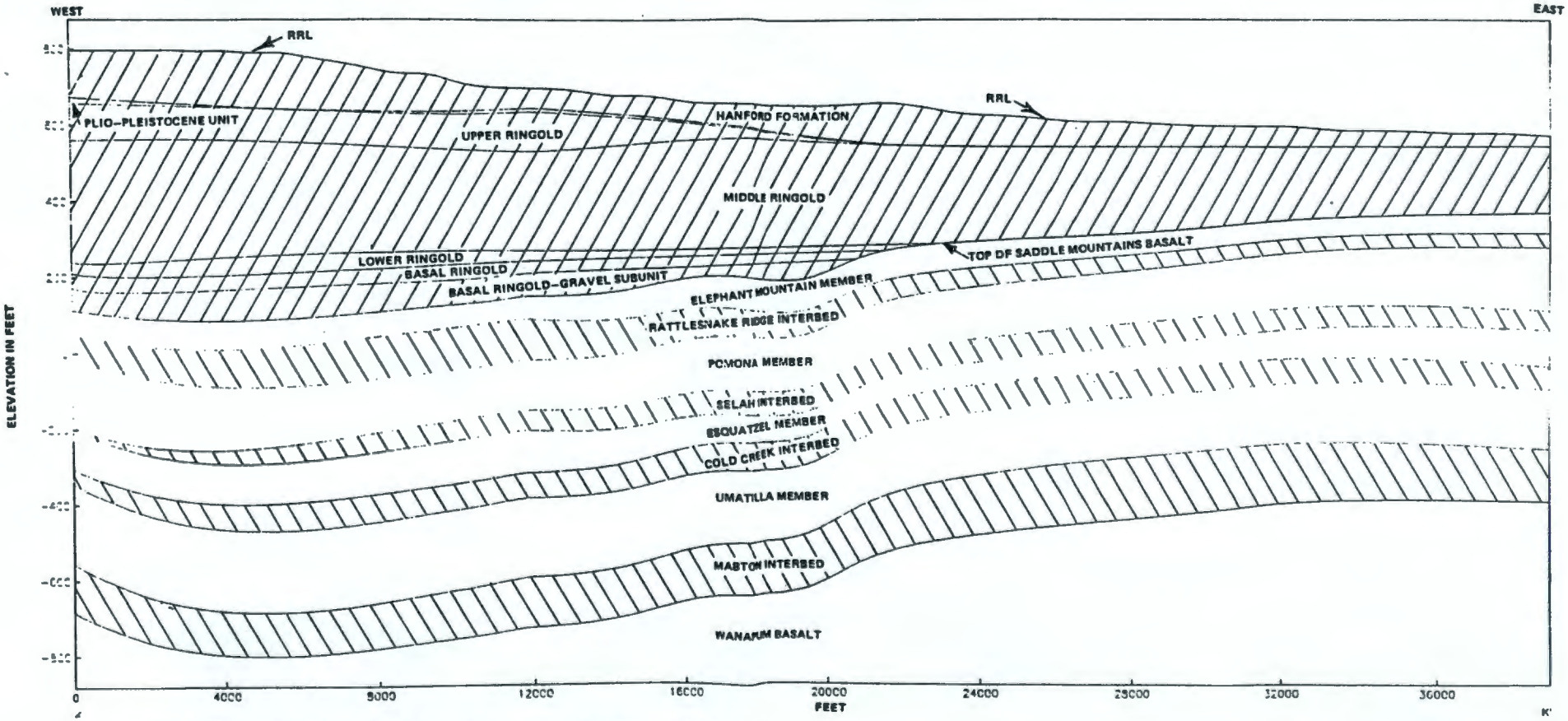

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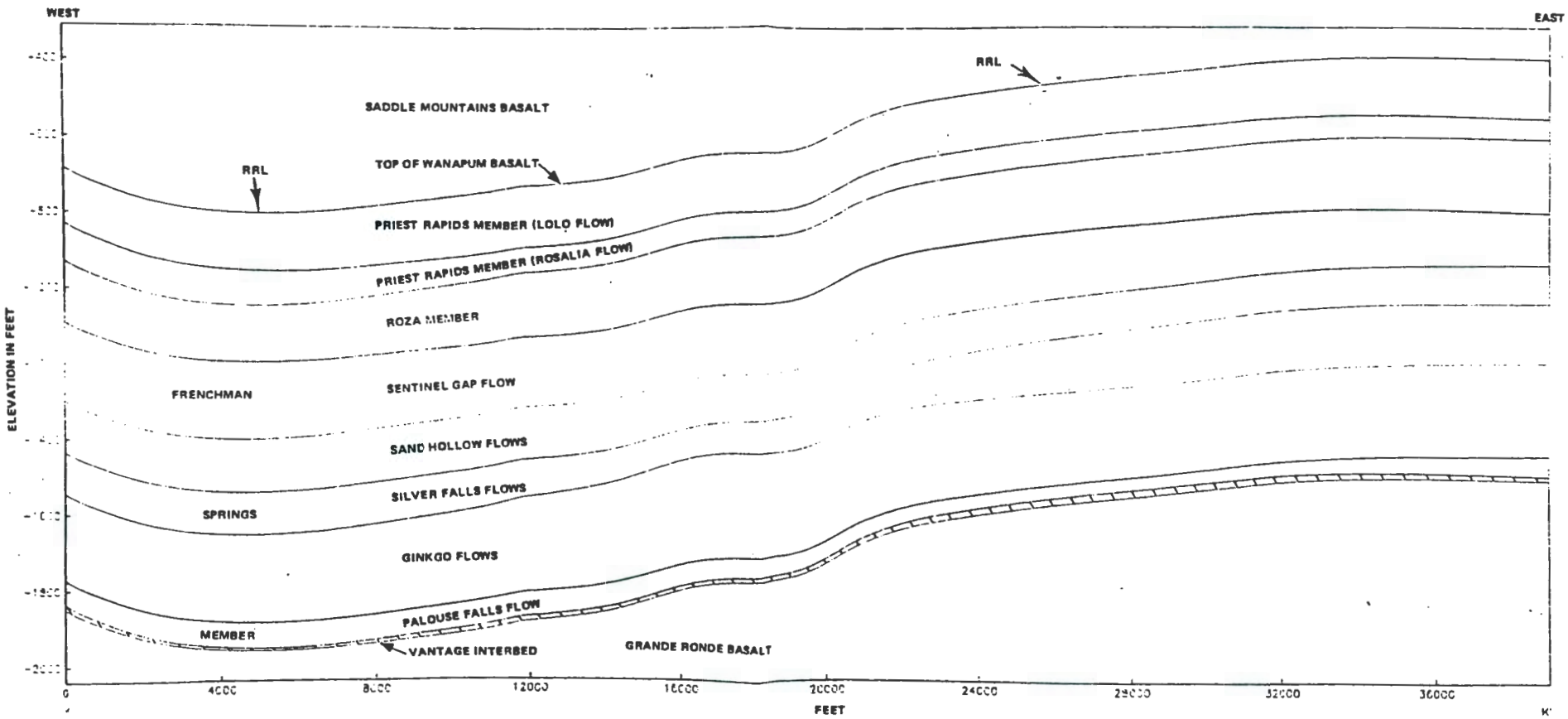

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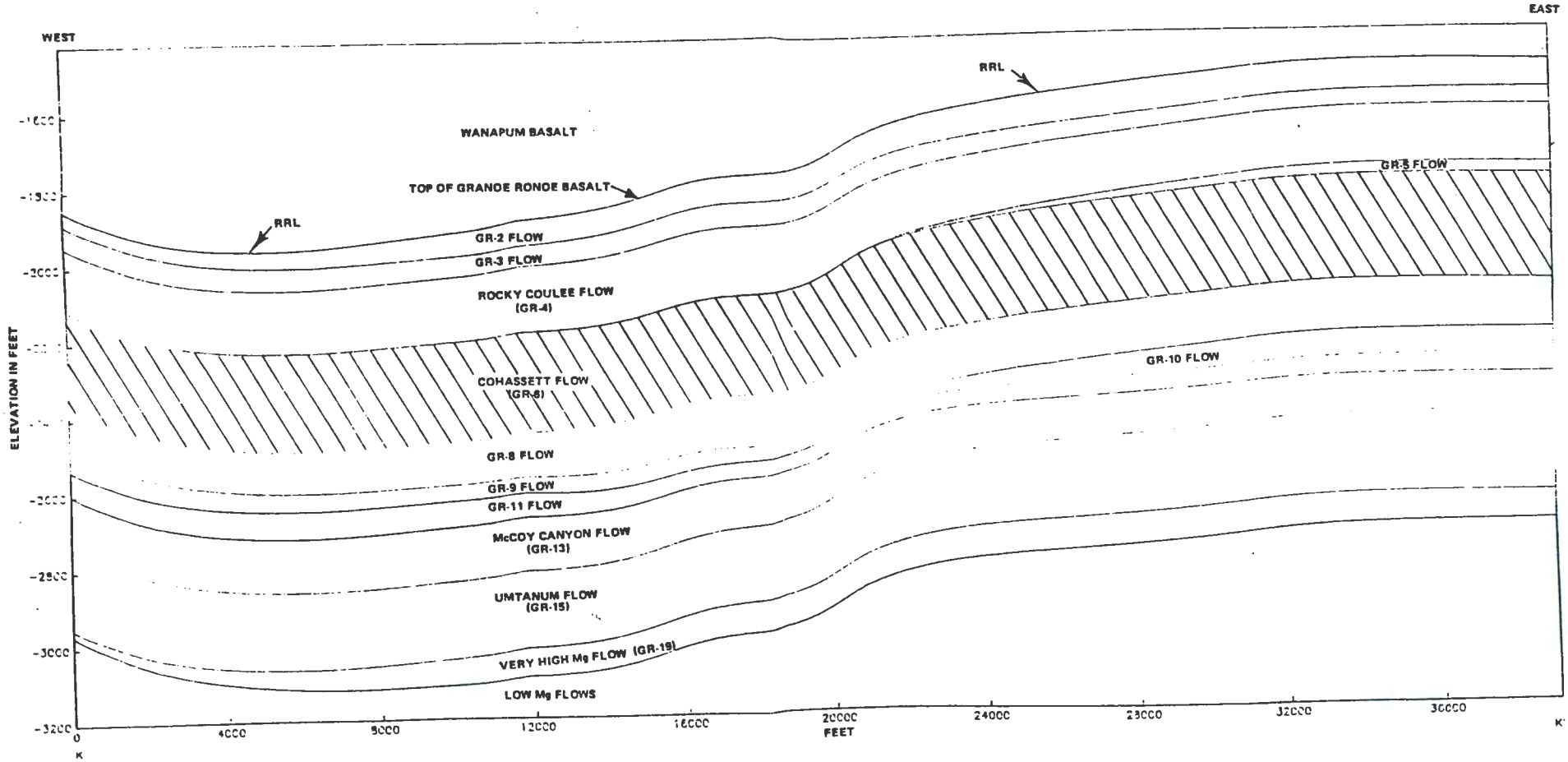

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