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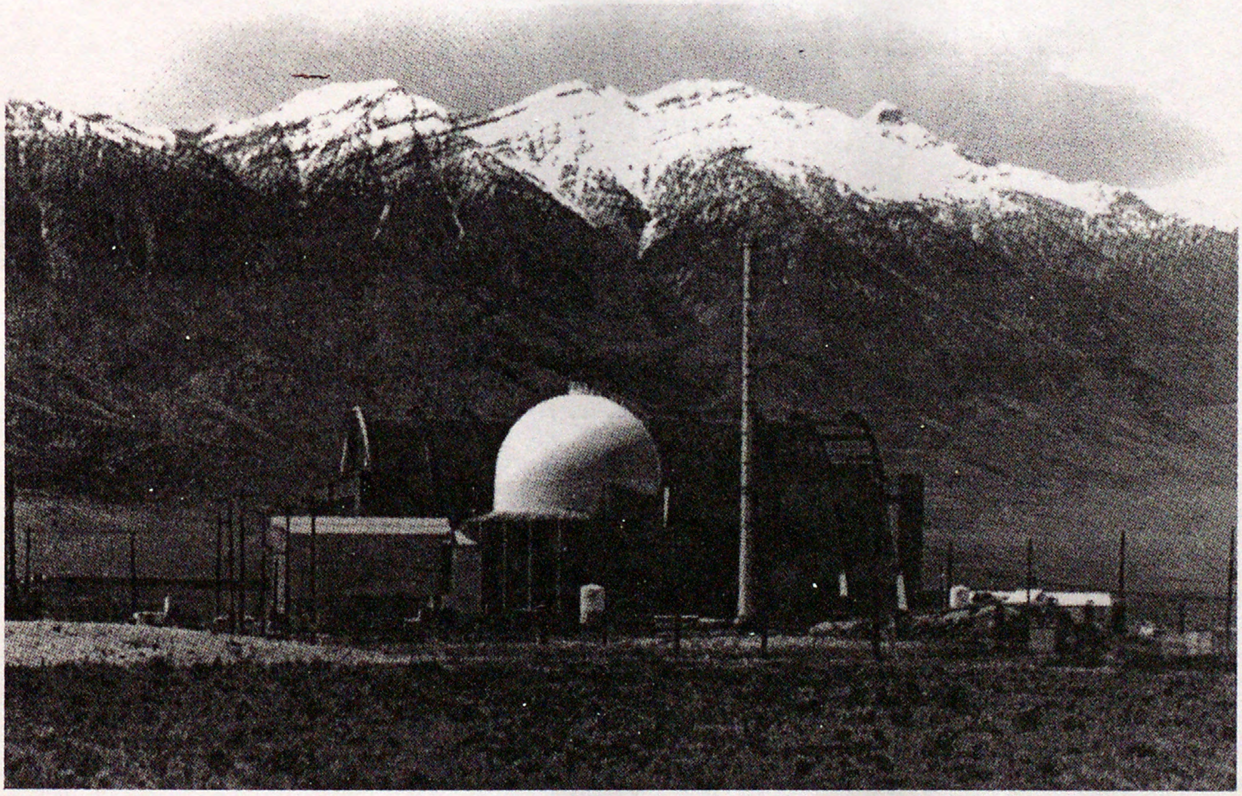
# STRATIGRAPHY OF THE UNSATURATED ZONE AND UPPERMOST PART OF THE SNAKE RIVER PLAIN AQUIFER AT TEST AREA NORTH, IDAHO NATIONAL ENGINEERING LABORATORY, IDAHO

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 95-4130



Prepared in cooperation with the
U.S. DEPARTMENT OF ENERGY



U.S. DEPARTMENT OF THE INTERIOR
MARCH 3, 1849

Cover: Containment and Service Building and the Aircraft Nuclear Propulsion Hanger at the Containment Test Facility (CTF), formerly the Loss of Fluid Test Facility (LOFT), Test Area North (TAN).

Photograph taken by John Capek, EG&G Inc., June 1984.

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June 1995

**U.S. DEPARTMENT OF THE INTERIOR**

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**U.S. GEOLOGICAL SURVEY**

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## CONTENTS



## FIGURES

## TABLE



## CONVERSION FACTORS AND VERTICAL DATUM

| Multiply | By | To Obtain |
|---|---|---|
| foot (ft) | 0.3048 | meter |
| mile (mi) | 1.609 | kilometer |
| square mile ($mi^2$) | 2.590 | square kilometer |
| acre | 0.4047 | hectare |
| cubic mile ($mi^3$) | 4.168 | cubic kilometer |
| gallon (gal) | 3.785 | liter |
| pound (lb) | 4.536 | kilogram |
| curie (Ci) | $3.7 \times 10^{10}$ | becquerel |

Sea level: In this report, "sea level" refers to the National Geodetic Vertical datum of 1929—a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

# STRATIGRAPHY OF THE UNSATURATED ZONE AND UPPERMOST PART OF THE SNAKE RIVER PLAIN AQUIFER AT TEST AREA NORTH, IDAHO NATIONAL ENGINEERING LABORATORY, IDAHO

By S. R. Anderson and Beverly Bowers


## Abstract

A complex sequence of basalt flows and sedimentary interbeds underlies Test Area North (TAN) at the Idaho National Engineering Laboratory in eastern Idaho. Wells drilled to depths of at least 500 feet penetrate 10 basalt-flow groups and 5 to 10 sedimentary interbeds that range in age from about 940,000 to 1.4 million years. Each basalt-flow group consists of one or more basalt flows from a brief, single or compound eruption. All basalt flows of each group erupted from the same vent and have similar ages, paleomagnetic properties, potassium contents, and natural-gamma emissions. Sedimentary interbeds consist of fluvial, lacustrine, and eolian deposits of clay, silt, sand, and gravel that accumulated for hundreds to hundreds of thousands of years during periods of volcanic quiescence. Basalt and sediment are elevated by hundreds of feet with respect to rocks of equivalent age south and east of the area, a relation that is attributed to past uplift at TAN. Basalt and sediment are unsaturated to a depth of about 200 feet below land surface. Rocks below this depth are saturated and make up the Snake River Plain aquifer. The effective base of the aquifer is at a depth of 885 feet below land surface. Detailed stratigraphic relations for the lowermost part of the aquifer in the depth interval from 500 to 885 feet were not determined because of insufficient data.

The stratigraphy of basalt-flow groups and sedimentary interbeds in the upper 500 feet of the unsaturated zone and aquifer was determined from natural-gamma logs, lithologic logs, and well cores. Basalt cores were evaluated for potassium-argon ages, paleomagnetic properties, petrographic characteristics, and chemical composition. Stratigraphic control was provided by differences in ages, paleomagnetic properties, potassium content, and natural-gamma emissions of basalt-flow groups and sedimentary interbeds.


## INTRODUCTION

Test Area North (TAN) is in the northern part of the Idaho National Engineering Laboratory (INEL) in eastern Idaho (fig. 1). TAN covers an area of about 7.5 $mi^2$ and consists of several experimental and support facilities for nuclear research (Kaminsky and others, 1994). This area, which includes the Initial Engine Test Facility (IET), the Specific Manufacturing Capability Facility (SMC), the Technical Support Facility (TSF), and the Water Reactor Research Test Facility (WRRTF) (fig. 2), is about 20 mi northeast of the Idaho Chemical Processing Plant (ICPP) and the Test Reactors Area (TRA) and about 30 mi northeast of the Radioactive Waste Management Complex (RWMC) (fig. 1). A variety of geologic and geophysical data have been collected from numerous wells at TAN (fig. 2) to determine local stratigraphic relations that may affect the movement of radioactive, chemical, and sanitary waste in the subsurface. These data have been evaluated with respect to similar data from wells at the ICPP, TRA, and RWMC to determine regional stratigraphic relations among these areas (Anderson and Lewis, 1989; Anderson, 1991). As used in this report, a well refers to any drill hole, core hole, borehole, or water well from which geologic and geophysical data have been collected.

From 1953 to 1972, significant volumes of low-level radioactive, chemical, and sanitary wastewater were discharged at TAN into the Snake River Plain aquifer through a 310 ft-deep disposal well, TSF DISP (fig. 2). The wastewater contained trichloroethylene, which has been detected in nearby wells sampled for water quality (Kaminsky and others, 1994). In 1972, the disposal well was replaced by a 35-acre infiltration pond. From 1959 to 1988, the period for which records of disposal are available, about 61 Ci of radioactivity were discharged in wastewater

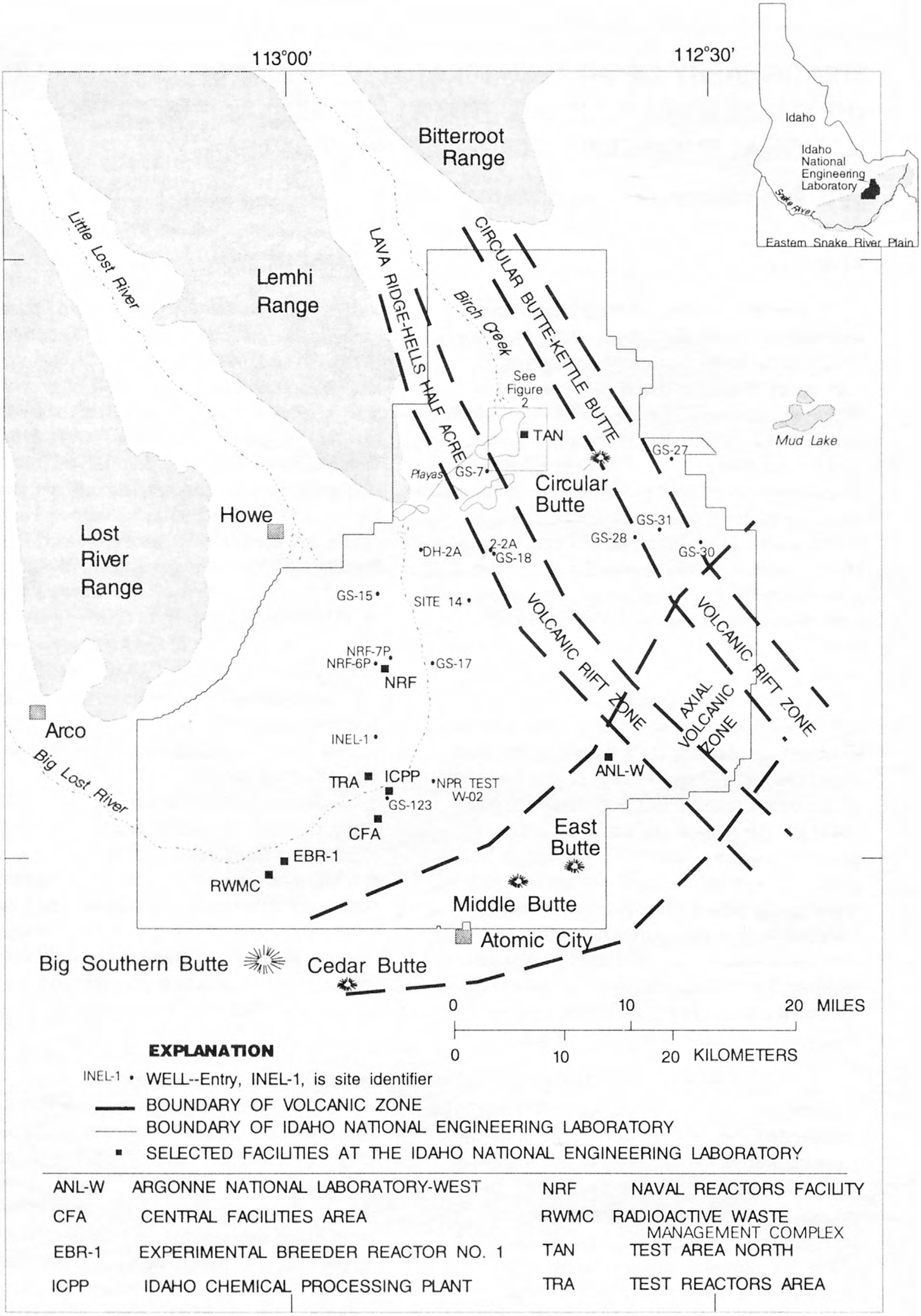


Figure 1.--Location of Test Area North and selected features at and near the Idaho National Engineering Laboratory.

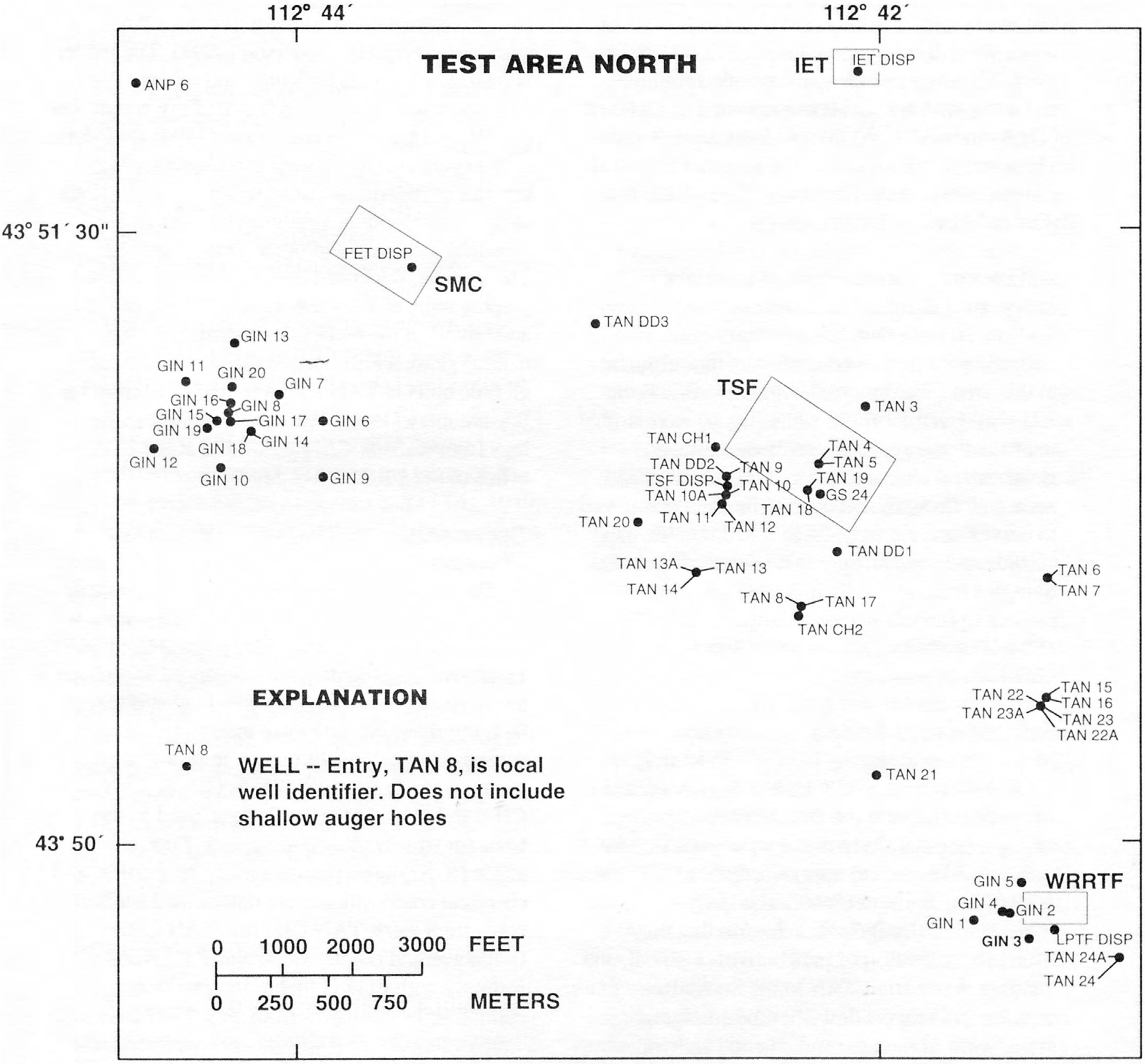


Figure 2.--Location of wells at Test Area North.

to the disposal well and infiltration pond (Orr and Cecil, 1991). From 1986 to 1988, the average volume of radioactive wastewater discharged to the infiltration pond was about 20.8 million gal/year. The average rate of disposal of radioactivity in this wastewater was 0.012 Ci/year. An average of about 31.5 million gal/year of chemical waste and 12 million gal/year of sewage waste were discharged to the pond from 1986 to 1988. The main constituents included chloride and sodium. Average annual amounts of 13,000 lb of chloride and 9,100 lb of sodium were disposed. The average annual amount of all other chemical constituents in the effluent was about 2,100 lb (Orr and Cecil, 1991).

Concern about the potential for migration of radioactive, chemical, and sanitary waste from TAN to the underlying Snake River Plain aquifer has prompted numerous studies of the subsurface in this area (Kaminsky and others, 1994). From 1953 to March 1993, 57 wells (fig. 2) were drilled to evaluate the geologic, geohydrologic, and geochemical characteristics of the unsaturated zone and the aquifer. These wells were completed to depths ranging from 74 to 1,114 ft below land surface and have an aggregate depth of 18,216 ft. Samples from the wells indicate that waste is present in the subsurface (Kaminsky and others, 1994), but additional data collection and study are needed to evaluate the extent of the contamination.

## Purpose and Scope

In 1991, the U.S. Geological Survey (USGS), in cooperation with the U.S. Department of Energy, began a study of the stratigraphy of the unsaturated zone and uppermost part of the Snake River Plain aquifer at TAN. The study was made to determine stratigraphic relations that may affect the migration of radioactive, chemical, and sanitary waste from TAN to the Snake River Plain aquifer. This report describes the stratigraphic framework of the unsaturated zone and uppermost part of the Snake River Plain aquifer at TAN using geologic and geophysical data collected through March 1993. Data collected for this and previous studies indicate that there are numerous basalt flows and sedimentary interbeds in the subsurface at TAN. This report describes the stratigraphic relations between groups of related basalt flows and sedimentary interbeds in the unsaturated zone and uppermost part of the aquifer to a depth of 500 ft below land surface. The stratigraphic framework described in this report is an extension of the framework at the RWMC described by Anderson and Lewis (1989) and of the framework at the ICPP and TRA (fig. 1) described by Anderson (1991). The reader is referred to reports by Kuntz and others (1980), Champion and others (1988), Lanphere and others (1993), and Lanphere and others (1994) for information concerning the ages and physical characteristics of individual basalt flows and the criteria used for subdividing stratigraphic units in the subsurface at TAN and other parts of the INEL. The altitude, thickness, and distribution of stratigraphic units at TAN are shown on figures 3-20 and table 1 at the end of this report. Selected natural-gamma logs used to differentiate stratigraphic units at TAN are presented in a report by Bartholomay (1990). Additional natural-gamma logs from wells at TAN are on file at the INEL office of the USGS.

## Approach

This report contains geologic sections, maps, and a table that describe the stratigraphic framework of the subsurface at TAN (figs. 3-20; table 1); all stratigraphic data are referenced to altitude above sea level and depth below land surface, in feet. Stratigraphic data were interpreted from natural-gamma logs, lithologic logs, and well cores. Cores from wells GIN 5, GIN 6, TAN CH1, and TAN CH2 (fig. 2) were used as the basis for stratigraphic correlations. Potassium-argon (K-Ar) ages, paleomagnetic properties, and chemical composition were determined for basalt cores from wells TAN CH1 and TAN CH2 (Lanphere and others, 1994; and T.R. Wood, formerly with EG&G Idaho, Inc., written commun., 1993). Cores from well TAN CH1 also were evaluated for petrographic characteristics; cores from wells GIN 5 and GIN 6 were evaluated only for paleomagnetic properties. Stratigraphic units in the cores were correlated with stratigraphic units in 53 other wells at TAN (fig. 2) by inspection of natural-gamma logs. These logs are sensitive to small differences in potassium content and natural-gamma emissions of basalt flows and sedimentary interbeds from different source areas (Anderson and Bartholomay, 1990). A straight-line interpolation was used to extend interpreted stratigraphic contacts from well to well on geologic sections (figs. 3-8). Using data shown on table 1, contours of altitude and thickness of stratigraphic units (figs. 9-20) were interpolated between wells to the nearest 25 or 50 ft. Large gamma emissions caused by manmade radionuclides were detected in the subsurface near well TSF DISP (fig. 2). Although emissions from these radionuclides appear to coincide with known geologic contacts and were detected in just two wells, additional cores from the subsurface may be needed to verify stratigraphic relations in this area.

Basalt flows underlying TAN were formed by lavas that issued from 10 different source vents. Flows were correlated with buried and exposed source vents using two methods. All basalt flows underlying TAN to a depth of 500 ft were correlated with source vents on the basis of natural-gamma logs (Anderson and Lewis, 1989; Anderson, 1991). Most of these vents are unidentified and are not shown on figure 1 because the correlations are preliminary; additional data are required for verification of these correlations. Selected basalt flows in the uppermost parts of wells GIN 5, GIN 6, TAN CH1, and TAN CH2 were correlated with a nearby surface vent, Circular Butte (fig. 1), on the basis of geologic ages, paleomagnetic properties, and petrographic characteristics of the flows (Kuntz and others, 1990; Lanphere and others, 1994). Correlations of other flows with source vents will require additional data.

## Acknowledgments

Data from wells drilled at TAN during this investigation were provided by Jon F. Kaminsky, Thomas R. Wood, and Allan H. Wylie, formerly with EG&G Idaho, Inc. Technical assistance and data from previous geologic investigations were provided by Duane E. Champion, Marvin A. Lanphere, and Mel A. Kuntz, USGS, Geologic Division.

## GEOHYDROLOGIC SETTING

The INEL is on the west-central part of the eastern Snake River Plain, a northeast-trending structural basin about 200 mi long and 50 to 70 mi wide (fig. 1). The INEL is underlain by a sequence of Tertiary and Quaternary volcanic rocks and sedimentary interbeds that is more than 10,000 ft thick (Doherty and others, 1979; Whitehead, 1992). The volcanic rocks consist mainly of basaltic lava flows, ash, and cinders in the upper part and rhyolitic ash flows and tuffs in the lower part; in places, the rocks are intruded by rhyolite domes that are as high as 2,000 ft above the surface of the plain. The basaltic rocks, which underlie the INEL to a depth of more than 3,000 ft, are interbedded with fluvial, lacustrine, and eolian deposits of clay, silt, sand, and gravel. Source vents for the basalt and rhyolite are concentrated on volcanic rift zones, such as the Circular Butte-Kettle Butte volcanic rift zone (fig. 1), that trend perpendicular to the long axis of the plain (Kuntz and others, 1992; Kuntz and others, 1990). Vents also are concentrated on the axial volcanic zone (fig. 1) in the center of the plain (R.P. Smith and W.R. Hackett, formerly with EG&G Idaho, Inc., written commun., 1990).

The basalt and sediment underlying the INEL are saturated at depth and together form the Snake River Plain aquifer. Depth to water at the INEL ranges from about 200 ft below land surface in the northern part to about 900 ft in the southern part; the general direction of ground-water flow is from northeast to southwest. The effective base of the aquifer at the INEL coincides with the top of a thick and widespread layer of clay, silt, sand, and altered basalt that is older than about 1.6 million years. The top of this layer is at a depth of about 1,000 ft below land surface in a 10,365-ft test well, INEL-1 (fig. 1) (Mann, 1986), and at depths ranging from 800 to 1,600 ft elsewhere in the western half of the INEL. The effective saturated thickness of the aquifer ranges from about 600 ft near TAN to about 1,200 ft near the ICPP (fig. 8); saturated thickness in the eastern half of the INEL is unknown because the wells in this area do not fully penetrate the aquifer. Hydraulic properties of the aquifer differ considerably from place to place depending on saturated thickness and the characteristics of the basalt and sediment. In places, the basalt and sediment in the uppermost part of the aquifer yield thousands of gallons per minute of water to wells, with negligible drawdown (Ackerman, 1991). Hydraulic data for the basalt, sediment, ash, and tuff underlying the aquifer are sparse, but data for INEL-1 indicate that these rocks and sediment are relatively impermeable compared with those that make up the aquifer (Mann, 1986). Localized zones of perched ground water, which are attributed mainly to infiltration from unlined percolation ponds and recharge from the Big Lost River, are present in basalt and sediment overlying the regional aquifer (Cecil and others, 1991).

TAN is underlain by numerous basalt flows, basalt-flow groups, and sedimentary interbeds to a depth of at least 1,114 ft. A basalt flow is a solidified body of rock that was formed by a lateral, surficial outpouring of molten lava from a vent or fissure (Bates and Jackson, 1980). A basalt-flow group consists of one or more basalt flows from a brief, single or compound eruption (Kuntz and others, 1980). All basalt flows of each group erupted from the same vent and have similar ages, paleomagnetic properties, potassium contents, and natural-gamma emissions. The basalt flows, which locally are altered, consist mainly of medium- to dark-gray beds of vesicular to dense olivine basalt. Individual flows are as much as 100 ft thick and in places are interbedded with cinders and thin layers of sediment. Sedimentary interbeds, which are most abundant between flow groups, accumulated on the ancestral land surface for hundreds to hundreds of thousands of years during periods of volcanic quiescence. Sedimentary interbeds are as much as 30 ft thick and consist of well to poorly sorted deposits of clay, silt, sand, and gravel. In places the interbeds contain cinders and basalt rubble.

Interpreted stratigraphic relations of basalt-flow groups and sedimentary interbeds in the unsaturated zone and uppermost part of the aquifer at TAN are shown in figures 3-20. Flow groups and interbeds in the lowermost part of the aquifer were not evaluated for detailed stratigraphic properties and in this report are referred to as undifferentiated basalt and sediment (figs. 3-8). Basalt and sediment are unsaturated to a depth of about 200 ft. Rocks below this depth are saturated and make up the Snake River Plain aquifer (figs. 3-8). During 1990 to 1992, depth to water ranged from 194 to 226 ft in 39 wells that penetrate 26 to 687 ft of the aquifer. The deepest well, TAN CH2, penetrates the effective base of the aquifer at a depth of 885 ft below land surface, an interpretation that is based on similar changes in lithologic properties below this depth in wells TAN CH2, GS 7, and 2-2A (fig. 8). The Snake River Plain aquifer consists of upper and lower parts in the areas south of TAN (Anderson, 1991). The basalt and sediment that make up the unsaturated zone and the aquifer at TAN are equivalent in age to those that make up the lowermost part of the aquifer near the ICPP (fig 8).

## STRATIGRAPHY OF THE UNSATURATED ZONE AND UPPERMOST PART OF THE SNAKE RIVER PLAIN AQUIFER

The unsaturated zone and the uppermost part of the Snake River Plain aquifer at TAN consist of 22 basalt flows and 5 to 10 sedimentary interbeds. These deposits are overlain by a veneer of surficial sediment. The 22 basalt flows make up 10 separate basalt-flow groups that erupted from 10 source vents near TAN. The basalt and sediment were subdivided into seven composite stratigraphic units that are used to describe stratigraphic relations in the subsurface. The top and base of each composite unit coincide with geologic contacts that are widespread and distinct in most natural-gamma logs from wells in the area.

### Basalt-Flow Groups and Sedimentary Interbeds

Each basalt-flow group at TAN was assigned an informal alphabetical designation of LM through R on the basis of its position and age, from youngest to oldest, in the stratigraphic section. Flow groups LM through R were named to reflect their older age compared with flow groups A through L (fig. 8), a previously described sequence of basalt-flow groups at the ICPP, TRA, and RWMC (Anderson and Lewis, 1989; Anderson, 1991). Only two interbeds at TAN, P-Q and Q-R, were named. These interbeds, which are widespread in the subsurface, were named to reflect their positions with respect to flow groups P, Q, and R. Flow groups LM(W) and LM(E) erupted from vents west and east of TAN, respectively.

Flow groups A through L occupy the upper 850 ft of the subsurface east of the ICPP in wells W-02 and NPR TEST (fig. 8). These flow groups, which make up the unsaturated zone and uppermost part of the aquifer at and near the ICPP, TRA, and RWMC, range in age from about 95,000 to 800,000 years (Anderson and Lewis, 1989; Anderson, 1991; D.E. Champion, USGS, written commun., 1993). Flow groups LM through R, which make up the unsaturated zone and uppermost part of the aquifer at TAN, range in age from about 940,000 to 1.4 million years (Lanphere and others, 1994). Flow groups LM through R are equivalent, in part, to the youngest basalt and sediment that make up the lowermost part of the aquifer below the base of flow group L in well W-02. Selected basalt cores from well W-02, which was drilled in 1991 adjacent to well NPR TEST, about 3 mi east of the ICPP (fig. 8), range in age from about 980,000 years at a depth of 1,200 ft to about 1.6 million years at a depth of 1,650 ft, near the effective base of the aquifer (M.A. Lanphere, USGS, written commun., 1993). Although some basalt flows in the depth interval from 850 to 1,650 ft in well W-02 may correlate with flow groups LM through R at TAN, detailed stratigraphic relations between these areas presently are uncertain.

Ages of basalt-flow groups LM through R, which are summarized on pages 7 and 8, were determined by correlating the flows with those of known ages at the land surface and with dated cores from wells TAN CH1 and TAN CH2 (Kuntz and others, 1990, D.E.; Lanphere and others, 1994). Surficial basalt flows near TAN, which collectively are referred to as LM, range in age from about 800,000 to 1.0 million years; two of these flows, LM(W) and LM(E) are present in the subsurface at TAN. Flow group LM(W), which underlies the western part of TAN, correlates with a dated surface flow that crops out near well ANP 6 (fig. 3). Flow group LM(W) was assigned an age of 939,000 years, the age that was determined for the outcrop 3 mi northwest of well ANP 6 (Kuntz and others, 1990). Flow group LM(E) underlies the eastern part of TAN and correlates with Circular Butte (fig. 1). Flow group LM(E) was assigned an age intermediate to those of flow groups LM(W) and N that is younger than the age determined for the outcrop near Circular Butte (Kuntz and others, 1990). A basalt core of flow group N from well TAN CH1 yielded an age of about 1.0 million years. A basalt core of flow group P from well TAN CH1 yielded an age of about 1.2 million years. Flow group R1, which locally interfingers with sedimentary interbed Q-R, has an age of about 1.4 million years on the basis of ages of cores from well TAN CH2. Flow group R1 yielded an age of about 1.6 million years on the basis of ages of cores from well TAN CH1, but this age was rejected in favor of the younger age from well TAN CH2. Flow group R2 has not been dated and tentatively was assigned the same age as flow group R1. Flow groups M, MN, O, and Q also have not been dated and were assigned ages intermediate to those of flow groups LM(W), N, P, and R1. K-Ar ages of about 1.9 to 2.5 million years determined for undifferentiated basalt above the effective base of the aquifer in wells TAN CH1 and TAN CH2 also were rejected. Instead, ages of 1.4 to 1.6 million years were assigned to this basalt on the basis of correlations using the combined data from wells TAN CH1, GS 7, 2-2A, and W-02 (fig. 8). A K-Ar age of about 2.5 million years was determined for a basalt core taken from below the effective base of the aquifer in well TAN CH2. This age may be correct, but it is much older than the age of deposits at a similar depth in well 2-2A. Ages assigned to flow groups LM through R are:

- flow group LM(W) - 939,000±154,000 years
- flow group LM(E) - 939,000±154,000 to 1.010±0.043 million years
- flow group M - 939,000±154,000 to 1.010±0.043 million years
- flow group MN - 939,000±154,000 to 1.010±0.043 million years
- flow group N - 1.010±0.043 million years
- flow group 0 - 1.010±0.043 to 1.248±0.069 million years

- flow group P - 1.248±0.069 million years
- flow group Q - 1.248±0.069 to 1.412±0.047 million years
- flow group R1 - 1.412±0.047 million years
- flow group R2 - 1.412±0.047 million years

Basalt-flow groups LM through R make up about 90 percent of the upper 500 ft of the subsurface at TAN; the remaining 10 percent consists of sediment (figs. 3-8). The average thickness of individual flow groups fully penetrated by wells in the upper 500 ft ranges from 15 ft for flow group LM(W) to 183 ft for flow group Q. Topographic relief of the top of flow groups ranges from 29 ft for flow group LM(E) to 170 ft for flow group P (figs. 3-8). Only flow groups P, Q, and R2 underlie the entire area. Sedimentary interbeds and other flow groups are, in places, not present. Flow groups LM through O and the upper part of P make up the unsaturated zone. Flow groups Q and R and the lower part of P are below the water table and, together with underlying deposits, make up the Snake River Plain aquifer. Detailed stratigraphic relations below the base of flow group R2 were not determined because this interval of basalt and sediment is penetrated by only 2 of the 57 wells at TAN. Well TAN CH2 penetrates the effective base of the Snake River Plain aquifer at a depth of 885 ft below land surface (fig. 8).

Flow groups LM through R and equivalent rocks make up the oldest part of the unsaturated zone and the Snake River Plain aquifer between TAN and the ICPP (fig. 8). Ages of these rocks range from about 800,000 to 1.6 million years and are similar to ages reported for the Bruneau Formation of the western Snake River Plain (Armstrong and others, 1975). Flow groups LM through R and equivalent rocks accumulated during the last half of the Matuyama Reversed-Polarity Chron and, therefore, have reversed paleomagnetic polarity. At TAN, these rocks are bounded by unconformities. Near the ICPP, these rocks overlie basalt deposited about 1.7 million years ago during the Olduvai Normal-Polarity Subchron and are overlain by basalt deposited about 780,000 years ago during the beginning of the Brunhes Normal-Polarity Chron (Mankinen and Dalrymple, 1979; D.E. Champion and M.A. Lanphere, USGS, written commun., 1993). Paleomagnetic boundaries at TAN (fig. 8) indicate only relative ages of deposits because deposits of Olduvai, latest Matuyama, and early Brunhes ages are not present in this area.

## Composite Stratigraphic Units

Seven composite stratigraphic units consisting of multiple basalt-flow groups and related sedimentary interbeds of similar age are used to describe the subsurface stratigraphy of TAN. The units, which are bounded by seven widespread and generally distinct geologic contacts, include the surficial sediment; flow groups LM(W), LM(E), and M and related sediment; flow groups MN and N and related sediment; flow group O and related sediment; flow group P and related sediment; flow group Q and related sediment; and flow groups R1 and R2 and related sediment. The geologic contacts include the base of the surficial sediment, the base of flow group M, the base of flow group N, the top of flow group P, the base of flow group P, the base of flow group Q, and the base of flow group R2. Sedimentary interbed P-Q is included with flow group Q and related sediment. Sedimentary interbed Q-R is included with flow groups R1 and R2 and related sediment. Stratigraphic relations of composite units are shown in figures 9-20 and table 1. Data for flow groups R1 and R2 and related sediment are not included in table 1 because only 2 of the 11 wells that penetrate this unit fully penetrate its base.

Composite stratigraphic units consist mainly of basalt (figs. 9-20 and table 1). The average thickness of units ranges from 36 ft for the surficial sediment and for flow groups LM(W), LM(E), and M and related sediment to 183 ft for flow group Q and related sediment. Average sediment content of units below the base of the surficial sediment ranges from less than 1 percent for flow group P and related sediment to 12 percent for flow groups R1 and R2 and related sediment. Topographic relief of the top of composite units ranges from 27 ft for the surficial sediment to 170 ft for flow group P and related sediment. Composite stratigraphic units above the base of flow group O are in the unsaturated zone.

Flow groups P, Q, and R and related sediment are saturated in the southwestern part of TAN. Flow groups Q and R and related sediment are the principal water-bearing units of the Snake River Plain aquifer above a depth of 500 ft in the northeastern part of TAN.

Surficial sediment.—Basalt flows at TAN are overlain by a veneer of surficial sediment that is fully penetrated by all 57 wells (figs. 3-10; table 1). In these wells, the base of surficial sediment is at a depth of 5 to 63 ft and ranges in altitude from 4,723 to 4,783 ft. Thickness of the surficial sediment ranges from 5 to 63 ft, averages 36 ft, and is greatest in well TAN 4. In this report, description of the distribution of surficial sediment is considered approximate because it does not include data from auger holes or reflect changes in sediment thickness caused by construction of waste ponds and other manmade features. The surficial sediment overlies flow groups LM(W), LM(E), and M.

Flow groups LM(W), LM(E), and M and related sediment.—Flow groups LM(W), LM(E), and M and related sediment make up the uppermost composite stratigraphic unit below the base of the surficial sediment (figs. 3-8 and 10-12; table 1). Flow group LM(W) consists of one flow that erupted about 3 mi northwest of well ANP 6 from an unnamed vent on the Lava Ridge-Hells Half Acre volcanic rift zone (fig. 1) (Kuntz and others, 1990). This flow group has a limited areal extent at TAN and is present only in wells ANP 6, GIN 7, GIN 13, and GIN 20. Flow group LM(E) consists of one flow that erupted about 3 mi east of well GIN 5 from Circular Butte (fig. 1) on the Circular Butte-Kettle Butte volcanic rift zone (Kuntz and others, 1990). This flow group also has a limited areal extent at TAN and is present only in wells IET DISP, TAN 8, TAN 15, TAN 16, TAN 22, TAN 22A, TAN 23, TAN 23A, TAN 24, and TAN 24A. Flow group M, which underlies most of the area and is thickest in wells TAN 23 and TAN 23A, consists of one to two flows from an unidentified, buried vent near TAN. Paleomagnetic properties of flow group M are similar to those of Circular Butte (fig. 1); however, flow group M was assigned to another source vent because it locally is separated by sediment from flow-group LM(E) and has a character on most gamma logs different from that of the younger, overlying flow. The composite unit of flow groups LM(W), LM(E), and M and related sediment was assigned an age that ranges from 939,000±154,000 to 1.010±0.043 million years. The unit overlies flow groups MN and N and related sediment and is overlain by the surficial sediment.

The top of this composite stratigraphic unit, which is penetrated by 48 of the 57 wells, is at a depth of 5 to 63 ft and ranges in altitude from 4,723 to 4,783 ft (table 1). The base of the unit, which is penetrated by 44 of the 57 wells, is at a depth of 39 to 92 ft and ranges in altitude from 4,688 to 4,743 ft. Thickness of the unit ranges from 0 to 74 ft, averages 36 ft in wells that fully penetrate its base, and is greatest in well GIN 20. Sediment content of the unit ranges from 0 to 11 percent and averages less than 1 percent in wells that fully penetrate its base; the number of sedimentary interbeds in the unit ranges from none to one.

Flow groups MN and N and related sediment.—Flow groups MN and N and related sediment form a moderately thick, widespread composite stratigraphic unit at TAN (figs. 3-8 and 12-14; table 1). Flow groups MN and N each consist of one to two flows that erupted from two unidentified, buried source vents near TAN. Paleomagnetic properties of flow groups MN and N are similar to those of Circular Butte (fig. 1); however, flow groups MN and N were assigned to other source vents because the flows are thickest northwest of TAN, are separated locally by sediment from flow group M, and have a character on most gamma logs different from that of younger, overlying flows. Flow groups MN and N and related sediment was assigned an age that ranges from 939,000±154,000 to 1.010±0.043 million years. The unit overlies flow group O and related sediment and is overlain by flow groups LM(W), LM(E), and M and related sediment.

The top of this composite stratigraphic unit, which is penetrated by 52 of the 57 wells, is at a depth of 37 to 92 ft and ranges in altitude from 4,688 to 4,749 ft (table 1). The base of the unit, which is penetrated by 48 of the 57 wells, is at a depth of 83 to 193 ft and ranges in altitude from 4,588 to 4,707 ft. Thickness of the unit ranges from 0 to 111 ft, averages 68 ft in wells that fully penetrate its base, and is greatest in well GIN 20. Sediment content of the unit ranges from 0 to 20 percent and averages 2 percent in wells that fully penetrate its base; the number of sedimentary interbeds in the unit ranges from none to two.

Flow group O and related sediment.—Flow group O and related sediment form a moderately thick, discontinuous composite stratigraphic unit at TAN (figs. 3-8 and 14-16; table 1). Flow group O consists of one to two flows that erupted from an unidentified, buried source vent near TAN. The unit, which is present mainly in the areas southwest of SMC, TSF, and WRRTF (fig. 1), was assigned an age that ranges from 1.010±0.043 to 1.248±0.069 million years. The unit overlies flow group P and related sediment and is overlain by flow groups MN and N and related sediment.

The top of this composite unit, which is penetrated by 30 of the 57 wells, is at a depth of 100 to 193 ft and ranges in altitude from 4,588 to 4,690 ft (table 1). The base of the unit, which is penetrated by 24 of the 57 wells, is at a depth of 120 to 217 ft and ranges in altitude from 4,570 to 4,681 ft. Thickness of the unit ranges from 0 to 81 ft, averages 50 ft in wells that fully penetrate its base, and is greatest in well TAN DD1. Sediment content of the unit ranges from 0 to 100 percent and averages 4 percent in wells that fully penetrate its base; the number of sedimentary interbeds in the unit ranges from none to two.

Flow group P and related sediment.—Flow group P and related sediment form a thick, widespread composite stratigraphic unit at TAN (figs. 3-8 and 16-18; table 1). The unit is underlain by sedimentary interbed P-Q in only 16 of the 36 wells that penetrate its base. The top and base of flow group P each have relief of about 170 ft that is attributed to uplift in the northeastern part of TAN after deposition of the flows. Flow group P consists of at least four flows that erupted from an unidentified, buried source vent near TAN. The composite unit of flow group P and related sediment was assigned an age of 1.248±0.069 million years. The unit overlies flow group Q and related sediment and is overlain by flow group O and related sediment in the southwestern part of TAN and by basalt and sediment that are younger than flow group O in the northeastern part of TAN.

The top of this composite unit, which is penetrated by 43 of the 57 wells, is at a depth of 63 to 217 ft and ranges in altitude from 4,570 to 4,740 ft (table 1). The base of the unit, which is penetrated by 36 of the 57 wells, is at a depth of 189 to 340 ft and ranges in altitude from 4,440 to 4,606 ft. Thickness of the unit ranges from 72 to 159 ft, averages 118 ft in wells that fully penetrate its base, and is greatest in well TAN DD3. Sediment content of the unit ranges from 0 to 9 percent and averages less than 1 percent in wells that fully penetrate its base; the number of sedimentary interbeds in the unit ranges from none to two.

Flow group Q and related sediment.—Flow group Q and related sediment also form a thick, widespread composite stratigraphic unit at TAN (figs. 3-8 and 18-20; table 1). The unit is underlain by sedimentary interbed Q-R in all 11 wells that penetrate its base. The top and base of flow group Q have relief of about 150 and 70 ft, respectively, that is attributed to subsidence and uplift during and after deposition of the flows. Flow group Q consists of at least five flows that erupted from an unidentified, buried source vent near TAN. The composite unit of flow group Q and related sediment was assigned an age that ranges from 1.248±0.069 to 1.412±0.047 million years. The unit overlies flow groups R1 and R2 and related sediment and is overlain by flow group P and related sediment.

The top of this composite unit, which is penetrated by 36 of the 57 wells, is at a depth of 189 to 340 ft and ranges in altitude from 4,440 to 4,606 ft (table 1). The base of the unit, which is penetrated by 11 of the 57 wells, is at a depth of 400 to 479 ft and ranges in altitude from 4,310 to 4,381 ft. Thickness of the unit ranges from 129 to 220 ft, averages 183 ft in wells that fully penetrate its base, and is greatest in well TAN 21. Sediment content of the unit ranges from 0 to 6 percent and averages 3 percent in wells that fully penetrate its base; the number of sedimentary interbeds in the unit ranges from none to three.

Flow groups R1 and R2 and related sediment.—Flow groups R1 and R2 and related sediment form a complex, moderately thick, widespread composite stratigraphic unit at TAN (figs. 3-8). Sedimentary interbed Q-R is present in the 11 deepest wells in the area and flow groups R1 and R2 are in 4 and 7 of these wells, respectively. Flow groups R1 and R2 and interbed Q-R have a total thickness of about 100 ft in wells TAN CH1 and TAN CH2. Flow group R1, which locally interfingers with interbed Q-R, is present in wells TAN CH1, TAN CH2, TAN 18, and TAN 23. Flow group R2, which underlies interbed Q-R, is present in wells TAN CH1, TAN CH2, TAN 18, TAN 21, TAN 22, TAN 22A, and TAN 23. Sedimentary interbed Q-R is present in wells TAN CH1, TAN CH2, TAN 18, TAN 19, TAN 21, TAN 22, TAN 22A, TAN 23, TAN 23A, TAN 24, and TAN 24A. The composite unit of flow groups R1 and R2 and related sediment was assigned an age of 1.412±0.047 million years. The unit overlies undifferentiated basalt and sediment in wells TAN CH1 and TAN CH2 and is overlain by flow group Q and related sediment in these and other wells that penetrate the unit.

The top of this composite unit, which is penetrated by 11 of the 57 wells, is at a depth of 400 to 479 ft and ranges in altitude from 4,310 to 4,381 ft. The base of the unit, which is penetrated by 2 of the 57 wells, TAN CH1 and TAN CH2 (figs. 3-8), is at a depth of 501 to 550 ft and ranges in altitude from 4,240 to 4,280 ft. Thickness of the unit is 101 ft in well TAN CH1 and 103 ft in well TAN CH2. Sediment content of this unit in wells TAN CH1 and TAN CH2 ranges from 9 to 16 percent and averages 12 percent; sedimentary interbed Q-R consists of two layers separated by flow group R1 in these wells.

Paleomagnetic properties and potassium contents of flow groups R1 and R2 in wells TAN CH1 and TAN CH2 suggest a more complex relation between the flows than was interpreted from geophysical logs. Flow group R1, which consists of a single flow in each of these wells, has a much lower potassium content than flow group R2; however, flow group R1 in well TAN CH2 has paleomagnetic properties that are more like those of flow group R2 than those of the adjacent flow group R1 in well TAN CH1. Paleomagnetic properties and potassium contents of flow groups R1 and R2 suggest that these flows erupted from at least two unidentified source vents near TAN. Because it was not possible with available data to determine detailed stratigraphic relations between flow groups R1 and R2, stratigraphic position of the flows with respect to sedimentary interbed Q-R was used as the main criteria for subdividing and determining the areal distribution of this composite stratigraphic unit.

## Stratigraphic and Depositional Relations

The eruptions of flow groups LM through R covered TAN and nearby areas with hundreds of feet of basalt, ash, and cinders from about 940,000 to 1.4 million years ago. Each eruption was followed by a long period of volcanic quiescence during which sediment accumulated in stream channels, flood plains, playas, and dunes. Distribution and thickness of basalt and sediment were controlled by the source and volume of each deposit and the topographic relief of underlying rocks. Topographic relief was controlled by subsidence, uplift, and distribution of basalt source vents, some of which grew as high as 300 ft. Although eruptions were infrequent and brief, they produced enormous volumes of basalt. Basalt, which accumulated at a rate much greater than that of sediment, makes up about 90 percent of the volume of deposits underlying TAN.

Flow groups R1 and R2 erupted from at least two unidentified source vents near TAN and covered older basalt and sediment from TAN to well 2-2A (figs. 3-8). Flow groups R1 and R2 also covered nearby areas north, east, and west of TAN. These basalt flows accumulated to a maximum thickness of about 100 ft and were overlain by sedimentary interbed Q-R. Flow groups R1 and R2 and sedimentary interbed Q-R were tilted and folded by subsidence and uplift between TAN and well 2-2A before or during the eruption of flow group Q. Uplift may have fractured these and older rocks near well 2-2A.

Flow group Q erupted from an unidentified source vent near TAN and accumulated in a widespread topographic depression formed by subsidence and uplift of flow groups R1 and R2 and older rocks (figs. 3-8 and 18-20). These basalt flows had enormous volume and spread from TAN to well GS 7, where they lapped against the northward-dipping surface of flow groups R1 and R2 in the area north of well 2-2A. Flow group Q also covered nearby areas north, east, and west of TAN. The basalt flows accumulated to a maximum thickness of 220 ft. Flow group Q was overlain, in places, by sedimentary interbed P-Q before the eruption of flow group P.

Flow group P erupted from an unidentified source vent near TAN and covered flow group Q from TAN to the area south of well GS 7 (figs. 3-8 and 16-18). Flow group P also covered nearby areas north, east, and west of TAN. These basalt flows had about the same volume as flow group Q and accumulated to a maximum thickness of 159 ft. Flow group P, which was overlain, in places, by thin layers of sediment, was folded and tilted by uplift of 50 to 170 ft in the northeastern part of TAN before the eruption of flow group O. Uplift probably fractured flow group P and older rocks in this area.

Flow group O erupted from an unidentified source vent near TAN and covered flow group P from TAN to the area south of well GS 7 (figs. 3-8 and 14-16). Flow group O, which lapped against the southward-dipping surface of flow group P along the flanks of the earlier uplift, spread beyond this feature and covered nearby areas north, east, and west of TAN. These basalt flows had less volume than flow groups P and Q and accumulated to a maximum thickness of 81 ft. Flow group O was overlain in places by thin layers of sediment before the eruptions of flow groups MN and N.

Flow groups MN and N erupted from two unidentified source vents near TAN and covered flow groups O and P from TAN to the area south of well GS 7 (figs. 3-8 and 12-14). Flow groups MN and N covered the earlier uplift and spread beyond this feature to nearby areas north, east, and west of TAN. These basalt flows had about the same volume as flow group O and accumulated to a maximum thickness of 111 ft. Flow groups MN and N were overlain in places by thin layers of sediment before the eruptions of flow groups LM(W), LM(E), and M.

Flow groups LM(W), LM(E), and M were the last basalt flows deposited at TAN. Flow group M, which erupted from an unidentified source vent near TAN, had about the same volume and distribution as flow groups MN and N (figs. 3-8 and 10-12). Flow groups LM(W) and LM(E) had much less volume, were more localized, and built higher shields than flow groups M through R, characteristics that are attributed to changes in eruptive styles after the eruption of flow group M. Flow groups LM(W) and LM(E), which erupted from surface vents on the Lava Ridge-Hells Half Acre and Circular Butte-Kettle Butte volcanic rift zones (fig. 1) had only enough volume to cover the most western and eastern parts of TAN. Flow groups LM(W) and M accumulated to a maximum thickness of 74 ft in the western part of TAN. Flow groups LM(E) and M accumulated to a maximum thickness of 70 ft in the eastern part of TAN. Flow groups LM(W), LM(E), and M were overlain by surficial sediment after a long period of erosion. TAN, which is situated between outcrops of LM(W) and LM(E), now is underlain by 5 to 63 ft of surficial sediment. Topographic relief of the top of flow group LM(E) between TAN and Circular Butte (fig. 1), the source of this flow group and the highest volcanic vent in the area, is about 300 ft.

The eruptions of flow groups LM through R deposited about 8 $mi^3$ of basalt within a 5-mi radius of TAN from about 940,000 to 1.4 million years ago. Similar paleomagnetic properties among successive flow groups suggest that these eruptions took place during four or five volcanic episodes during this period. Each episode probably lasted no more than a few hundred years and was followed by a period of sediment accumulation that lasted for hundreds to hundreds of thousands of years. Flow groups R1 and R2, which comprise about 19 percent of the total volume of the upper 500 ft of rocks, probably erupted during a volcanic episode about 1.4 million years ago. Flow groups O, P, and Q, which comprise about 63 percent of this volume, may have erupted during a single episode about 1.2 million years ago or during two episodes about 1.2 and 1.3 million years ago. Flow groups LM(E), M, MN, and N comprise about 18 percent of the volume, and probably erupted during a volcanic episode about 1 million years ago. Flow group LM(W), which forms a minor part of the uppermost layer of basalt, erupted about 940,000 years ago. The volumes of flow groups M through R were large compared with those of flow groups LM(W) and LM(E). The eruptions of flow groups M through R produced moderately thick to thick, continuous layers of basalt that covered areas ranging from about 75 to 200 $mi^2$. Later eruptions, which included those of flow groups LM(W), LM(E), and other LM groups north and west of TAN, formed many thin, discontinuous layers of basalt that covered areas ranging from about 5 to 15 $mi^2$. The youngest known eruption in this part of the INEL occurred about 800,000 years ago in the area north of TAN (Kuntz and others, 1990). Volcanism near TAN ceased about 800,000 years ago but continued in other parts of the INEL to a much more recent time. The depositional hiatus at and near TAN, which is attributed to uplift and cessation of volcanism in the area about 800,000 years ago, is the longest known hiatus at the INEL during the past 1.6 million years. By contrast, the eruptions of basalt-flow groups A through L (Anderson and Lewis, 1989; Anderson, 1991) covered flow groups LM through R and equivalent rocks with about 600 to 1,200 ft of younger basalt flows in the southern and eastern parts of the INEL during the past 800,000 years.

## Structural Implications

Stratigraphic relations show that flow groups LM through R and equivalent rocks between TAN and the ICPP (figs. 3-8) are tilted and folded. Deformation resulted from simultaneous subsidence and uplift distributed across areas of tens to hundreds of square miles (Anderson, 1991). Subsidence was accompanied by basaltic volcanism and generally was greatest near clustered source vents of similar age. Uplift probably was related to the intrusion and doming of silicic magmas beneath previously deposited basalt flows and sedimentary layers. Localized differential structural movements related to subsidence and uplift likely fractured basalt flows in places. Some lavas that were extruded during deformation ponded in structurally generated topographic depressions as deep as several hundred feet. Deformation and volcanism were episodic and shifted from place to place. Most older rocks that were deformed by subsidence and uplift eventually were covered by younger basalt and sediment and are no longer visible at the land surface. Areas of subsidence are characterized by inwardly dipping layers that are overlain by thick, progressively younger deposits. Areas of uplift are characterized by outwardly-dipping layers that are overlain by thin, intermittently younger deposits. Uplift is attributed to silicic volcanism because the style of deformation is similar to that caused by rhyolite domes at the land surface in nearby areas (Kuntz and others, 1990; Kellogg and Embree, 1986). Tilted and fractured basalt flows cover some rhyolite domes at the land surface and probably cover concealed domes near the RWMC, ICPP, TRA, and TAN.

The western half of the INEL subsided and was overlain by basalt and sediment from about 3.2 to 1.6 million years ago.The basalt and sediment accumulated in a shallow lake or playa that covered the area. Thick layers of clay and silt accumulated near wells 2-2A, GS 15, and INEL-1 (figs. 1 and 8). Sediment interfingered with basalt near TAN and the ICPP. This sediment and basalt accumulated at an average rate of about 65 ft per 100,000 years. These deposits are altered, are about 1,000 ft thick, and form the effective base of the Snake River Plain aquifer. Although the areal extent of the deposits beyond the western half of the INEL is unknown, ages of the deposits are similar to those reported by Kimmel (1982) for the Glenns Ferry Formation. This sedimentary formation, which crops out in southern Idaho, directly underlies basalt flows of the Snake River Plain aquifer where it discharges to the Snake River about 100 mi southwest of the INEL (Whitehead, 1992).

Subsidence and volcanism increased in parts of the INEL about 1.6 million years ago. The area between TAN and the ICPP subsided and was overlain by about 800 ft of basalt and sediment from about 1.6 million to 800,000 years ago. Flow groups LM through R and equivalent rocks accumulated in the depression at an average rate of about 100 ft per 100,000 years. Deposits of this age either did not accumulate in or were eroded from the area mountainward from the Big Lost River (fig. 1). This area did not subside or subsided at a much slower rate than the area between TAN and the ICPP. Flow groups LM through R and equivalent rocks accumulated in the eastern half of the INEL, but their distribution and thickness are uncertain. These and older deposits may have been fractured by differential subsidence near the Big Lost River; the deposits probably were fractured by uplift at and near TAN.

Stratigraphic relations of flow groups LM through R and equivalent rocks were caused, in part, by three uplifts that occurred at and near TAN. The first uplift, which occurred about 1.4 million years ago before the eruption of flow group Q, elevated rocks near well 2-2A about 200 ft (fig. 8). The second uplift, which occurred about 1.2 million years ago before the eruption of flow group O, elevated rocks in the northeastern part of TAN about 50 to 170 ft (figs. 3-7). The third uplift, which occurred about 800,000 years ago after the eruption of flow group LM(W), elevated rocks in the northernmost part of the INEL about 900 ft (fig. 8). Each uplift is attributed to the doming of silicic magmas beneath a cover of basalt and sediment at least 3,000 ft thick. Domes range from about 5 to 200 $mi^2$ in areal extent and probably are covered by tilted, folded, and fractured basalt flows. The youngest and largest dome, which is concealed by a veneer of surficial sediment near its center and flow groups A through L and related sediment near its flanks, underlies the area north of wells DH 2A and SITE 14 and northwest of wells GS 28, GS 31, and GS 27 (figs. 1 and 8).

Subsidence increased at the INEL about 800,000 years ago and gradually lowered older rocks, including the dome at TAN, by hundreds of feet with respect to the adjacent mountain ranges. The area was covered by flow groups A through L and related sediment (fig. 8) (Anderson and Lewis, 1989; Anderson, 1991). The thickest deposits accumulated south and east of TAN from about 800,000 to 200,000 years ago. About 600 to 1,200 ft of basalt and sediment accumulated during this period at rates that ranged from about 100 to 200 ft per 100,000 years. Thickness and accumulation rates of these deposits were greatest near the axial volcanic zone, where maximum subsidence and volcanism occurred. Thickness and accumulation rates of deposits were least near the ICPP, TRA, and RWMC, where periodic uplift occurred (Anderson, 1991). Near TAN, flow groups A through L and related sediment lapped against and eventually covered the subsiding dome. The dome remained elevated with respect to other parts of the INEL until about 200,000 years ago.

Volcanism and accumulation rates of deposits markedly decreased at the INEL about 200,000 years ago. This decrease coincided with either a shift in the area of maximum subsidence from the axial volcanic zone to the central parts of the INEL or uplift of the axial volcanic zone (fig. 1). During the past 200,000 years, the central parts of the INEL from TAN to the RWMC have subsided about 400 ft but have been covered by less than 75 ft of basalt and sediment. During this time, surficial sediment accumulated in most areas of the INEL. The largest amount of surficial sediment accumulated near the Big Lost River and between the terminus of the river and Mud Lake (fig. 1). Thick sediment in wells SITE 14, 2-2A, GS 18, and GS 27 (figs. 1 and 8), which are near the southern and eastern flanks of the concealed dome near TAN, probably was deposited by the ancestral river and lake before modern drainages developed. The ancestral river probably terminated south of the dome near wells SITE 14, 2-2A, and GS 18. The modern river terminates on the concealed dome near well GS 7 (fig. 1).

Ages of concealed domes at the ICPP, TRA, RWMC, and TAN coincide with the ages of four rhyolite domes and one latite flow at the land surface near the southern and southeastern boundaries of the INEL (Kuntz and others, 1990; Anderson, 1991). Shapes of the domes are similar to that of the Buckskin Dome (Kellogg and Embree, 1986), an older 25 $mi^2$ intrusion about

50 mi southeast of the INEL that is covered by tilted and fractured basalt flows. Big Southern Butte, Middle Butte, East Butte, and an unnamed rhyolite dome between Middle and East Buttes (fig. 1) are 10 to 15 mi south and southeast of the ICPP and TRA. Big Southern and Middle Buttes are capped by deformed basalt flows, and the rhyolitic rocks of Middle and East Buttes may intrude the older unnamed rhyolite dome that crops out between them. Ages of Big Southern, Middle, and East Buttes range from about 300,000 to less than 1.1 million years; the unnamed rhyolite dome between Middle and East Buttes was dated at about 1.4 million years (Kuntz and others, 1990). A thick latite flow from Cedar Butte (fig. 1), which lies to the east of Big Southern Butte, was indirectly dated at about 450,000 years on the basis of ages of underlying and overlying basalt flows in the subsurface east of the vent (Anderson, 1991). Ages of the concealed domes at the ICPP, TRA, RWMC, and TAN and the four rhyolite domes and one latite flow at the land surface near the INEL suggest that silicic volcanism occurred in the southern, southeastern, and northern parts of the INEL from about 1.4 million to 300,000 years ago. Silicic volcanism and uplift of domes, which affected areas of about 1 to 200 $mi^2$, occurred in many places coincident with the eruption of basaltic magmas and widespread subsidence. The complex structural relations at TAN and between TAN and the ICPP are a result of these differing and sometimes simultaneous magmatic and structural processes.

## Hydrologic Implications

Stratigraphic, depositional, and structural relations in the unsaturated zone ultimately will affect the migration of radioactive, chemical, and sanitary waste from TAN to the Snake River Plain aquifer. Basalt flows, although relatively impermeable, contain numerous fractures that are potential avenues for downward flow of contaminated water. Sedimentary interbeds may facilitate or retard downward flow depending on the size and sorting characteristics of clasts. Lateral flow and perching of water is possible along the tops of some clay and silt interbeds, and discontinuous interbeds may divert flow toward underlying or adjacent basalt flows. Lateral flow and perching of water is most likely near wells GIN 6 through GIN 20 (figs. 2 and 4) at depths of 50 to 100 ft, where locally continuous layers of clay and silt are present between flow groups M, MN, and N. Flow above this and other localized layers of sediment such as those in wells FET DISP, GIN 3, TAN CH1, TAN 9, TAN 10, and TAN 24A (figs. 2-7) between a depth of 40 to 150 ft may be diverted along bedding surfaces until it reaches open vertical fractures or wells open to deeper parts of the unsaturated zone and aquifer.

Vertical fractures caused by subsidence and uplift may cut across many basalt flows and sedimentary interbeds, especially in the area affected by uplift of flow group P and older rocks in the northeastern part of TAN (figs. 3-7). These fractures may provide avenues for downward flow of contaminated water through the unsaturated zone and increase the permeability of the aquifer. Basalt and sediment also may be fractured in places from uplift between TAN and wells DH 2A, SITE 14, GS 28, GS 31, and GS 27 (figs. 1 and 8). These fractures, which likely consist of radial and concentric segments, may provide preferential pathways for ground-water flow and movement of waste between TAN and well SITE 14 (fig. 8).

Waste that migrates to parts of the aquifer where basalt and sediment are not fractured may be retarded in its downward travel between the water table and the top of sedimentary interbed Q-R. This interbed, which consists mainly of clay and silt, is present in all wells drilled to the base of flow group Q (figs. 3-7). Interbed Q-R, which locally interfingers with flow group R1, is at a depth of 400 to 500 ft below land surface in the immediate vicinity of TAN. The interbed is about 50 to 150 ft below the bottom of the disposal well, TSF DISP (fig. 5), where substantial volumes of low-level radioactive, chemical, and sanitary wastewater were discharged into the aquifer from 1953 to 1972 (Orr and Cecil, 1991). Interbed Q-R is sufficiently thick and widespread to retard mixing of ground water between the more permeable basalt flows of flow groups Q and R2 situated above and below the interbed, respectively. Water samples collected above interbed Q-R contain high levels of trichloroethylene compared with samples collected below the interbed (Kaminsky and others, 1994).

Further study is needed to determine the effects of geologic characteristics on the migration of radioactive, chemical, and sanitary waste through the unsaturated zone and the Snake River Plain aquifer at TAN. Factors that need further study include: the distribution and lithology of individual basalt flows of each flow group; the distribution and characteristics of individual flow contacts, fractures, and vesicles; the lithology and mineralogy of sedimentary interbeds; and the distribution of hydraulic properties of basalt and sediment. Hydraulic properties determined by direct measurement and extrapolated by indirect measurement need to coincide with observed stratigraphic boundaries because log signatures of induced gamma radiation indicate numerous, layer-dependent density differences with depth. Geochemical properties, such as sorption coefficients, also need to be evaluated.

Additional deep test wells and continuous cores are needed to evaluate hydrologic implications of the dome between TAN and wells DH 2A, SITE 14, GS 28, GS 31, and GS 27 (figs. 1 and 8). This dome may affect the southward migration of waste in the aquifer from TAN in several ways. Ground water eventually will migrate from the older rocks at TAN to the younger rocks near the southern flank of the dome. The younger basalt flows in this area generally have larger hydraulic conductivities than the older basalt flows at TAN, but wells near the southern flank of the dome penetrate thick layers of clay and silt in the uppermost part of the aquifer. Interpreted stratigraphic relations between wells 2-2A and SITE 14 (fig. 8) suggest that uplift was sufficiently large to fracture older rocks in this area. These structural and stratigraphic features probably cause preferential pathways and complex gradients for ground-water flow in the aquifer between TAN and well SITE 14.

Additional deep test wells and continuous cores also are needed to evaluate geohydrologic characteristics below the base of flow group R2 that could affect the movement of waste at and near TAN. The undifferentiated basalt and sediment between the base of flow group R2 and the effective base of the aquifer in well TAN CH2 correlate with deposits in wells GS 7, 2-2A, and W-02 (fig. 8) that are transmissive on a regional scale. The undifferentiated basalt and sediment below the effective base of the aquifer in well TAN CH2 correlate with deposits in wells GS 7, 2-2A, GS 15, W-02, and INEL-1 (figs. 1 and 8) that are several orders of magnitude less transmissive than the basalt and sediment that make up the aquifer (Mann, 1986). Additional deep test wells and continuous cores to a depth of 885 ft are needed to better evaluate geohydrologic characteristics in the lowermost part of the aquifer at TAN. One test well and one continuous core in the depth interval from 885 to 2,000 ft are needed to better evaluate geohydrologic characteristics below the effective base of the aquifer.

## SUMMARY AND CONCLUSIONS

Wells drilled to depths of at least 500 ft at TAN penetrate a complex sequence of basalt flows and sedimentary interbeds that ranges in age from about 940,000 to 1.4 million years. The sequence includes 10 basalt-flow groups and 5 to 10 sedimentary interbeds. Each basalt-flow group consists of one or more basalt flows from a brief, single or compound eruption. All basalt flows of each group erupted from the same vent and have similar ages, paleomagnetic properties, potassium contents, and natural-gamma emissions. Sedimentary interbeds consist of fluvial, lacustrine, and eolian deposits of clay, silt, sand, and gravel that accumulated for hundreds to hundreds of thousands of years during periods of volcanic quiescence. Basalt and sediment were tilted, folded, and fractured by subsidence and uplift. Basalt and sediment are unsaturated to a depth of about 200 ft below land surface. Deposits below this depth are saturated and make up the Snake River Plain aquifer. The effective base of the aquifer is at a depth of 885 ft below land surface. Detailed stratigraphic relations were not determined for the lowermost part of the aquifer in the depth interval from 500 to 885 ft because of insufficient data. Basalt and sediment between the land surface and the effective base of the aquifer at TAN correlate with rocks that make up the lowermost part of the Snake River Plain aquifer in the southern and eastern parts of the INEL.

The stratigraphy of basalt-flow groups and sedimentary interbeds was determined from natural-gamma logs, lithologic logs, and well cores. Basalt cores were evaluated for potassium-argon ages, paleomagnetic properties, petrographic characteristics, and chemical composition. Stratigraphic control was provided by differences in ages, paleomagnetic properties, potassium content, and natural-gamma emissions of basalt-flow groups and sedimentary interbeds.

Results of this investigation indicate a need for additional geologic data. Additional cores evaluated for geologic ages, paleomagnetic properties, petrographic characteristics, and chemical composition are needed to verify stratigraphic relations in the unsaturated zone and uppermost part of the aquifer. Verification of structural interpretations will require similar data from selected basalt outcrops in areas adjacent to TAN. Determination of stratigraphic relations and geohydrologic characteristics in the lowermost part of the aquifer will require additional test holes and cores to a depth of at least 885 ft. A test hole completed to a depth of 2,000 ft is needed to evaluate geohydrologic characteristics below the effective base of the aquifer. Additional deep test holes and continuous cores also are needed south of TAN to better evaluate stratigraphic and structural relations that may affect the southward migration of waste in the aquifer. Identification of additional basalt flows in cores and outcrops will improve interpretations of stratigraphic and structural relations at TAN and elsewhere on the INEL and eastern Snake River Plain.

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## EXPLANATION

• P — BASALT — Basalt - flow group composed of one or more related flows. Letter, P, indicates sequence of group from top to bottom of section. Locally includes cinders and thin layers of sediment

CLAY, SILT, SAND, AND GRAVEL — Major sedimentary interbed. Locally Includes cinders and basalt rubble

GEOLOGIC CONTACT — Queried where uncertain

TAN CH1 / 600 — WELL — Entry, TAN CH1, is local well identifier. Dashed line indicates measured or estimated water level in aquifer in 1992. Arrow indicates measured water level in aquifer in 1990-1992. Number, 600, at bottom of well is total depth of well, in feet below land surface

## Location of Section

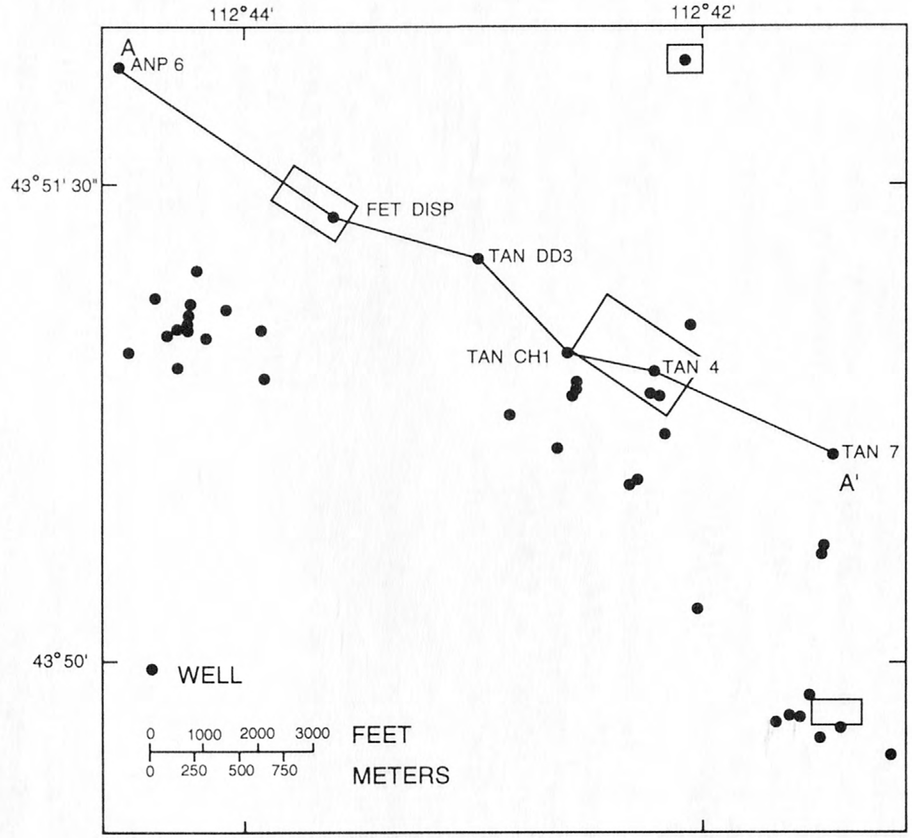



Figure 3.--Geologic section A-A' at Test Area North.

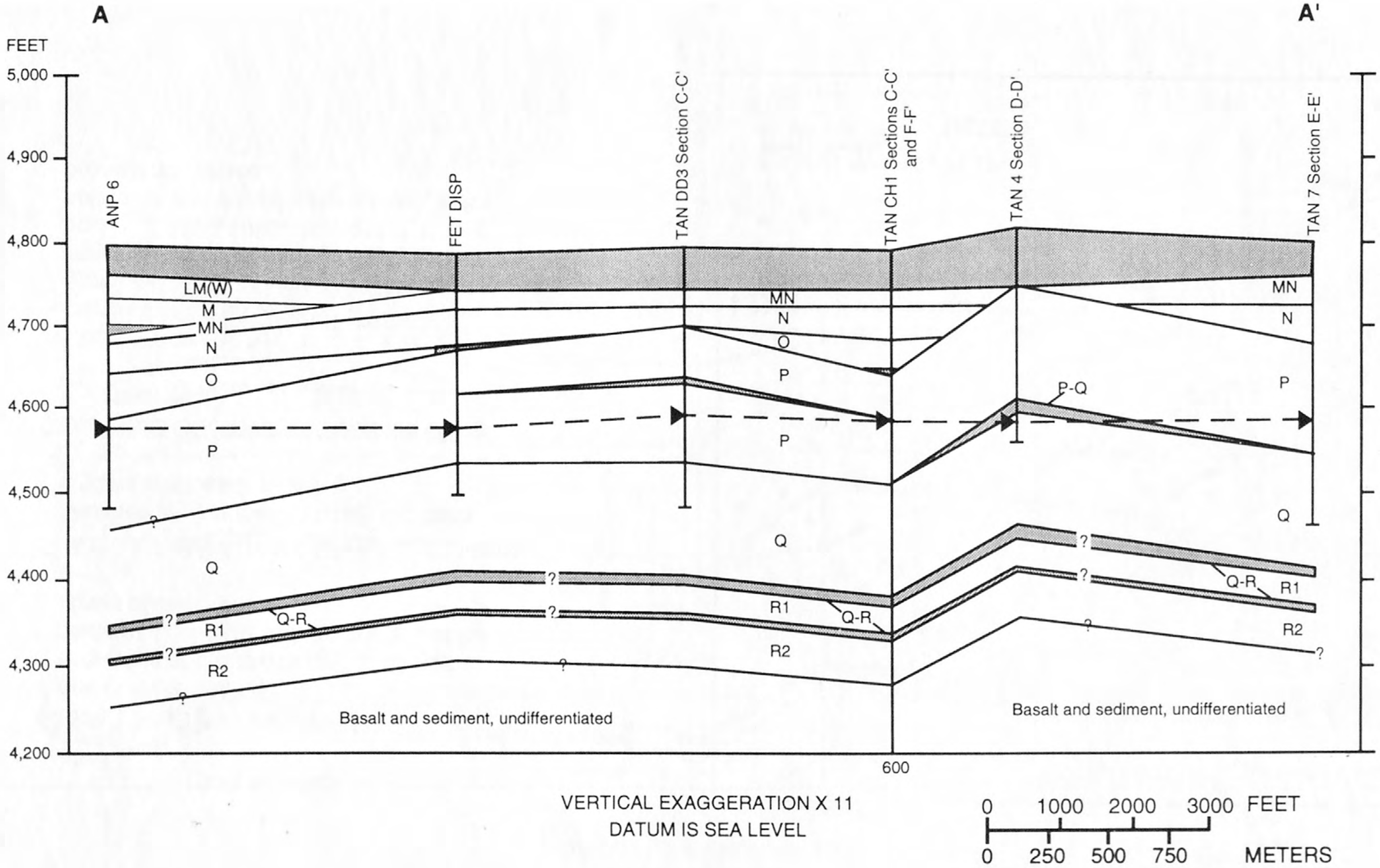
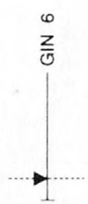



Figure 3.--Geologic section A-A' at Test Area North.--Continued

## EXPLANATION

| | |
|---|---|
| P | BASALT — Basalt - flow group composed of one or more related flows. Letter, P, indicates sequence of group from top to bottom of section. Locally includes cinders and thin layers of sediment |
| (shaded box) | CLAY, SILT, SAND, AND GRAVEL — Major sedimentary interbed. Locally Includes cinders and basalt rubble |
| (line) | GEOLOGIC CONTACT — Queried where uncertain |




WELL — Entry, GIN 6, is local well identifier. Dashed line indicates measured or estimated water level in aquifer in 1992. Arrow indicates measured water level in aquifer in 1990-1992. Number, 1,114, at bottom of well is total depth of well, in feet below land surface

### Location of Section

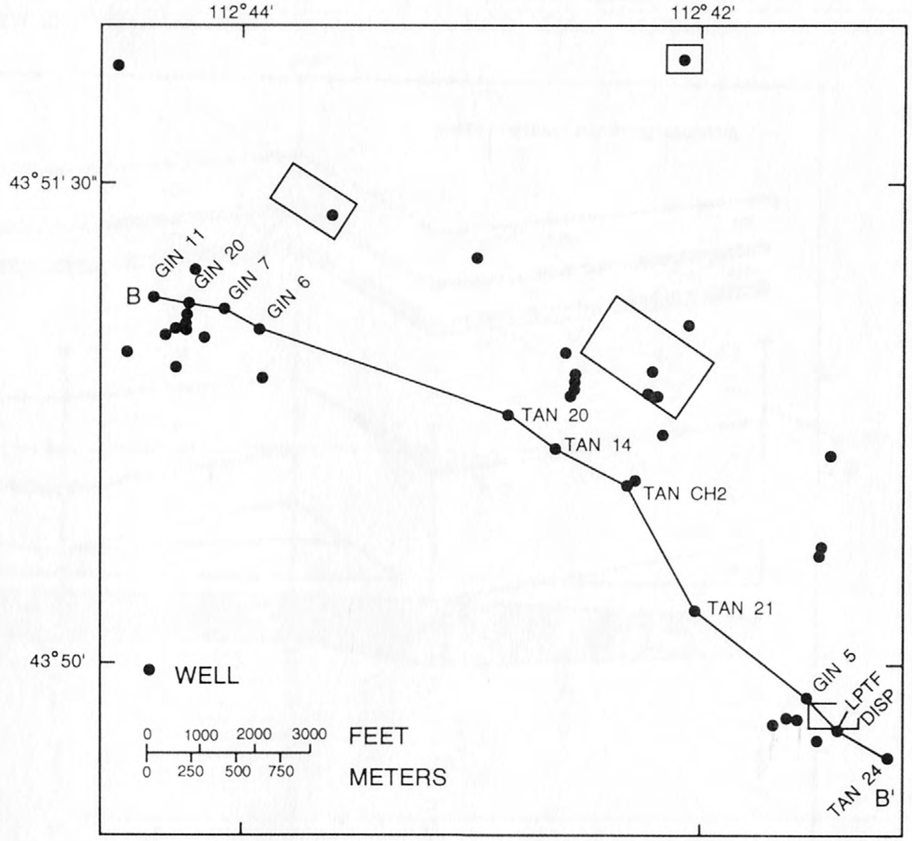



Figure 4.--Geologic section B-B' at Test Area North.

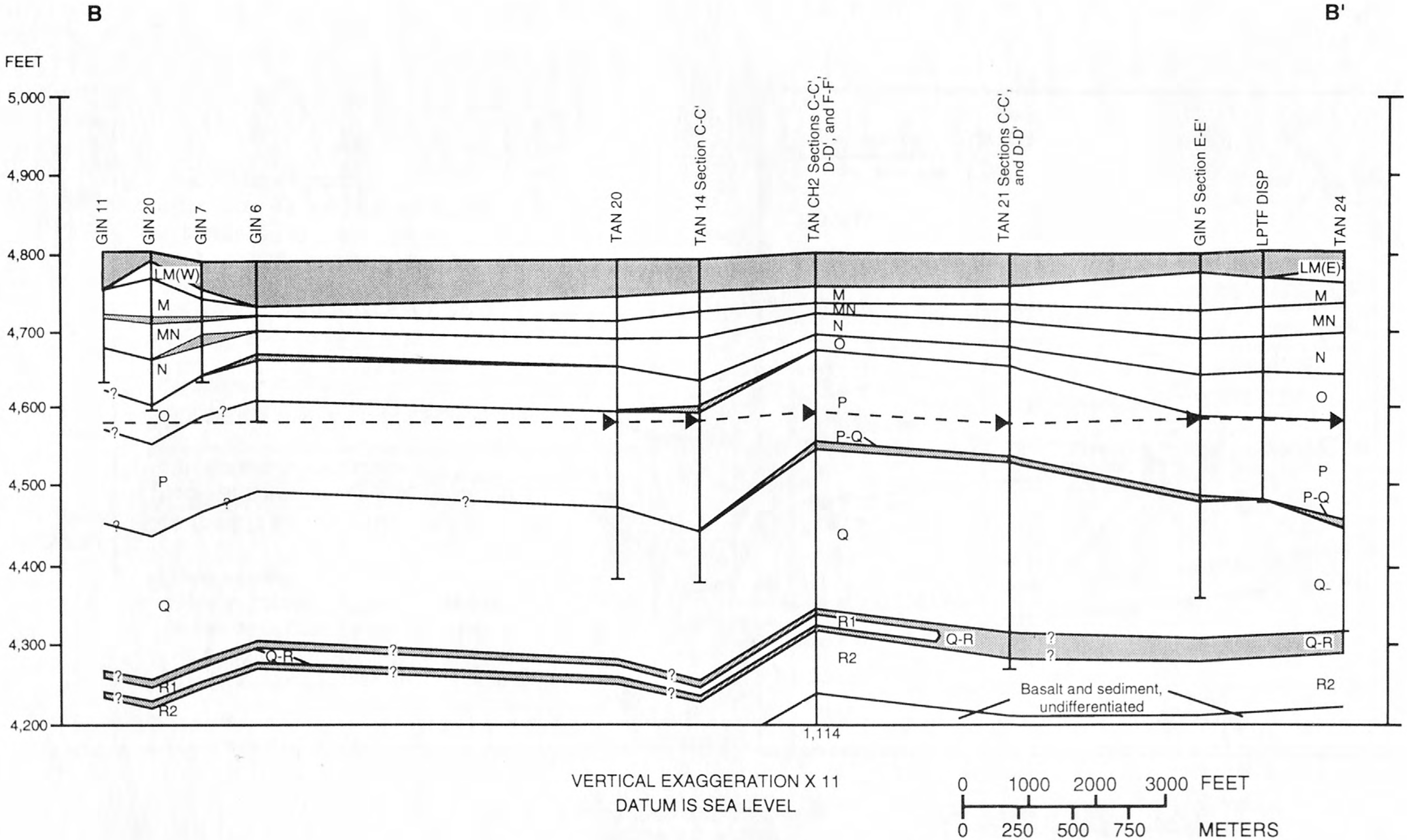



Figure 4.--Geologic section B-B' at Test Area North.--Continued

EXPLANATION


BASALT — Basalt - flow group composed of one or more related flows. Letter, P, indicates sequence of group from top to bottom of section. Locally includes cinders and thin layers of sediment

CLAY, SILT, SAND, AND GRAVEL — Major sedimentary interbed. Locally includes cinders and basalt rubble

GEOLOGIC CONTACT — Queried where uncertain

WELL — Entry, GIN 1, is local well identifier. Dashed line indicates measured or estimated water level in aquifer in 1992. Arrow indicates measured water level in aquifer in 1990-1992. Number, 600, at bottom of well is total depth of well, in feet below land surface

Location of Section

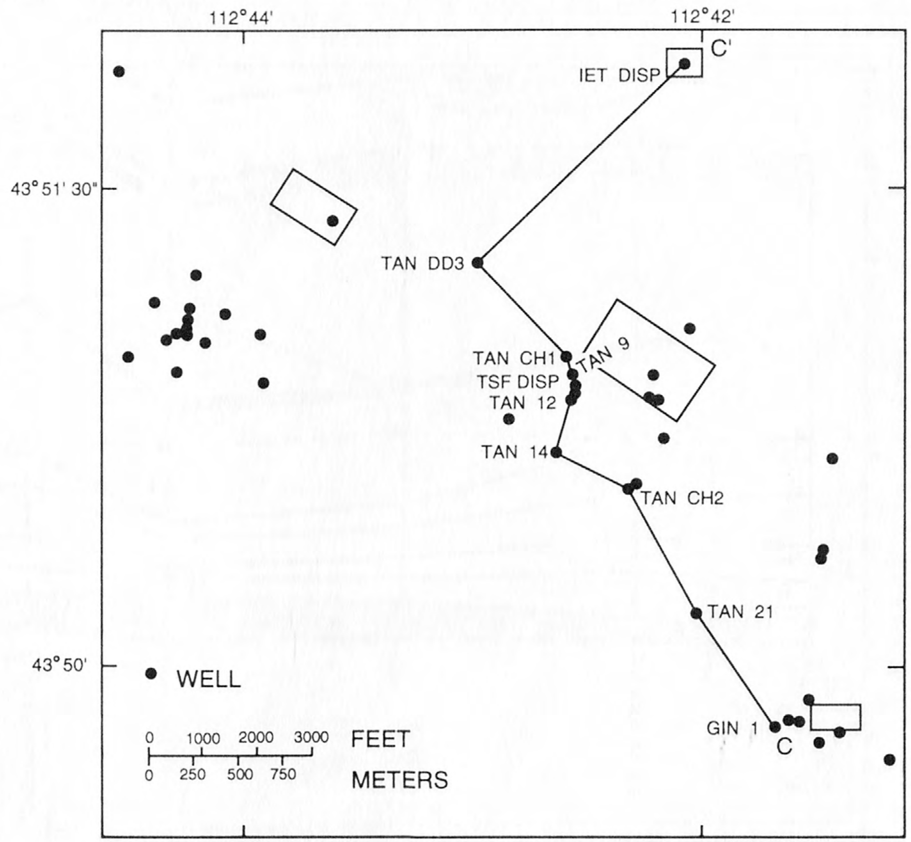



Figure 5.--Geologic section C-C' at Test Area North.

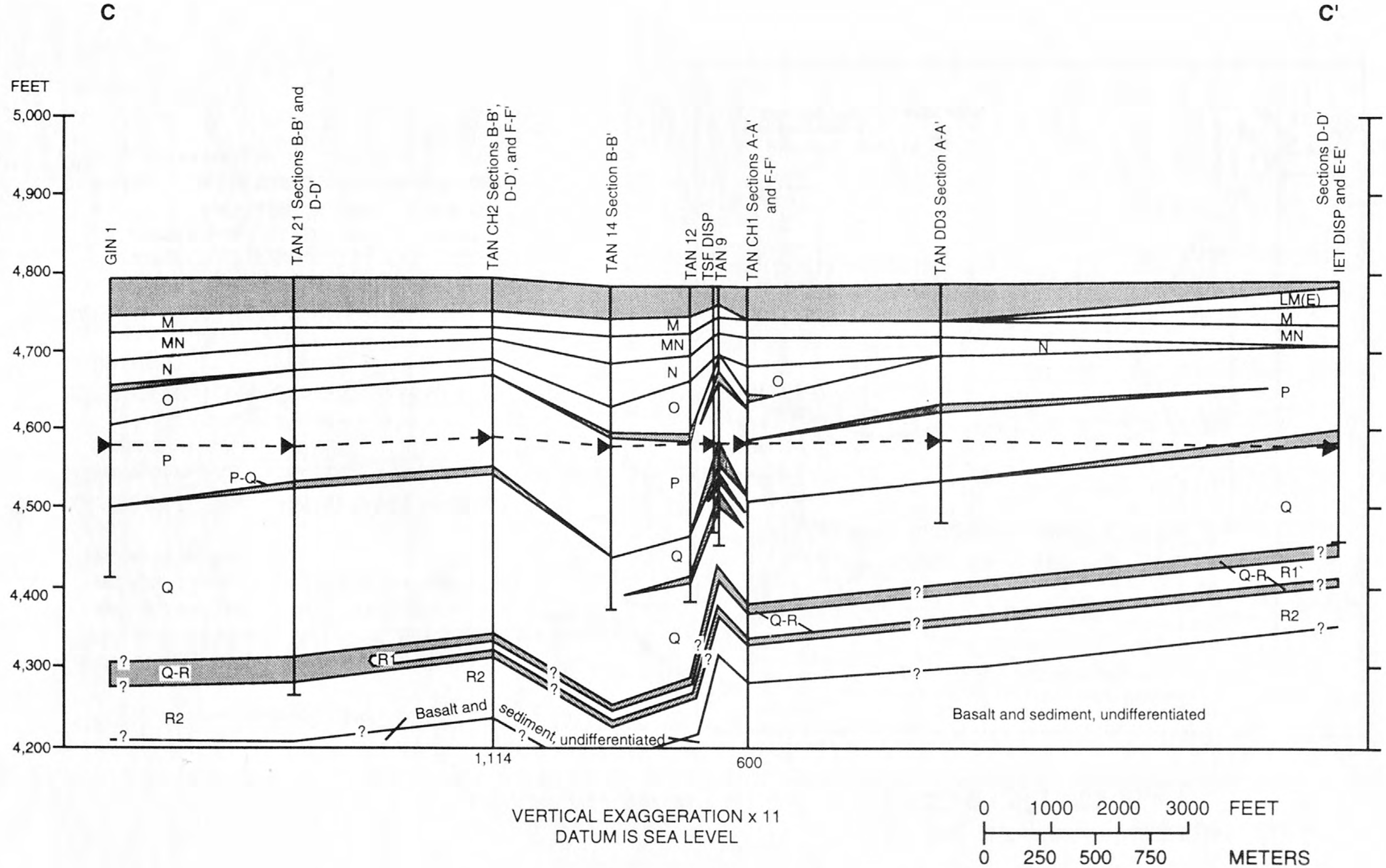



Figure 5.--Geologic section C-C' at Test Area North.--Continued

EXPLANATION

P — BASALT — Basalt - flow group composed of one or more related flows. Letter, P, indicates sequence of group from top to bottom of section. Locally includes cinders and thin layers of sediment

CLAY, SILT, SAND, AND GRAVEL — Major sedimentary interbed. Locally includes cinders and basalt rubble

GEOLOGIC CONTACT — Queried where uncertain

GIN 2 / 1,114 — WELL — Entry, GIN 2, is local well identifier. Dashed line indicates measured or estimated water level in aquifer in 1992. Arrow indicates measured water level in aquifer in 1990-1992. Number, 1,114, at bottom of well is total depth of well, in feet below land surface

## Location of Section

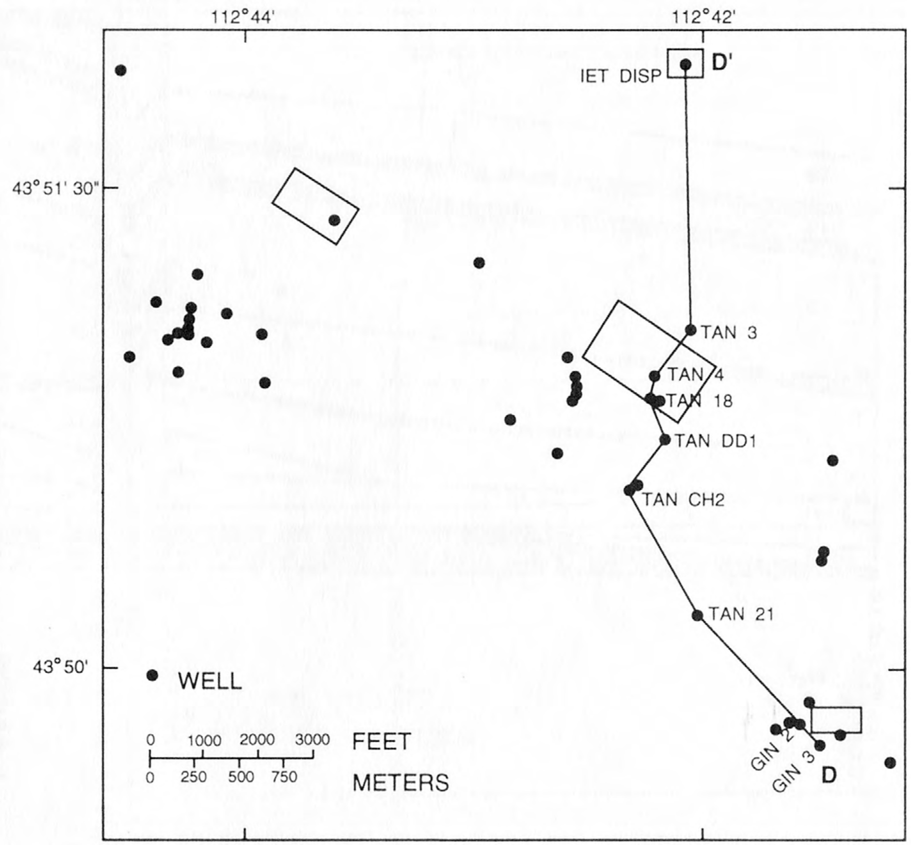



Figure 6.--Geologic Section D-D' at Test Area North.

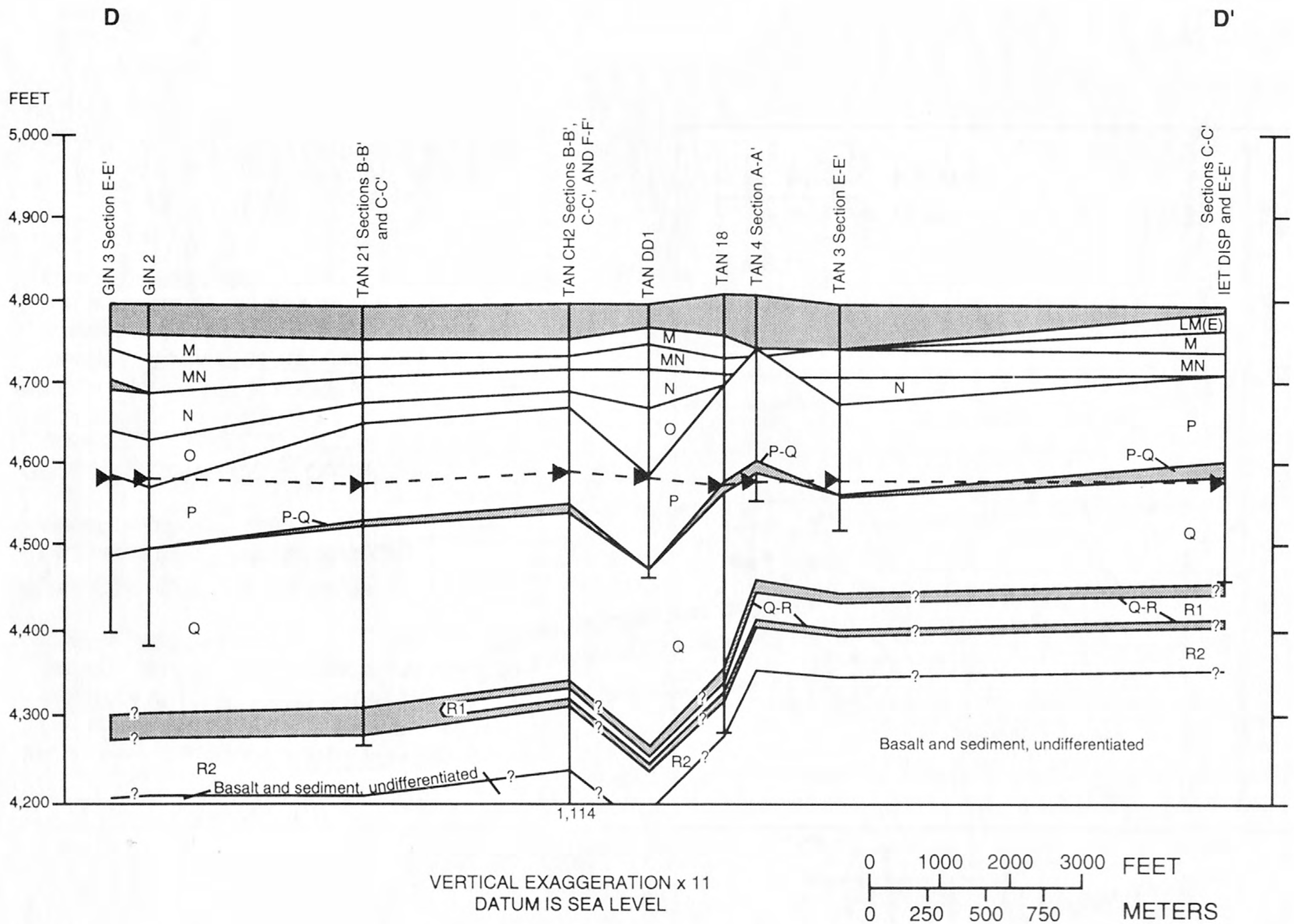



Figure 6.--Geologic section D-D' at Test Area North.--Continued

EXPLANATION

P — BASALT — Basalt - flow group composed of one or more related flows. Letter, P, indicates sequence of group from top to bottom of section. Locally includes cinders and thin layers of sediment

CLAY, SILT, SAND, AND GRAVEL — Major sedimentary interbed. Locally includes cinders and basalt rubble

GEOLOGIC CONTACT — Queried where uncertain

GIN 5 — WELL — Entry, GIN 5, is local well identifier. Dashed line indicates measured or estimated water level in aquifer in 1992. Arrow indicates measured water level in aquifer in 1990-1992

Location of Section

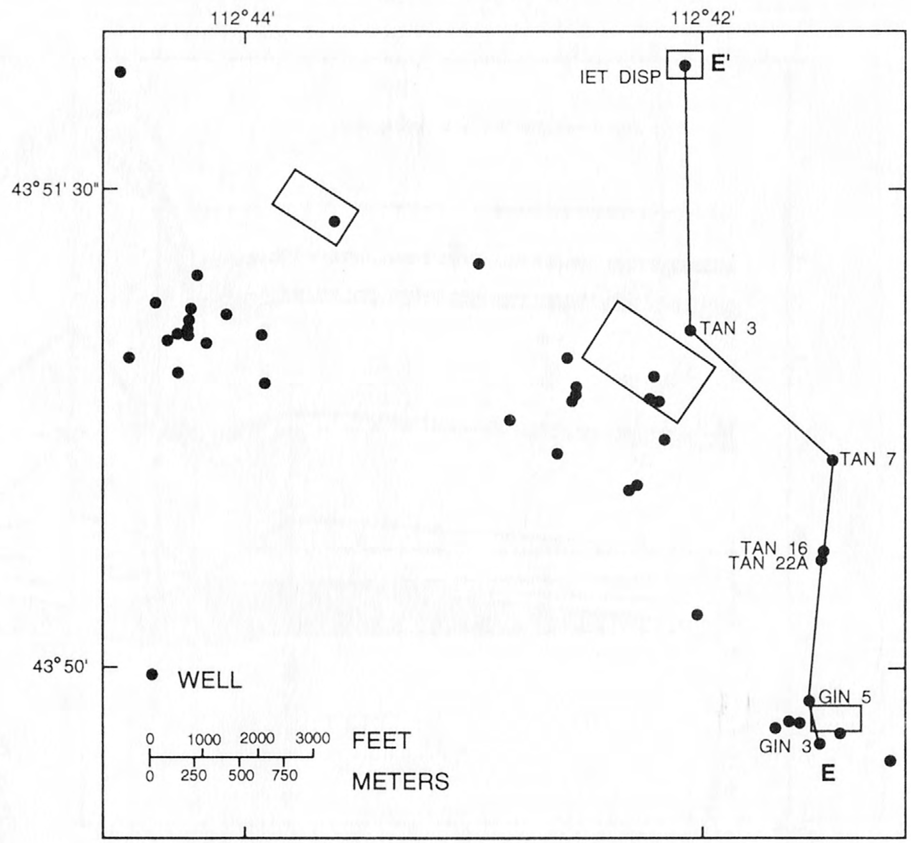



Figure 7.--Geologic section E-E' at Test Area North.

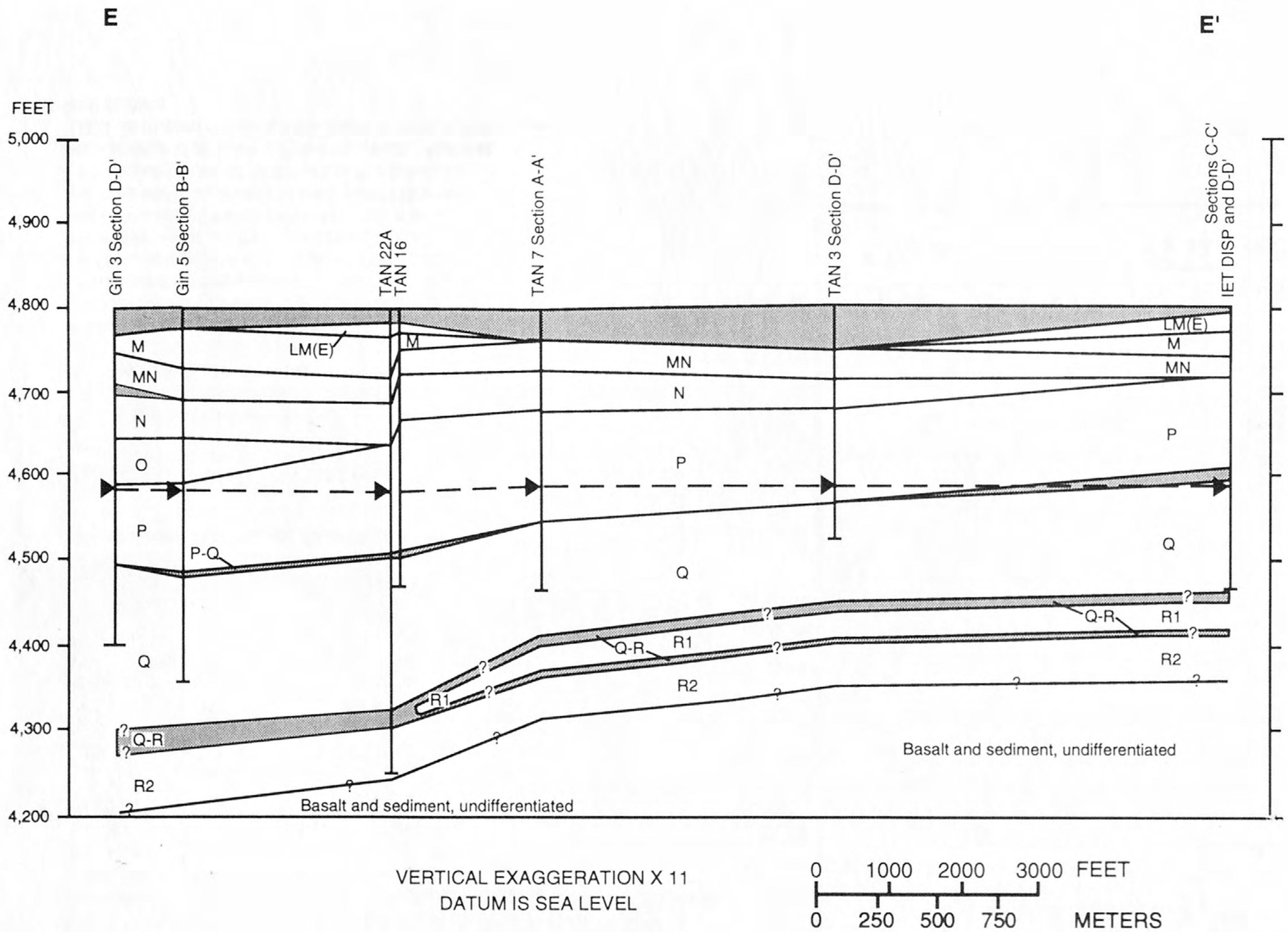



Figure 7.--Geologic section E-E' at Test Area North.--Continued

## EXPLANATION

BASALT - FLOW GROUPS A THROUGH L AND RELATED SEDIMENT, UNDIFFERENTIATED -- Includes unaltered basalt and sediment in the youngest part of the unsaturated zone and the Snake River Plain aquifer. Age of sequence ranges from about 95,000 to 800,000 years

BASALT - FLOW GROUPS LM THROUGH R AND RELATED SEDIMENT; BASALT AND SEDIMENT, UNDIFFERENTIATED -- Includes unaltered to altered basalt and sediment in the oldest part of the unsaturated zone and the Snake River Plain aquifer. Age of sequence ranges from about 800,000 to 1.6 million years

BASALT AND SEDIMENT, UNDIFFERENTIATED -- Includes altered basalt and sediment that form the effective base of the Snake River Plain aquifer

GEOLOGIC CONTACT -- Queried where uncertain


WELL -- Dashed where projected to section. Entry, GS 7, is local well identifier. Dashed line indicates measured or estimated water level in aquifer in 1992. Solid arrow indicates measured water level in aquifer in 1991 or 1992. Upper open arrow indicates paleomagnetic boundary between the Brunhes Normal - Polarity Chron, B, and the Matuyama Reversed - Polarity Chron, M; rocks below this boundary have an age of at least 780,000 years. Lower open arrow indicates upper paleomagnetic boundary of the Olduvai Normal-Polarity Subchron, 0; rocks below this boundary have an age of at least 1.7 million years. Number, 5,000, at bottom of well is total depth of well, in feet below land surface

## Location of section

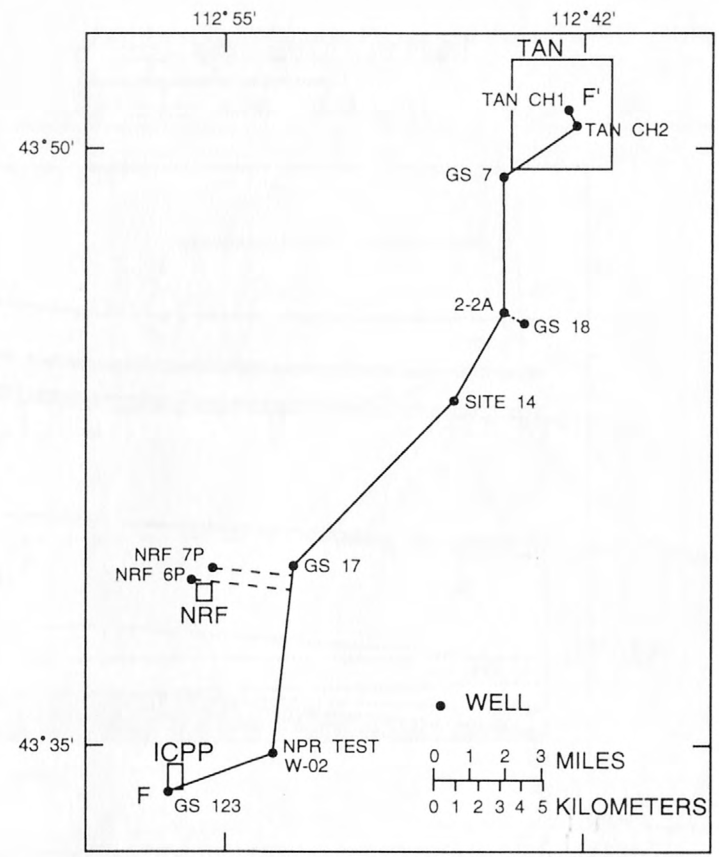



Figure 8.--Geologic section F-F' between the Idaho Chemical Processing Plant and Test Area North.

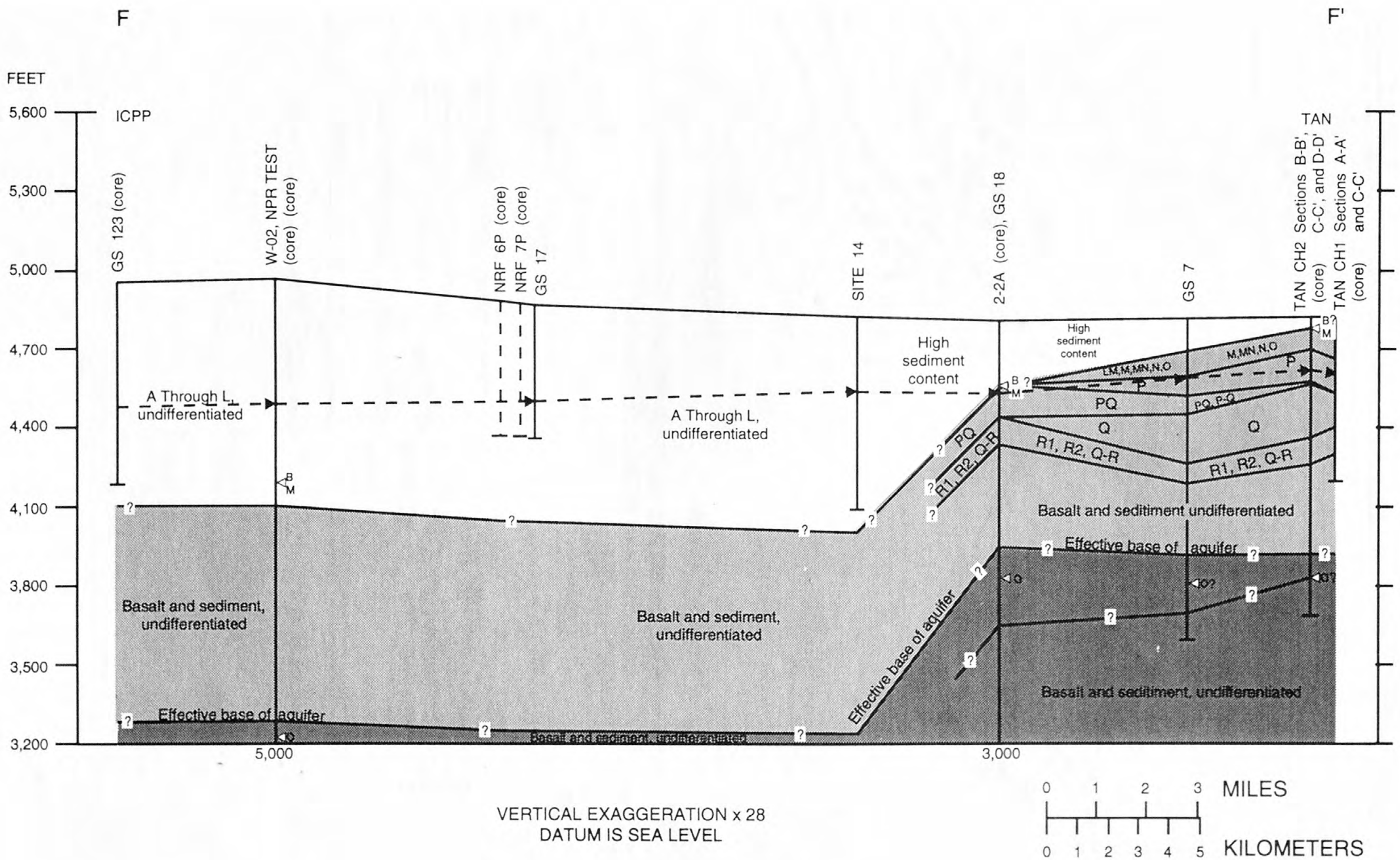



Figure 8.--Geologic section F-F' between the Idaho Chemical Processing Plant and Test Area North.--Continued

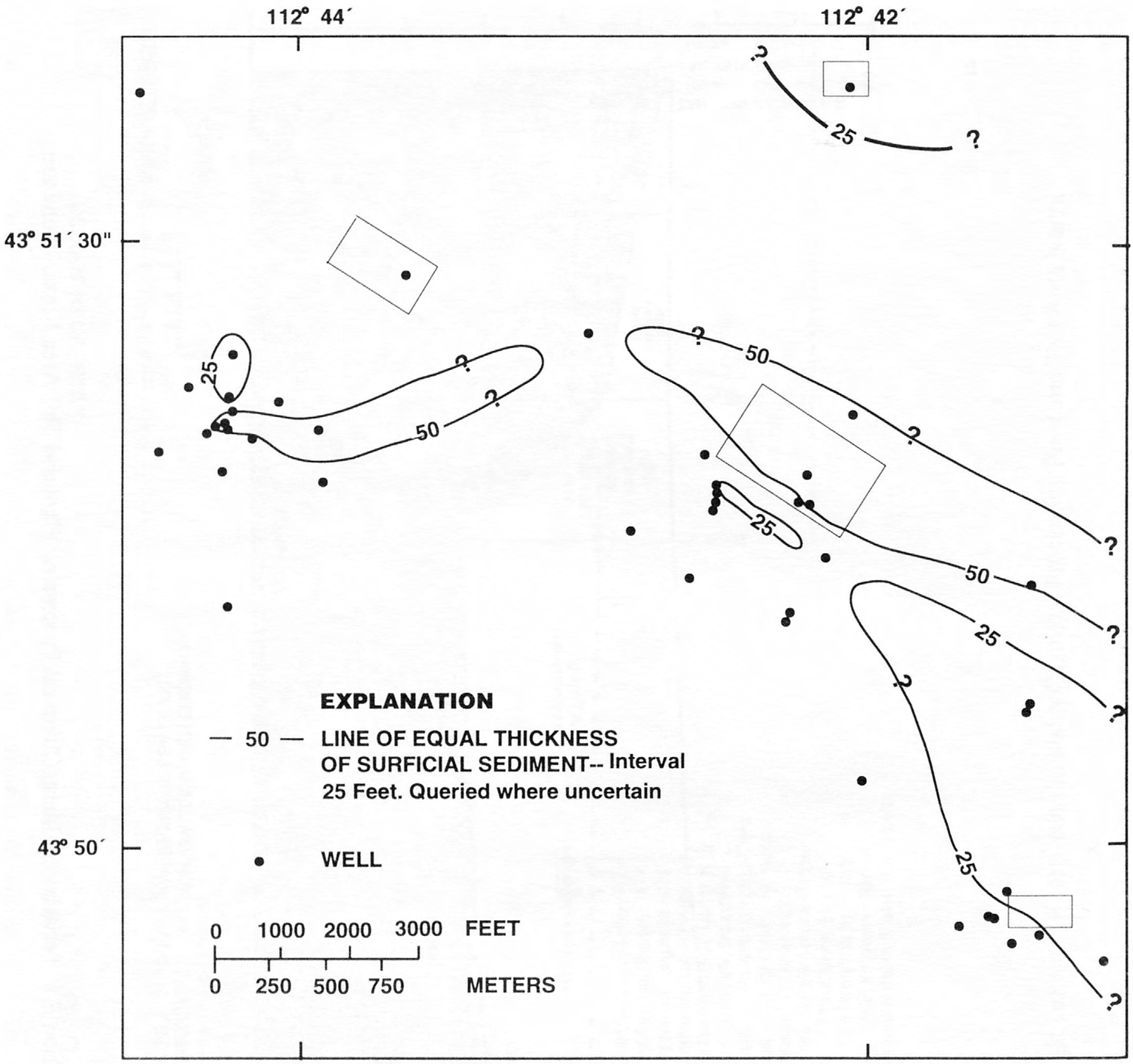



Figure 9.--Thickness of surficial sediment at Test Area North.

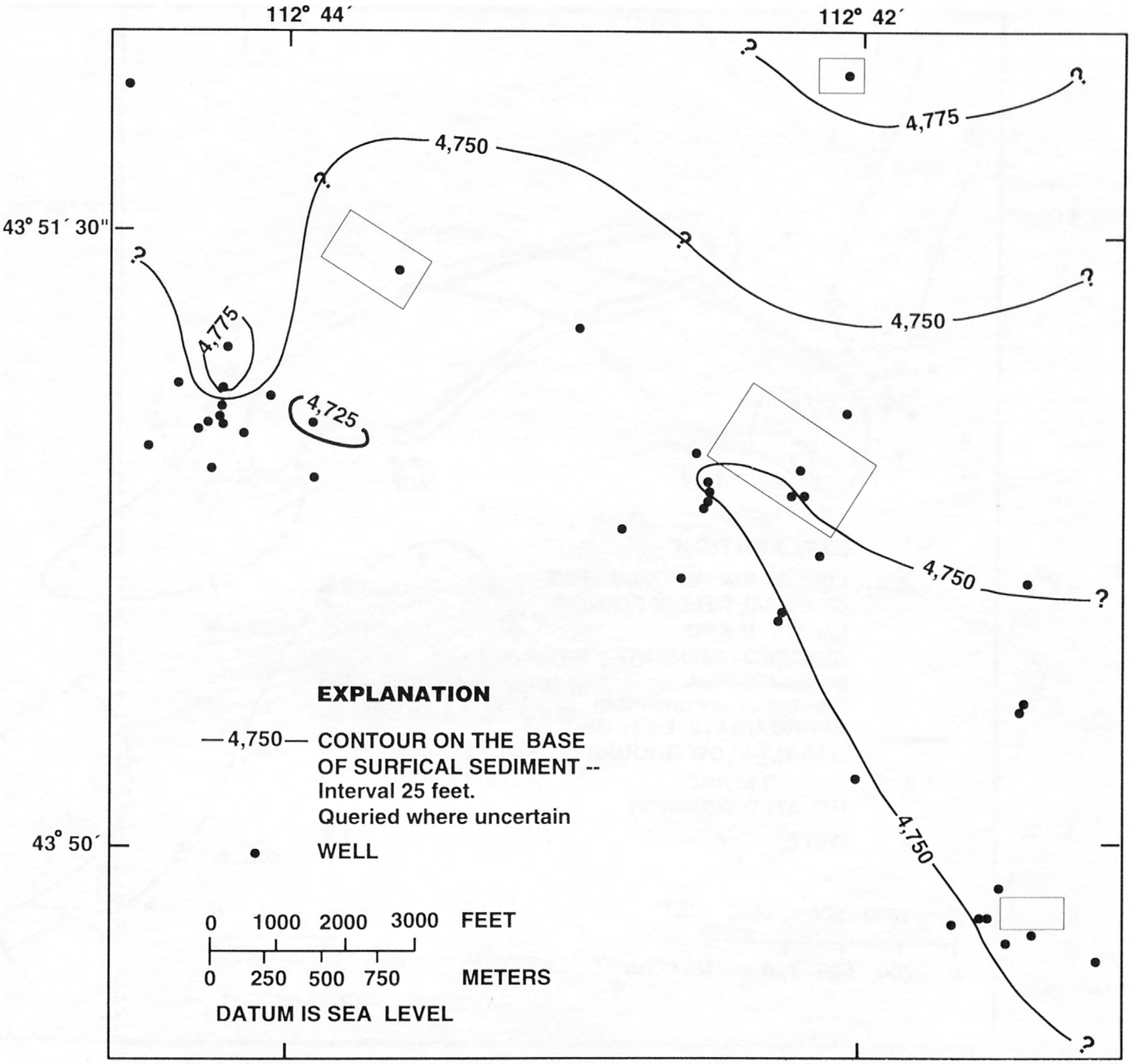



Figure 10.--Altitude of the base of surficial sediment at Test Area North.

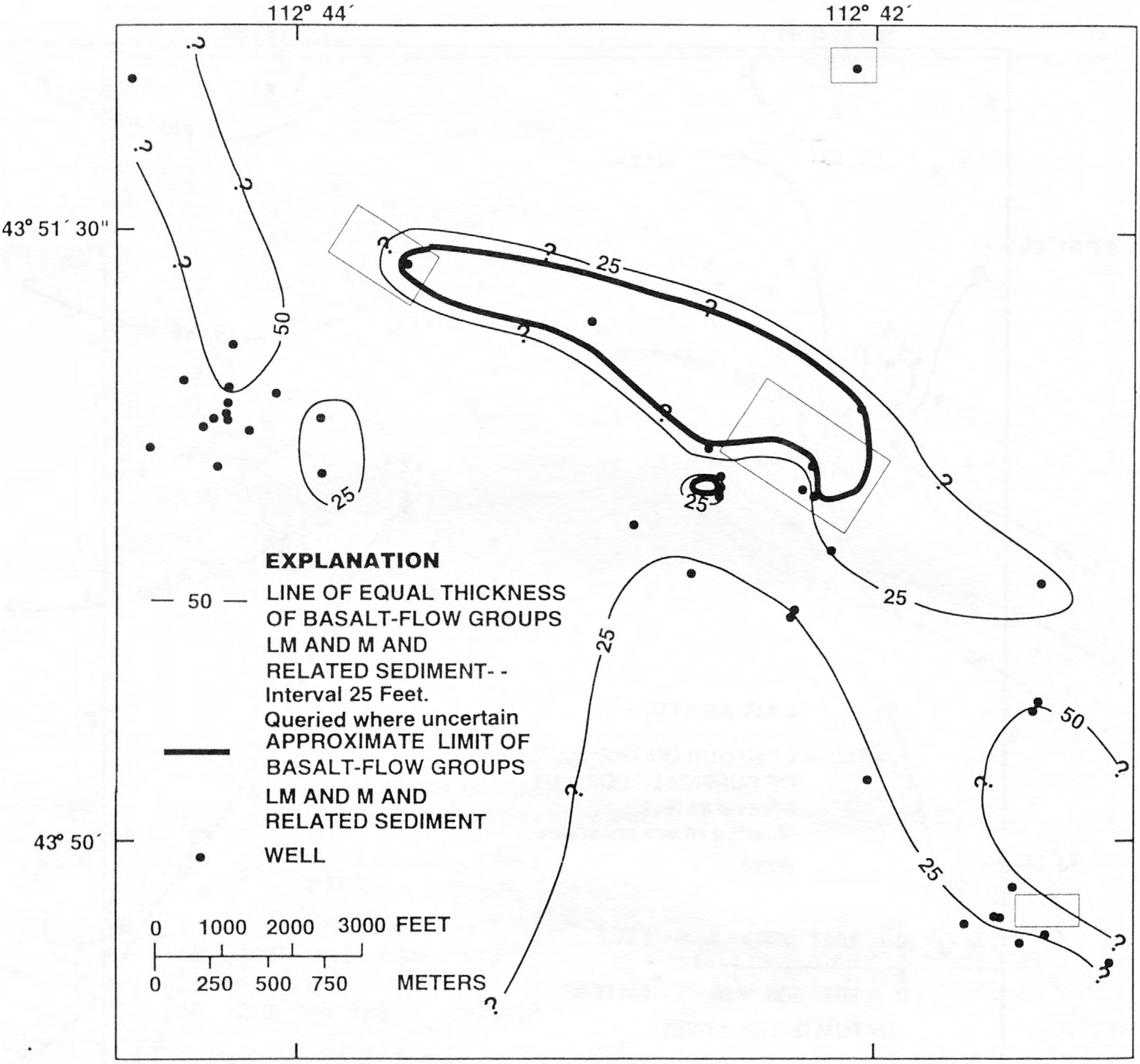



Figure 11.--Thickness of basalt-flow groups LM(W), LM(E), and M and related sediment at Test Area North.

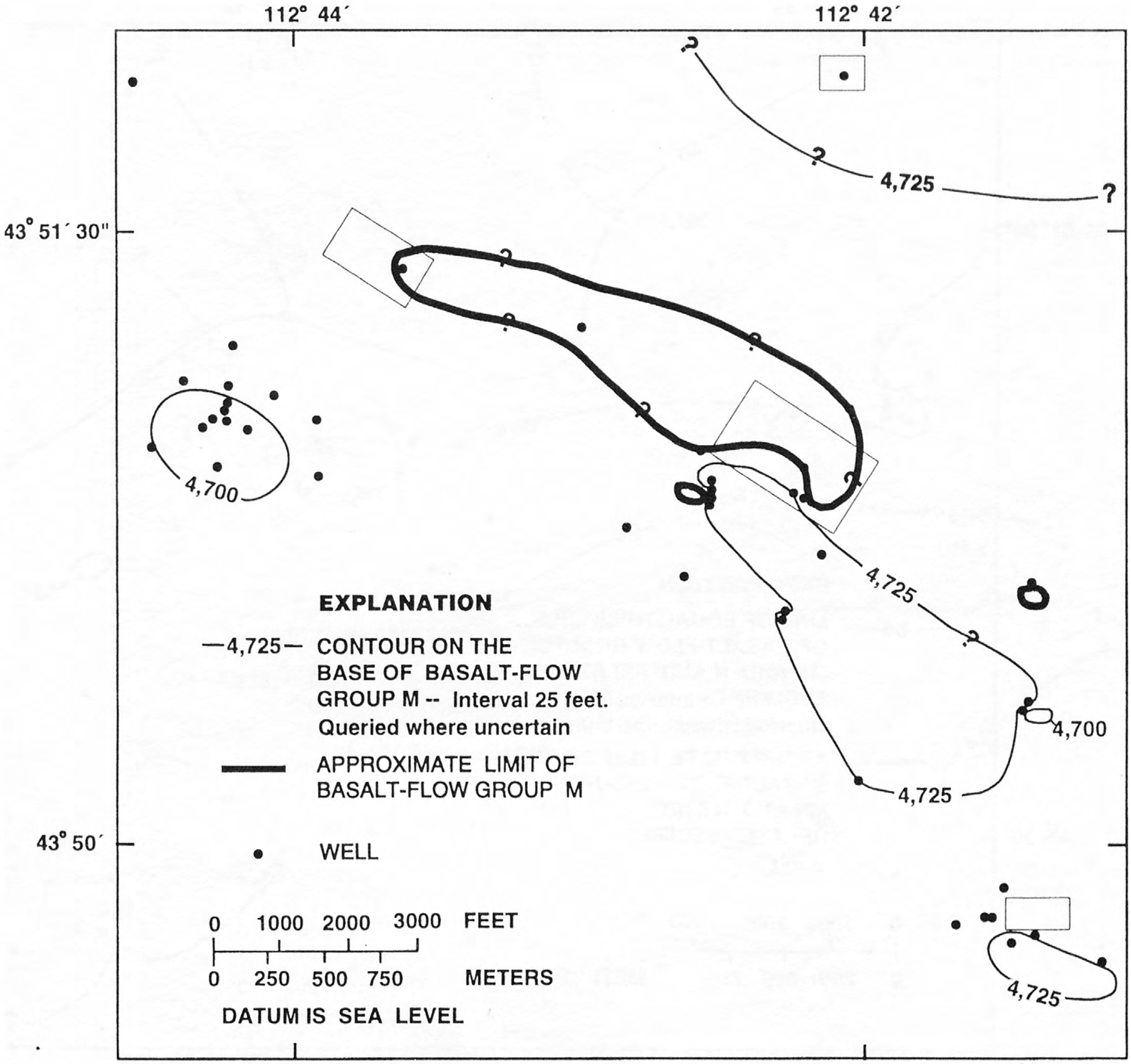



Figure 12.--Altitude of the base of basalt-flow group M at Test Area North.

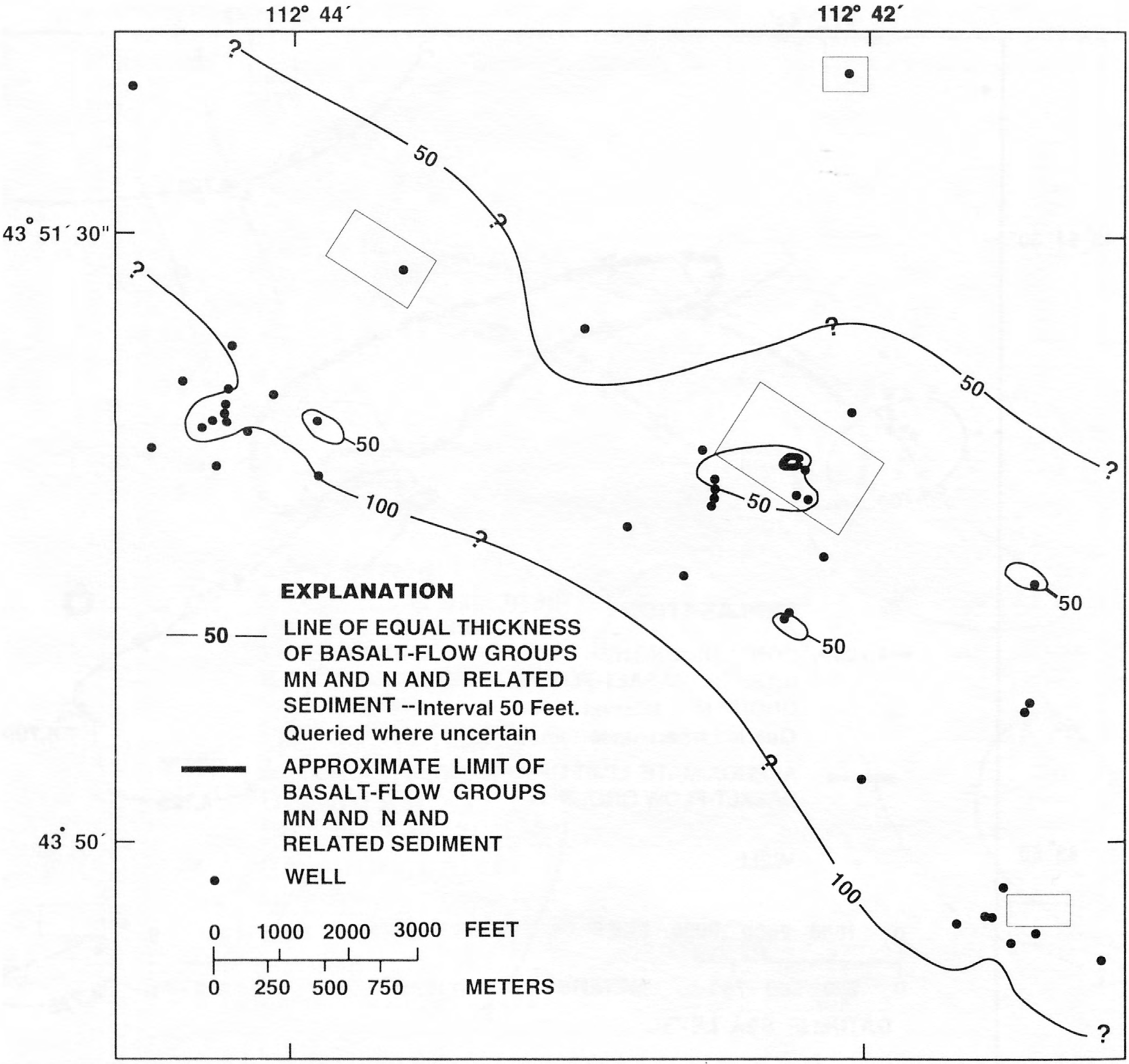



Figure 13.--Thickness of basalt-flow groups MN and N and related sediment at Test Area North.

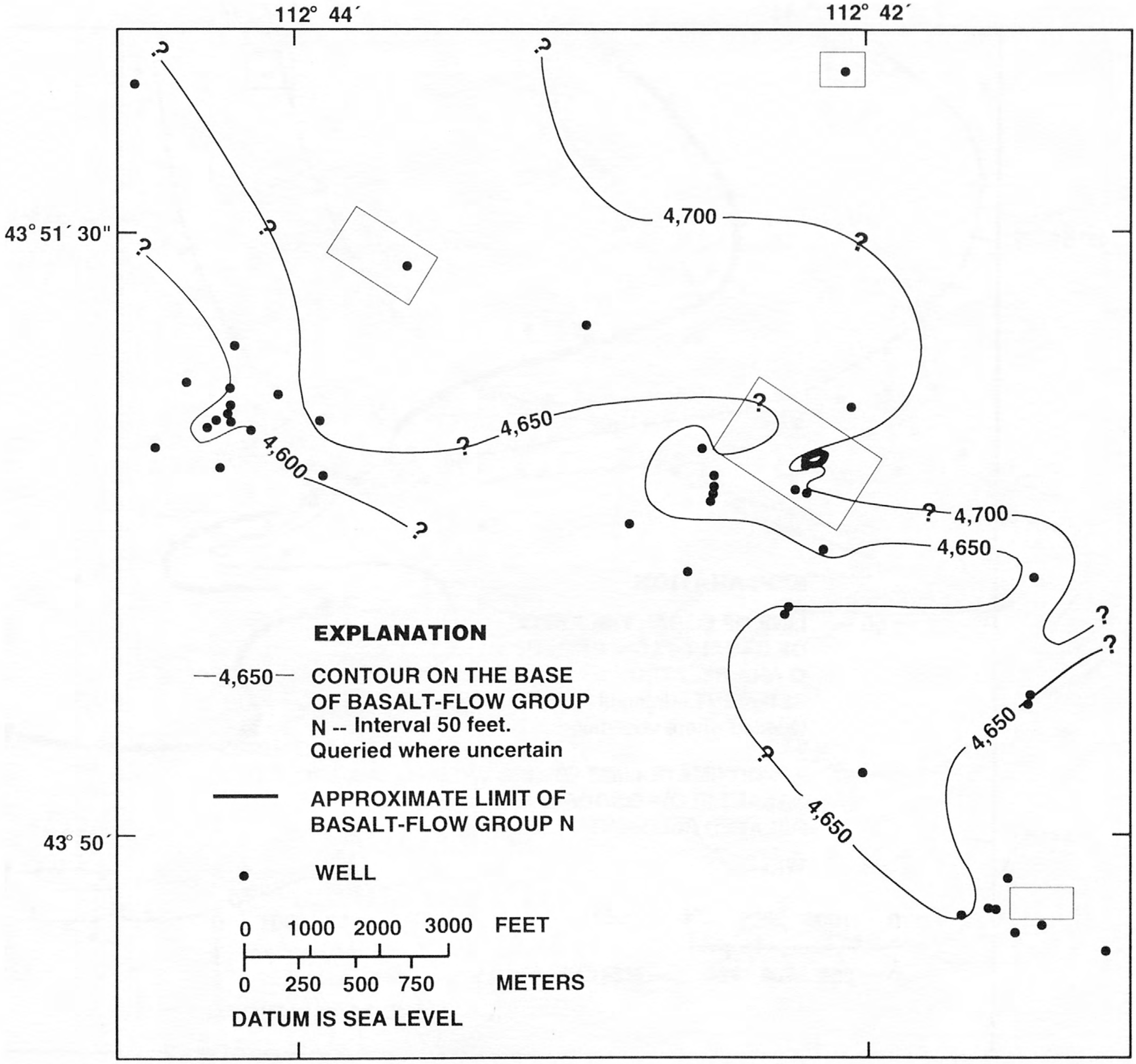



Figure 14.--Altitude of the base of basalt-flow group N at Test Area North.

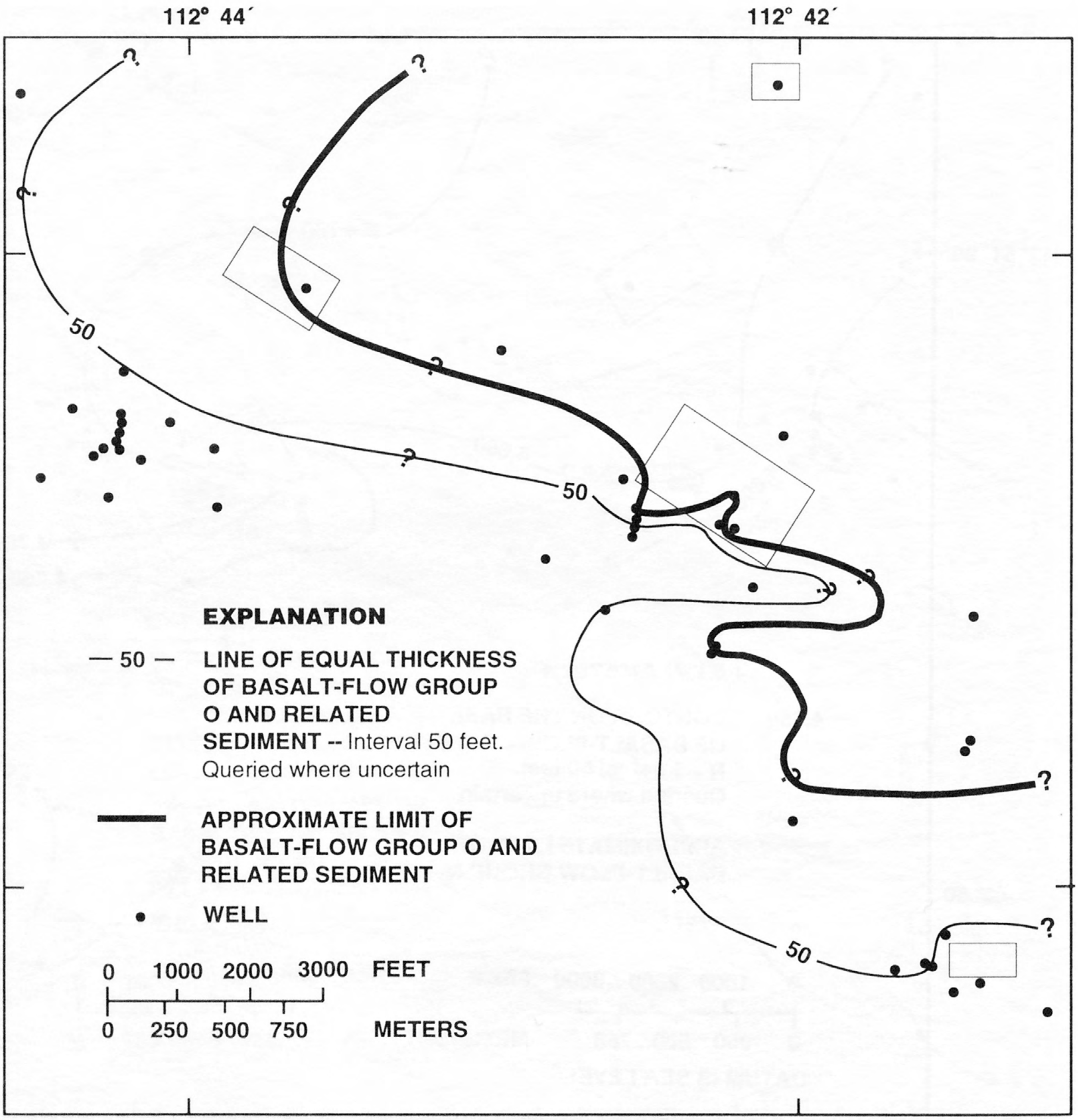



Figure 15.--Thickness of basalt-flow group O and related sediment at Test Area North.

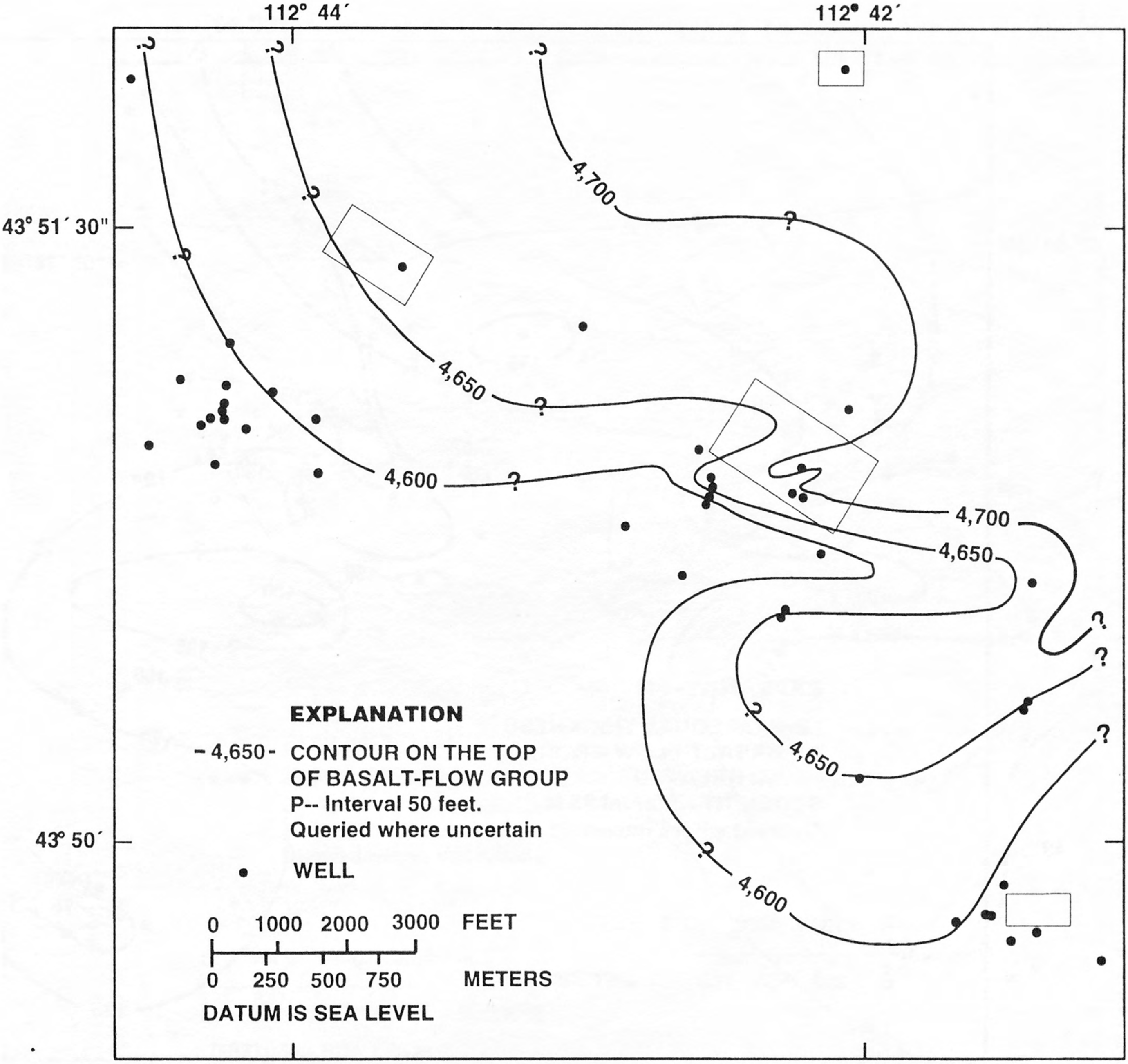



Figure 16.--Altitude of the top of basalt-flow group P at Test Area North.

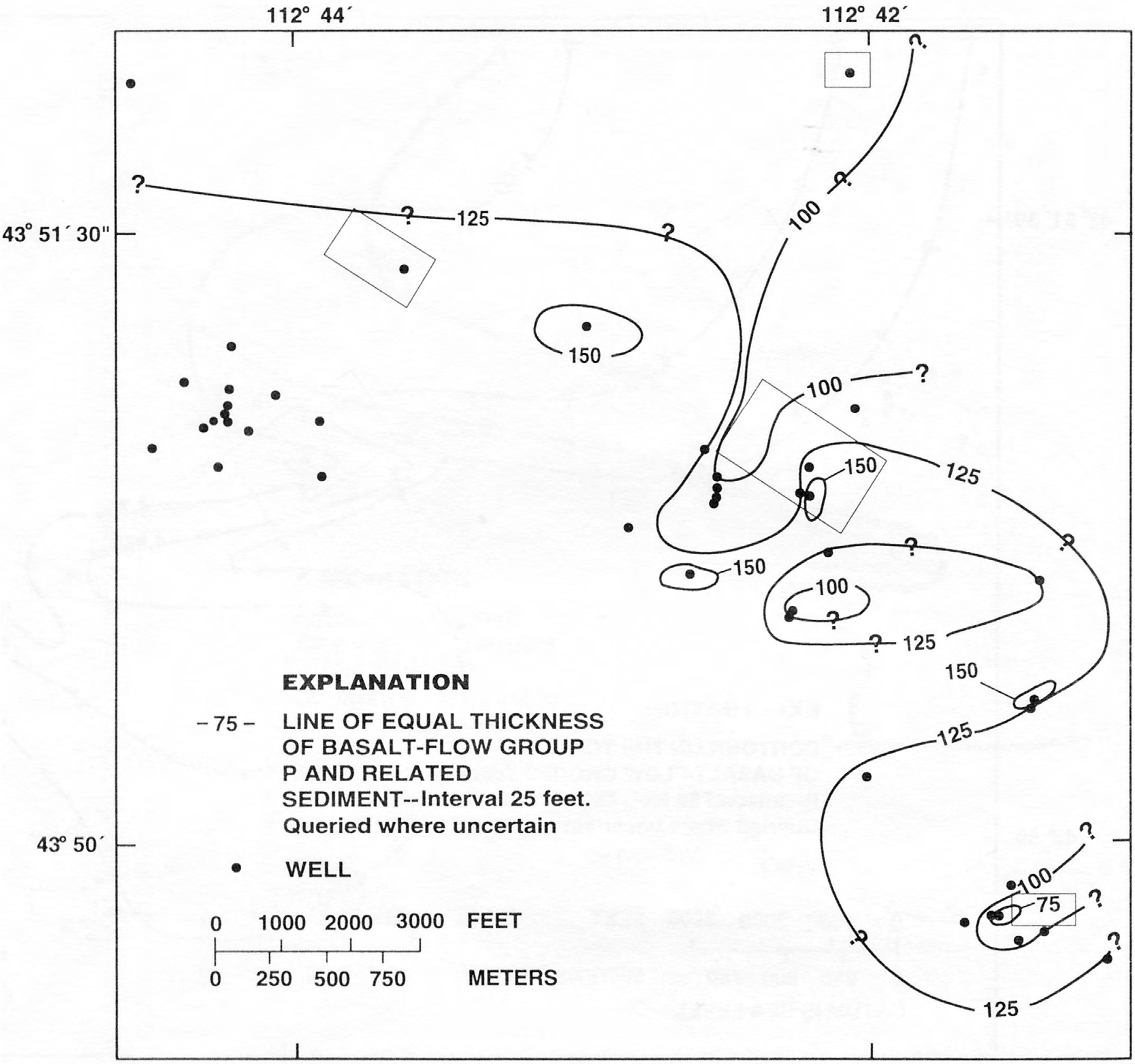



Figure 17.--Thickness of basalt-flow group P and related sediment at Test Area North.

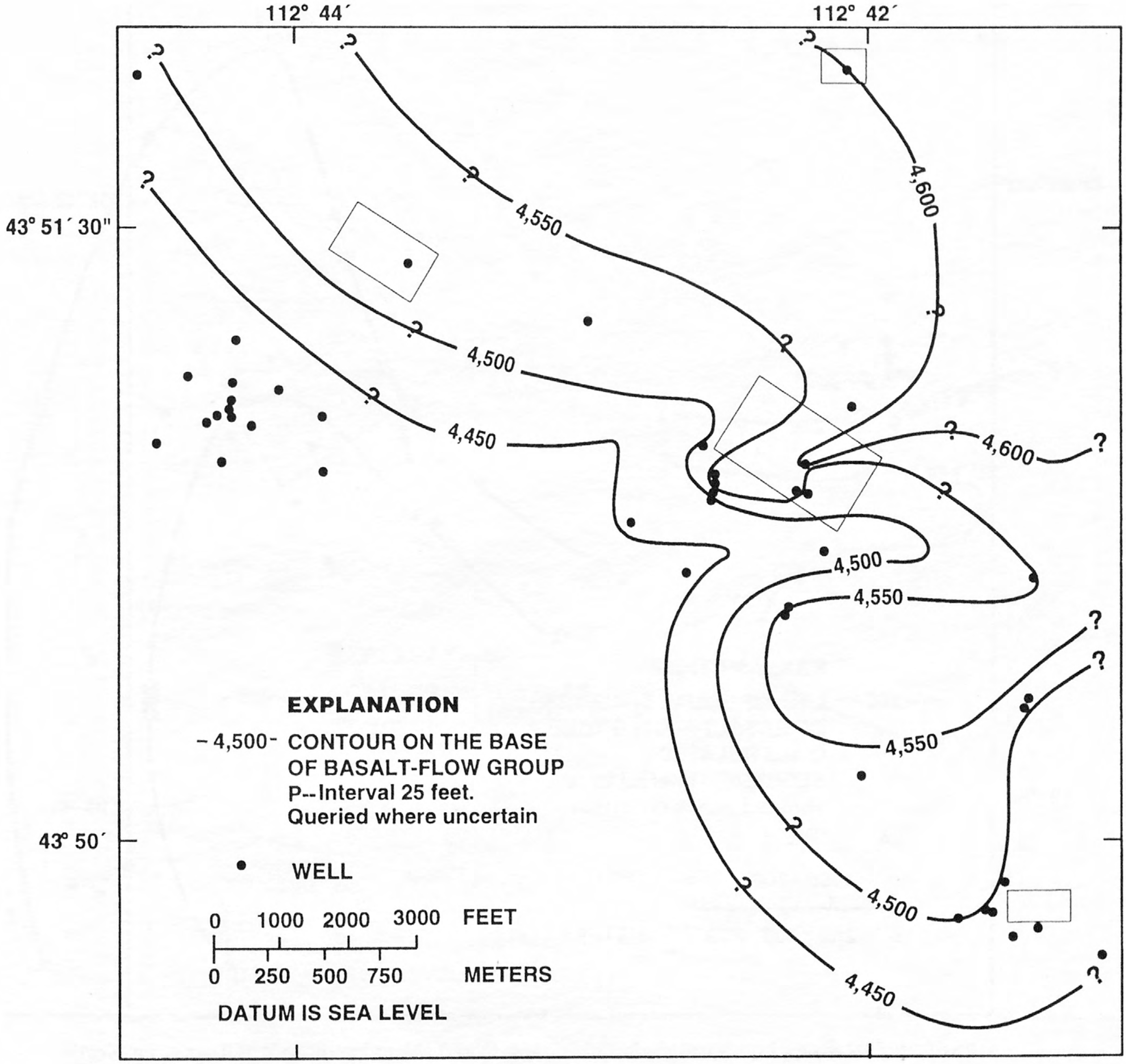



Figure 18.--Altitude of the base of basalt-flow group P at Test Area North.

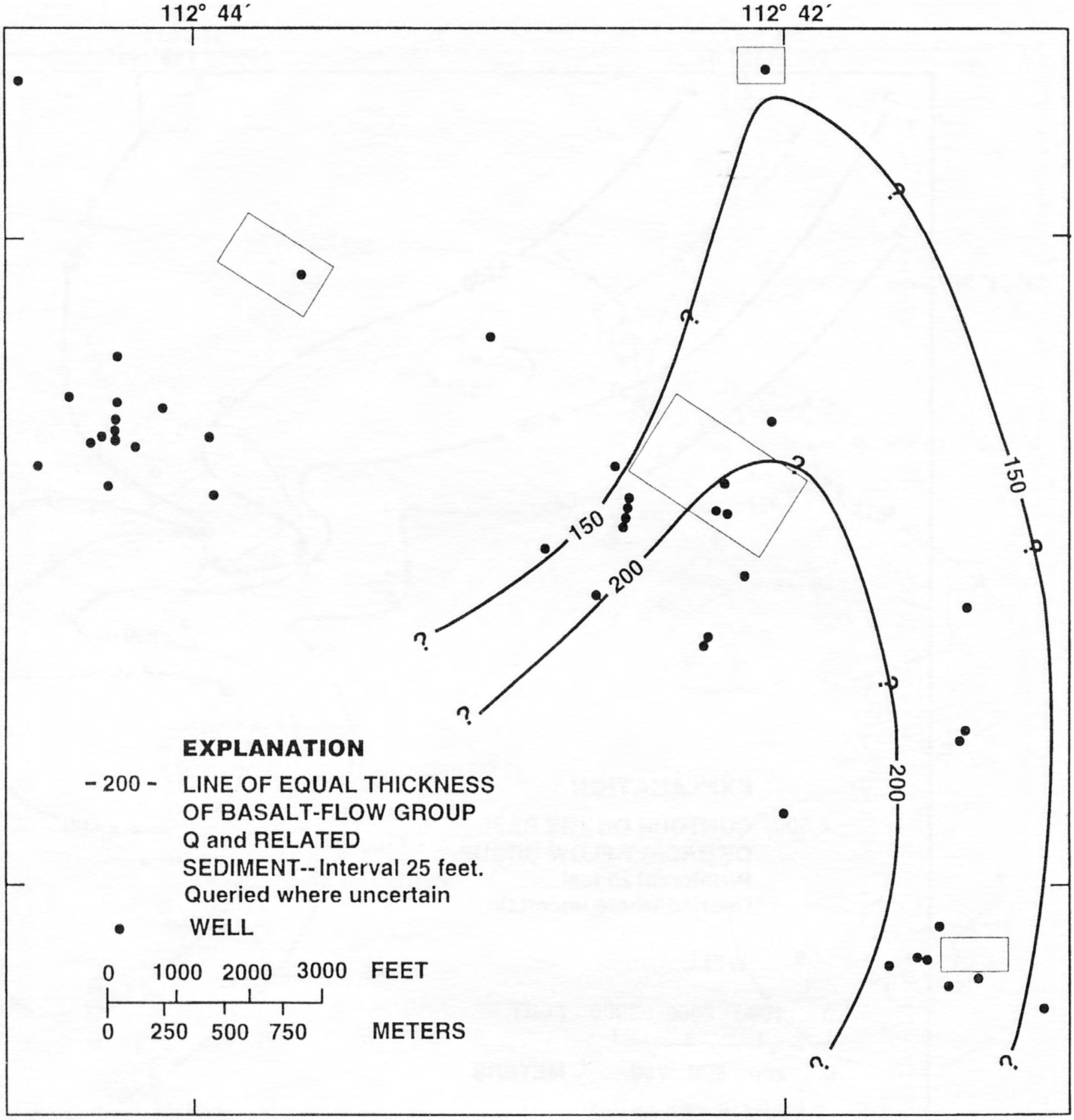



Figure 19.--Thickness of basalt-flow group Q and related sediment at Test Area North.

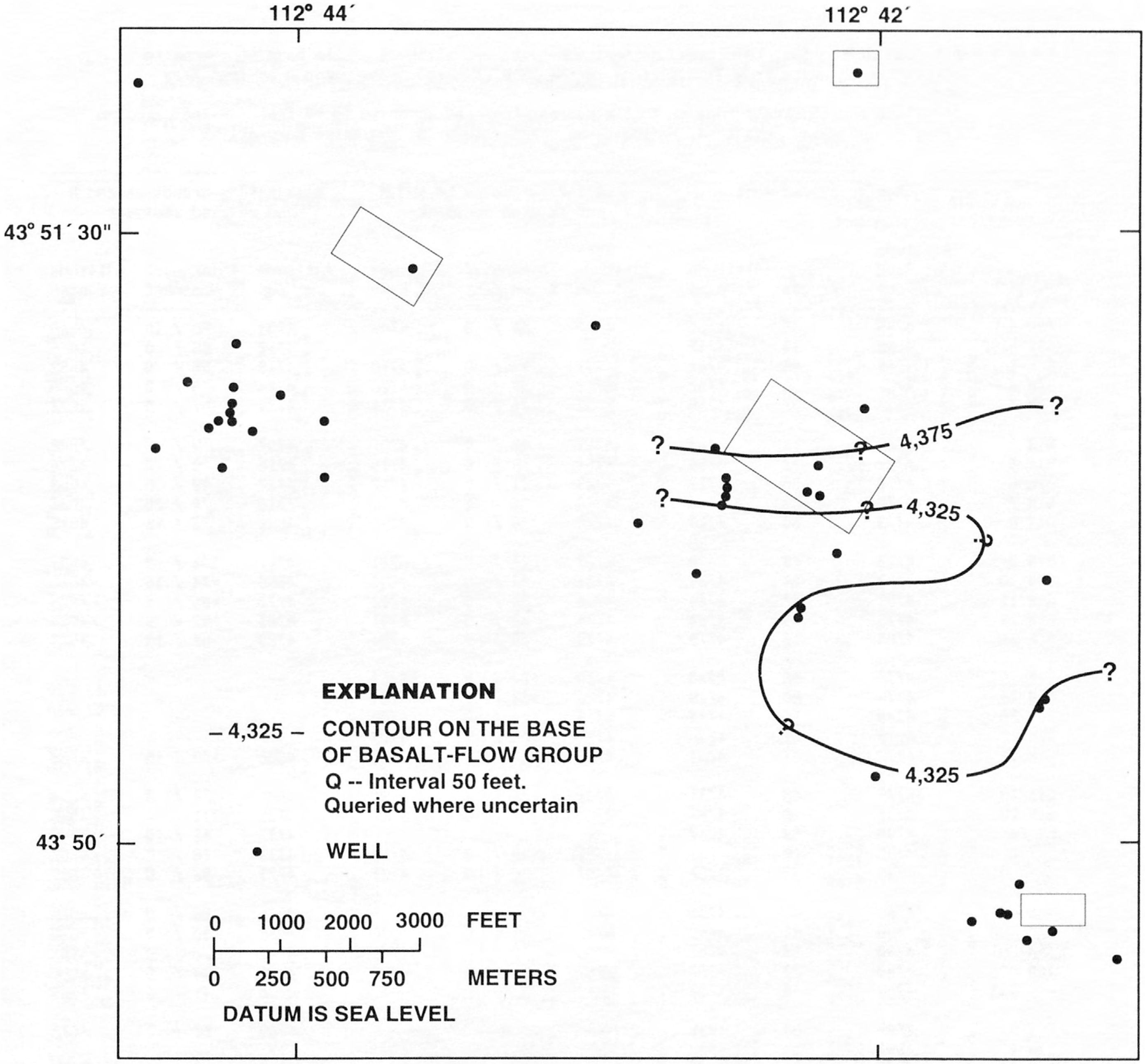



Figure 20.--Altitude of the base of basalt-flow group Q at Test Area North.

Table 1.--Altitude of the top, thickness, percent sediment, and altitude of the base of composite stratigraphic units from land surface to the base of basalt-flow group Q at Test Area North

[Altitude and thickness rounded to the nearest foot and accurate to +2 feet. --Indicates no data; < indicates less than; > indicates greater than; % indicates percent]

| | Surficial Sediment | | | Basalt-flow groups LM and M and related sediment | | | Basalt-flow groups MN and N and related sediment | | |
|---|---|---|---|---|---|---|---|---|---|
| Well | Altitude of land surface | Thickness | Altitude of base | Altitude of top | Thickness/ % sediment | Altitude of base | Altitude of top | Thickness/ % sediment | Altitude of base |
| ANP 6 | 4795 | 33 | 4762 | 4762 | 59 / 0 | 4703 | 4703 | 58 / 19 | 4645 |
| FET DISP | 4780 | 38 | 4742 | -- | -- | -- | 4742 | 66 / 0 | 4676 |
| GIN 1 | 4787 | 46 | 4741 | 4741 | 23 / 0 | 4718 | 4718 | 66 / 0 | 4652 |
| GIN 2 | 4787 | 35 | 4752 | 4752 | 32 / 0 | 4720 | 4720 | 95 / 0 | 4625 |
| GIN 3 | 4787 | 32 | 4755 | 4755 | 21 / 0 | 4734 | 4734 | 97 / 8 | 4637 |
| GIN 4 | 4787 | 34 | 4753 | 4753 | 46 / 0 | 4707 | 4707 | 79 / 0 | 4628 |
| GIN 5 | 4787 | 23 | 4764 | 4764 | 49 / 0 | 4715 | 4715 | 79 / 0 | 4636 |
| GIN 6 | 4778 | 55 | 4723 | 4723 | 11 / 0 | 4712 | 4712 | 49 / 0 | 4663 |
| GIN 7 | 4779 | 33 | 4746 | 4746 | 36 / 0 | 4710 | 4710 | 74 / 20 | 4636 |
| GIN 8 | 4779 | 50 | 4729 | 4729 | 40 / 0 | 4689 | 4689 | 73 / 12 | 4616 |
| GIN 9 | 4776 | 48 | 4728 | 4728 | 17 / 0 | 4711 | 4711 | 102 / 8 | 4609 |
| GIN 10 | 4777 | 43 | 4734 | 4734 | 44 / 0 | 4690 | 4690 | >74 / 18 | <4616 |
| GIN 11 | 4791 | 47 | 4744 | 4744 | 31 / 0 | 4713 | 4713 | >85 / 4 | <4628 |
| GIN 12 | 4779 | 45 | 4734 | 4734 | 33 / 0 | 4701 | 4701 | >62 / 6 | <4639 |
| GIN 13 | 4784 | 5 | 4779 | 4779 | 70 / 0 | 4709 | 4709 | >67 / 19 | <4642 |
| GIN 14 | 4778 | 48 | 4730 | 4730 | >27 / 0 | <4703 | -- | -- | -- |
| GIN 15 | 4779 | 50 | 4729 | 4729 | >24 / 0 | <4705 | -- | -- | -- |
| GIN 16 | 4779 | 35 | 4744 | 4744 | >40 / 0 | <4704 | -- | -- | -- |
| GIN 17 | 4779 | 41 | 4738 | 4738 | >35 / 0 | <4703 | -- | -- | -- |
| GIN 18 | 4778 | 47 | 4731 | 4731 | 43 / 0 | 4688 | 4688 | 100 / 15 | 4588 |
| GIN 19 | 4779 | 48 | 4731 | 4731 | 36 / 0 | 4695 | 4695 | 77 / 8 | 4618 |
| GIN 20 | 4791 | 8 | 4783 | 4783 | 74 / 0 | 4709 | 4709 | 111 / 4 | 4598 |
| GS 24 | 4796 | 59 | 4737 | -- | -- | -- | 4737 | 42 / 10 | 4695 |
| IET DISP | 4790 | 9 | 4781 | 4781 | 48 / 0 | 4733 | 4733 | 26 / 0 | 4707 |
| LPTF DISP | 4790 | 33 | 4757 | 4757 | 36 / 0 | 4721 | 4721 | 82 / 0 | 4639 |
| TAN CH1 | 4781 | 44 | 4737 | -- | -- | -- | 4737 | 58 / 0 | 4679 |
| TAN CH2 | 4790 | 41 | 4749 | 4749 | 21 / 0 | 4728 | 4728 | 38 / 0 | 4690 |
| TAN DD1 | 4790 | 27 | 4763 | 4763 | 20 / 0 | 4743 | 4743 | 76 / 0 | 4667 |
| TAN DD2 | 4780 | 23 | 4757 | 4757 | 27 / 0 | 4730 | 4730 | 44 / 0 | 4686 |
| TAN DD3 | 4786 | 48 | 4738 | -- | -- | -- | 4738 | 43 / 0 | 4695 |
| TAN 3 | 4792 | 53 | 4739 | -- | -- | -- | 4739 | 67 / 0 | 4672 |
| TAN 4 | 4803 | 63 | 4740 | -- | -- | -- | -- | -- | -- |
| TAN 5 | 4803 | 58 | 4745 | -- | -- | -- | 4745 | 60 / 0 | 4685 |
| TAN 6 | 4787 | 50 | 4737 | 4737 | 20 / 0 | 4717 | 4717 | 50 / 0 | 4667 |
| TAN 7 | 4786 | 37 | 4749 | -- | -- | -- | 4749 | 79 / 0 | 4670 |
| TAN 8 | 4792 | 40 | 4752 | 4752 | 38 / 0 | 4714 | 4714 | 70 / 0 | 4644 |
| TAN 9 | 4782 | 25 | 4757 | 4757 | 14 / 0 | 4743 | 4743 | 47 / 0 | 4696 |
| TAN 10 | 4782 | 35 | 4747 | 4747 | 26 / 0 | 4721 | 4721 | 69 / 13 | 4652 |
| TAN 10A | 4780 | 34 | 4746 | -- | -- | -- | 4746 | 71 / 0 | 4675 |
| TAN 11 | 4780 | 36 | 4744 | 4744 | 17 / 0 | 4727 | 4727 | 71 / 0 | 4656 |
| TAN 12 | 4780 | 36 | 4744 | 4744 | 22 / 0 | 4722 | 4722 | 60 / 0 | 4662 |
| TAN 13 | 4780 | 40 | 4740 | 4740 | 24 / 0 | 4716 | 4716 | 75 / 0 | 4641 |
| TAN 13A | 4780 | 38 | 4742 | 4742 | 23 / 0 | 4719 | 4719 | 77 / 0 | 4642 |
| TAN 14 | 4780 | 39 | 4741 | 4741 | 24 / 8 | 4717 | 4717 | 88 / 0 | 4629 |
| TAN 15 | 4786 | 16 | 4770 | 4770 | 37 / 0 | 4733 | 4733 | 53 / 0 | 4680 |

Table 1.--Altitude of the top, thickness, percent sediment, and altitude of the base of composite stratigraphic units from land surface to the base of basalt-flow group Q at Test Area North--Continued

[Altitude and thickness rounded to the nearest foot and accurate to +2 feet. --Indicates no data; < indicates less than; > indicates greater than; % indicates percent]

| | Basalt-flow group O and related sediment | | | Basalt-flow group P and related sediment | | | Basalt-flow group Q and related sediment | | |
|---|---|---|---|---|---|---|---|---|---|
| Well | Altitude of top | Thickness/ % sediment | Altitude of base | Altitude of top | Thickness/ % sediment | Altitude of base | Altitude of top | Thickness/ % sediment | Altitude of base |
| ANP 6 | 4645 | 54 / 0 | 4591 | 4591 | >101 / 0 | <4490 | -- | -- | -- |
| FET DISP | 4676 | 6 /100 | 4670 | 4670 | 132 / 0 | 4538 | 4538 | >34 / 0 | <4504 |
| GIN 1 | 4652 | 48 / 8 | 4604 | 4604 | 103 / 0 | 4501 | 4501 | >87 / 0 | <4414 |
| GIN 2 | 4625 | 55 / 0 | 4570 | 4570 | 72 / 0 | 4498 | 4498 | >114 / 0 | <4384 |
| GIN 3 | 4637 | 53 / 0 | 4584 | 4584 | 95 / 0 | 4489 | 4489 | >90 / 0 | <4399 |
| GIN 4 | 4628 | 46 / 0 | 4582 | 4582 | 97 / 0 | 4485 | 4485 | > 4 / 0 | <4481 |
| GIN 5 | 4636 | 51 / 0 | 4585 | 4585 | 105 / 0 | 4480 | 4480 | >126 / 3 | <4354 |
| GIN 6 | 4663 | 57 / 9 | 4606 | 4606 | >29 / 0 | <4577 | -- | -- | -- |
| GIN 7 | 4636 | > 8 / 0 | <4628 | -- | -- | -- | -- | -- | -- |
| GIN 8 | 4616 | >40 / 0 | <4576 | -- | -- | -- | -- | -- | -- |
| GIN 9 | 4609 | >37 / 0 | <4572 | -- | -- | -- | -- | -- | -- |
| GIN 10 | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| GIN 11 | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| GIN 12 | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| GIN 13 | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| GIN 14 | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| GIN 15 | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| GIN 16 | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| GIN 17 | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| GIN 18 | 4588 | >8 / 0 | <4580 | -- | -- | -- | -- | -- | -- |
| GIN 19 | 4618 | >38 / 0 | <4580 | -- | -- | -- | -- | -- | -- |
| GIN 20 | 4598 | >5 / 0 | <4593 | -- | -- | -- | -- | -- | -- |
| GS 24 | -- | -- | -- | 4695 | 156 / 6 | 4539 | 4539 | >69 / 0 | <4470 |
| IET DISP | -- | -- | -- | 4707 | 106 / 0 | 4601 | 4601 | >140 / 10 | <4461 |
| LPTF DISP | 4639 | 59 / 0 | 4580 | 4580 | 103 / 0 | 4477 | 4477 | >4 / 0 | <4473 |
| TAN CH1 | 4679 | 42 / 14 | 4637 | 4637 | 127 / 0 | 4510 | 4510 | 129 / 0 | 4381 |
| TAN CH2 | 4690 | 20 / 0 | 4670 | 4670 | 117 / 0 | 4553 | 4553 | 210 / 3 | 4343 |
| TAN DD1 | 4667 | 81 / 0 | 4586 | 4586 | 113 / 0 | 4473 | 4473 | >8 / 0 | <4465 |
| TAN DD2 | -- | -- | -- | 4686 | 99 / 0 | 4587 | 4587 | >67 / 48 | <4520 |
| TAN DD3 | -- | -- | -- | 4695 | 159 / 4 | 4536 | 4536 | >51 / 0 | <4485 |
| TAN 3 | -- | -- | -- | 4672 | 108 / 0 | 4564 | 4564 | >41 / 0 | <4523 |
| TAN 4 | -- | -- | -- | 4740 | 134 / 0 | 4606 | 4606 | >49 / 0 | <4557 |
| TAN 5 | 4685 | 4 /100 | 4681 | 4681 | 127 / 0 | 4554 | 4554 | >54 / 0 | <4500 |
| TAN 6 | -- | -- | -- | 4667 | 118 / 0 | 4549 | 4549 | >25 / 0 | <4524 |
| TAN 7 | -- | -- | -- | 4670 | 128 / 0 | 4542 | 4542 | >80 / 0 | <4462 |
| TAN 8 | -- | -- | -- | 4644 | 84 / 0 | 4560 | 4560 | >19 / 0 | <4541 |
| TAN 9 | -- | -- | -- | 4696 | 116 / 9 | 4580 | 4580 | >124 / 27 | <4456 |
| TAN 10 | 4652 | 70 / 8 | 4582 | 4582 | >58 / 0 | <4524 | -- | -- | -- |
| TAN 10A | 4675 | 71 / 0 | 4604 | 4604 | >74 / 0 | <4530 | -- | -- | -- |
| TAN 11 | 4656 | 75 / 5 | 4581 | 4581 | 103 / 0 | 4478 | 4478 | >11 / 0 | <4467 |
| TAN 12 | 4662 | 77 / 12 | 4585 | 4585 | 118 / 0 | 4467 | 4467 | >81 / 6 | <4386 |
| TAN 13 | 4641 | 51 / 10 | 4590 | 4590 | >65 / 0 | <4525 | -- | -- | -- |
| TAN 13A | 4642 | 53 / 13 | 4589 | 4589 | >53 / 0 | <4536 | -- | -- | -- |
| TAN 14 | 4629 | 38 / 8 | 4591 | 4591 | 151 / 0 | 4440 | 4440 | >64 / 0 | <4376 |
| TAN 15 | -- | -- | -- | 4680 | >149 / 0 | <4531 | -- | -- | -- |

Table 1.--Altitude of the top, thickness, percent sediment, and altitude of the base of composite stratigraphic units from land surface to the base of basalt-flow group Q at Test Area North--Continued

[Altitude and thickness rounded to the nearest foot and accurate to +2 feet. --Indicates no data; < indicates less than; > indicates greater than; % indicates percent]

| | Surficial Sediment | | | Basalt-flow groups LM and M and related sediment | | | Basalt-flow groups MN and N and related sediment | | |
|---|---|---|---|---|---|---|---|---|---|
| Well | Altitude of land surface | Thickness | Altitude of base | Altitude of top | Thickness/ % sediment | Altitude of base | Altitude of top | Thickness/ % sediment | Altitude of base |
| TAN 16 | 4787 | 17 | 4770 | 4770 | 31 / 0 | 4739 | 4739 | 79 / 0 | 4660 |
| TAN 17 | 4789 | 40 | 4749 | 4749 | 40 / 0 | 4709 | 4709 | 75 / 0 | 4634 |
| TAN 18 | 4803 | 48 | 4755 | 4755 | 28 / 0 | 4727 | 4727 | 33 / 0 | 4694 |
| TAN 19 | 4803 | 46 | 4757 | 4757 | 34 / 0 | 4723 | 4723 | 34 / 0 | 4689 |
| TAN 20 | 4781 | 45 | 4736 | 4736 | 32 / 0 | 4704 | 4704 | 57 / 0 | 4647 |
| TAN 21 | 4787 | 39 | 4748 | 4748 | 23 / 0 | 4725 | 4725 | 52 / 0 | 4673 |
| TAN 22 | 4788 | 17 | 4771 | 4771 | 47 / 0 | 4724 | 4724 | 79 / 0 | 4645 |
| TAN 22A | 4787 | 17 | 4770 | 4770 | 65 / 0 | 4705 | 4705 | 75 / 0 | 4630 |
| TAN 23 | 4787 | 20 | 4767 | 4767 | 70 / 0 | 4697 | 4697 | 71 / 0 | 4626 |
| TAN 23A | 4787 | 18 | 4769 | 4769 | 66 / 0 | 4703 | 4703 | 74 / 0 | 4629 |
| TAN 24 | 4789 | 23 | 4766 | 4766 | 41 / 0 | 4725 | 4725 | 90 / 0 | 4635 |
| TAN 24A | 4789 | 22 | 4767 | 4767 | 45 / 11 | 4722 | 4722 | 91 / 0 | 4631 |

Table 1.--Altitude of the top, thickness, percent sediment, and altitude of the base of composite stratigraphic units from land surface to the base of basalt-flow group Q at Test Area North--Continued

[Altitude and thickness rounded to the nearest foot and accurate to +2 feet. --Indicates no data; < indicates less than; > indicates greater than; % indicates percent]

| | Basalt-flow group O and related sediment | | | Basalt-flow group P and related sediment | | | Basalt-flow group Q and related sediment | | |
|---|---|---|---|---|---|---|---|---|---|
| Well | Altitude of top | Thickness/ % sediment | Altitude of base | Altitude of top | Thickness/ % sediment | Altitude of base | Altitude of top | Thickness/ % sediment | Altitude of base |
| TAN 16 | -- | -- | -- | 4660 | 153 / 0 | 4507 | 4507 | >44 / 20 | <4463 |
| TAN 17 | -- | -- | -- | 4634 | 80 / 0 | 4554 | 4554 | >116 / 9 | <4438 |
| TAN 18 | -- | -- | -- | 4694 | 117 / 0 | 4577 | 4577 | 217 / 4 | 4360 |
| TAN 19 | -- | -- | -- | 4689 | 111 / 0 | 4578 | 4578 | 218 / 6 | 4360 |
| TAN 20 | 4647 | 57 / 0 | 4590 | 4590 | 130 / 0 | 4460 | 4460 | >79 / 0 | <4381 |
| TAN 21 | 4673 | 24 / 0 | 4649 | 4649 | 118 / 0 | 4531 | 4531 | 220 / 2 | 4311 |
| TAN 22 | -- | -- | -- | 4645 | 139 / 0 | 4506 | 4506 | 185 / 2 | 4321 |
| TAN 22A | -- | -- | -- | 4630 | 125 / 0 | 4505 | 4505 | 183 / 3 | 4322 |
| TAN 23 | -- | -- | -- | 4626 | 121 / 0 | 4505 | 4505 | 185 / 2 | 4320 |
| TAN 23A | -- | -- | -- | 4629 | 123 / 0 | 4506 | 4506 | 185 / 2 | 4321 |
| TAN 24 | 4635 | 57 / 0 | 4578 | 4578 | 128 / 0 | 4450 | 4450 | 140 / 4 | 4310 |
| TAN 24A | 4631 | 53 / 0 | 4578 | 4578 | 129 / 0 | 4449 | 4449 | 136 / 3 | 4313 |