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A Study of Production/Injection Data from Slim Holes and Large-Diameter Wells at the Takigami Geothermal Field, Kyushu, Japan

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ABSTRACT

Production and injection data from nine slim holes and sixteen large-diameter wells at the Takigami Geothermal Field, Kyushu, Japan were analyzed in order to establish relationships (1) between injectivity and productivity indices, (2) between productivity/injectivity index and borehole diameter, and (3) between discharge capacity of slim holes and large-diameter wells. Results are compared with those from the Oguni and Sumikawa fields. A numerical simulator (WELBOR) was used to model the available discharge data from Takigami boreholes. The results of numerical modeling indicate that the flow rate of large-diameter geothermal production wells with liquid feedzones can be predicted using data from slim holes. These results also indicate the importance of proper well design.

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Introduction

Since a major impediment to the exploration for and assessment of new geothermal areas worldwide is the high cost of conventional rotary drilling, it would be desirable to be able to utilize low-cost small-diameter (diameter < 15 cm) slim holes for definitive reservoir assessment. As a part of its geothermal research program, the U.S. Department of Energy (DOE) through Sandia National Laboratories (Sandia) initiated a research effort to demonstrate that slim holes can be used (1) to provide reliable geothermal reservoir parameter estimates and (2) to predict the behavior of large-diameter geothermal wells (Combs and Dunn, 1992). To date, the DOE/Sandia slim-hole technology program has consisted of two primary elements, *i.e.*, (1) examination and analysis of slim hole and large-diameter well data from Japanese geothermal fields and (2) drilling of slim holes in several geothermal fields in the western United States to compare with offset large-diameter production wells.

Studies of production and injection data from slim holes and large-diameter wells from two Japanese geothermal fields (*i.e.*, Oguni and Sumikawa) have previously been carried out by Garg, *et al.* (1994a, 1994b, 1995a) and by Garg and Combs (1994, 1995). As of mid-1995, DOE/Sandia had funded the drilling of three slim holes in three different geothermal fields in the western United States. The first of the latter series of slim holes was drilled as an offset borehole to an existing large-diameter well at the Steamboat Hills Geothermal Field, Nevada (Finger *et al.*, 1994; Combs and Goranson, 1995). Production and injection data from the Oguni, Sumikawa, and Steamboat Hills geothermal fields have recently been summarized by Garg and coworkers (1995b). While the aforementioned studies have provided valuable insights into the production/injection characteristics of slim holes and large-diameter wells, additional data are needed to establish a statistically valid relationship between the injectivity/productivity of slim holes and of large-diameter wells.

During the past year, S-Cubed—under a contract with Sandia National Laboratories—approached Idemitsu Geothermal Company Ltd. (Idemitsu) for release of their proprietary data for use in DOE/Sandia's slim-hole technology program. As a result of these negotiations, Idemitsu kindly agreed to let S-Cubed use pertinent data from the Takigami Geothermal Field. Like the Oguni Geothermal Field, the Takigami Geothermal Field is located within the Hohi geothermal region, Kyushu, Japan. Since 1979, Idemitsu has carried out an extensive exploration and reservoir assessment program in the area. As of early 1995, Idemitsu had drilled more than thirty-five boreholes (including redrills and side-tracks); the deepest borehole in the Takigami field (large-diameter well TT-1) has a total depth of about 3000 meters. The reservoir fluid in the Takigami field is single-phase liquid; discharge from both the slim holes and large-diameter wells does not lead to *in situ* boiling. With the availability of data from the Takigami Geothermal Field, it is now possible to draw firm conclusions regarding the relationship between the discharge/injection characteristics of slim holes and of large-diameter wells with liquid feedzones.

In the present report, we examine data from nine slim holes and sixteen large-diameter wells at the Takigami Geothermal Field. A brief overview of the Takigami Geothermal Field is presented in Section 2. The drilling information and downhole pressure and temperature surveys are analyzed in Section 3 to determine feedzone locations, pressures and temperatures. The feedzone pressures (and temperatures) for individual boreholes are then synthesized (Section 3) to determine the fluid state in the reservoir. Estimates of injectivity and productivity indices are presented in Section 4.

Relationship between the productivity and injectivity indices of slim holes and of large-diameter wells is also explored in Section 4. Characteristic discharge data and variation of maximum discharge rate with borehole diameter are discussed in Section 5. Finally, in Section 6, the conclusions and recommendations for geothermal reservoir evaluation using discharge and injection data from slim holes are presented.

Section 2

An Overview of Takigami Geothermal Field

2.1 Introduction

The Takigami Geothermal field is located in northeastern Hohi geothermal region, Oita Prefecture, Kyushu, Japan. The Otake and Hatchobaru geothermal power stations are situated about 15 km to the southeast of the Takigami area (see Figure 2.1). The Hohi geothermal region also includes the Oguni and Sugawara Geothermal Fields. Although the Hohi region contains numerous hot springs, fumaroles and hydrothermal alteration halos, no surface geothermal manifestations are present in the Takigami area. Since 1979, Idemitsu Geothermal Company has carried out extensive geological, geochemical, and geophysical surveys, as well as a comprehensive well drilling program in the area. Because of the lack of surface manifestations, the boreholes were sited on the basis of magnetotelluric, remote sensing, and other geophysical surveys (Takenaka and Furuya, 1991). As of early 1995, Idemitsu had drilled more than thirty-five boreholes (including redrills and sidetracks) in the area. Idemitsu and Kyushu Electric Power Company (KEPCO) plan to commission a 25 MWe power plant at Takigami some time in 1996.

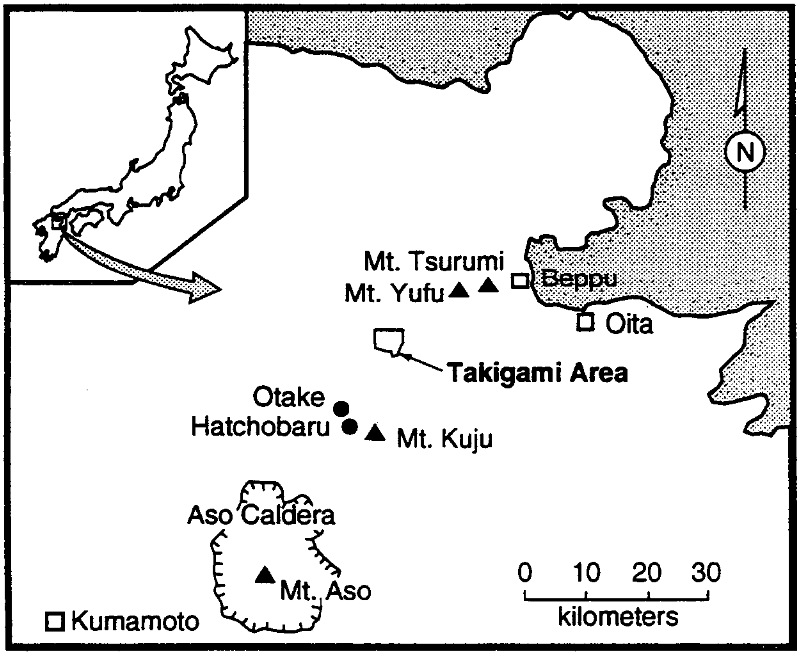

Figure 2.1. Map of the Hohi region, northeast Kyushu, Japan, showing the location of the Takigami Geothermal Field (adapted from Takenaka and Furyua (1991)).

2.2 Geological Setting and Subsurface Stratigraphic Sequence

The Takigami borefield is shown in Figure 2.2; the area depicted is about 24 km^2. The terrain is highest in the southwest, and drops off to the north and to the east. Idemitsu has used numerous drilling logs to delineate the geological sequence which underlies the Takigami area. In order of increasing depth, these formations are (Furuya, 1988):

Noinedake volcanics: Late Pleistocene (0.4–0.7 Ma) volcanics from Mt. Noine (mainly andesite).

Kusu formation: Late Pleistocene volcanics.

Ajibaru formation: Late Pleistocene (0.7 Ma) volcanics (mainly andesite).

Takigami formation: Early Pleistocene volcanic rocks. Takigami formation is subdivided into upper (dacites), middle (andesites) and lower (dacites) parts.

Usa group: Tertiary rocks comprised of altered andesite lava flows and pyroclastics.

The Usa group is the deepest so far reached by drilling; the deepest borehole at Takigami (TT-1) bottomed in this formation at –2293 m ASL. The pre-Tertiary granitic basement has yet to be encountered at Takigami.

Borehole-to-borehole stratigraphic correlations indicate that a NW-SE striking fault (Noine fault, see Figure 2.2) bisects the Takigami Geothermal Field into a western and an eastern part. The dip on the Noine fault is to the west; the Usa group drops almost 1000 meters to the west of the Noine fault (Figure 2.3). The Takigami formation overlying the Usa group is quite thick on the western side; it is rather thin on the eastern side of the Noine fault. The absence of large offsets in the Ajibaru formation implies that the faulting took place prior to the deposition of the Ajibaru formation (0.7 Ma). A study of surface lineaments indicates the existence of several E-W striking faults (Takenaka and Furuya, 1991); these faults are, however, accompanied by small displacements.

2.3. Hydrothermal Alteration and Feedzone Locations

Drill core and cuttings have been studied by x-ray diffraction to identify hydrothermal alteration minerals in the Takigami area. The hydrothermal alteration zones are classified by Yamamoto (1988) as either acidic (pyrophyllite, dickite, alunite, kaolinite) or as intermediate (montmorillonite, mixed layer, and sericite-chlorite). The low-permeability acidic alteration zone is located in the western part of the Takigami formation and along the Noine fault zone (Figure 2.4). The acidic alteration zone and intermediate alteration zone overlap each other. The montmorillonite zone is located about 300–700 meters below the surface and has a thickness of 220–790 meters (Yamamoto, 1988). The Noinedake volcanics and other Quaternary rocks overlying the montmorillonite zone show little or no hydrothermal alteration; these rocks are quite permeable. The upper surface of the sericite-chlorite zone is located within the lower Takigami and the Usa formations. The montmorillonite zone is more or less impermeable and acts as a cap rock for the geothermal system. By way of contrast, the low content of expandable and plastic montmorillonite in the sericite-chlorite zone contributes to the higher permeability of this layer (Yamamoto, 1988).

A detailed analysis of downhole data (Section 3) has been carried out by the authors; the feedzones for most Takigami boreholes are located within the lower Takigami formation and the Usa groups (see Table 2.1). Production wells TT-2, TT-7, an TT-8S3 produce from fractures in the Usa formation; the remaining production wells TT-14R, TT-16S and TT-13S derive hot fluid from the lower Takigami formation. The good correlation between the sericite-chlorite zone and feedzones for Takigami boreholes emphasizes the importance of geological studies in formulating conceptual models of geothermal systems.

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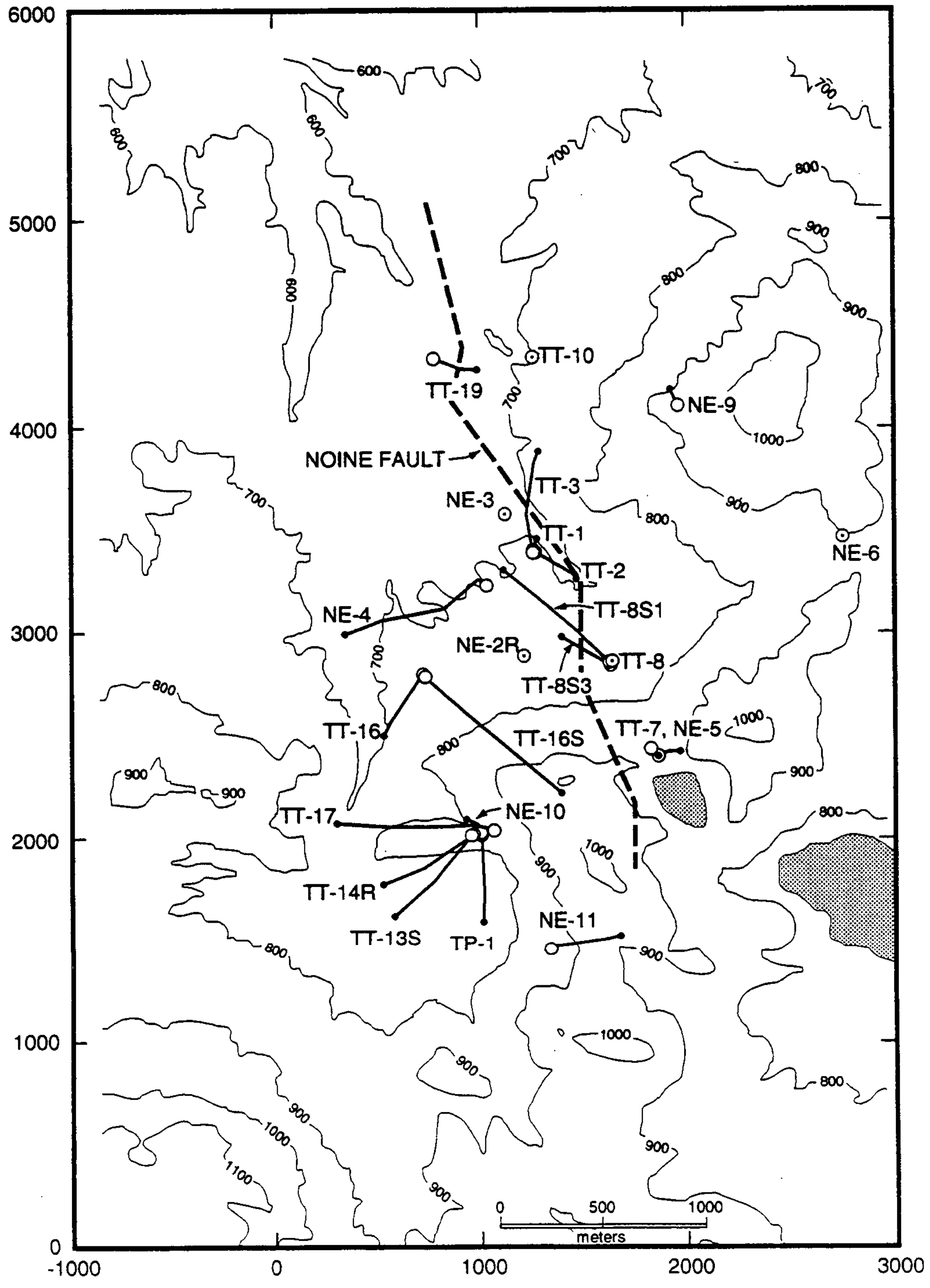

Figure 2.2. A topographic map of Takigami borefield. The origin of the local co-ordinate system is located at 33°11′ latitude and 131°16′ longitude. The northwest-southeast trending Noine fault (dashed line) bisects the Takigami field into a western and an eastern part.

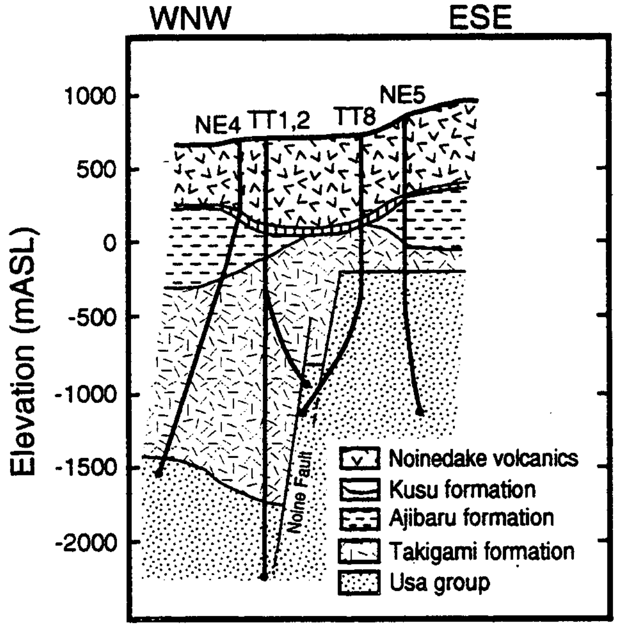

Figure 2.3. A generalized east-west geologic cross-section through the Takigami Geothermal Field (adapted from Yamamoto (1988)).

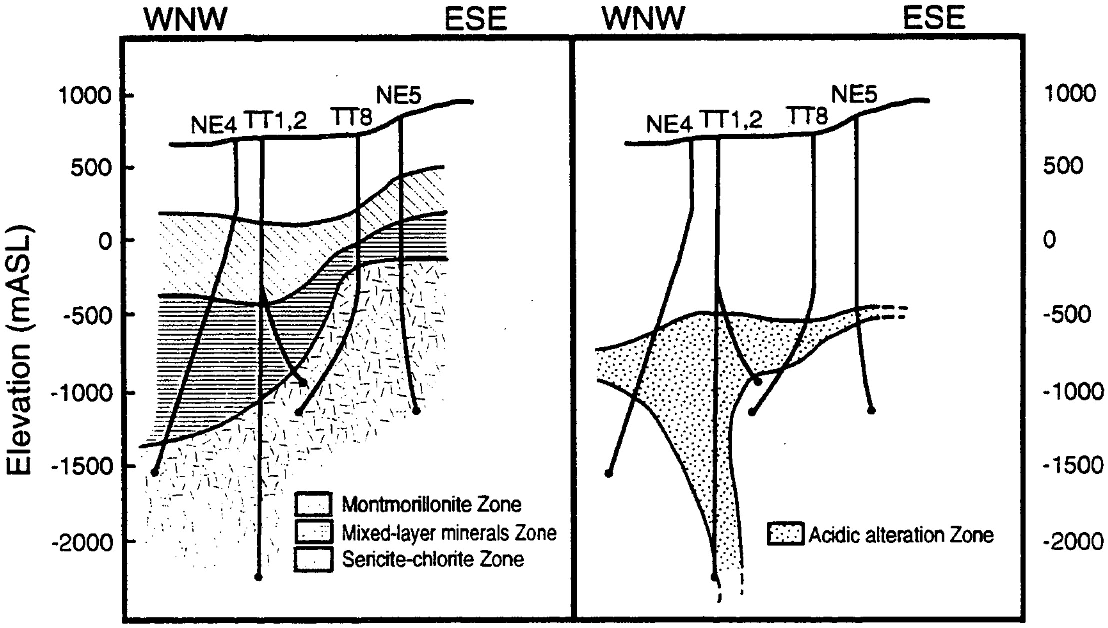

Figure 2.4. Hydrothermal alteration zones in the Takigami Geothermal Field (adapted from Yamamoto (1988)).

Table 2.1. Correlation of feedzones for Takigami boreholes with formations.

Borehole Name	Wellhead Elevation (m ASL)	Feedpoint Depth (m TVD)	Feedpoint Formation
NE-2R	746.0	1800.	Undefined
NE-3(i)	694.0	1680.	Lower Takigami
NE-3	694.0	2275.	Lower Takigami
NE-4	707.0	2230.	Usa Group
NE-5(i1)	874.0	1080.	Upper Takigami
NE-5(i2)	874.0	1180.	Usa Group
NE-5	874.0	1660.	Usa Group
NE-6(i1)	897.0	700.	Usa Group
NE-6(i2)	897.0	740.	Usa Group
NE-6	897.0	1630.	Usa Group
NE-9	914.0	1115.	Lower Takigami
NE-10	832.0	1650.	Lower Takigami
NE-11	825.5	1340.	Middle Takigami
NE-11R	825.5	1850.	Usa Group
TP-1	824.5	1820.	Lower Takigami
TT-1	708.5	2970.	Usa Group
TT-2	708.5	1580.	Usa Group
TT-3	708.5	1880.	Undefined
TT-7	872.5	1070.	Usa Group
TT-8(i)	764.0	840.	Upper Takigami
TT-8S1(i)	764.0	1050.	Usa Group
TT-8S3	764.0	1870.	Usa Group
TT-10	700.0	1275.	Lower Takigami
TT-13S	824.5	2100.	Lower Takigami
TT-14R	824.5	1730.	Lower Takigami
TT-16	756.5	2300.	Usa Group
TT-16S	756.5	1740.	Lower Takigami
TT-18	664.0	1300.	Undefined
TT-19	667.5	1350.	Middle Takigami
TT-23	667.5	1420.	Lower Takigami

2.4 Fluid State

At Takigami, subsurface temperatures are highest in the south and southwest, and decline to the north and to the east. The highest temperature (250°C) so far measured at Takigami is in borehole NE-10 at –1330 m ASL in the southern part of the field. Temperatures in excess of 240°C have been recorded in southern boreholes NE-4, TT-13S, TT-14R and TT-16S. In Section 3, the authors have performed a detailed examination of feedpoint pressures for Takigami boreholes. The stable shutin pressures are closely fit by the following empirical correlation (Section 3.2):

$$P = 51.144 - 0.08651\ (Z + 25.52\ X_E).$$

Here P is the feedzone pressure in bars, Z is the feedzone elevation in meters above sea level (m ASL), and X_E is the distance to the east in kilometers from the origin (33°11′ latitude, and 131°16′ longitude).

The vertical pressure gradient in the Takagami Geothermal Field is 8.651 kPa/m and corresponds to a hydrostatic gradient at about 185°C. This implies fluid upflow in regions of the subsurface where tempreatures exceed 185°C. The pressure correlation indicates a regional pressure gradient (and hence fluid outflow) to the east. The Takigami temperatures and pressures are such that the reservoir fluid is single-phase liquid in the natural state. Furthermore, production from all the existing Takigami boreholes is not accompanied by *in situ* boiling.

The reservoir fluids are of the Na-Cl type with a near neutral pH. The fluid salinity is quite low, and varies from about 600 ppm Cl in the western part to about 300 ppm Cl in the eastern part of the reservoir (Takenaka and Furuya, 1991). The non-condensable gas contents of fluid discharged from Takigami boreholes is less than 0.3 mmol/mol (Takenaka and Furuya, 1991); CO_2 constitutes the bulk (68% to 85% by volume) of non-condensable gases.

2.5 Reservoir Permeability

As discussed earlier in Section 2.3, most of the feedzones for Takigami boreholes are located in the lower Takigami formation and Usa group. Permeability in the Takigami Geothermal Field, like other volcanic geothermal areas, is due primarily to the pervasive network of fractures. Idemitsu has performed several long-term pressure interference tests; data from these tests have been analyzed by Shimada (1988), by Gotoh (1990), and by Itoi *et al.* (1990). The transmissivity (*i.e.*, permeability-thickness product) for the southwestern part of the field (*i.e.*, production area) is estimated to be ~50 darcy-meters (Shamada, 1988). Analyses of pressure interference data also indicate (Gotoh, 1990) that the transmissivity in the northern sector of the field (injection area) is much higher (200 to 300 darcy-meters).

Section 3

Analysis of Downhole Data

As of early-1995, Idemitsu had drilled eleven (including two redrills) slim holes (diameter ≤ 15 cm) and twenty-seven (including one redrill and seven side tracks) large-diameter (> 15 cm) wells. No useful injection and/or production data have been made available to the authors for two slim holes (NE-1, NE-2) and eleven large-diameter wells (TT-4, TT-4S, TT-8S2, TT-11, TT-13, TT-14, TT-15, TT-17, TT-17S, TT-20, TT-22). In this section, we will analyze available drilling (circulation loss, well completion and geologic data) and downhole PT (*i.e.*, pressure, temperature and water level) surveys to obtain feedzone depths, pressures and temperatures for the twenty-five (9 slim holes, 16 large-diameter wells) boreholes listed in Table 3.1. The essential well completion and drilling data required in the interpretations, are presented in Appendix A.

At the Takigami Geothermal Field, most of the downhole pressure measurements are made with Kuster tools. Since these Kuster gauges are not usually recalibrated in the field, it is highly desirable to have repeat measurements with different tools. The importance of ensuring the accuracy and reliability of measuring tools cannot be over emphasized. It appears that many of the pressure measurements made with Kuster tool KPG-24021 are incorrect. The water level and temperature data can be used to calculate the downhole pressure distribution in the borehole; this pressure distribution can in turn be used to verify the accuracy of downhole pressure measurements.

All except four of the Takigami boreholes were directionally drilled. Because of borehole deviation, the measured depths along the borehole (MD) must be corrected for borehole deviation to derive true vertical depths (TVD) from the surface. Depths will also be sometimes given in terms of elevations (meters) above sea level; thus –800 ASL denotes an elevation of 800 meters below sea level. Casing, liner and borehole dimensions are generally given in mm for slim holes (borehole diameter ≤ 15 cm) and in inches for large-diameter (borehole diameter > 15 cm) wells.

3.1 Feedzone Locations, Pressures, and Temperatures

Slim Hole NE-2R

Slim hole NE-2R was drilled with total circulation loss below a depth of ~1605 m TVD. The section of the borehole open to formation extends from ~1686 m TVD to 2010 m TVD. Selected temperature surveys for NE-2R are displayed in Figure 3.1. The temperature survey of January 21, 1983, recorded about a month after a discharge test, shows a temperature inversion; the maximum temperature (~194°C) occurs at about 1600 m TVD. A later temperature survey (see temperature survey of November 8, 1985) indicates that the temperature at 1600 m TVD is ~198°C. The temperature survey of September 21, 1984, taken several months after an injection test, implies that the injected water was lost below a depth of ~1685 m TVD (i.e. in the open part of the borehole). During a discharge test performed in November and December 1982, the measured wellhead enthalpy was about 753 kJ/kg; this corresponds to a liquid temperature of 178°C. Since a temperature of 180°C was recorded at ~1800 m TVD on January 21, 1983, it is reasonable to assume that the major feedpoint for NE-2R is located at ~1800 m TVD (-1054 m ASL).

A pressure survey recorded in slim hole NE-2R on March 9, 1985 is displayed in Figure 3.2; the pressure (extrapolated) at 1800 m TVD (–1054 m ASL) is about 128 bars. The latter pressure value is not considered to be reliable in that the measured pressure gradient in the hole implies the presence

Continued on page 3-5

Table 3.1. Takigami boreholes with production or injection data.

Borehole Name	Measured Depth (meters)	Vertical Depth (m TVD)	Open Hole Diameter (mm)	Production/ Injection Data
NE-2R	2010	2010	79	P
NE-3	2303	2303	101	P
NE-4	2406	2243	79	P,I
NE-5	2003	1999	98*, 79	P,I
NE-6	1882	1882	100*, 81	P,I
NE-9	1152	1148	60	I
NE-10	2174	2164	79	I
NE-11	1448	1382	100	P,I
NE-11R	2000	1889	100	P,I
TP-1	2151	2031	216	I
TT-1	3003	3001	216	P,I
TT-2	1668	1609	216	P,I
TT-3	2811	2736	216	I
TT-7	1115	1109	216	P,I
TT-8	1105	1105	311	P,I
TT-8S1	2203	1963	311*, 216	P,I
TT-8S3	1950	1876	216	P,I
TT-10	1285	1285	159	I
TT-13S	2707	2582	216	P,I
TT-14R	2114	1961	216	P,I
TT-16	2537	2461	311	I
TT-16S	2157	1850	216	P,I
TT-18	1500	1372	159	I
TT-19	1429	1377	311	I
TT-23	1740	1632	216	I

*Test at Intermediate Depth

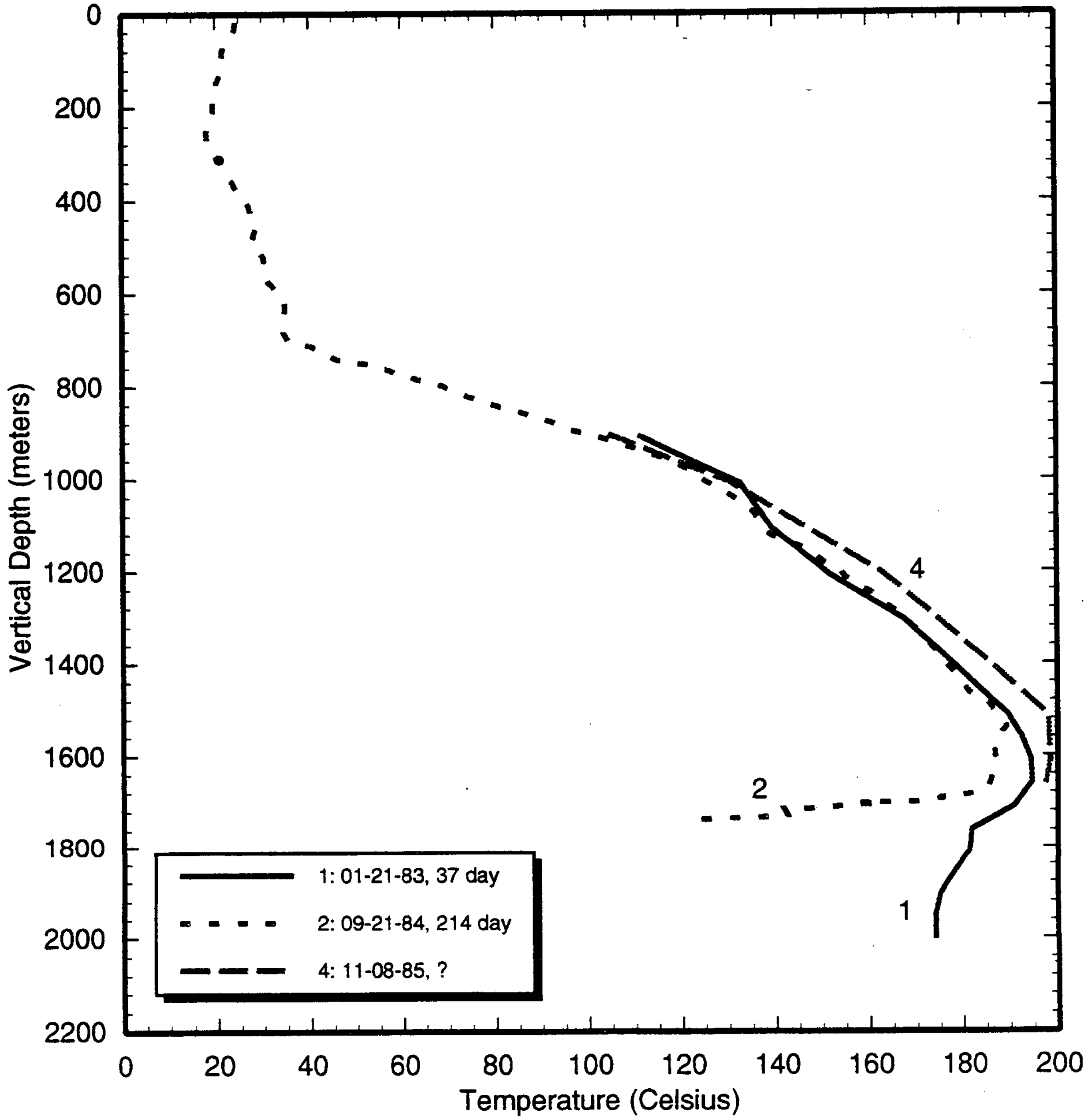

Figure 3.1. Temperature surveys in slim hole NE-2R.

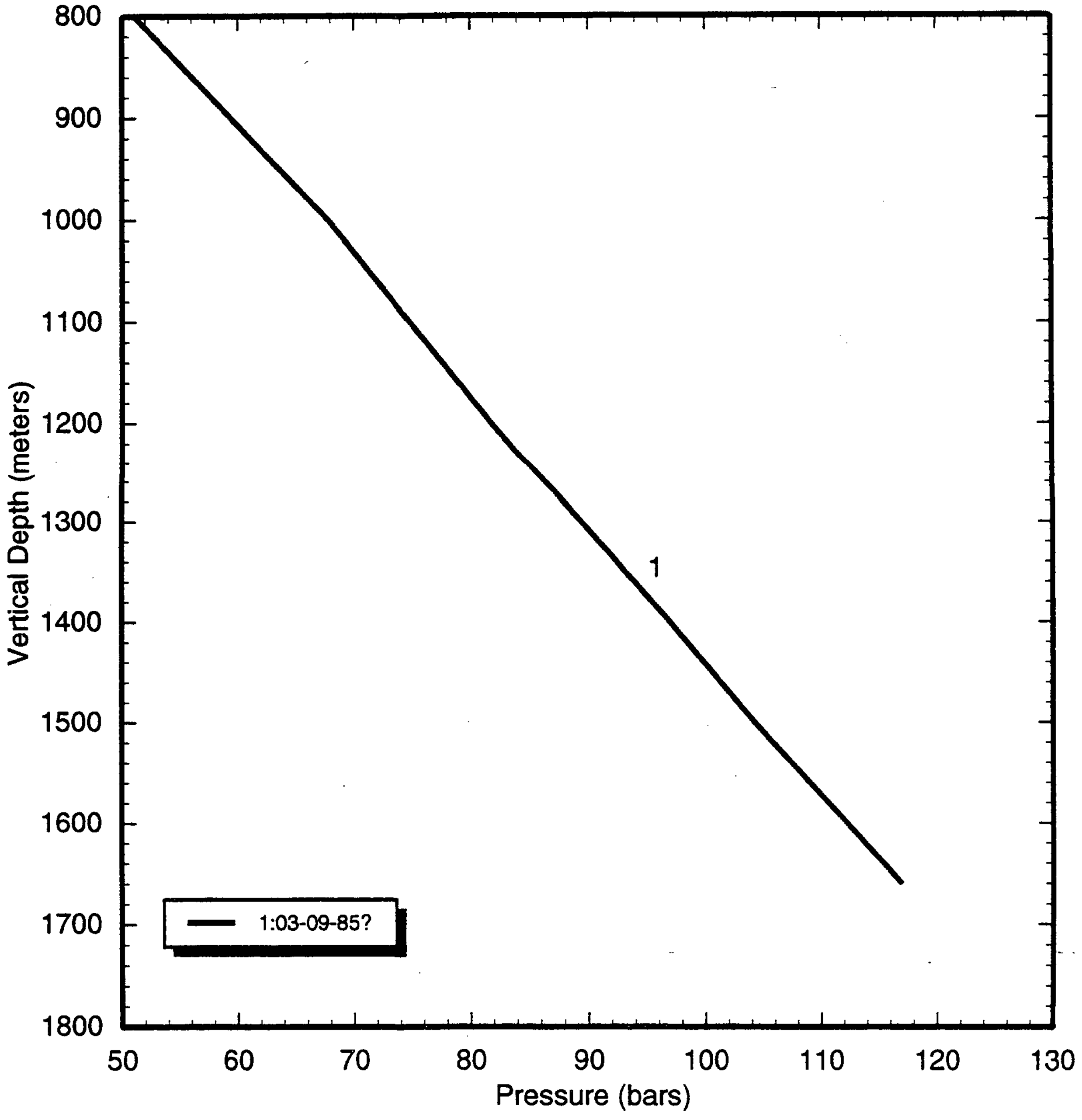

Figure 3.2. A pressure survey in slim hole NE-2R.

of a much hotter liquid (average temperature greater than 260°C) than that actually present (temperature ~190°C) in the borehole at the time of the pressure survey.

Slim Hole NE-3

Slim hole NE-3 was discharged in October 1982 after the borehole had been drilled to a depth of 1688.8 m TVD (open hole: 1675 m TVD to 1688.8 m TVD ?; open hole diameter: 101 mm). During the latter discharge test, the borehole discharged a mixture of liquid water and steam with an enthalpy equal to that of liquid water at a temperature of ~192°C. A temperature survey run in the well after the discharge test on October 17, 1982 (Figure 3.3) indicated a temperature of 192°C at 1680 m TVD.

The completed hole (total depth: 2303 m TVD, open hole below 1675 m TVD) was first discharged in January and February 1983. The enthalpy of the discharged fluid during the January/February 1983 test was essentially the same as that for the October 1982 test. Temperature surveys of September 25, 1984 and March 12, 1985 , taken after an injection test, show a persistent cold zone below a depth of ~2000 m TVD; this implies that the principal feedzone for NE-3 is located below 2000 m TVD. A temperature survey taken during a discharge test in May 1983 (Figure 3.3) shows an essentially isothermal profile above the measurement depth (~2275 m TVD). The latter temperature survey suggests that NE-3 discharges liquid water (temperature ~197°C) from a feedzone at ~2275 m TVD (–1581 m ASL).

Selected pressure surveys recorded in NE-3 are displayed in Figure 3.4. The static pressure at 2275 m TVD (–1581 m ASL) is ~186.5 bars. The latter pressure value is identical with that (186.5 bars) computed from water level and temperature survey taken on December 18, 1982 (Figure 3.5).

Slim Hole NE-4

Temperature profiles recorded on January 18, 1986 and January 27, 1986 (Figure 3.6) during a discharge test show an essentially isothermal profile extending from 2230 m TVD to about 1000 m TVD. A total circulation loss was encountered at ~2228 m TVD (2390.6 m MD). Thus, it is likely that the principal feedzone for NE-4 is located at about 2230 m TVD. The discharge temperature surveys indicate that the feedzone temperature is 242(±5)°C. A shutin temperature survey taken on April 11, 1986 (shutin time 65 days) gave a temperature of ~244°C at 2230 m TVD.

A pressure survey taken on January 27, 1987 (Figure 3.7) indicates a pressure of 186.5 bars at 2230 m TVD (–1523 m ASL). The latter pressure value is not too different from that (184.5 bars) computed from water level and temperature survey taken on April 11, 1986 (Figure 3.8).

Slim Hole NE-5

Slim hole NE-5 was discharged on February 15–16, 1985 and on March 15–17, 1985 after the borehole had been drilled to 1109 m MD (open hole below 997 m MD) and 1427.6 m MD (open hole below 997 m MD), respectively. Temperature surveys in the partially-drilled hole are displayed in Figure 3.9. During the February 1985 test, the borehole produced liquid water (temperature = 209°C) from a feedzone at or below 1080 m TVD. The principal feedzone during the March 1985 test was apparently located at ~1180 m TVD; the feedzone temperature is about 205°C. A temperature survey taken during an injection test on March 18, 1985 shows that all of the injected fluid enters the formation above 1420 m TVD. Pressure surveys in the partially-drilled hole are shown in Figure 3.10. Apparently, no static pressure surveys were taken either prior to or after the February 1985 discharge test. A comparison of pressure surveys taken on March 16,1985 (during discharge) and March 19, 1985) indicates a very small (~0.2 bars) pressure drop at 1180 m TVD due to well discharge. The static pressure at 1180 m TVD (–306 m ASL) is about 74 bars.

Attempts to discharge the completed hole (total depth: 2003.1 m MD, uncemented liner/open hole below 1428.3 m MD) were unsuccessful.

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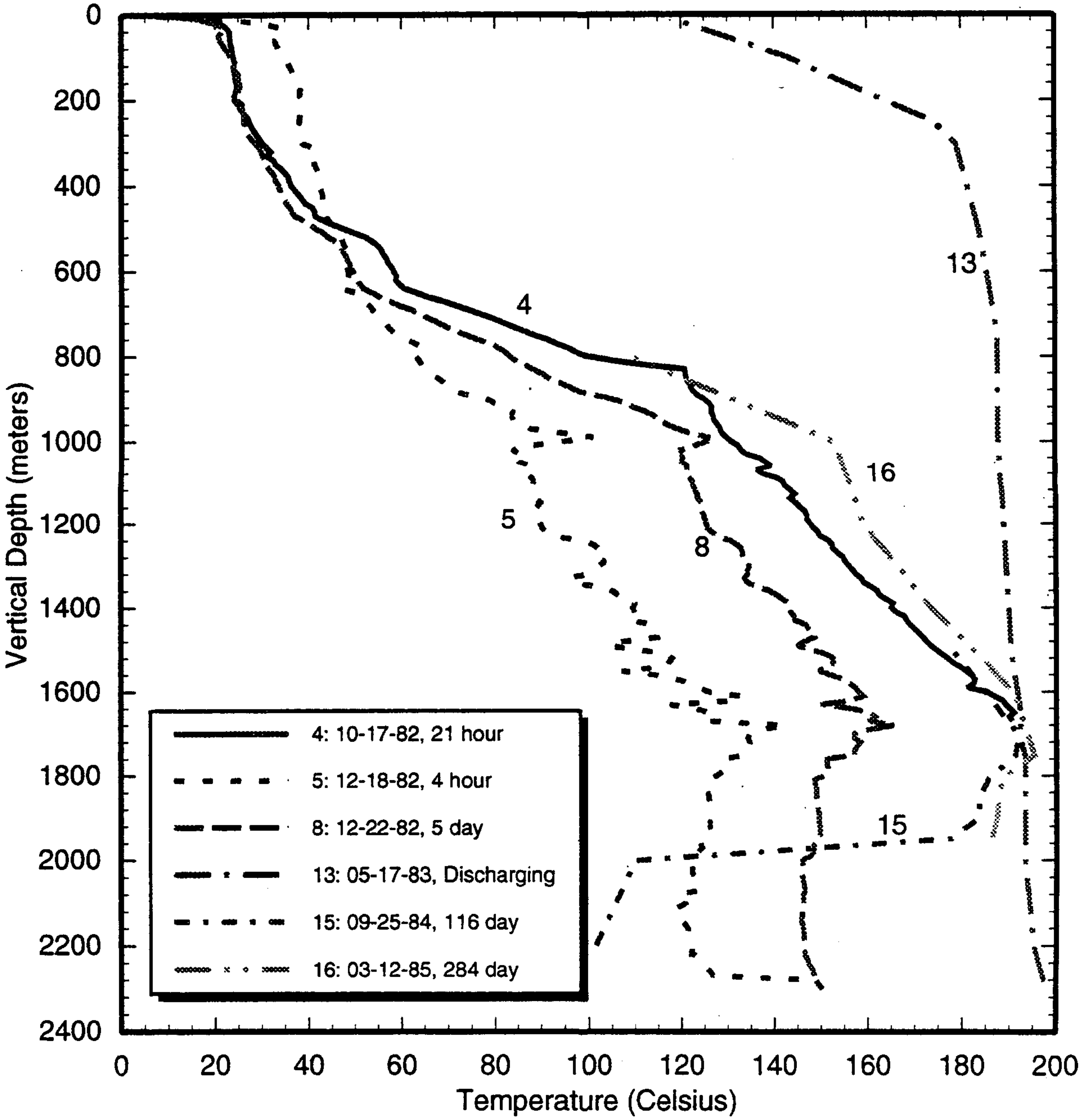

Figure 3.3 Temperature surveys in slim hole NE-3.

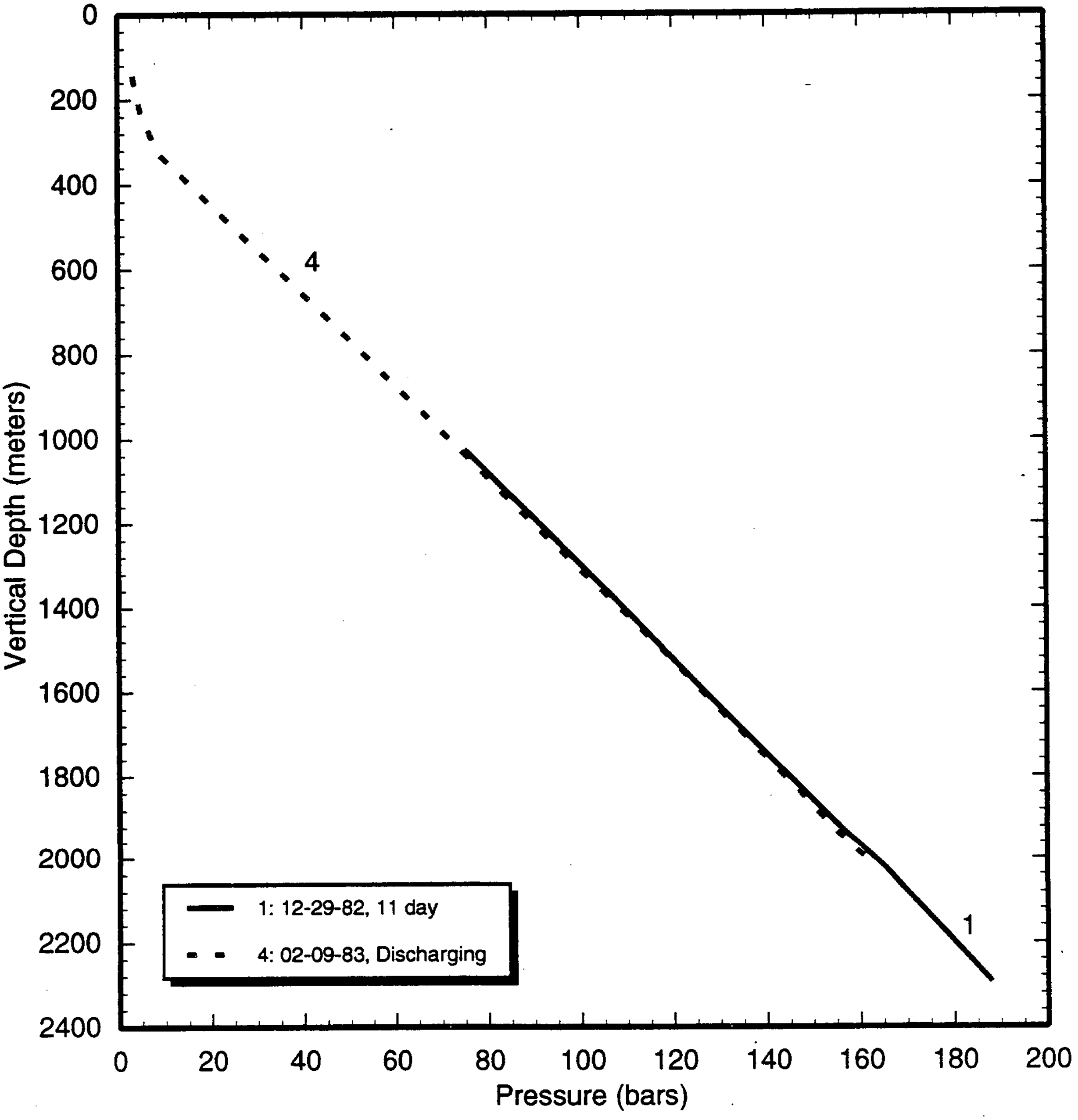

Figure 3.4 Pressure surveys in slim hole NE-3.

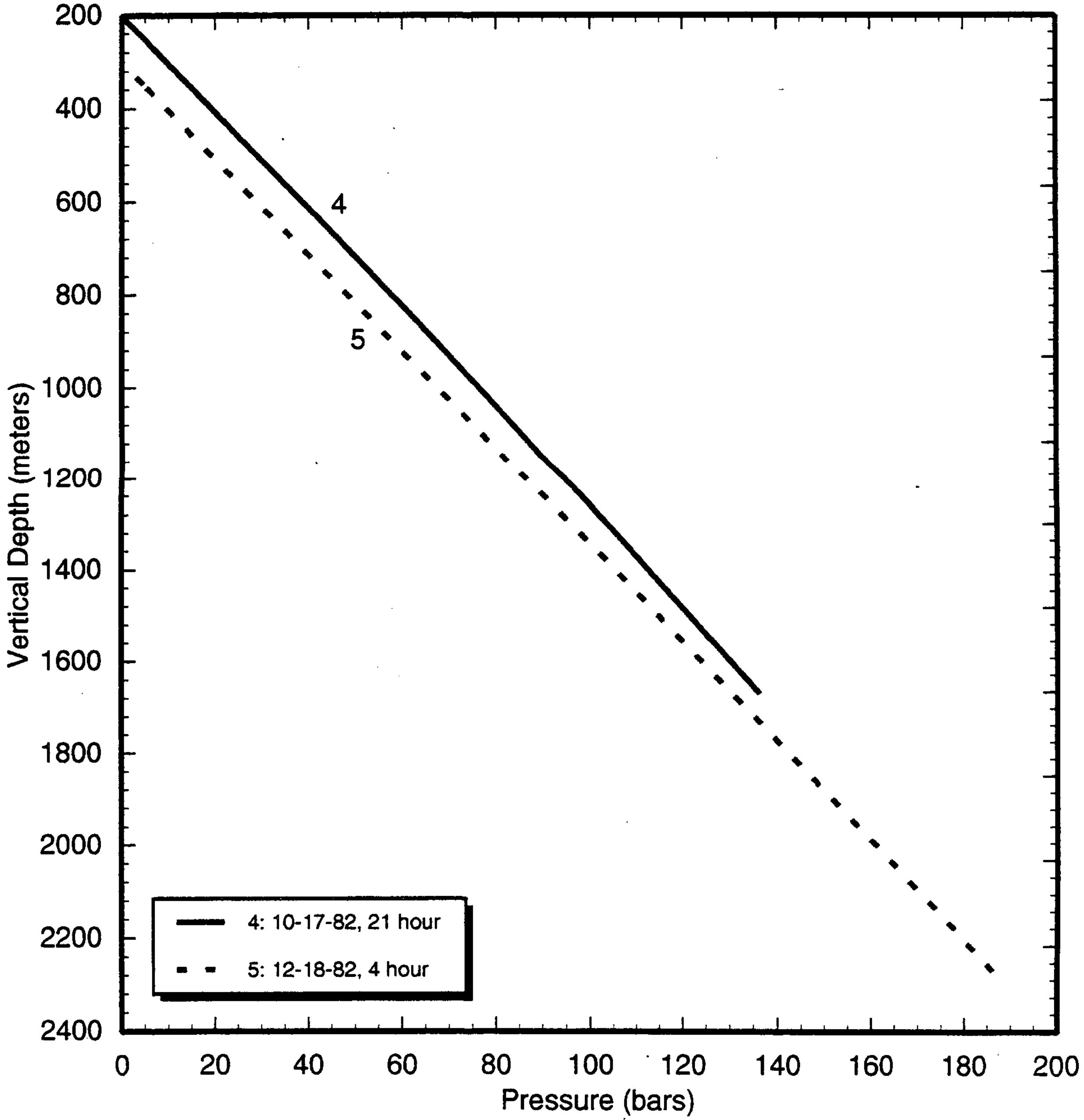

Figure 3.5. Pressures computed from water level and temperature data in slim hole NE-3.

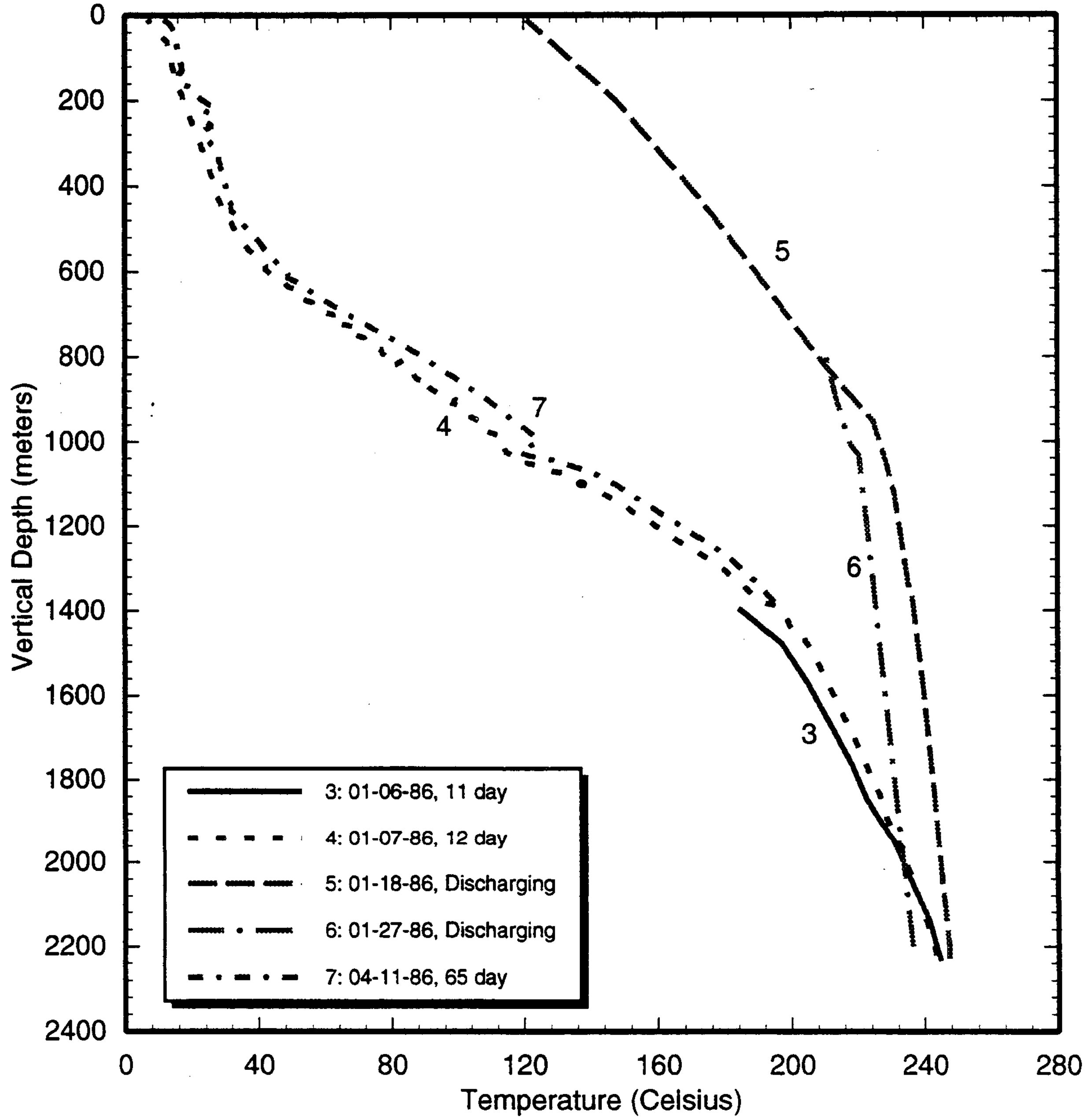

Figure 3.6. Temperature surveys in slim hole NE-4.

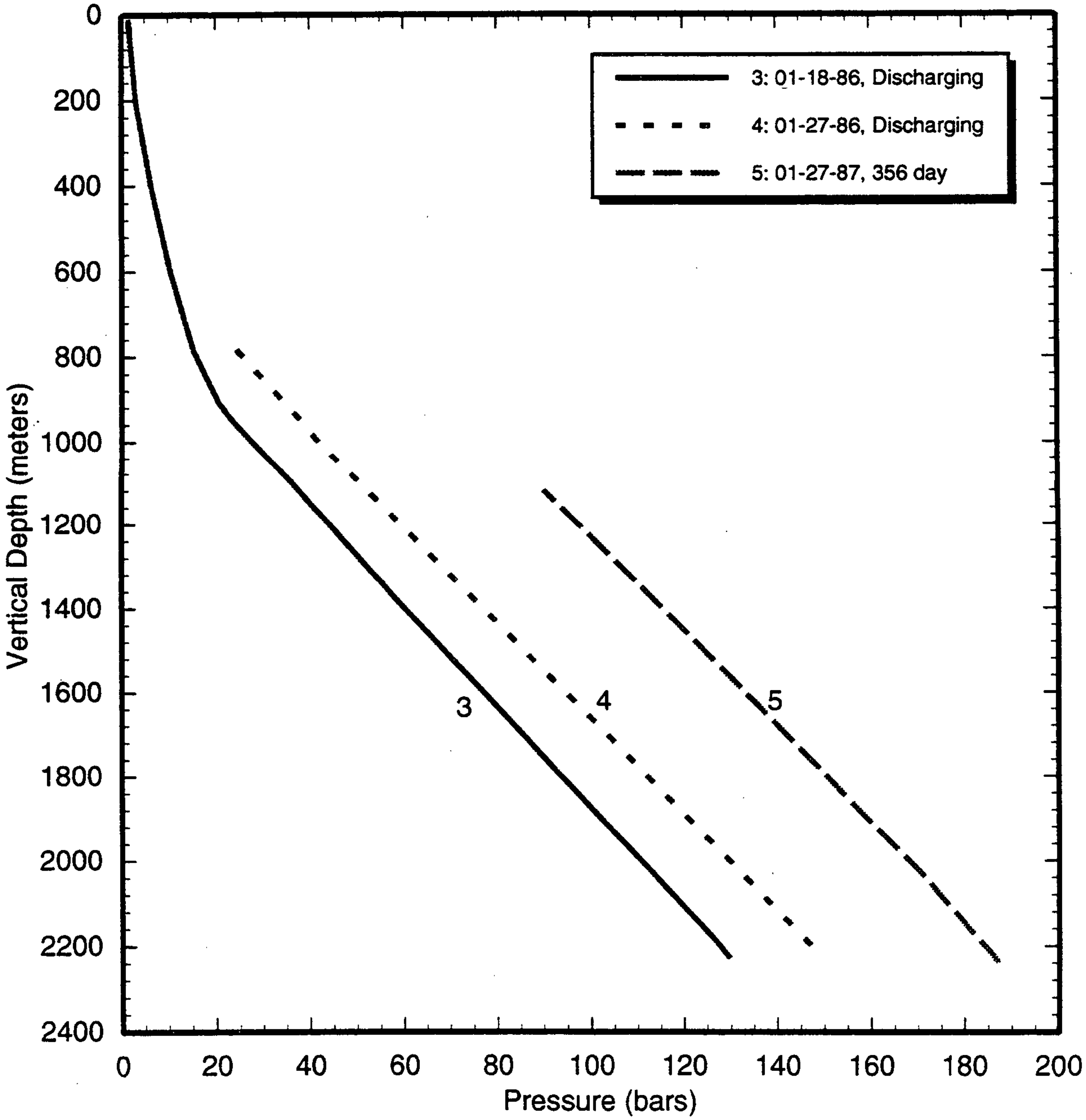

Figure 3.7. Pressure surveys in slim hole NE-4.

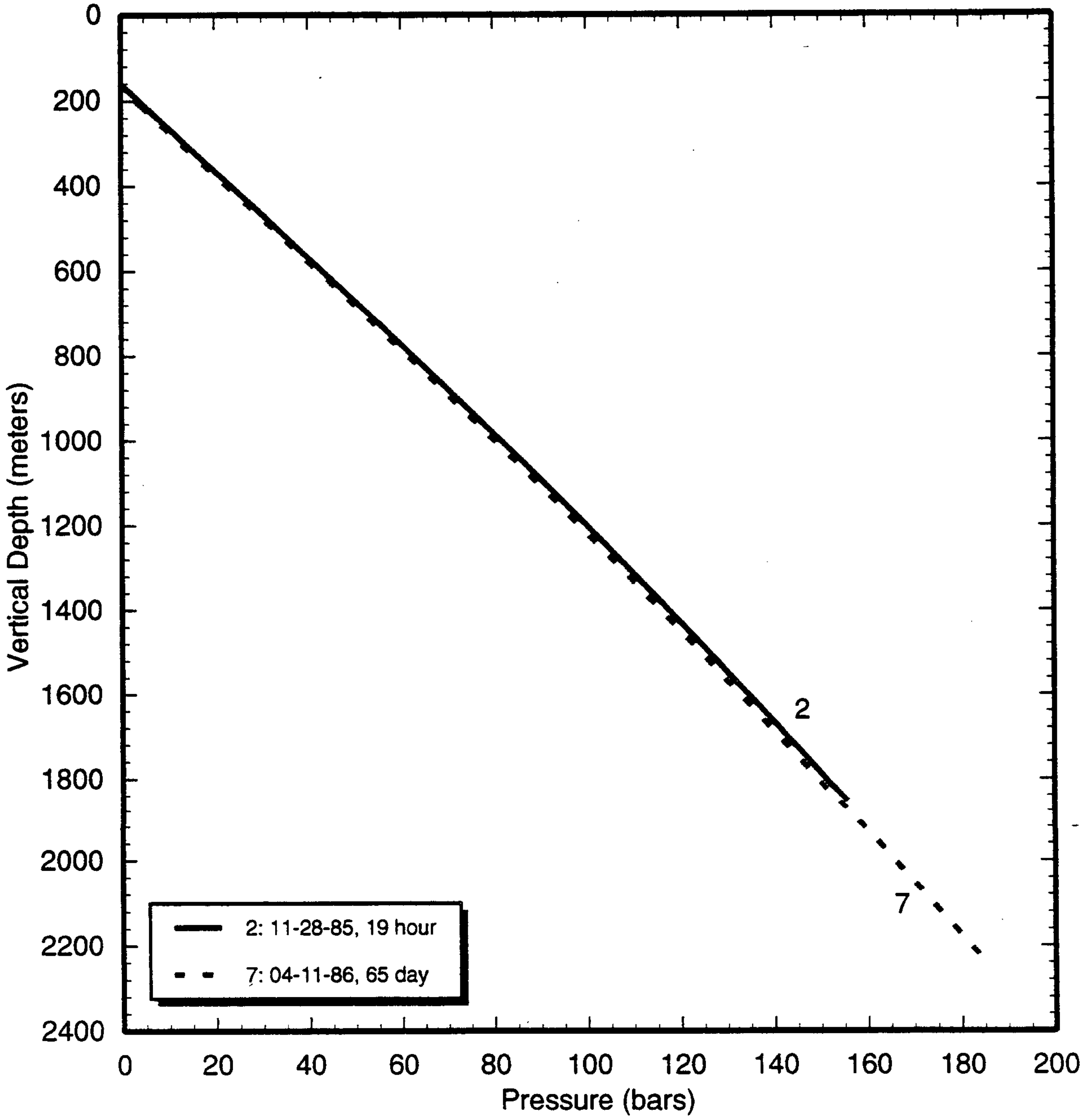

Figure 3.8. Pressures computed from water level and temperature data in slim hole NE-4.

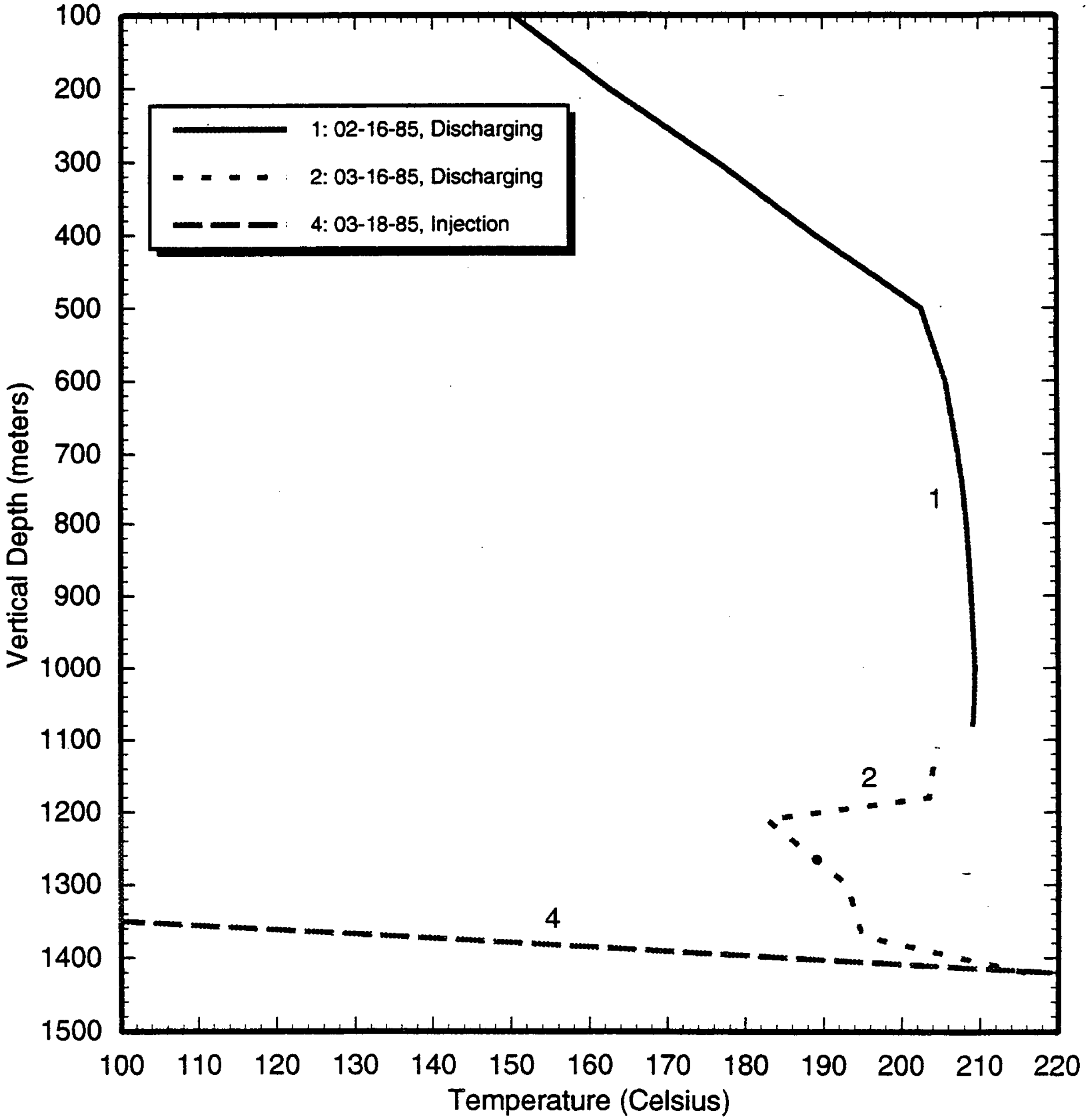

Figure 3.9. Temperature surveys in partially-drilled slim hole NE-5.

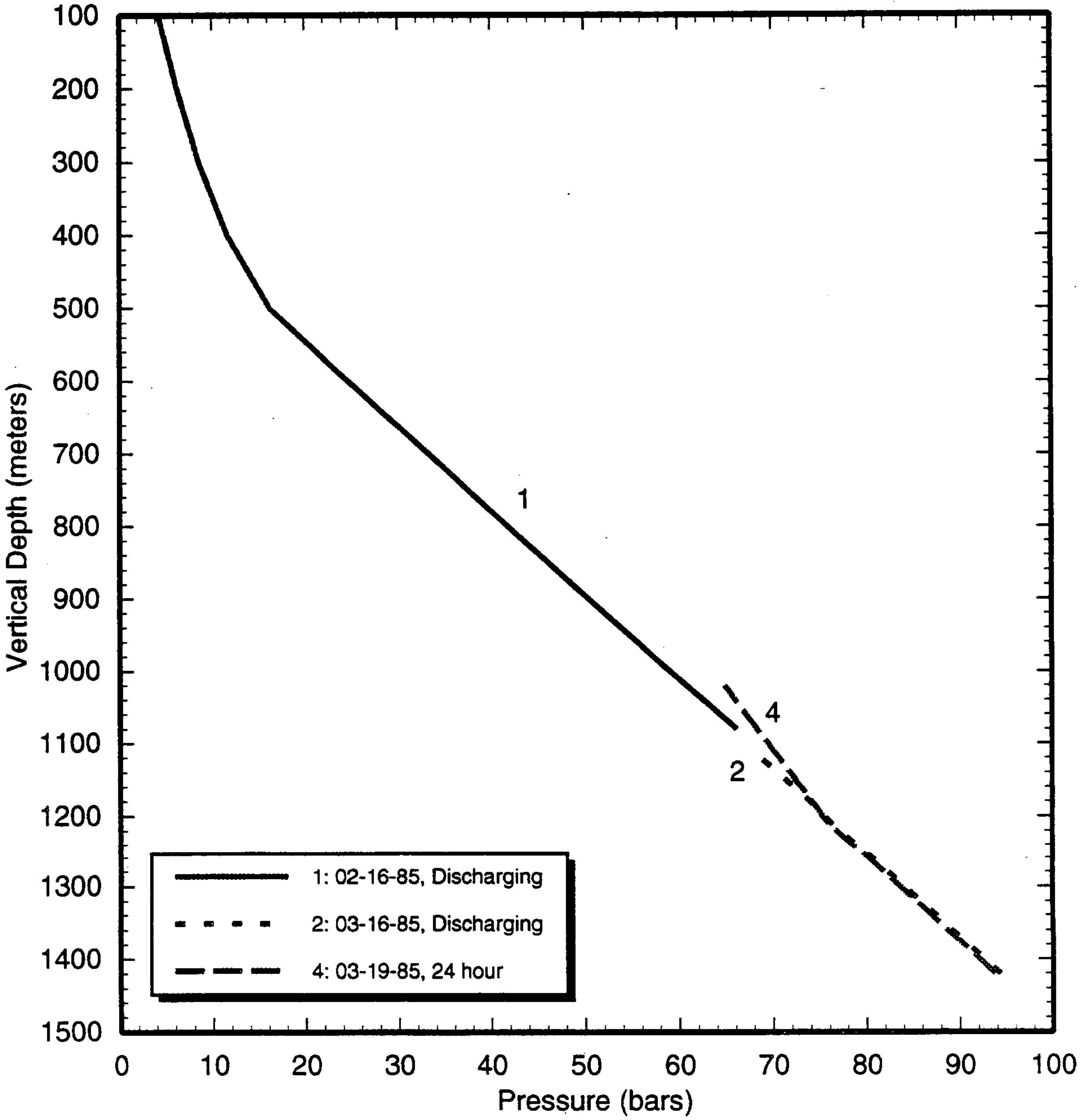

Figure 3.10. Pressure surveys in partially-drilled slim hole NE-5.

Temperature surveys in the completed hole (Figure 3.11) show a distinct temperature inversion. The maximum temperature (~214°C) occurs at about 1100 m TVD; the bottomhole temperature is a little more than 185°C. Temperature survey of May 19, 1985, taken shortly after an injection test, shows an isothermal zone from ~1530 m TVD to ~1850 m TVD; this isothermal zone (depth interval: 1480 m TVD to 1850 m TVD) is also present in the temperature survey of June 8, 1985. An isothermal zone indicates permeability at both its end points. Since NE-5 was drilled with total loss of circulation below a depth of 1077 m TVD, mud loss data are not useful for locating the principal feedzone. In the absence of any other data, it will be assumed that the principal feedzone for NE-5 is located at about 1660 (±190) m TVD. Static pressure surveys in the completed hole are shown in Figure 3.12; the pressure at 1660 m TVD (–786 m ASL) is about 114 bars. The latter pressure value is close to that (116 bars) computed from water level and temperature data taken on June 8, 1985 (Figure 3.13).

Slim Hole NE-6

Discharge tests on NE-6 were performed on February 14–15, 1985 and on March 14–17, 1985 after the borehole had been drilled to 763.5 m TVD (open hole below 685 m TVD) and 1403 m TVD (open hole below 685 m TVD), respectively. A temperature survey taken during the February 1985 discharge test (Figure 3.14) shows an isothermal zone above ~700 m TVD; this implies the discharge of liquid water (temperature ~192°C) from a feedzone at about 700 m TVD. The latter feedzone location most likely corresponds to the complete circulation loss horizon at 704 m TVD. The temperature survey of March 14, 1985—taken during the March 1985 discharge test—shows two isothermal zones (950 m TVD–760 m TVD, above 740 m TVD); this indicates the presence of feedzones at 950 m TVD (temperature ~161°C) and ~740 m TVD. A comparison of the temperature profile taken during the March 1985 test with that recorded on February 14, 1985 suggests that the feedzone at 740 m TVD provided the bulk of liquid during the March 1985 test. A temperature survey recorded on March 17, 1985 during an injection test indicates that all of the injected fluid is lost at or above 950–1100 m TVD.

Available pressure surveys for NE-6 are shown in Figure 3.15. Apparently, no static pressure surveys were taken either prior to or after the February 1985 test. A comparison of pressure surveys taken on March 15 (during discharge), and March 17, 1985 (shutin and injection) indicates a rather small change in pressure at 740 m TVD due to discharge or injection. The static pressure at 740 m TVD (157 m ASL) is ~34 bars.

Attempts to discharge the completed hole (total depth: 1881.7 meters, $2^1/_2$-inch uncemented liner in NQ hole below 1400 meters) were unsuccessful. The temperature survey of April 24, 1985 was taken shortly after the termination of bailing operations; this temperature survey shows an isothermal zone from ~1390 m TVD to ~1870 m TVD. In the absence of other data, it will be assumed that the principal feedzone for NE-6 is at ~1630 (±240) m TVD. The feedzone temperature is ~186°C. The pressure at 1630 m TVD (–733 m ASL) , as estimated from the pressure survey of April 24, 1985, is ~110.5 bars.

Slim Hole NE-9

Temperature survey of February 12, 1986 , taken shortly after reaching target depth, shows depressed temperatures in the depth interval from ~1105 m TVD to ~1130 m TVD (Figure 3.16). Slim hole NE-9 was drilled with total circulation loss below a depth of 1107 m TVD. Thus, the principal feedzone for NE-9 is located at about 1115 m TVD (–201 m ASL). The stable feedzone temperature (see temperature survey of April 11, 1986) is about 185°C.

A pressure survey taken on February 22, 1986 (shutin time = 2 hours) gave a pressure of 63.5 bars at 1115 m TVD (Figure 3.17). Pressures computed from water level and temperature data are displayed in Figure 3.18; the pressure at 1115 m TVD is about 64.5 bars.

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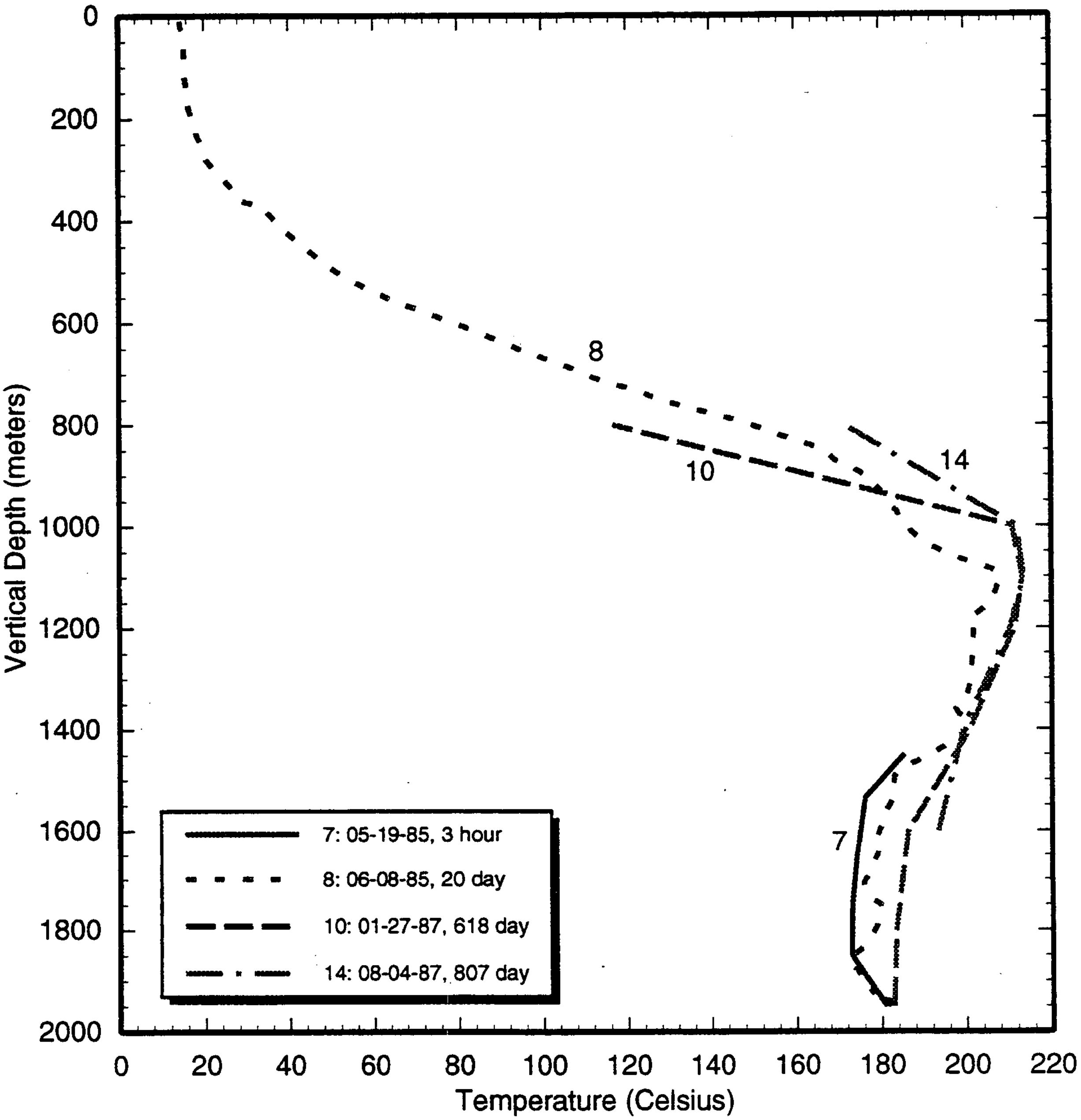

Figure 3.11. Temperature surveys in slim hole NE-5.

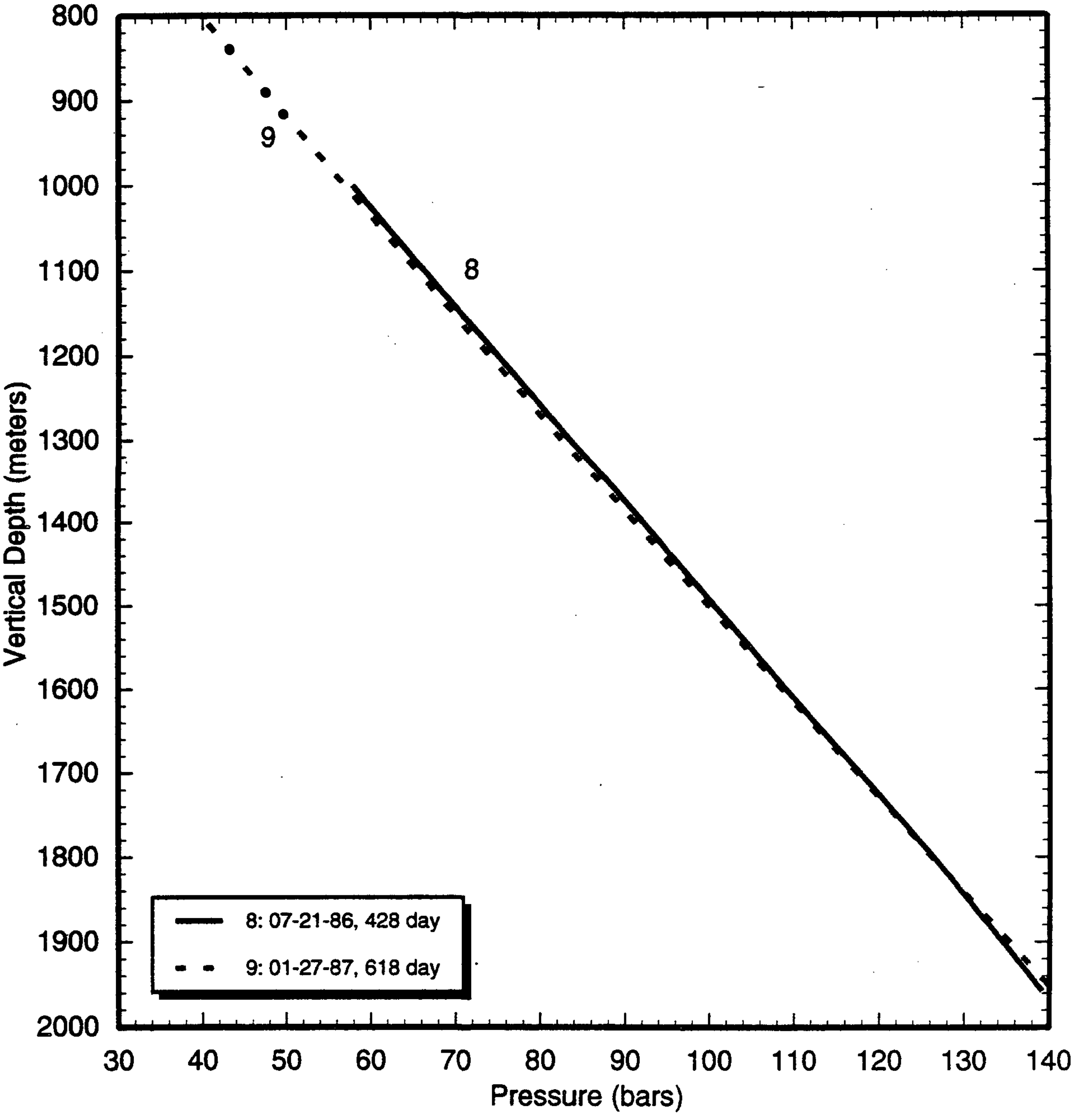

Figure 3.12. Pressure surveys in slim hole NE-5.

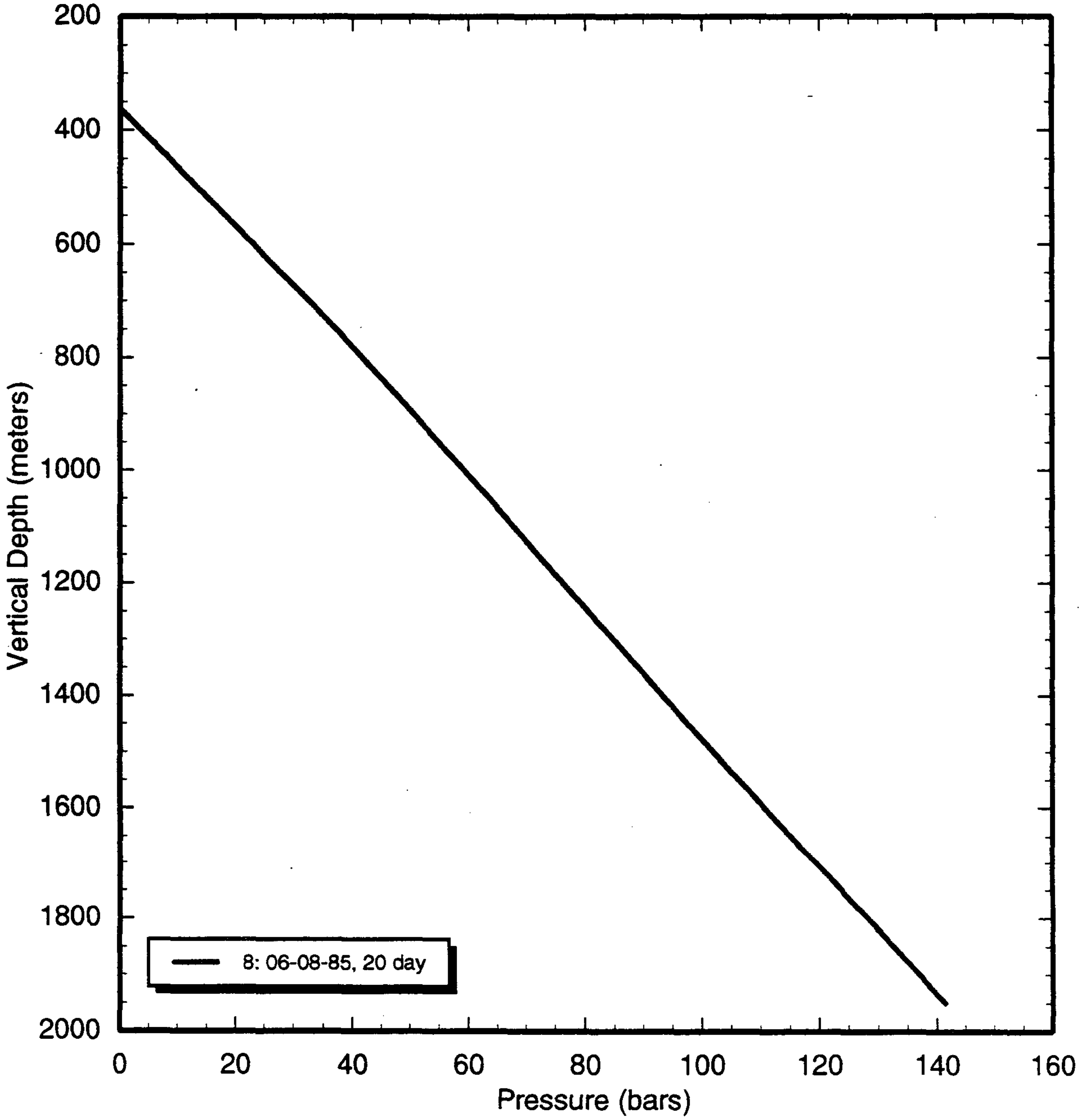

Figure 3.13. Pressures computed from water level and temperature data in slim hole NE-5.

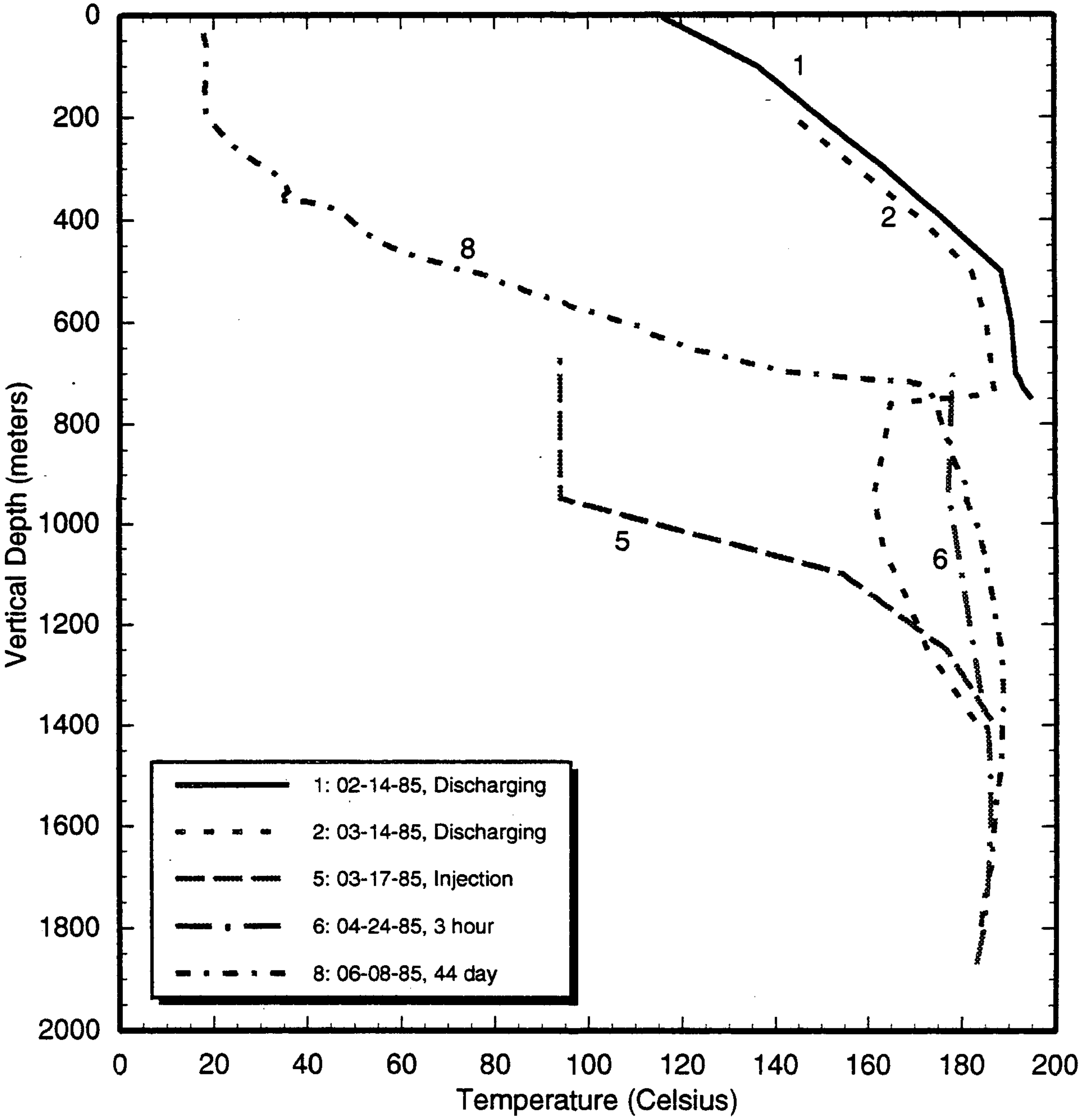

Figure 3.14. Temperature surveys in slim hole NE-6.

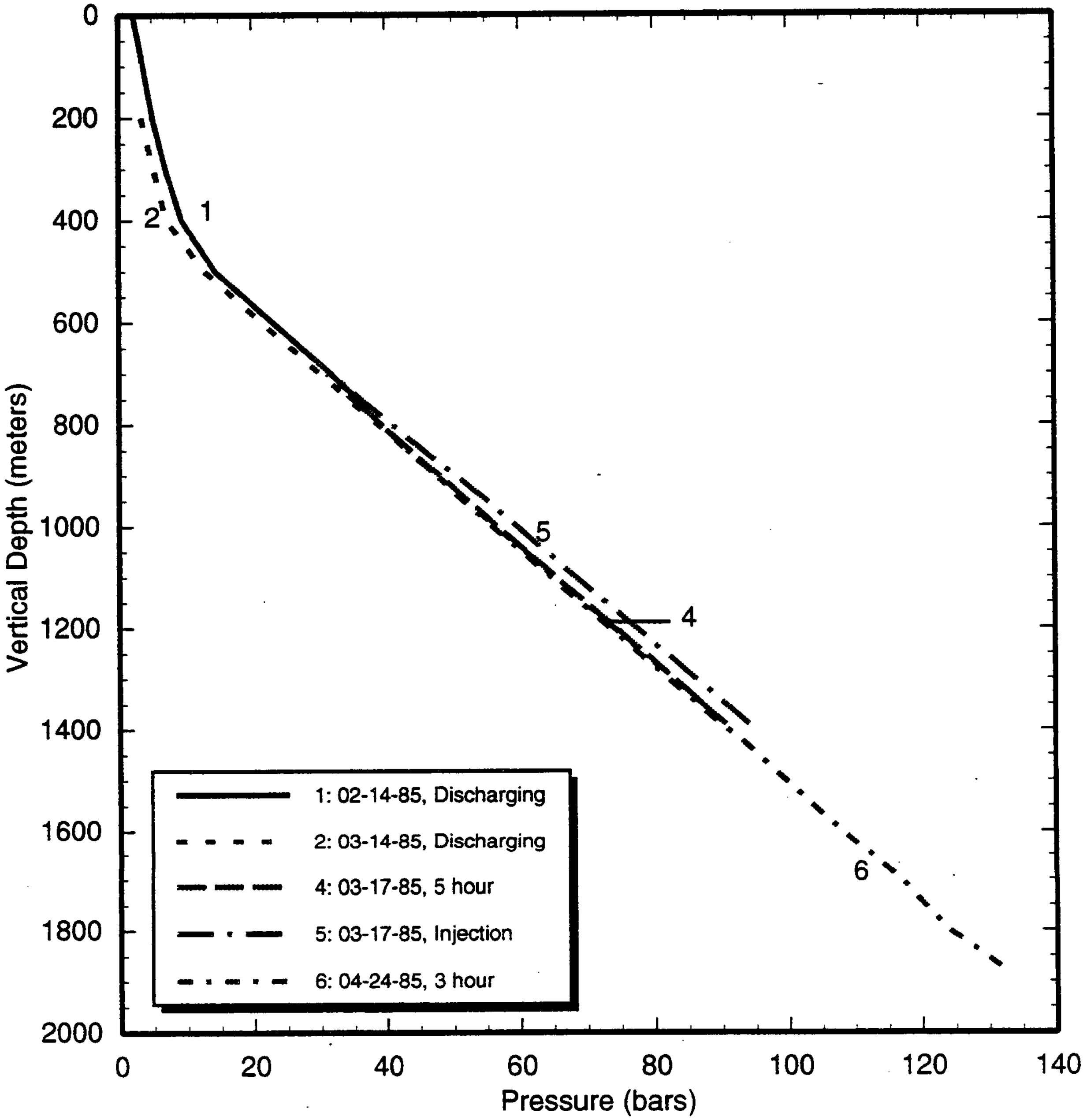

Figure 3.15. Pressure surveys in slim hole NE-6.

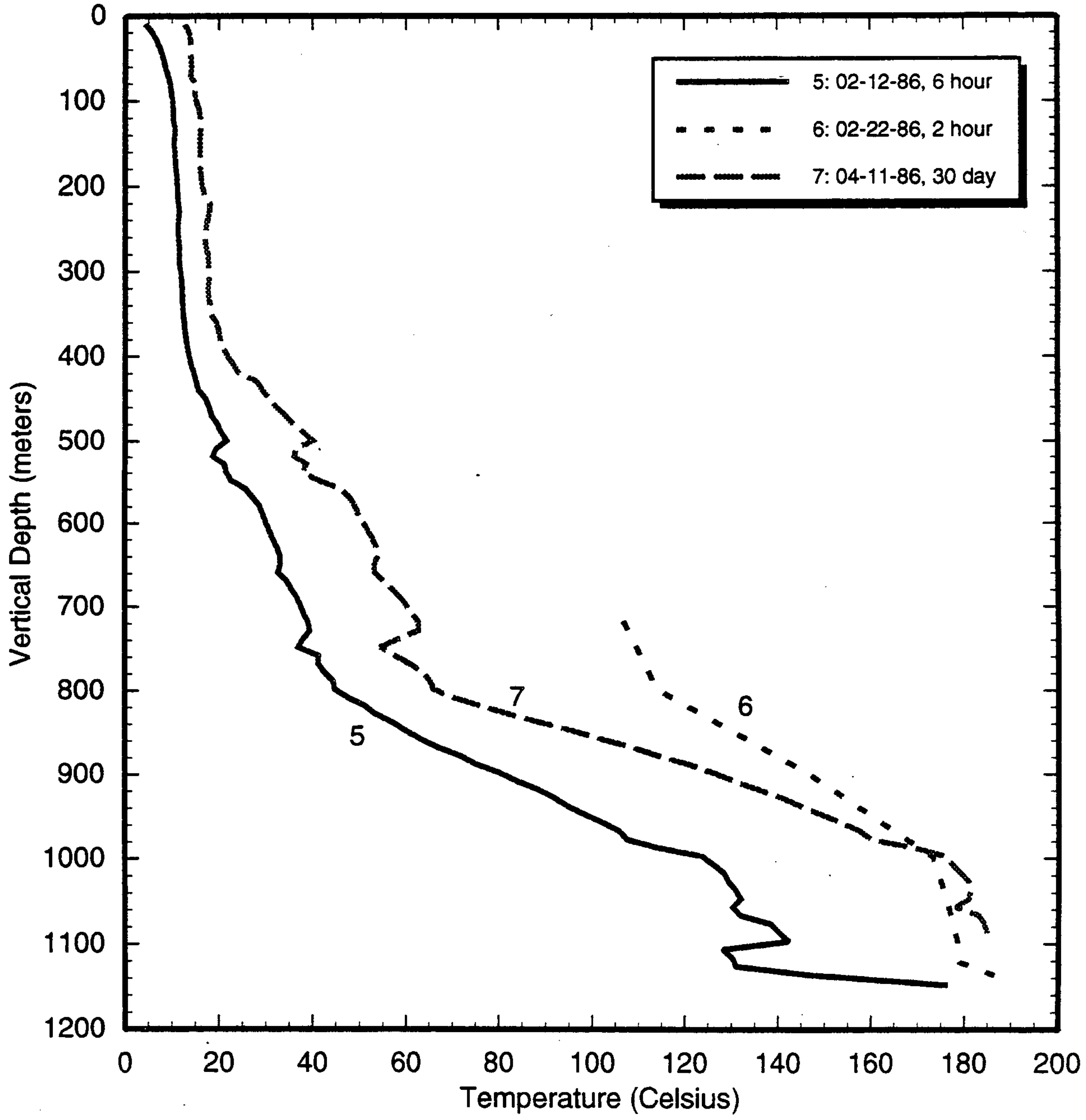

Figure 3.16. Temperature surveys in slim hole NE-9.

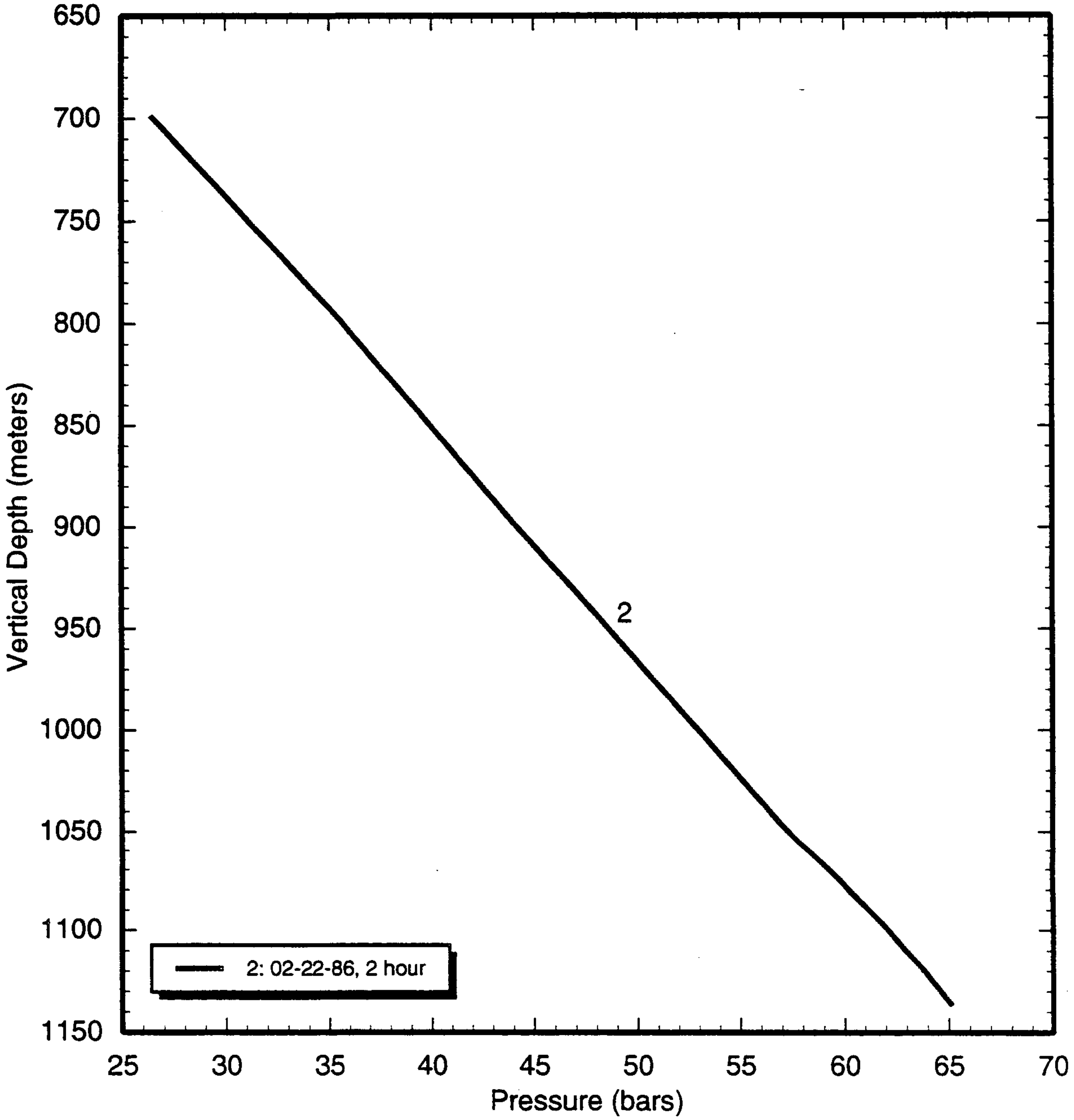

Figure 3.17. A pressure survey in slim hole NE-9.

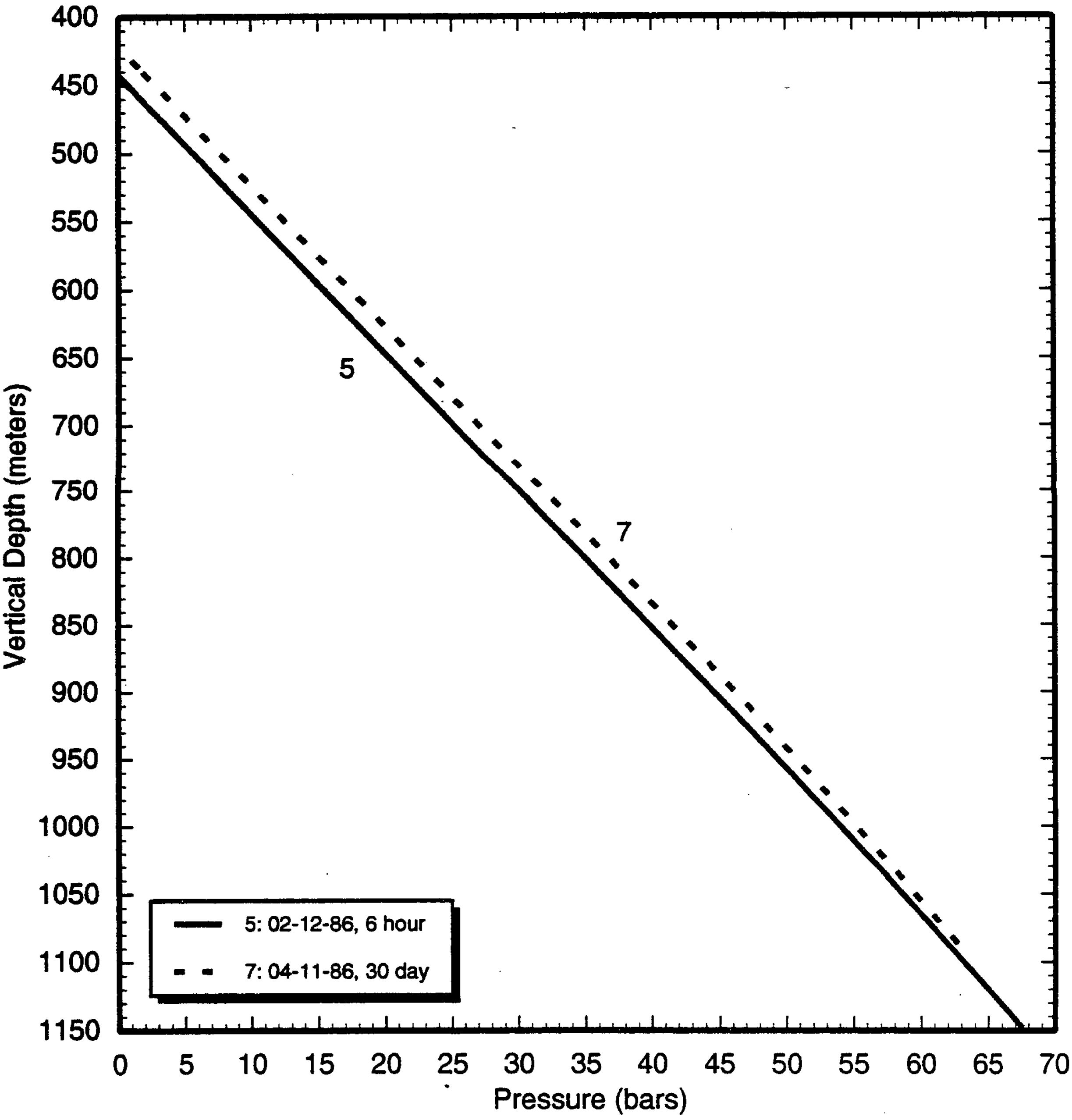

Figure 3.18. Pressures computed from water level and temperature data in slim hole NE-9.

Slim Hole NE-10

Temperature surveys in both the partially-drilled (depth: 1841.9 m MD) and the completed (depth: 2174.0 m MD) borehole exhibit depressed temperatures at about 1650 m TVD (Figure 3.19). Slim hole NE-10 was drilled with a total circulation loss below a depth of ~1640 m TVD. It is likely that a zone centered at 1650 m TVD accepted a large quantity of cold water during drilling and injection tests. We conclude that the principal feedzone for NE-10 is located at about 1650 m TVD (–818 m ASL). The feedzone temperature is around 220°C. The maximum temperature occurs towards bottom hole, and is ~250°C.

Two shutin pressure surveys for NE-10 are shown in Figure 3.20; the pressure at 1650 m TVD is 124(±2) bars. The latter pressure value is 3.5 bars higher than that (120.5 bars) computed from water level and temperature data recorded on February 4, 1986 (Figure 3.21).

Slim Hole NE-11

All the available temperature surveys (Figure 3.22) for NE-11 were taken during a discharge test in September 1986; the presence of an essentially isothermal zone above the measurement depth (~1336 m TVD) implies the existence of a liquid feedzone (temperature ~196°C) at or below this depth. Slim hole NE-11 was drilled with total circulation loss below a depth of ~1180 m TVD. In the absence of other data, it will be assumed that the principal feedzone for NE-11 is located at about 1340 m TVD (–514.5 m ASL).

The single available shutin pressure survey (Figure 3.23) does not extend to the feedzone depth. Extrapolating the pressure survey of September 7, 1986, the pressure at 1340 m TVD (–514.5 m ASL) is estimated to be 90 bars; the latter pressure estimate may be in substantial error.

Slim Hole NE-11R

Slim hole NE-11R was drilled as a side track from slim hole NE-11 with total circulation loss below a depth of about 1398 m TVD (1475 m MD). Temperature surveys taken during an injection test on January 6, 1987 (Figure 3.24) clearly indicate loss of some injected fluid at ~1400 m TVD; rest of the fluid travels down the borehole and is injected into the formation at ~1850 m TVD. The feedzones at 1400 m TVD and 1850 m TVD are confirmed by a heatup survey (shutin time: 14 hours) recorded on December 25, 1986; the latter temperature survey also indicates internal flow (inflow at 1400 m TVD and outflow at 1850 m TVD) in the borehole at the time of the temperature survey. The temperature survey of February 18, 1987 implies that NE-11R discharges liquid water (temperature ~183°C) from the feedzone at 1850 m TVD. The long shutin temperature survey of November 30,1987 indicates that the feedzone temperature may be somewhat higher (187°C) than that measured during the February 1987 discharge test. A temperature inversion is clearly seen in the November 30, 1987 temperature record; the maximum temperature (213°C) occurs at a depth of ~1240 m TVD.

A pressure survey taken on February 19, 1987 (Figure 3.25) after the discharge test indicates that the pressure at 1850 m TVD (–1024.5 m ASL) is ~135 bars. The latter pressure value is about 2 bars higher than that (133 bars) computed from water level and temperature profile of January 6, 1987 (Figure 3.26).

Well TP-1

A temperature survey taken during an injection test on November 20, 1993 (Figure 3.27) implies that the injected fluid is lost at about 1820 m TVD. The latter location for the feedzone is also confirmed by a change in temperature gradient at this depth in the two heatup profiles shown in Figure 3.27.

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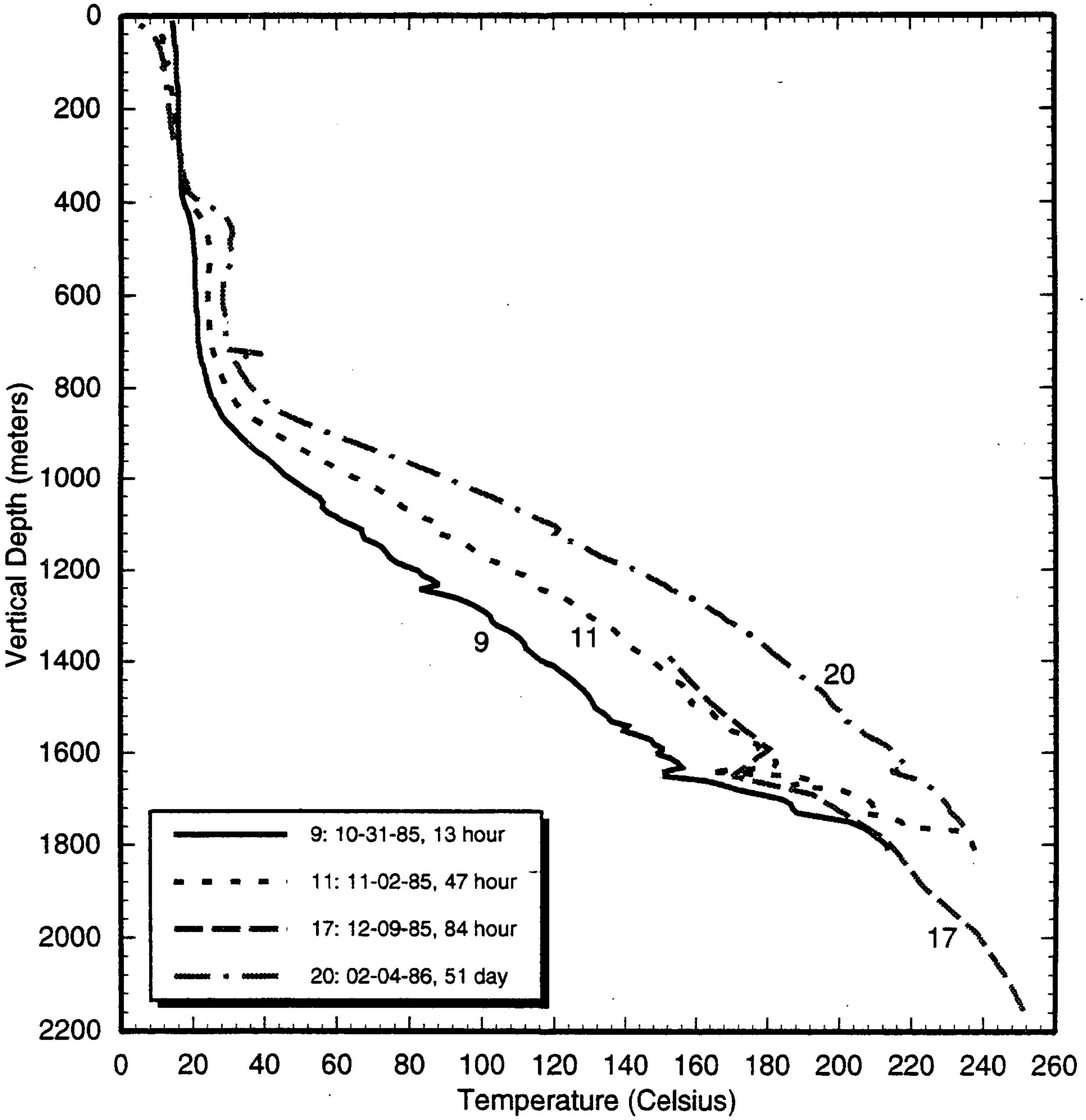

Figure 3.19. Temperature surveys in slim hole NE-10.

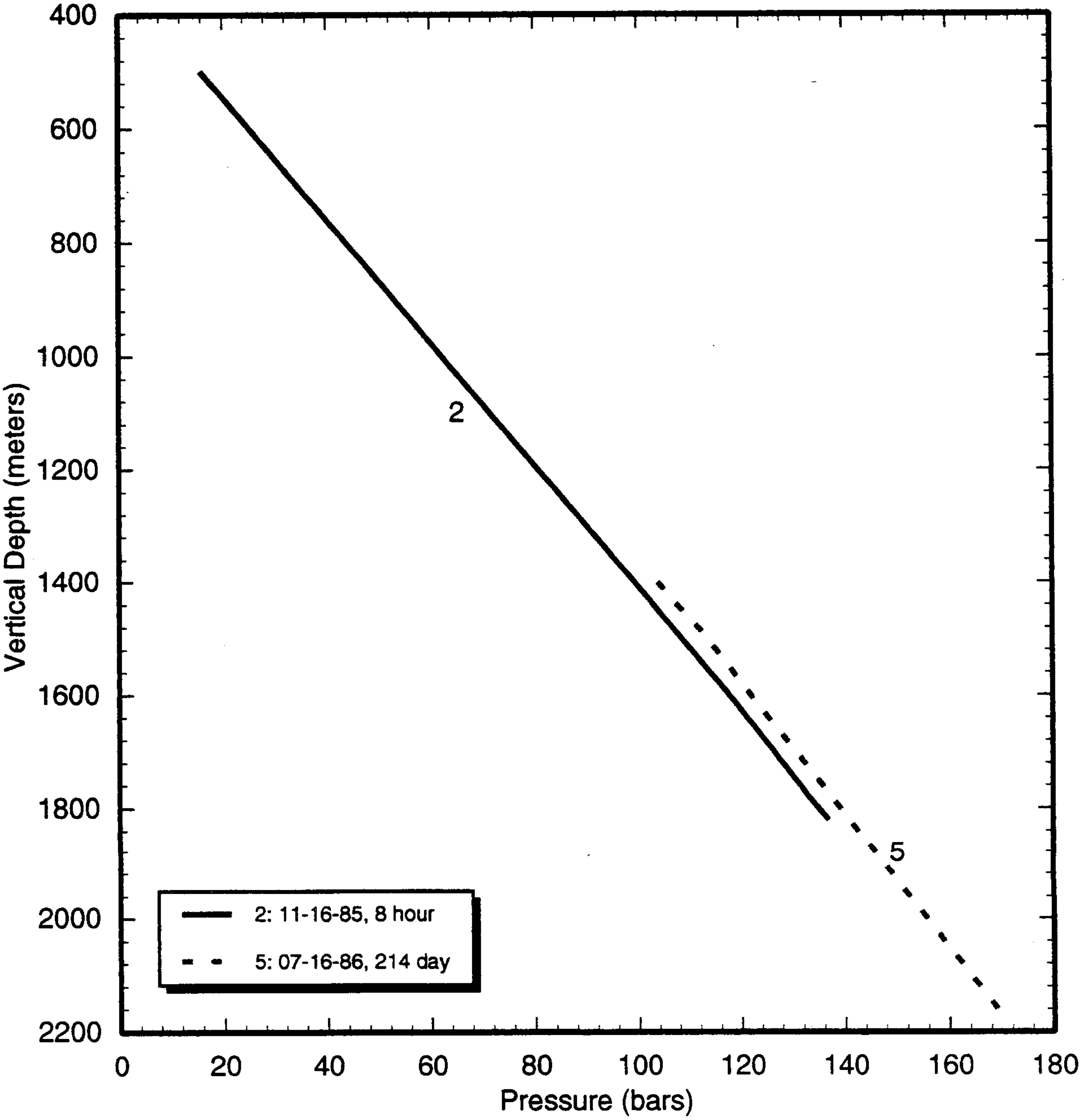

Figure 3.20. Pressure surveys in slim hole NE-10.

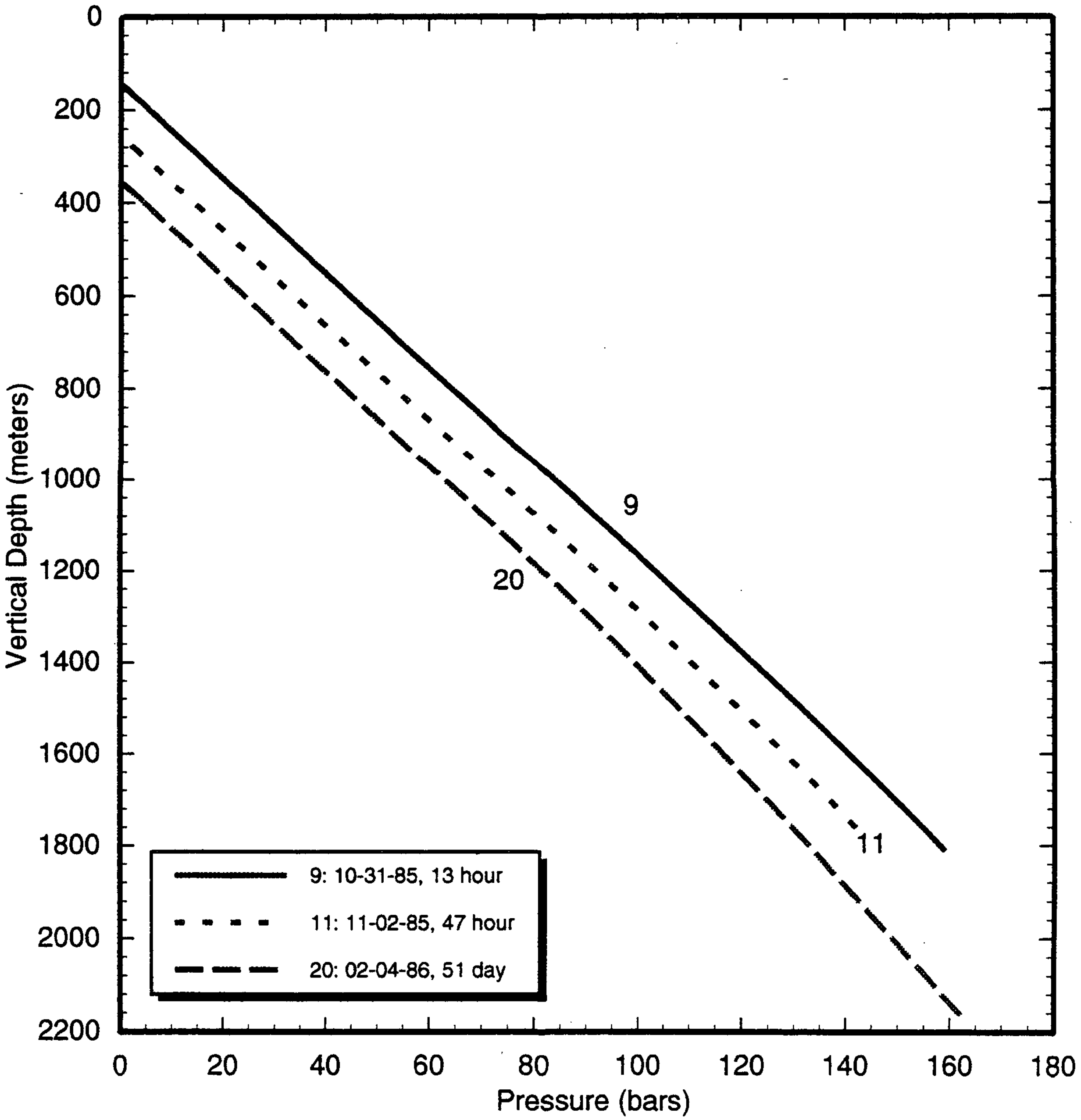

Figure 3.21. Pressures computed from water level and temperature data in slim hole NE-10.

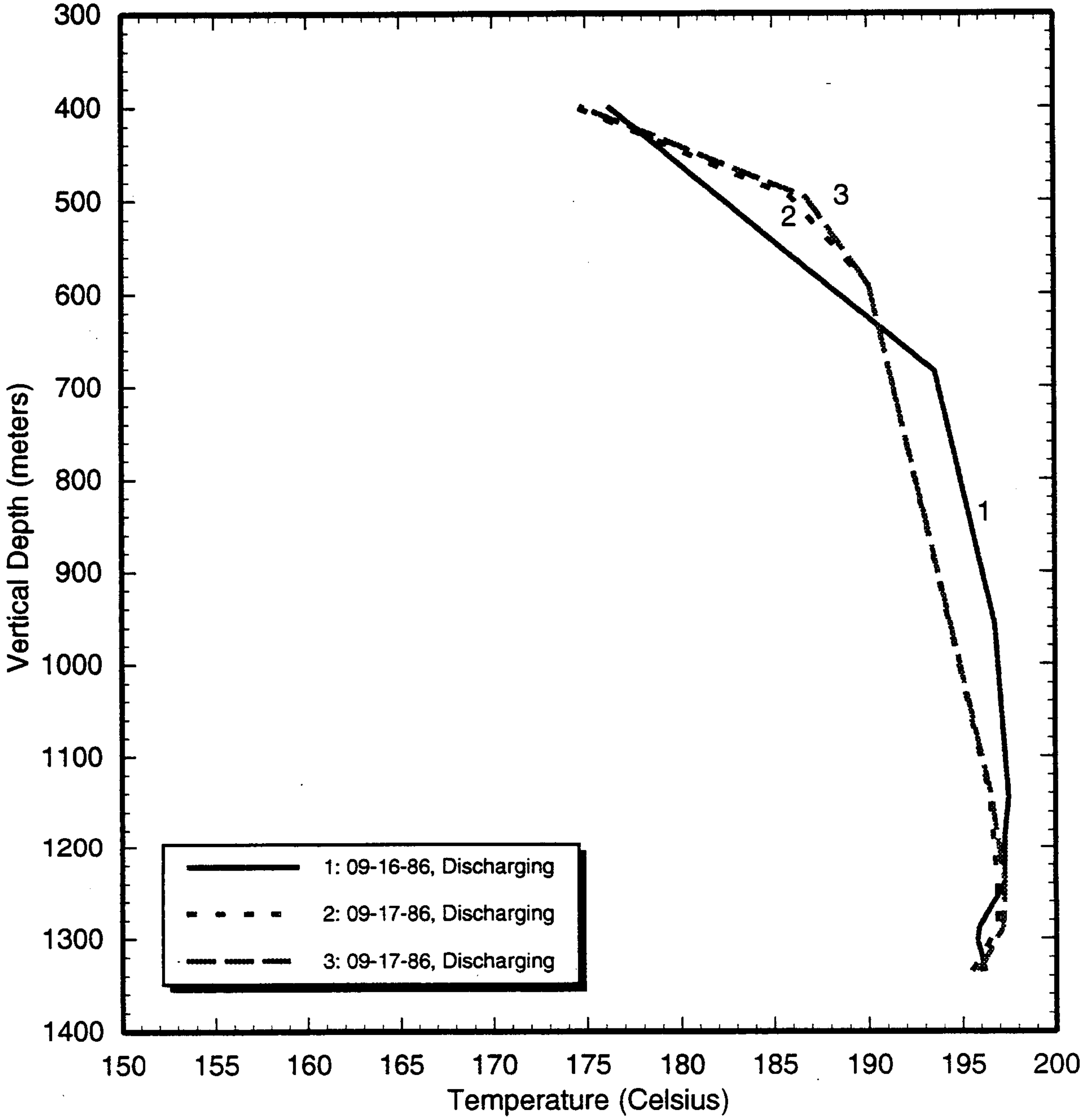

Figure 3.22. Temperature surveys in slim hole NE-11.

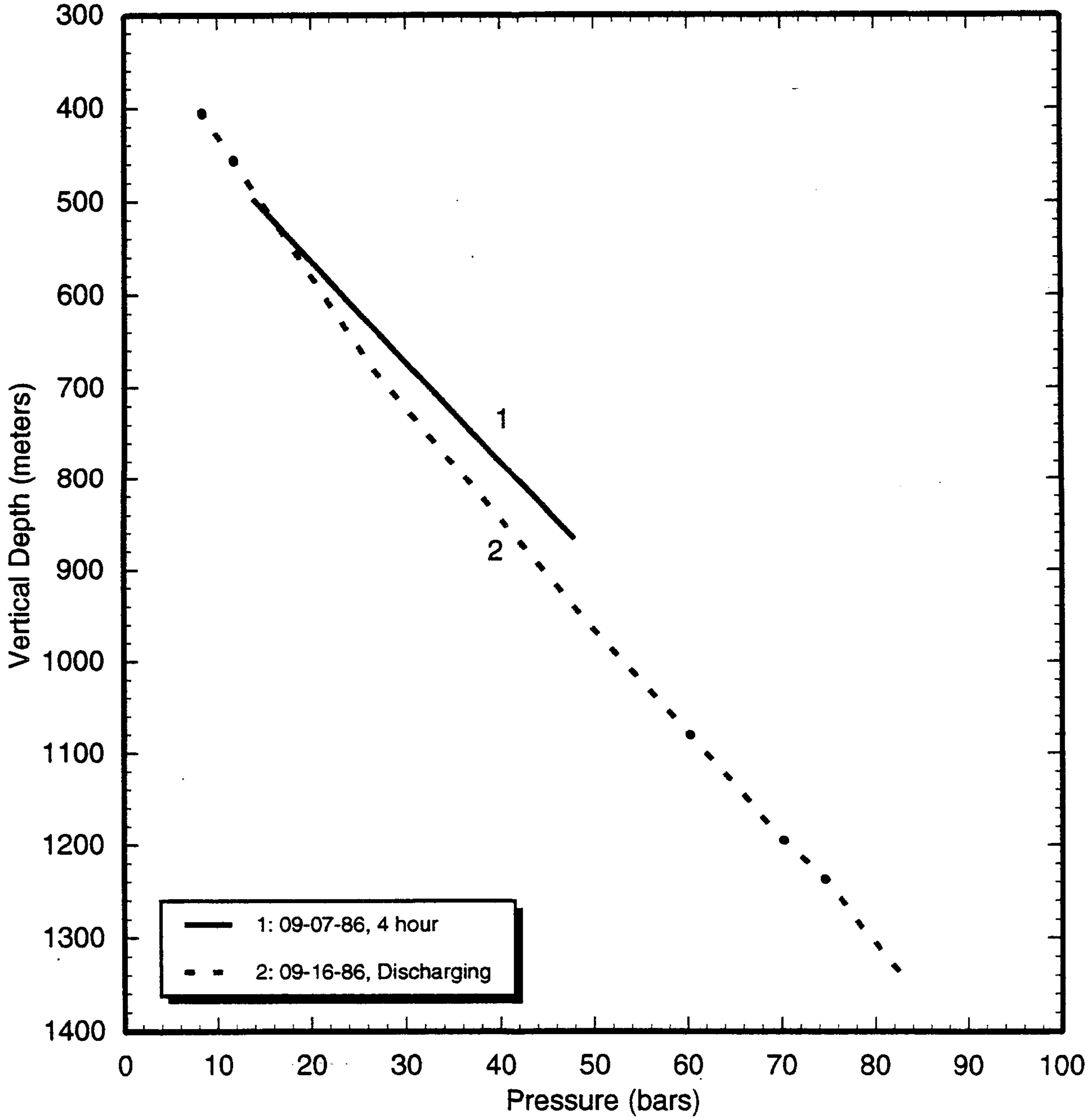

Figure 3.23. Pressure surveys in slim hole NE-11.

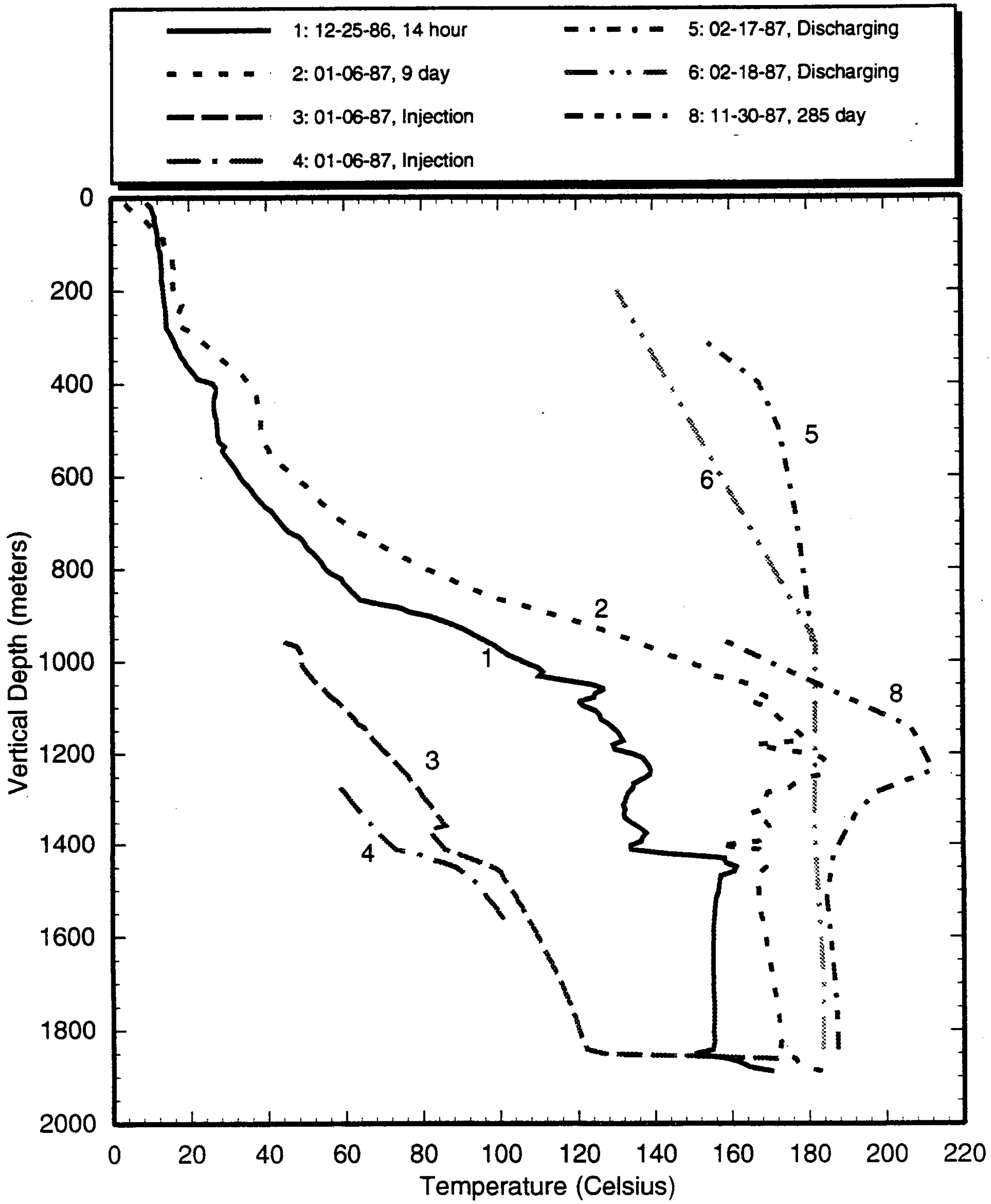

Figure 3.24. Temperature surveys in slim hole NE-11R.

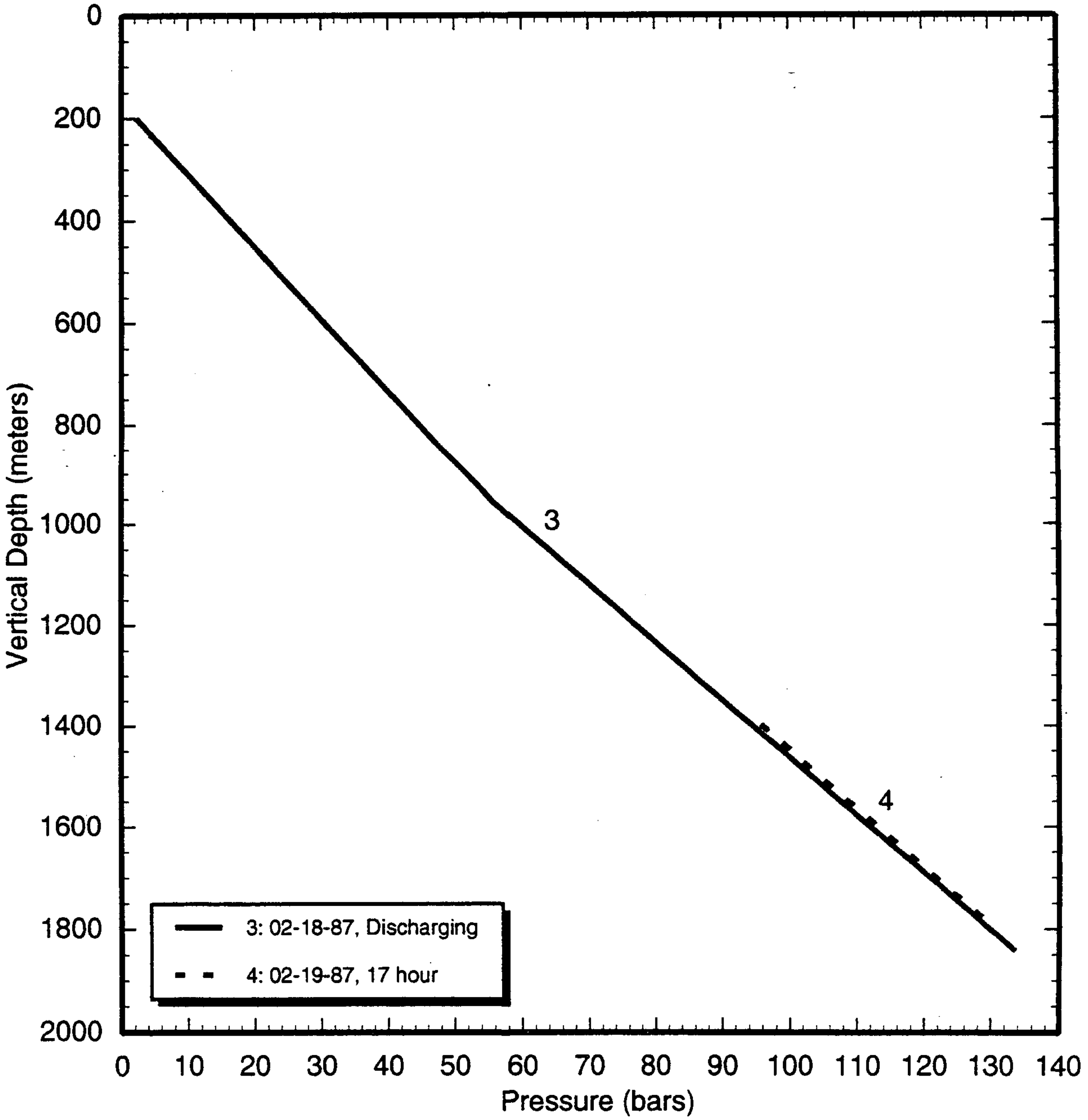

Figure 3.25. Pressure surveys in slim hole NE-11R.

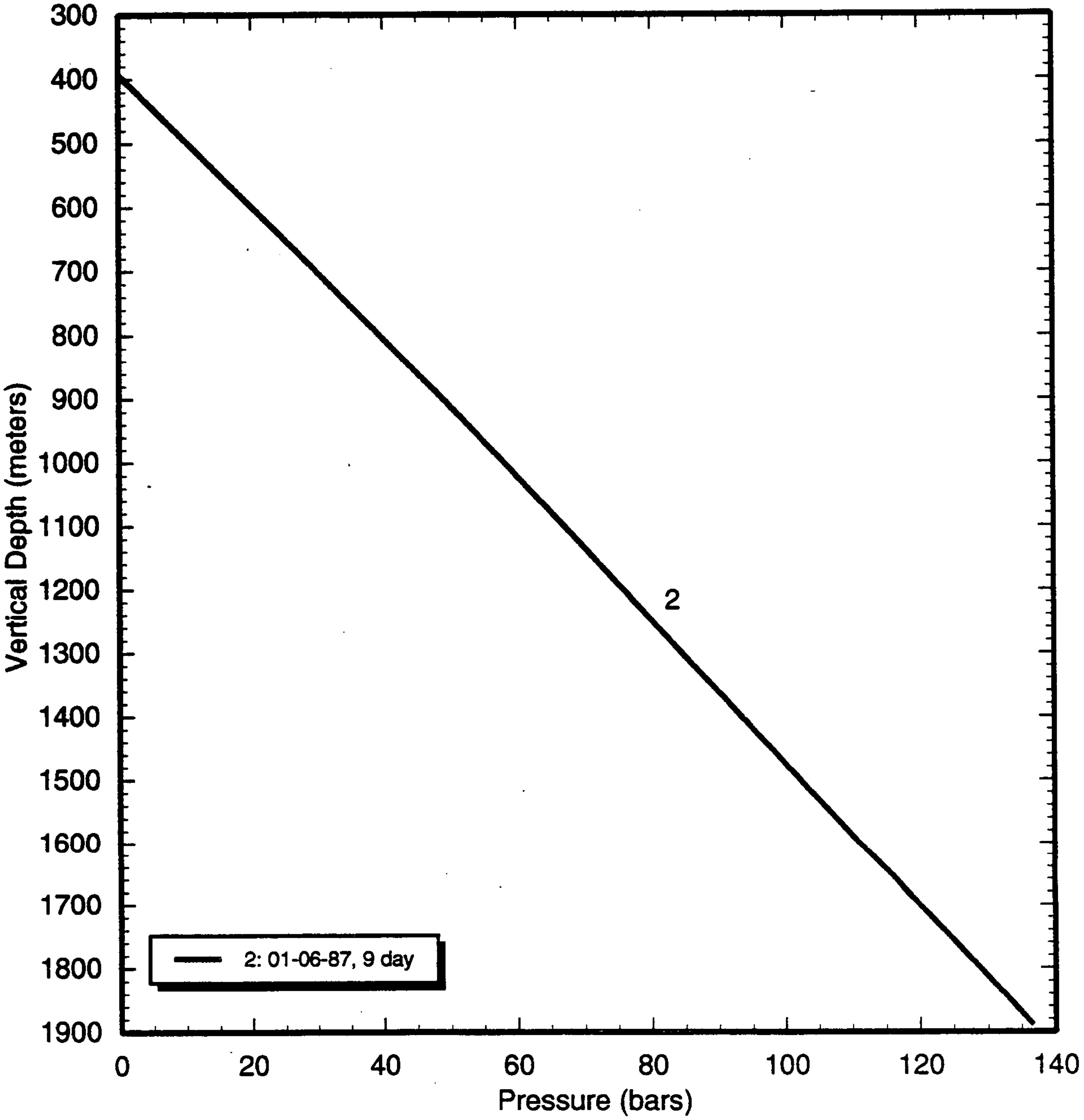

Figure 3.26. Pressures computed from water level and temperature data in slim hole NE-11R.

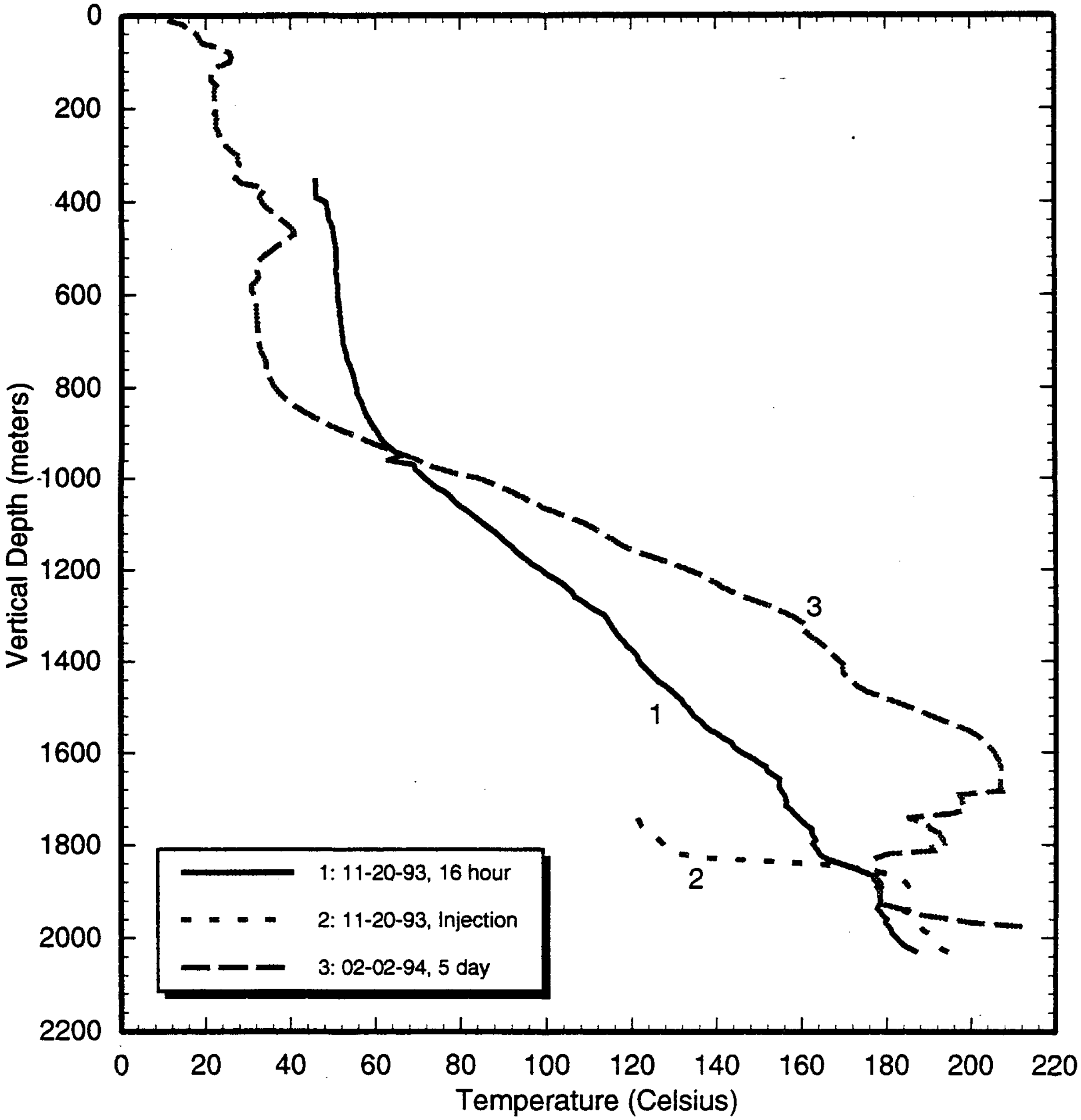

Figure 3.27. Temperature surveys in well TP-1.

Pressures computed from water level and temperature data are displayed in Figure 3.28; the pressure at 1820 m TVD (–995.5 m ASL) is about 134 bars.

Well TT-1

A temperature survey taken during an injection test on November 16, 1983 displays a large change in temperature gradient at ~2970 m TVD (Figure 3.29); this identifies the principal feedzone for well TT-1. The feedzone temperature is about 202°C. The maximum temperature (215°C) occurs at a depth of about 2200 m TVD.

Selected pressure profiles for TT-1 are shown in Figure 3.30. The static pressure measurements in TT-1 exhibit a great variability. The pressure at 2970 m TVD (–2261.5 m ASL) is ~244(±4) bars.

Well TT-2

The temperature survey taken on January 25, 1984 after an injection test (Figure 3.31) shows a cold zone centered at ~1580 m TVD; this identifies the principal feedzone for TT-2. A total circulation loss zone was encountered nearby at a depth of ~1607 m TVD. The feedzone location at 1580 m TVD is confirmed by a change in temperature gradient at this depth in the temperature survey of April 18, 1984. Although the temperature survey of June 3, 1984 during a discharge test extends to a depth of only ~1545 m TVD, these temperature data are consistent with the production of liquid (temperature: ~200°C) from the feedzone at 1580 m TVD. The long shutin time temperature survey recorded on August 23, 1993 indicates that the feedzone temperature may be somewhat higher (~205°C) than that indicated by the June 3, 1984 temperature survey.

A shutin pressure survey recorded with Kuster gauge 24021 on March 8, 1985 (Figure 3.32) gave a pressure of 119.5 bars at 1580 m TVD. There are indications (see preceding discussion for slim hole NE-2R) that pressures surveys taken with this particular gauge in March 1985 are not reliable. Pressures computed from water level and temperature data of August 23, 1993 are shown in Figure 3.33; the pressure at 1580 m TVD (–871.5 m ASL) is 122.5 bars.

Well TT-3

Temperature surveys recorded on April 11, 1984 (shutin time: 12 hours) and April 12, 1984 (shutin time: 8 hours) show a cold zone centered at ~1880 m TVD (Figure 3.34). A major circulation zone was encountered nearby at ~1870 m TVD. In the absence of other data, it will be assumed that the major entry for TT-3 is located at 1880 m TVD.

A pressure survey taken on April 19, 1984 is shown in Figure 3.35; the pressure at 1880 m TVD (–1171.5 m ASL) is about 149 bars. The latter pressure value is in good agreement with that (150 bars) computed from water level and temperature data (Figure 3.36).

Well TT-7

Well TT-7 was drilled with a large circulation loss below a depth of ~1070 m TVD. A temperature survey recorded on December 16, 1990 (Figure 3.37) exhibited a large change in temperature between ~1065 m TVD and ~1076 m TVD. The authors do not know if cold water was being injected into well TT-7 on December 16, 1990. The temperature survey recorded on August 29, 1986 extends to a depth of only ~700 m TVD; these temperature data are consistent with the discharge of liquid water (temperature > 206°C) from a feedzone deeper than 700 m TVD. In the absence of other data, it shall be assumed that the principal fluid entry for TT-7 is located at about 1070 m TVD. The maximum temperature occurs towards bottomhole and is ~217°C.

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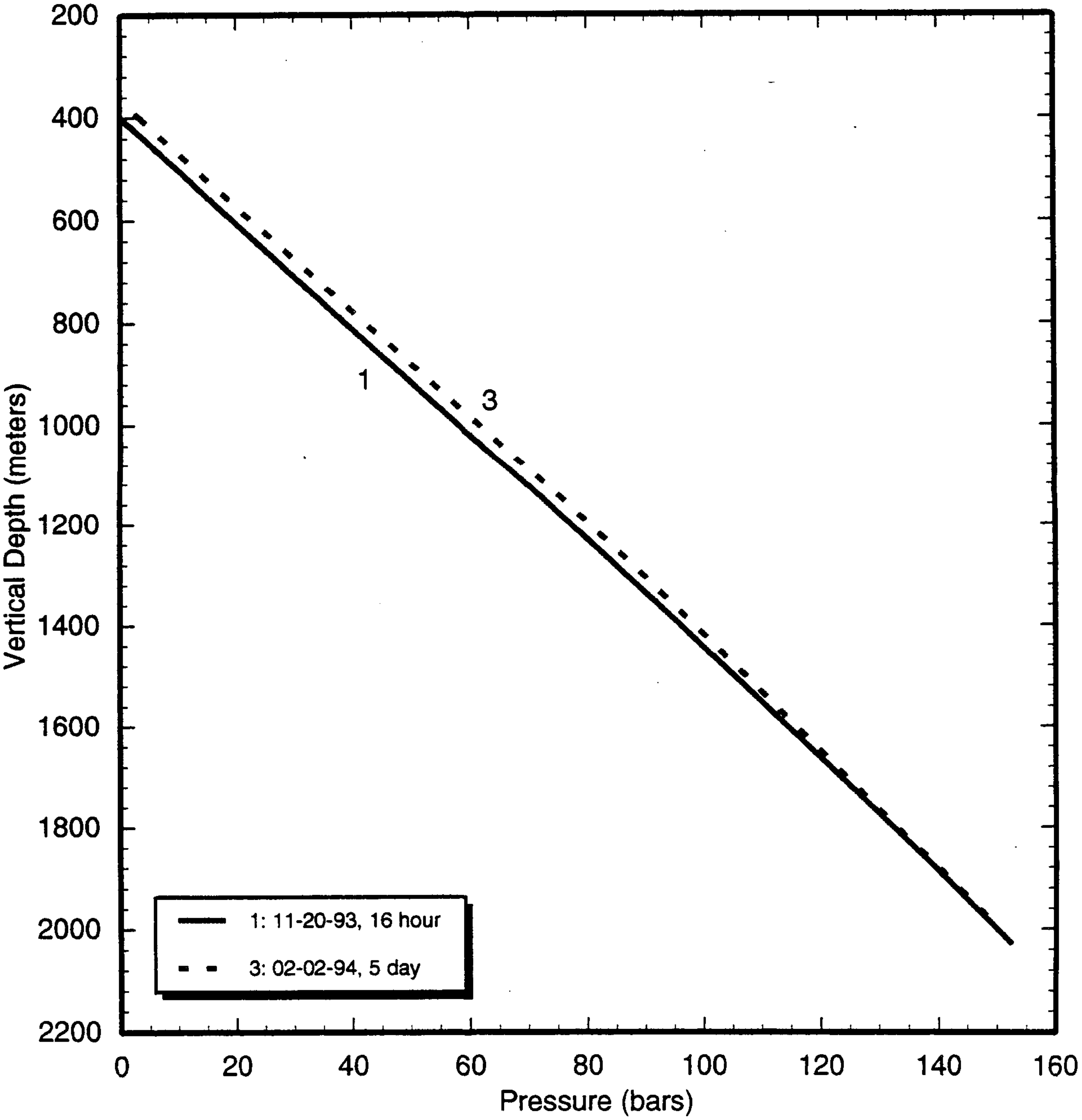

Figure 3.28. Pressures computed from water level and temperature data in well TP-1

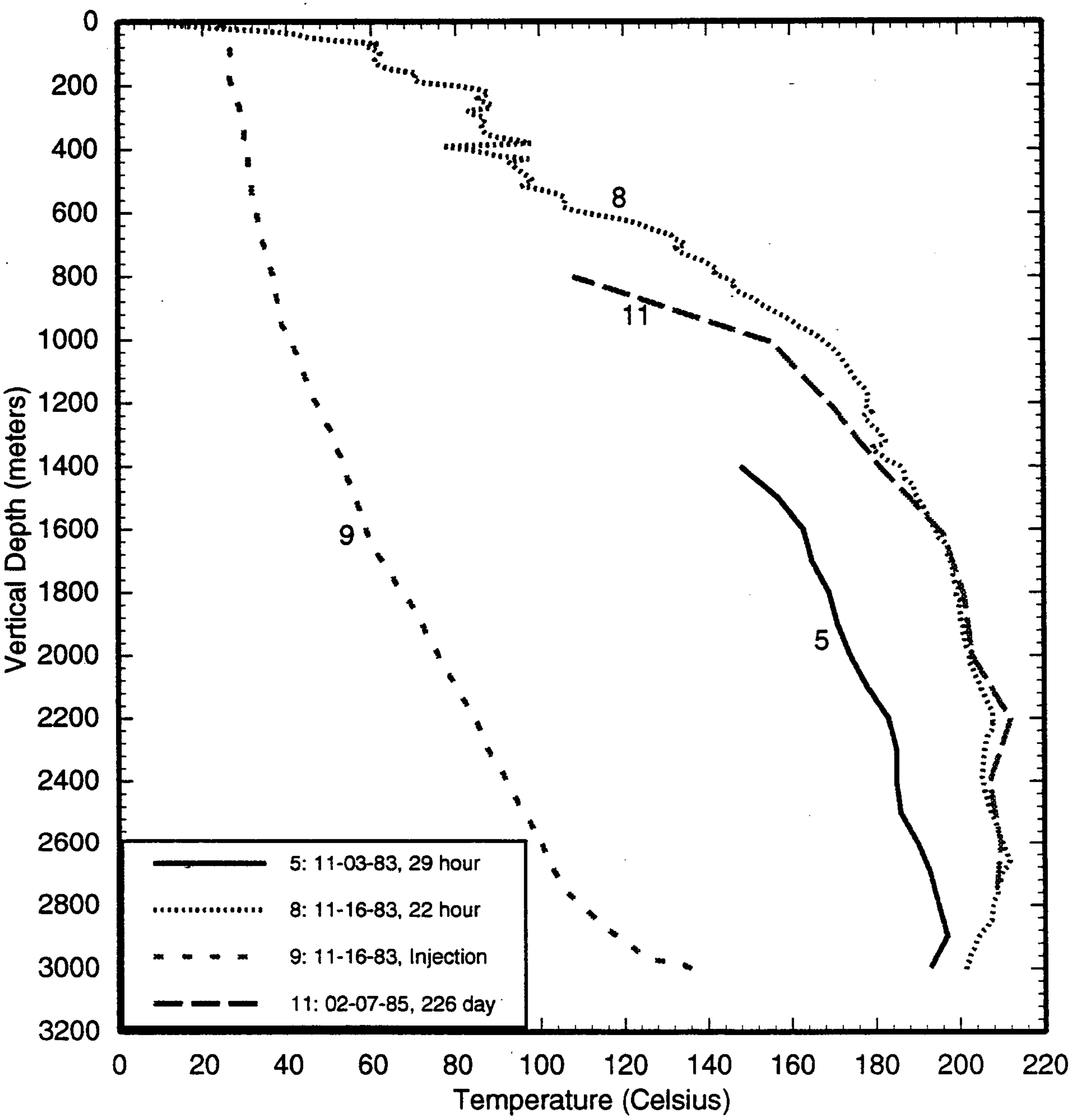

Figure 3.29. Temperature surveys in well TT-1.

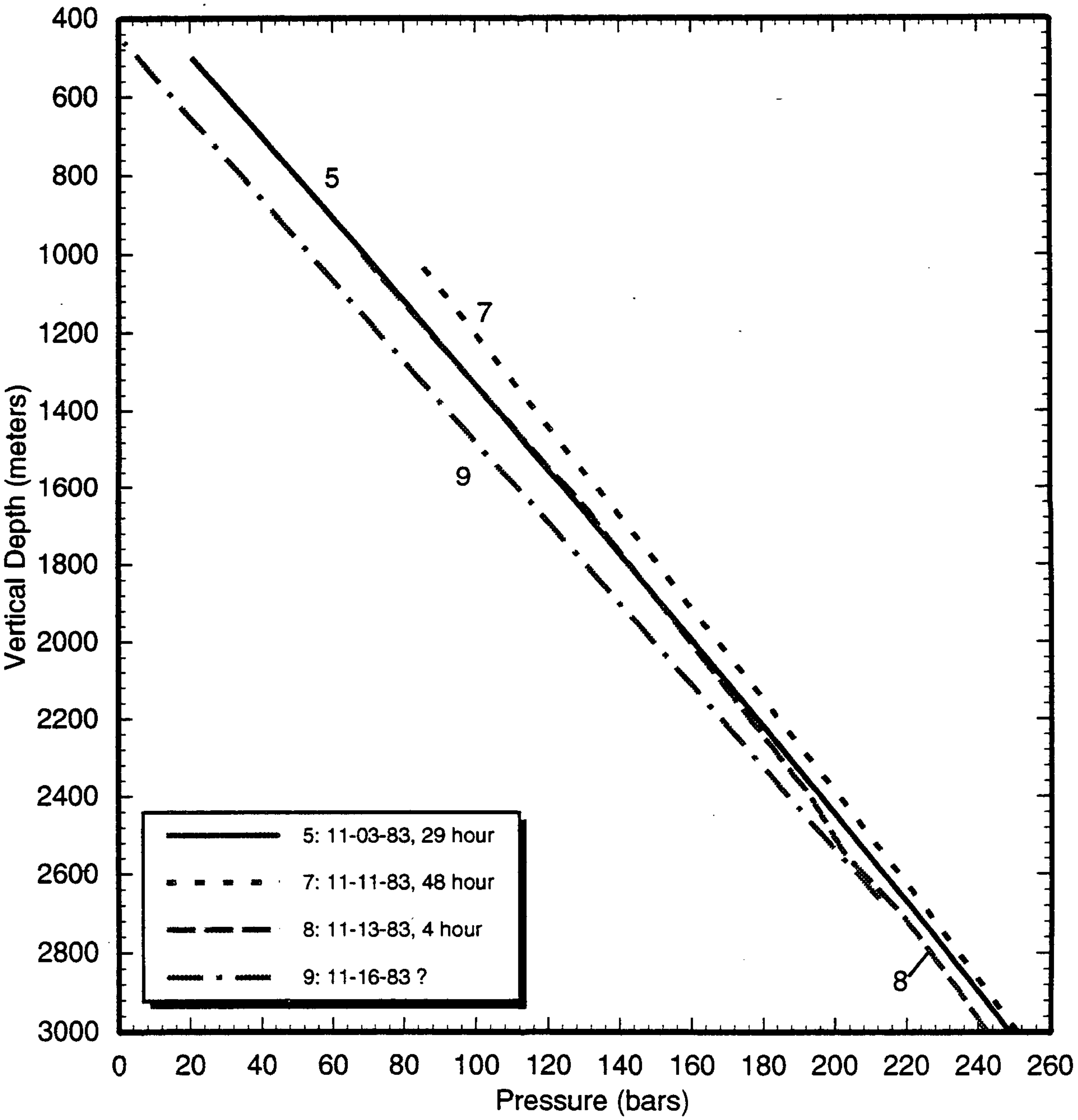

Figure 3.30. Pressure surveys in well TT-1.

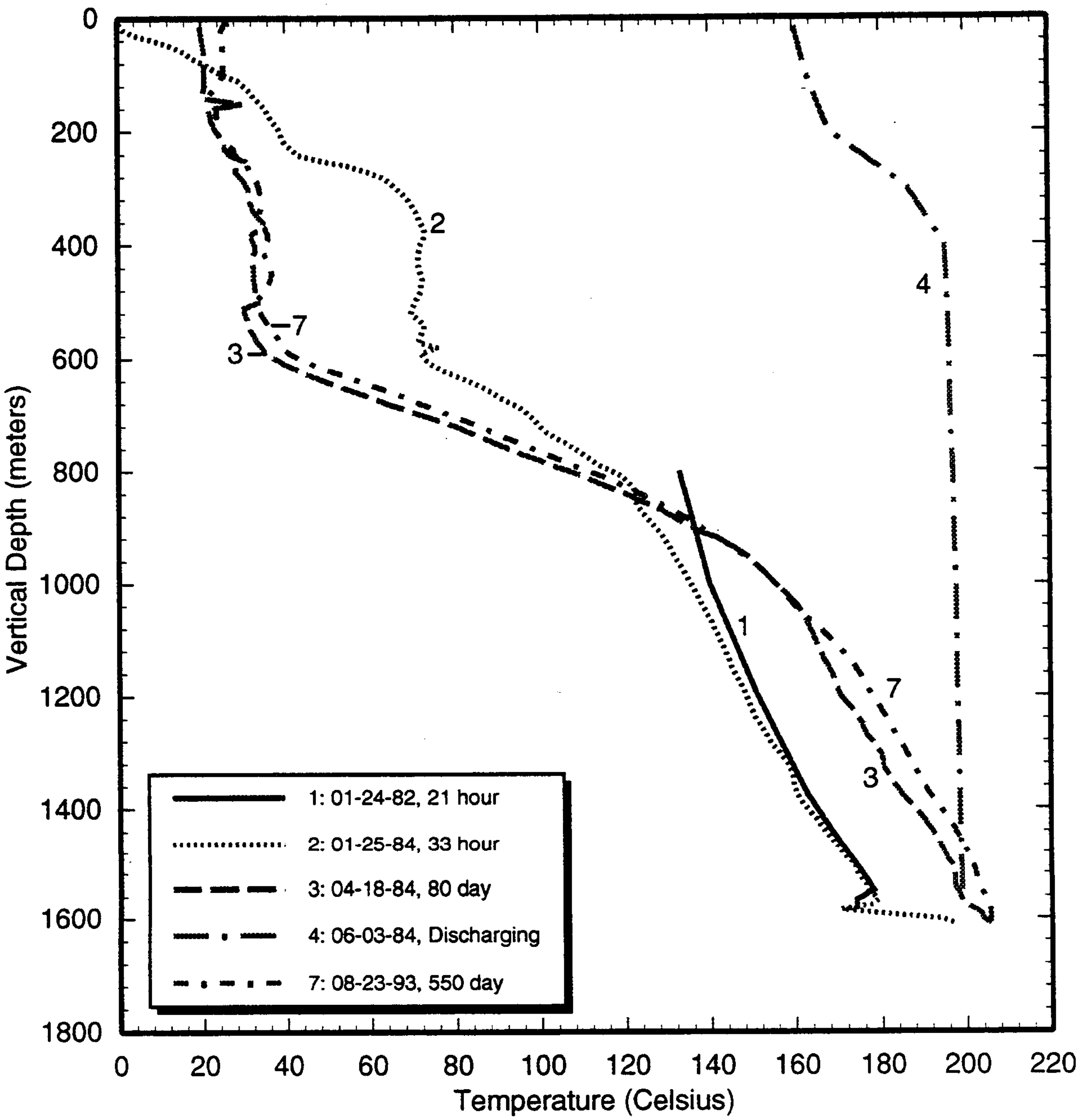

Figure 3.31. Temperature surveys in well TT-2.

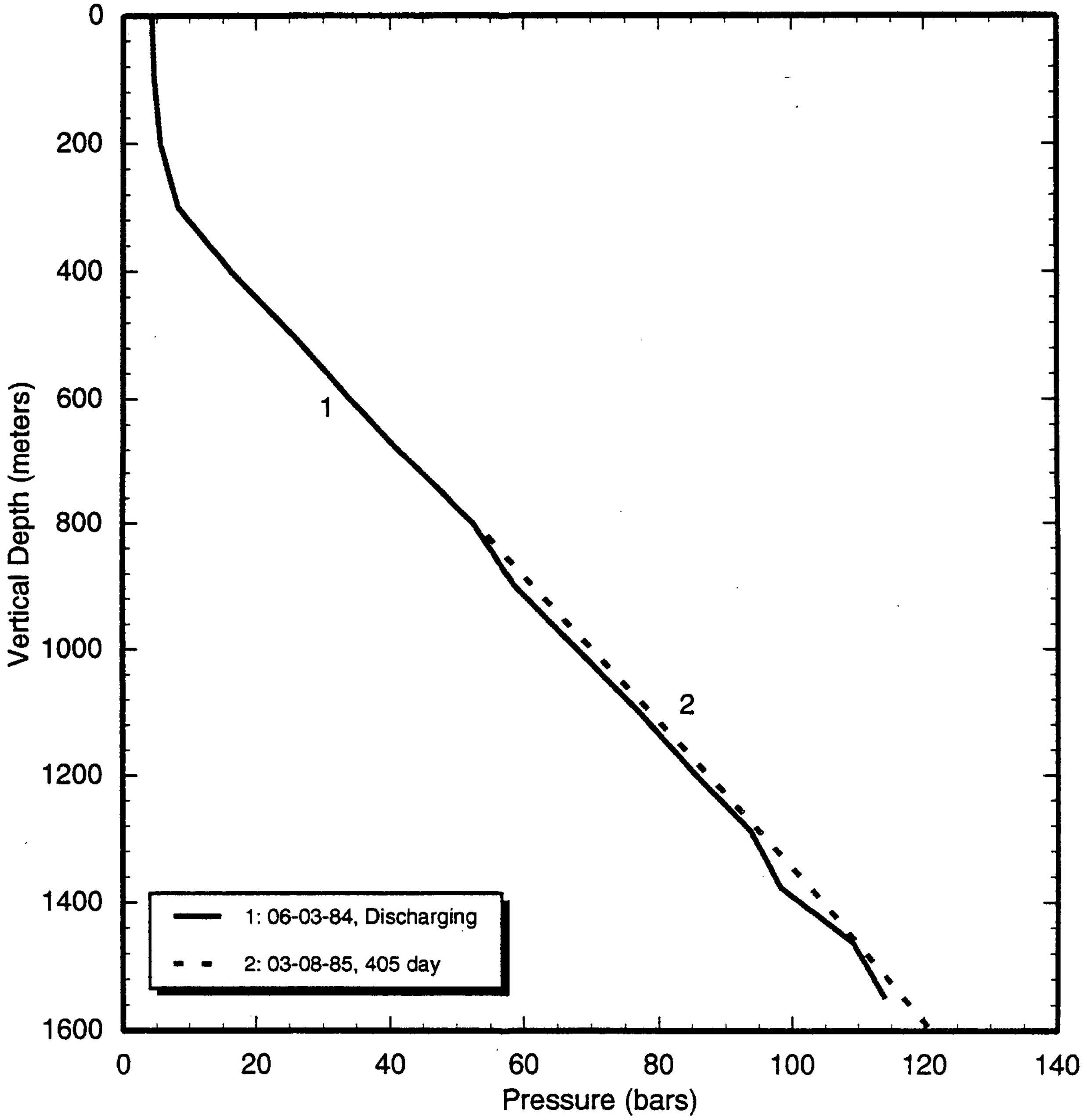

Figure 3.32. Pressure surveys in well TT-2.

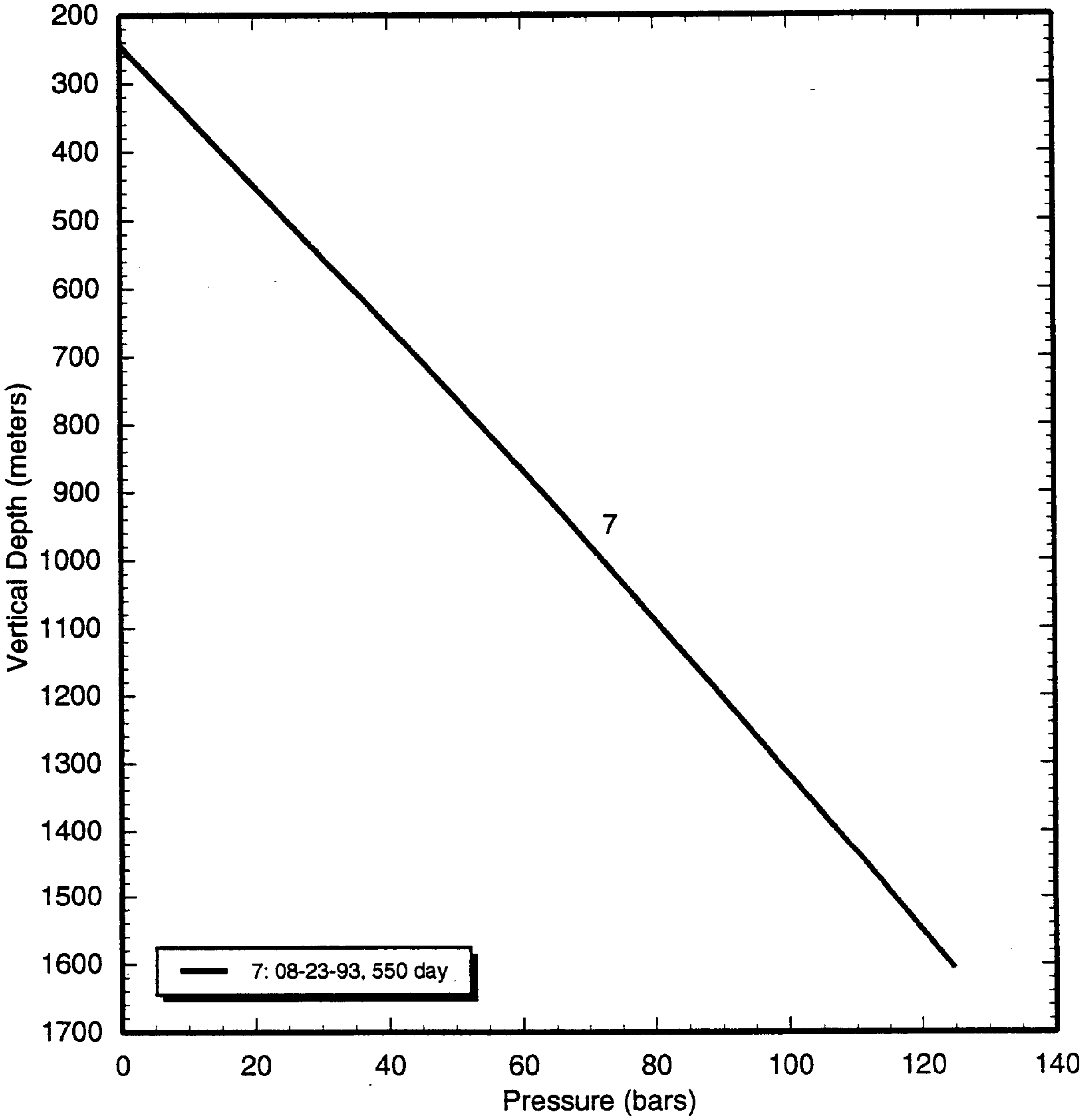

Figure 3.33. Pressures computed from water level and temperature data in well TT-2.

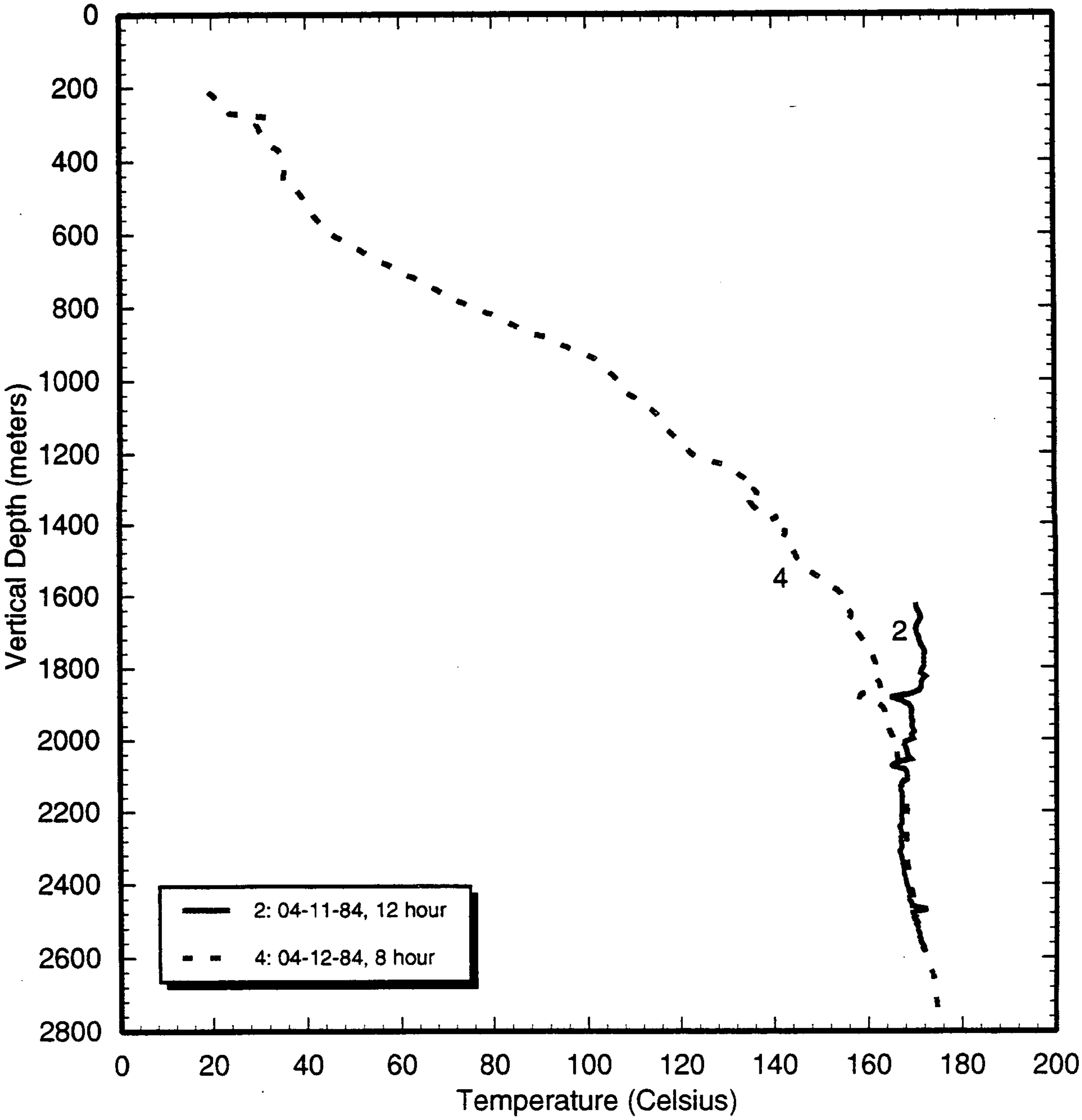

Figure 3.34. Temperature surveys in well TT-3.

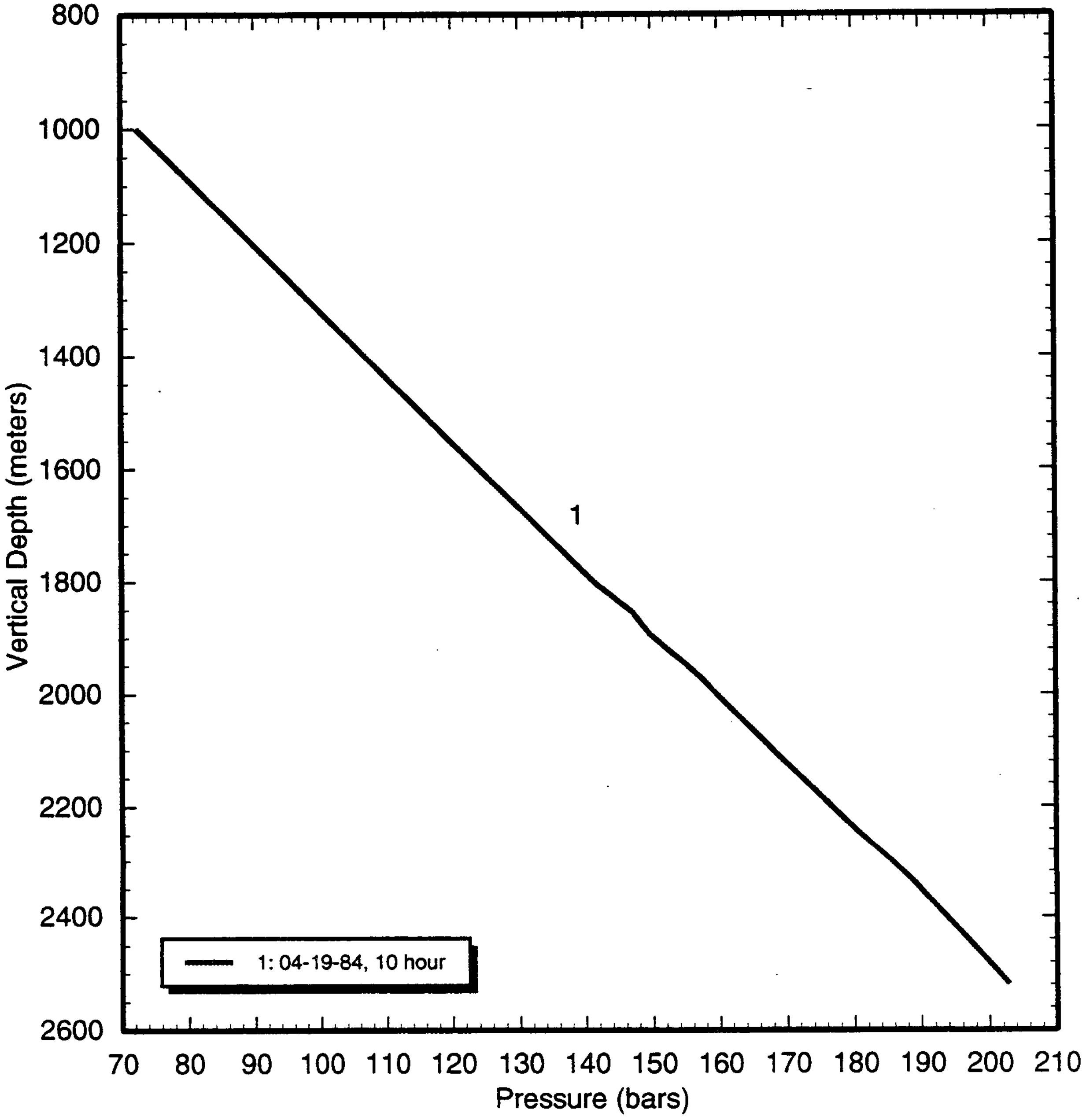

Figure 3.35. A pressure survey recorded in well TT-3 on April 19, 1984.

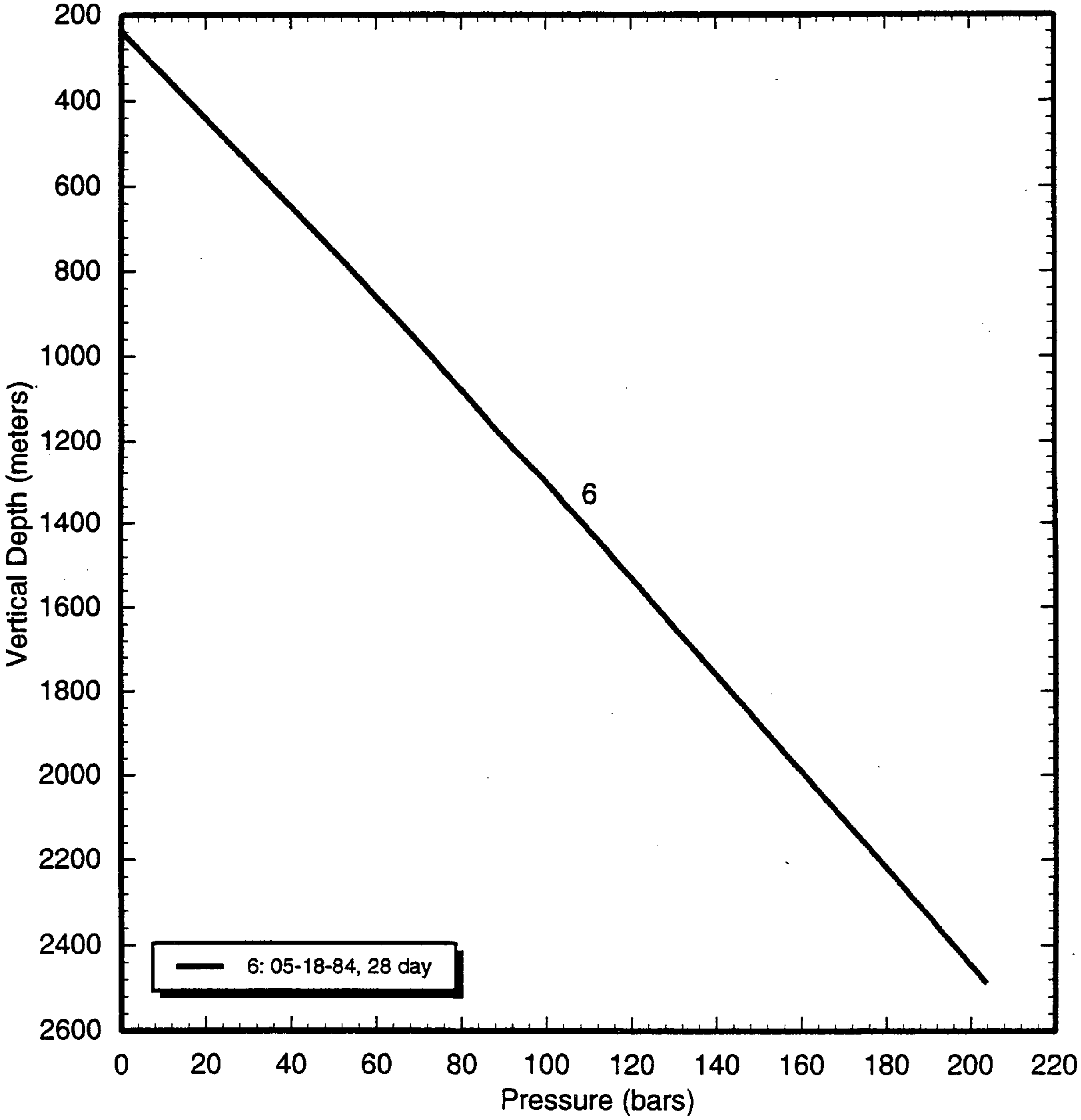

Figure 3.36. Pressures computed from water level and temperature data in well TT-3.

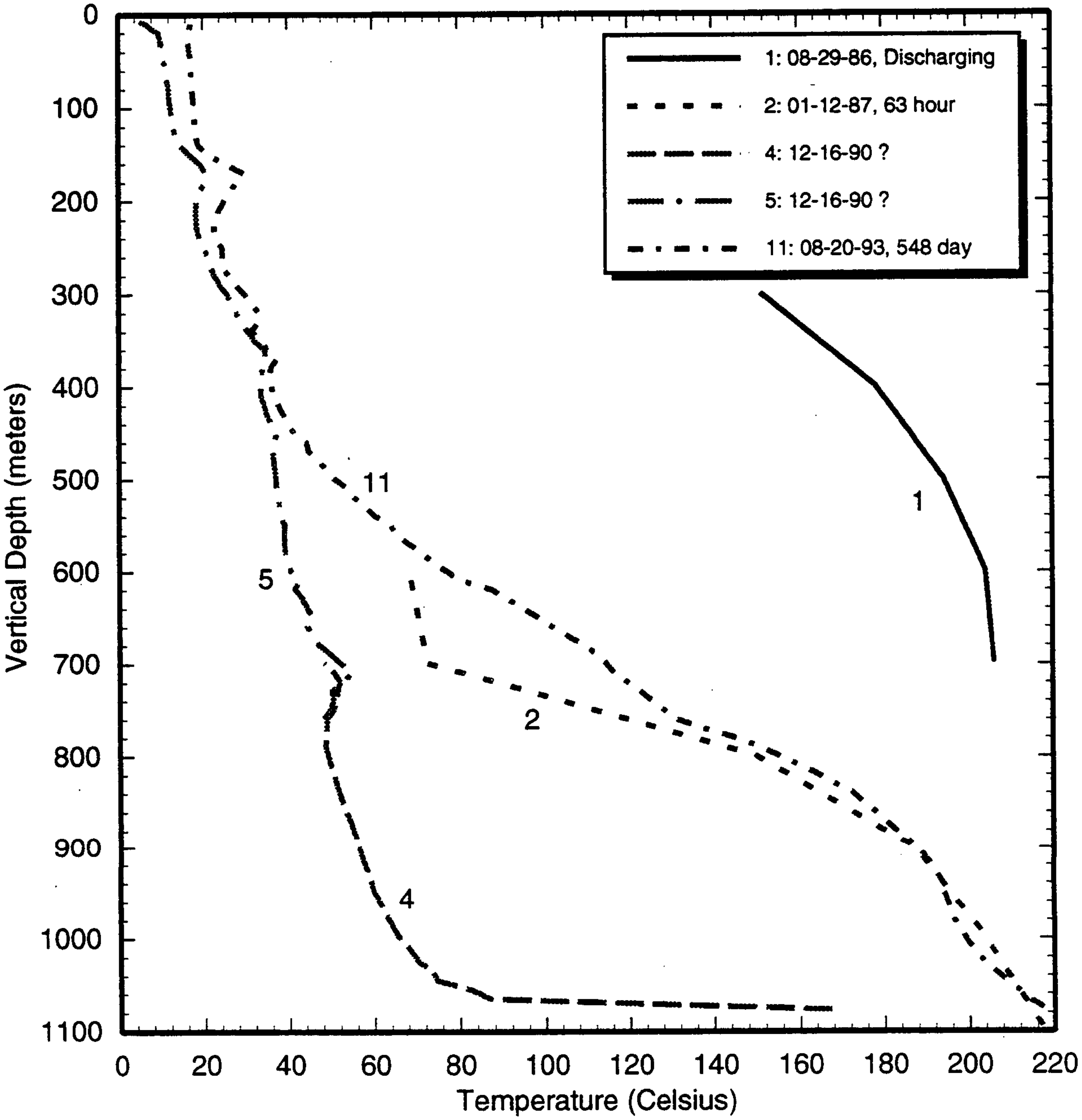

Figure 3.37. Temperature surveys in well TT-7.

The pressure survey taken on August 22, 1986 (Figure 3.38) does not extend to the feedzone depth; extrapolating the pressure data, the feedzone pressure (feedzone depth= 1070 m TVD= –197.5 m ASL) is estimated to be 64 bars. The latter pressure value is in good agreement with that (~64.5 bars) computed from water level and temperature data (Figure 3.39).

Well TT-8

After the well was drilled to a depth of 854.4 m MD (854.2 m TVD; open interval below 822.3 m TVD), both injection and discharge tests were performed in late August and early September 1986. Available temperature and pressure surveys are shown in Figures 3.40 and 3.41, respectively. Pressure and temperature surveys taken during the discharge test on August 31, 1986 imply that the well produces from a liquid feedzone (temperature ~180°C) located below the measurement depth (791.3 m TVD). Well TT-8 was drilled with a large circulation loss over the depth interval from ~840 m TVD to ~854.5 m TVD. In the absence of other data, it will be assumed that the principal feedzone for TT-8 (at the time of August/September 1986 tests) is at ~840 m TVD (–76 m ASL).

A pressure profile computed from water level and temperature data is shown in Figure 3.42; the pressure at 840 m TVD (–76 m ASL) is 55.5 bars.

Well TT-8S1

Well TT-8S1 was drilled as a sidetrack from well TT-8. After TT-8S1 was drilled to a depth of 1224 m MD (= 1212.6 m TVD; 12-$^1/_4$ inch open hole below 822.3 m TVD), both injection and discharge tests were performed from October 4, 1986 to October 9, 1986. Drilling was then resumed and TT-8S1 was drilled to a final depth of 2202.8 m MD (1963.2 m TVD). In the depth interval from 820 m TVD to 1220 m TVD, large circulation losses were encountered at 840–913 m TVD and at 1200–1220 m TVD. The temperature survey recorded on December 1, 1986 (Figure 3.43) shows cold zones centered at ~870 m TVD and at ~1230 m TVD. An isothermal zone extending from ~900 m TVD to ~1210 m TVD can be seen in the temperature survey taken on October 9, 1986 after the discharge test; these temperature data imply permeability at 850–900 m TVD and at 1210–1220 m TVD. Although the temperature survey taken during the discharge test on October 7, 1986 does not extend below 800 m TVD, these temperature data are consistent with the production of liquid water (temperature ~162°C) from a feedzone (or feedzones) below 800 m TVD. Thus, it is likely that at the time of October 1986 test, the major feedzone for well TT-8S1 was located at 1050 (± 180) m TVD.

Available pressure surveys for TT-8S1 are displayed in Figure 3.44; the pressure at 1050 m TVD (–286 m ASL) is estimated to be ~70.5 bars.

Well TT-8S3

Well TT-8S3 was drilled as a sidetrack from well TT-8. Temperature surveys taken during well discharge on May 1, 1987 and April 6, 1988 (Figure 3.45) indicate that the well produces liquid water from a feedzone at or below ~1837 m TVD (depth of temperature surveys). Since a total circulation loss zone was encountered at 1875.9 m TVD (i.e. at bottomhole), it will be assumed that the principal feedzone for TT-8S3 is located at ~1870 m TVD. The feedzone temperature (see temperature surveys of April 6, 1988, October 22, 1988, and August 23, 1993) is ~214°C. A temperature inversion is seen in long shutin time temperature surveys; the maximum temperature (~224°C) occurs at a depth of ~1620 m TVD.

Available pressure surveys in well TT-8S3 are displayed in Figure 3.46. Extrapolating the pressure survey of November 25, 1987, the stable feedzone (at 1870 m TVD or –1106 m ASL) is estimated to be 142 bars. The latter pressure value is in good agreement with the pressure obtained (142.5 bars) from water level and temperature data (Figure 3.47).

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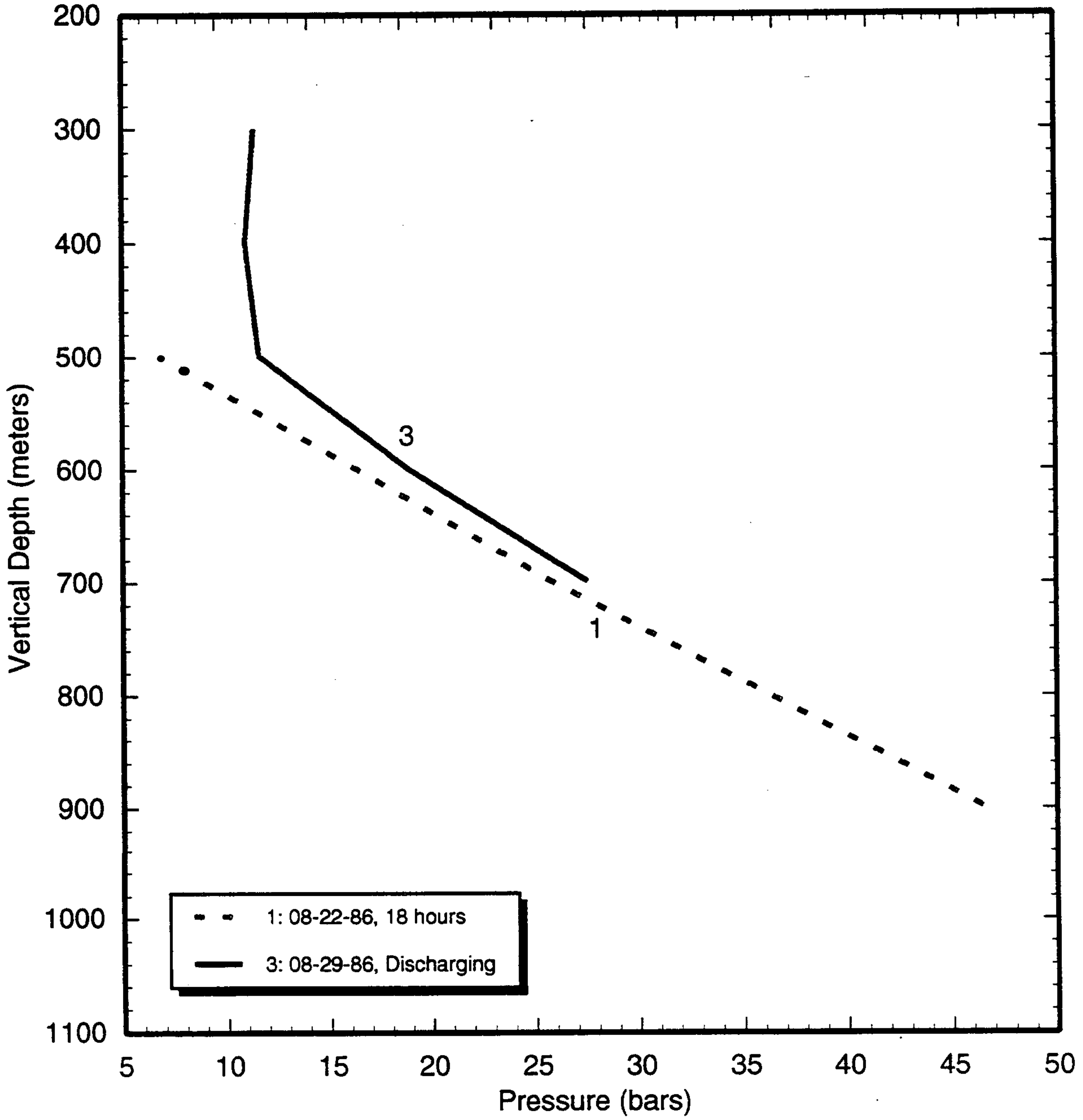

Figure 3.38. Pressure surveys in well TT-7.

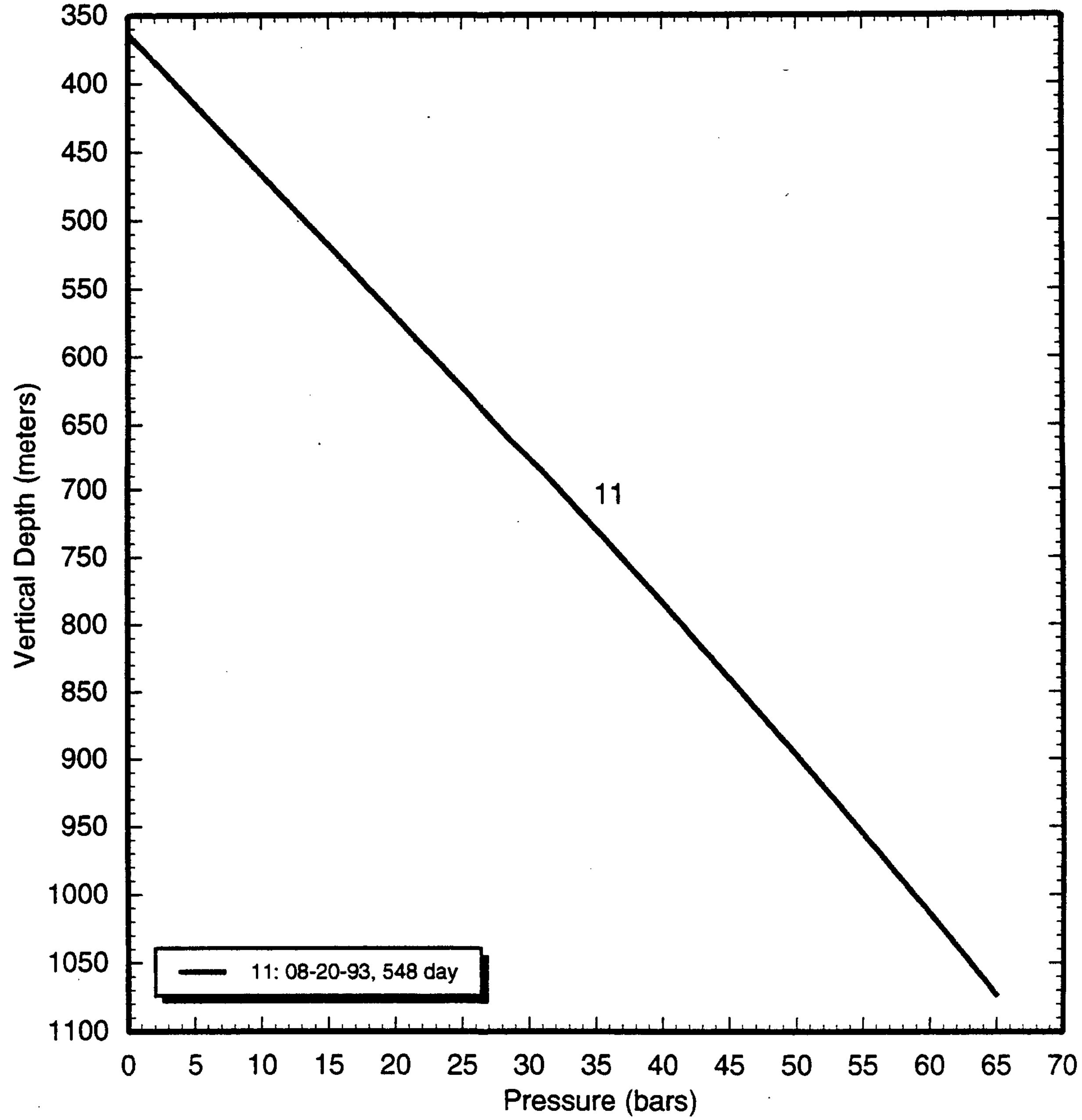

Figure 3.39. Pressures computed from water level and temperature data in well TT-7.

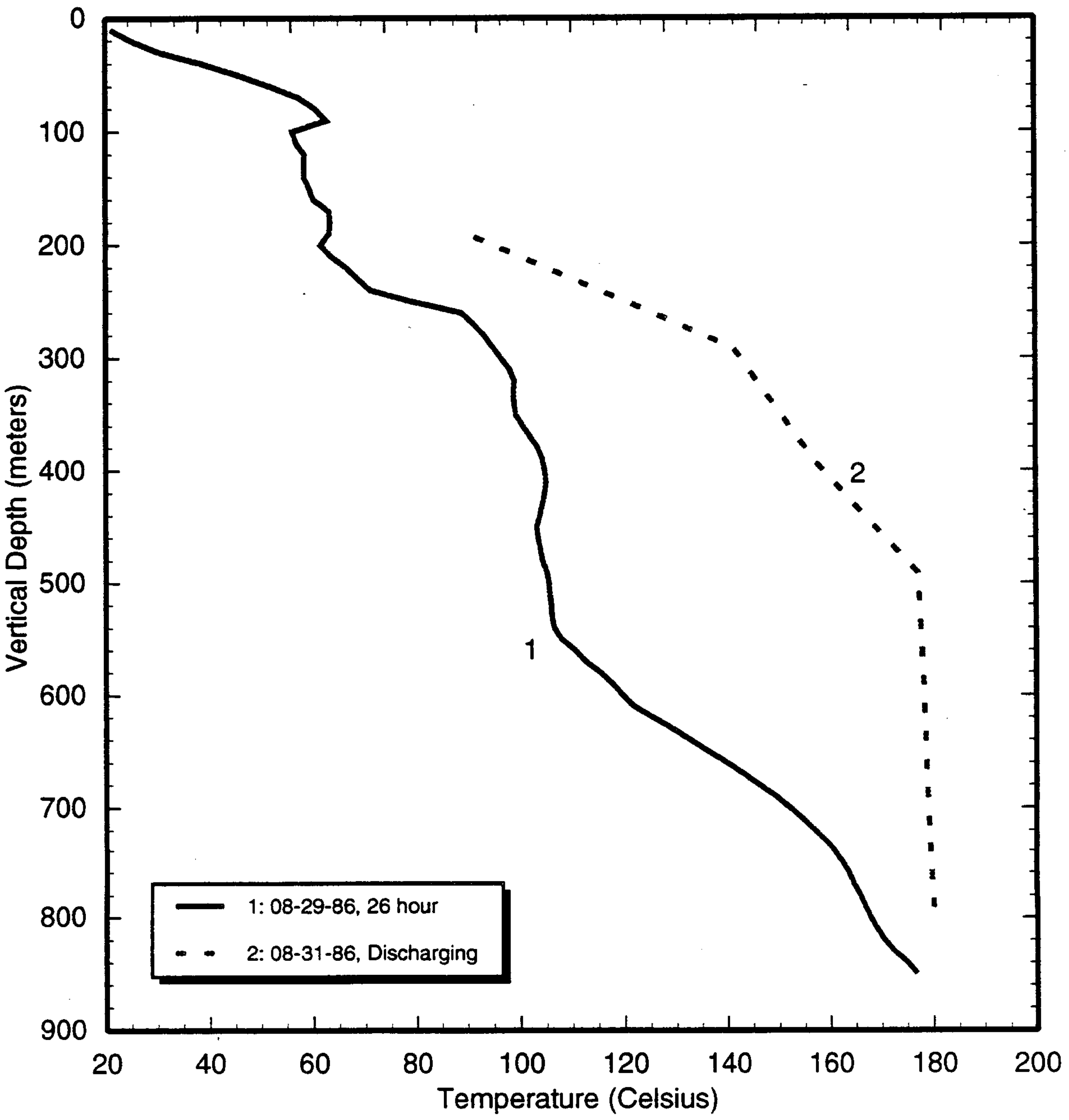

Figure 3.40. Temperature surveys in well TT-8.

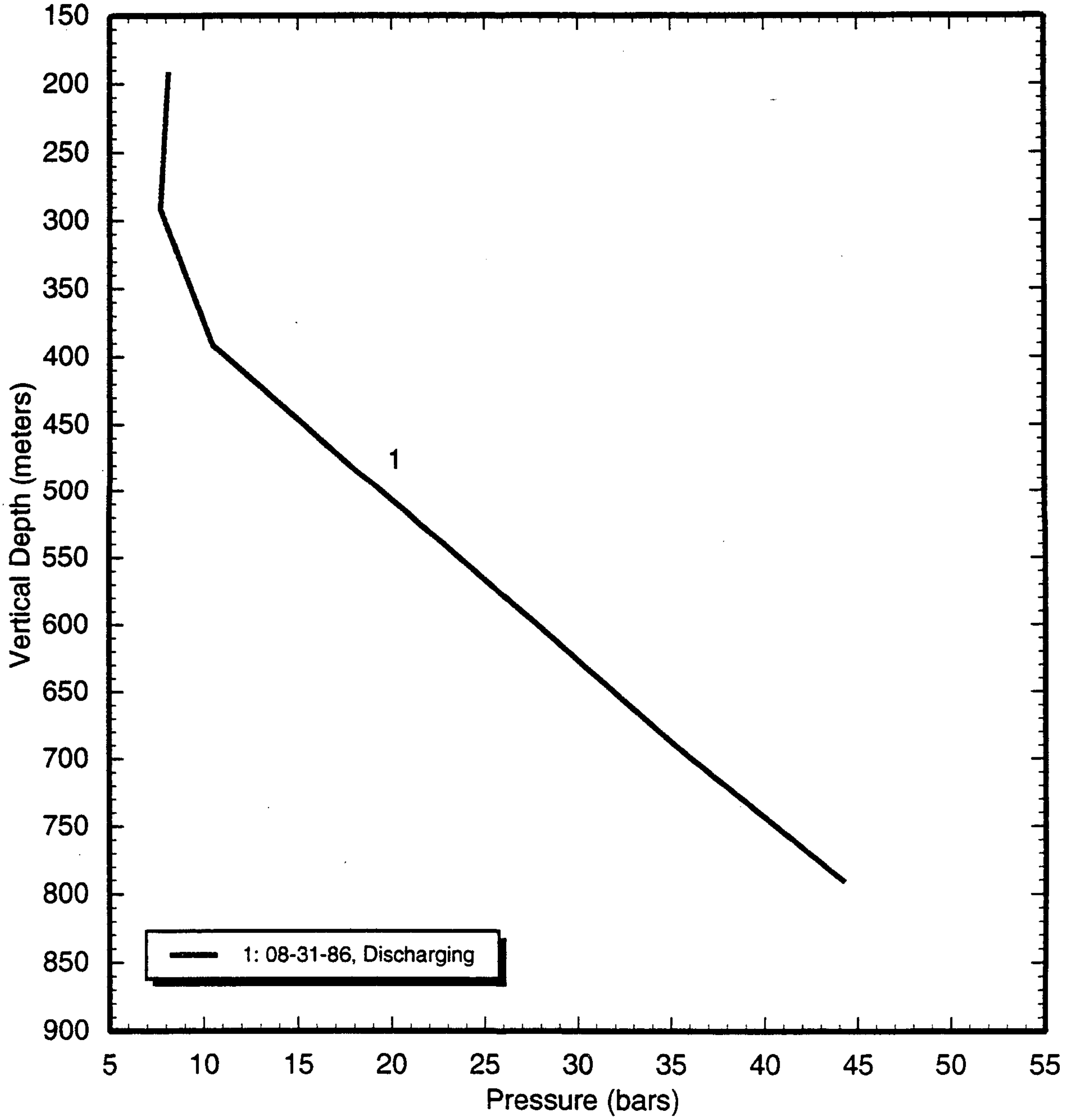

Figure 3.41. A pressure survey taken in well TT-8 during a discharge test on August 31, 1986.

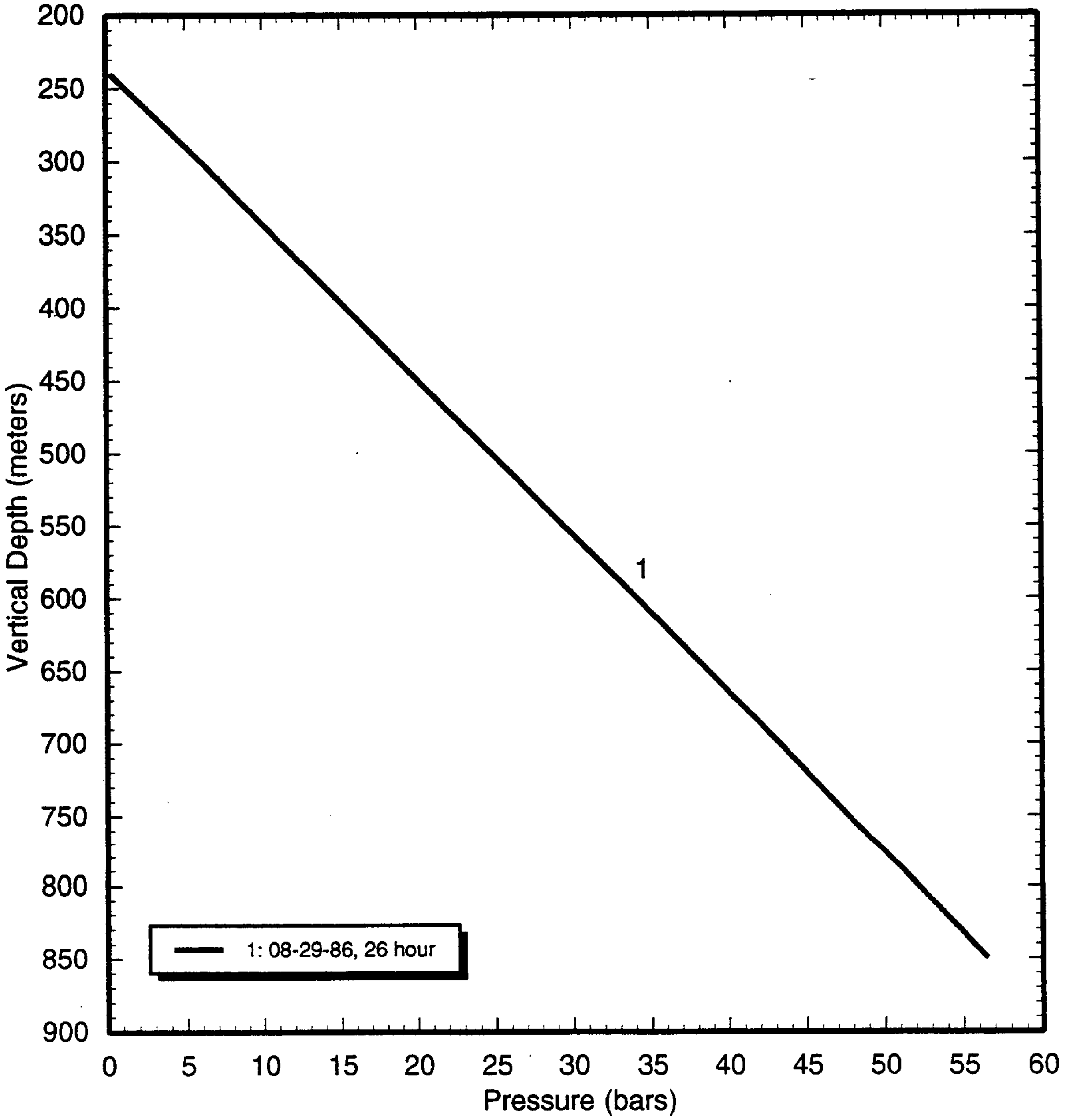

Figure 3.42. Pressures computed from water level and temperature data in well TT-8.

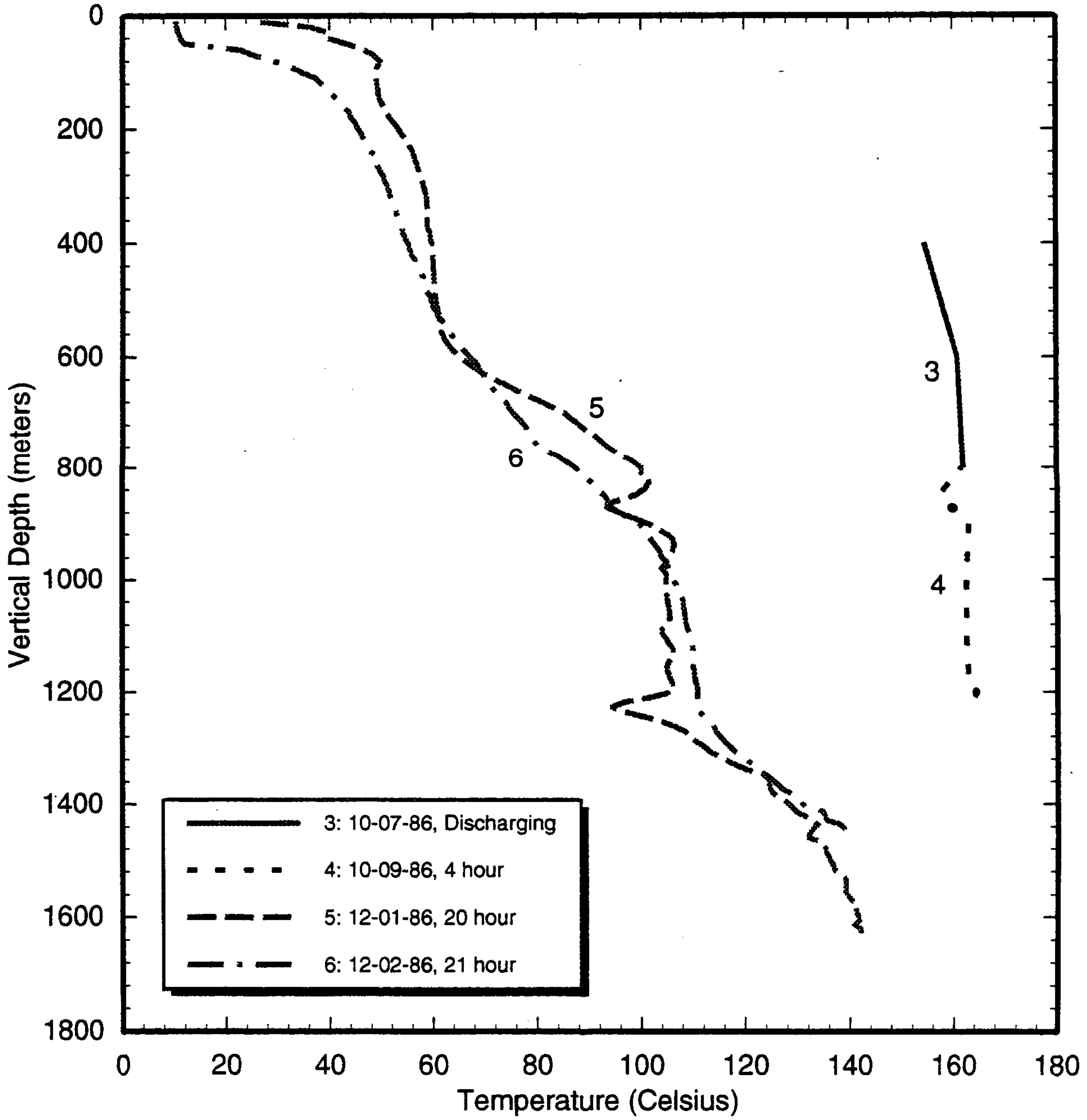

Figure 3.43. Temperature surveys in well TT-8S1.

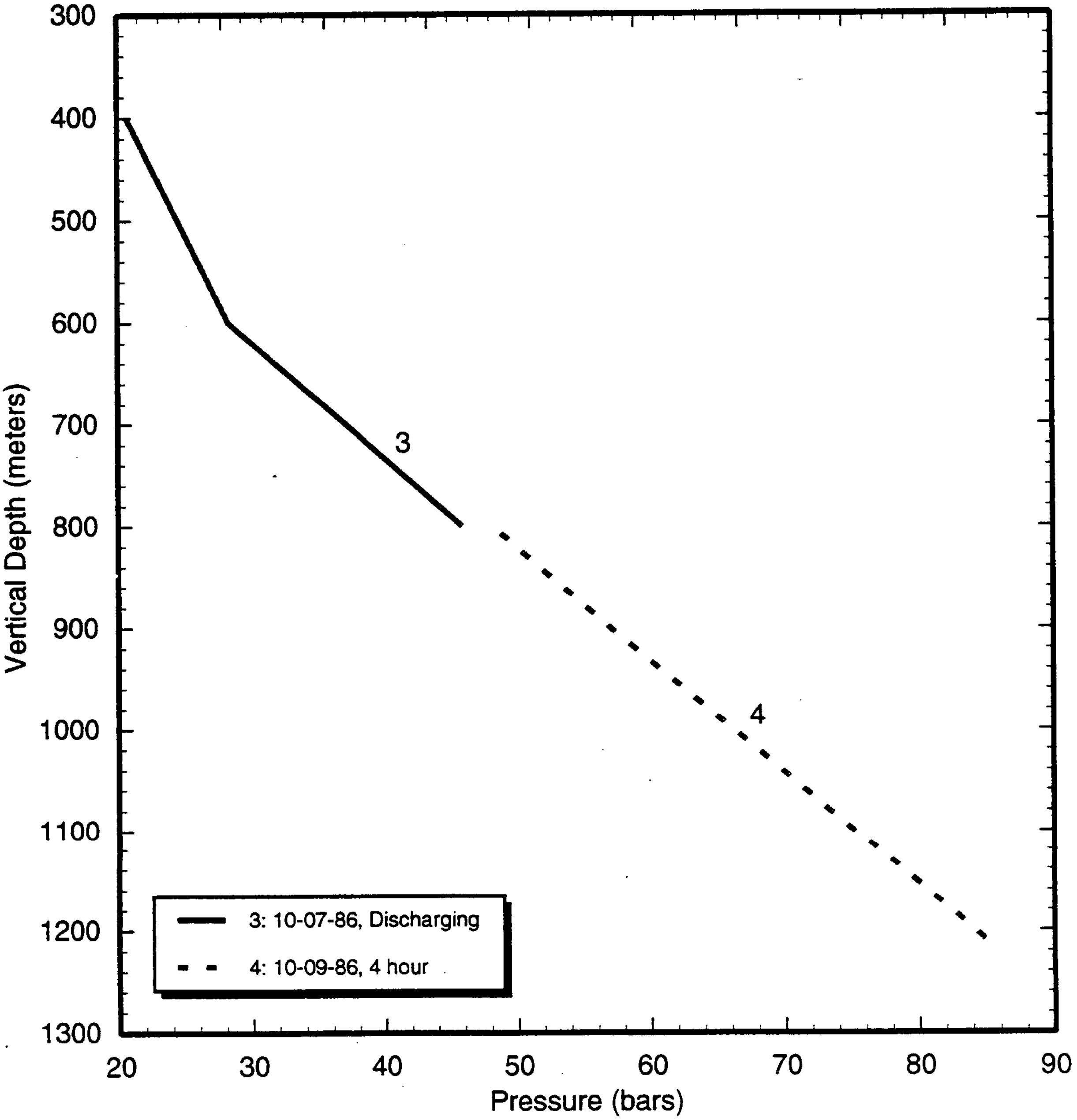

Figure 3.44. Pressure surveys in well TT-8S1.

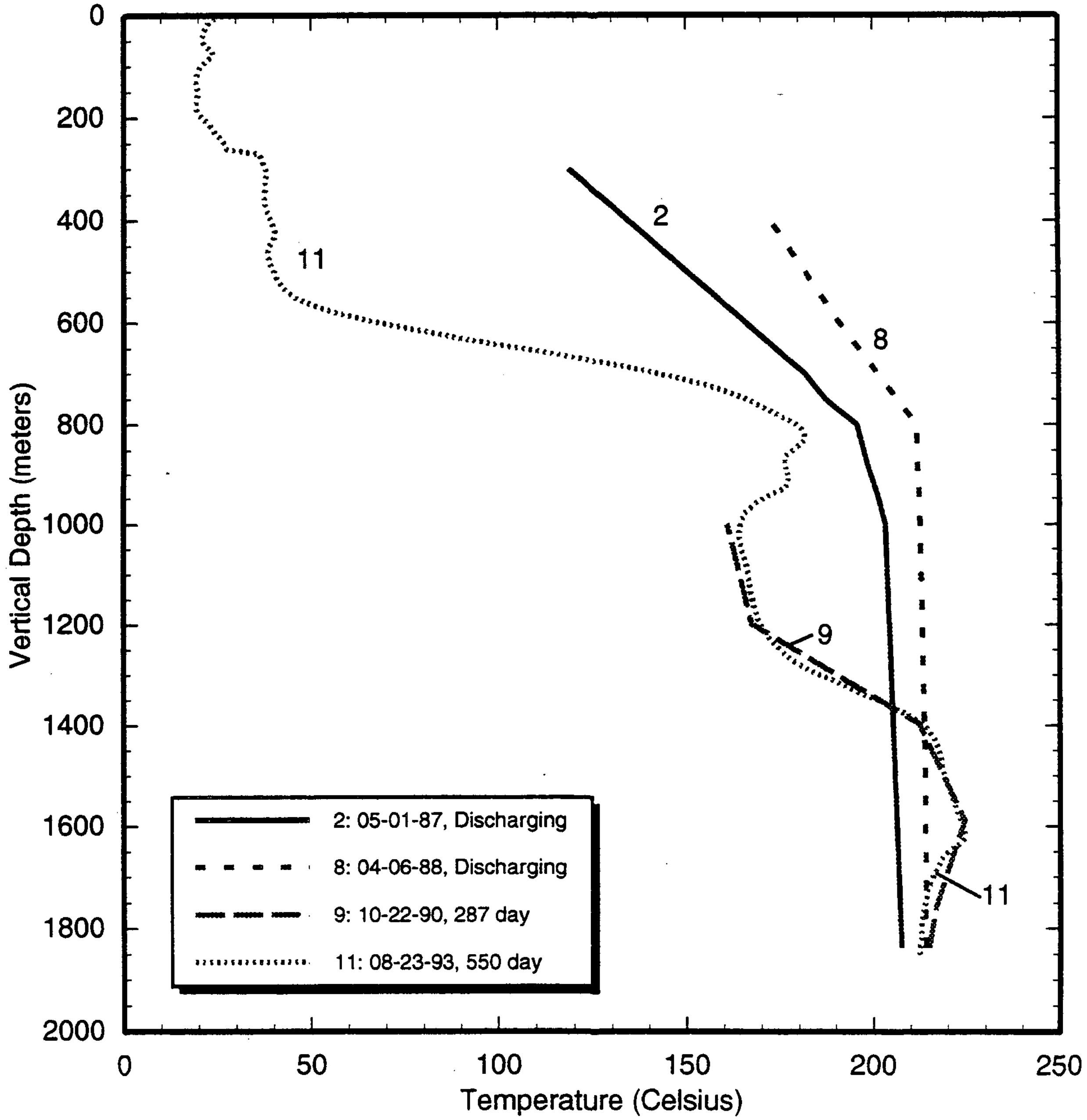

Figure 3.45. Temperature surveys in well TT-8S3.

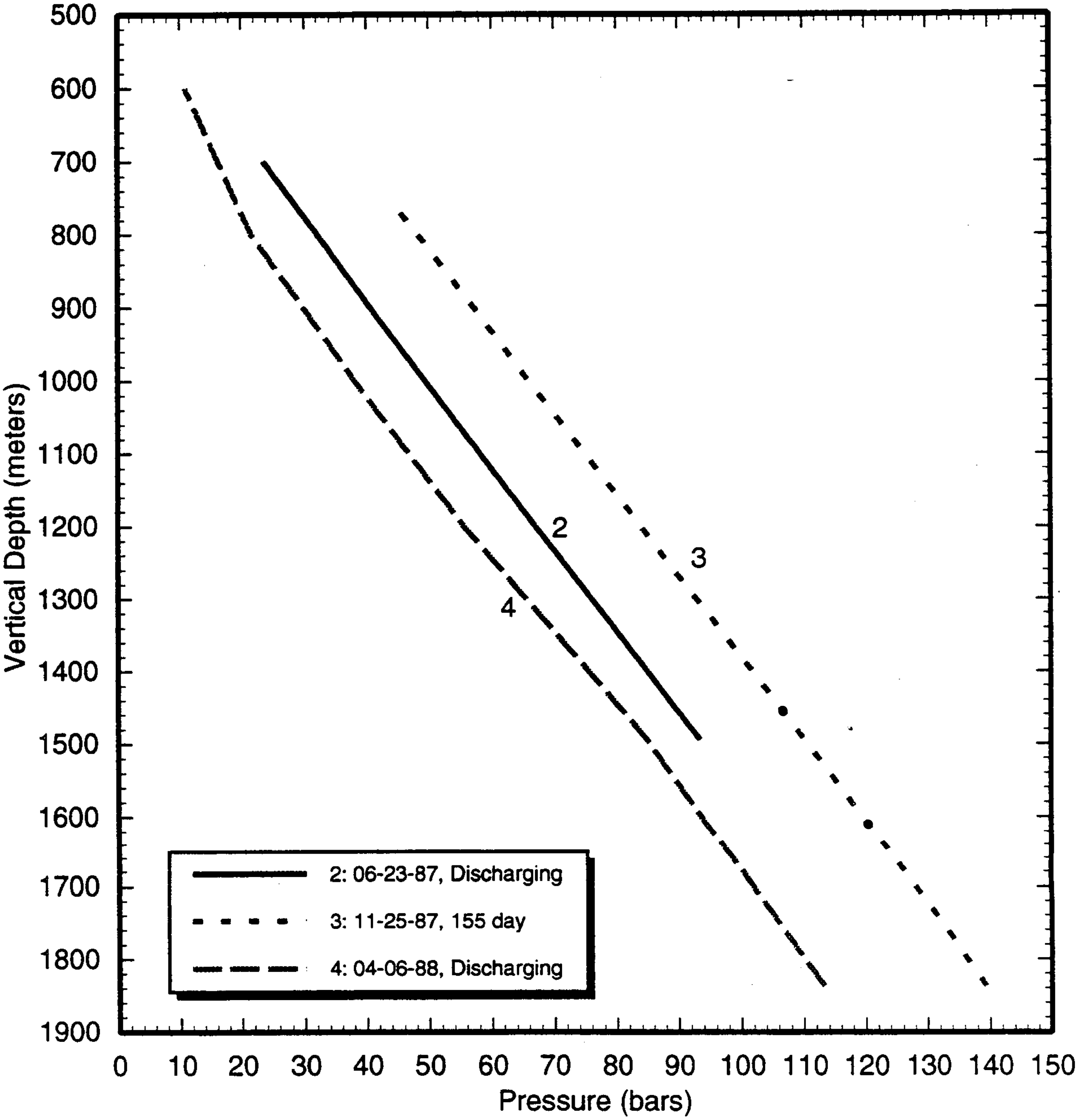

Figure 3.46. Pressure surveys in well TT-8S3.

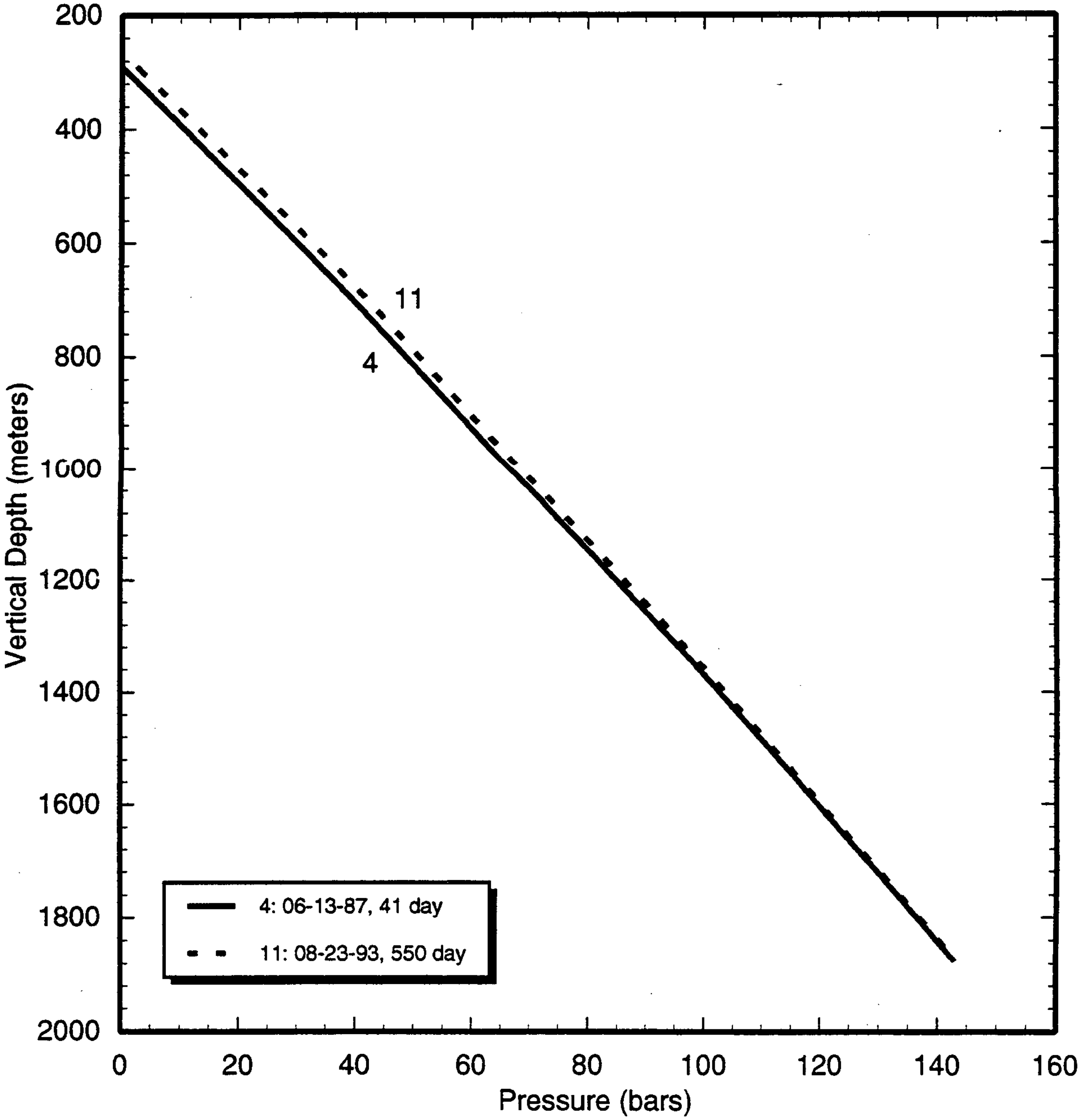

Figure 3.47. Pressures computed from water level and temperature data in well TT-8S3.

Well TT-10

In the well interval open to formation (1196.8 m TVD to 1284.5 m TVD), total circulation loss was encountered below a depth of ~1275 m TVD. The temperature survey of July 27, 1987 (Figure 3.48), taken shortly after an injection test, shows a rapid warmup at 1275 m TVD. Thus both the temperature and circulation loss data suggest that the principal feedzone for TT-10 is located at ~1275 m TVD. The maximum temperature (168°C) occurs at the bottom of the well.

Available pressure surveys for TT-10 are displayed in Figure 3.49; the pressure at 1275 m TVD (–575 m ASL) is about 98 bars (see pressure survey of September 22, 1986 in Figure 3.49). The latter pressure value is in excellent agreement with that (97.5 bars) computed from water level and temperature data (Figure 3.50).

Well TT-13S

Temperature surveys taken during and after an injection test on September 12, 1987 (Figure 3.51) indicate that at least part of the injected fluid is lost at about 2100 m TVD. Unfortunately, none of the other temperature surveys extend to a depth much below 2100 m TVD; thus, it is not possible to either confirm or deny the presence of fluid entries deeper than 2100 m TVD. All of the temperature surveys taken while the well was discharging are consistent with the production of liquid water from a permeable zone at or below 2100 m TVD. Based on temperatures measured in the discharging well, estimates of feedzone temperature range from a low of 230°C to a high of 245°C. Several shutin temperature surveys have recorded a temperature of ~245 to 250°C at 2100 m TVD. The discharge test of January 1988 was initiated after an injection test; it is possible that the feedzone temperature (~230°C) had not fully recovered at the time the temperature survey of January 19, 1988 was taken. Modeling of characteristic test data from several discharge tests (Section 5.2) indicates that the feedzone temperature is ~236 (±1)°C.

Downhole pressure surveys for TT-13S are shown in Figure 3.52; the stable pressure at 2100 m TVD (–1275.5 m ASL) is ~158 bars. Since the pressure profile computed from water level and temperature data does not extend to the feedzone depth, it is necessary to extrapolate the profile shown in Figure 3.53 in order to estimate the feedzone pressure (158 bars). The agreement between the measured and computed (extrapolated) values must be regarded as fortuitous.

Well TT-14R

The temperature survey of November 20, 1986 (Figure 3.54) , taken 9 hours after an injection test, shows a sharp change in temperature gradient at about 1730 m TVD; this probably indicates the major feedzone for well TT-14R. The temperature survey recorded on November 7, 1988 during a discharge test extends to a depth of ~1680 m TVD; these temperature data are consistent with the production of liquid (temperature ~236°C) from a feedzone deeper than 1680 m TVD. In the absence of other data, it will be assumed that the principal feedzone for TT-14R is located at ~1730 m TVD. The maximum temperature (~238 to 240°C) occurs towards the bottom of the borehole.

Available pressure surveys for well TT-14R are displayed in Figure 3.55; the stable pressure at 1730 m TVD (–905.5 m ASL) is ~131.5 bars. The latter pressure estimate is in good agreement with that (~131 bars) obtained by extrapolating the pressure profile shown in Figure 3.56.

Well TT-16

A temperature survey taken on January 6, 1988 (Figure 3.57) shows a sharp change in temperature gradient at ~2300 m TVD; this identifies the major fluid entry for well TT-16. The long term shutin temperature survey of November 3, 1988 shows a temperature inversion; the maximum temperature (~245°C) occurs at about 2060 m TVD. The feedzone temperature is ~215 (±)°C.

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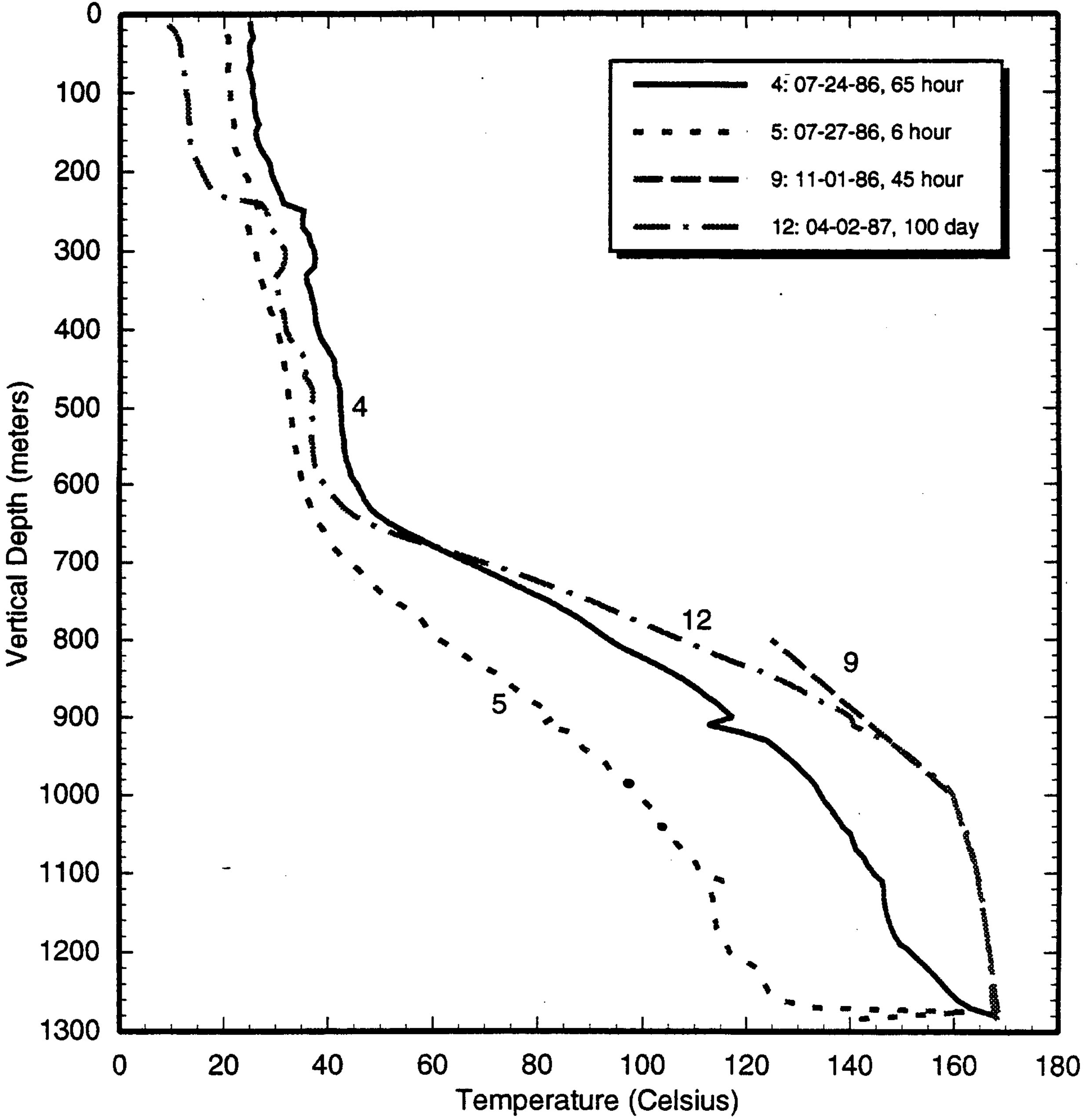

Figure 3.48. Temperature surveys in well TT-10.

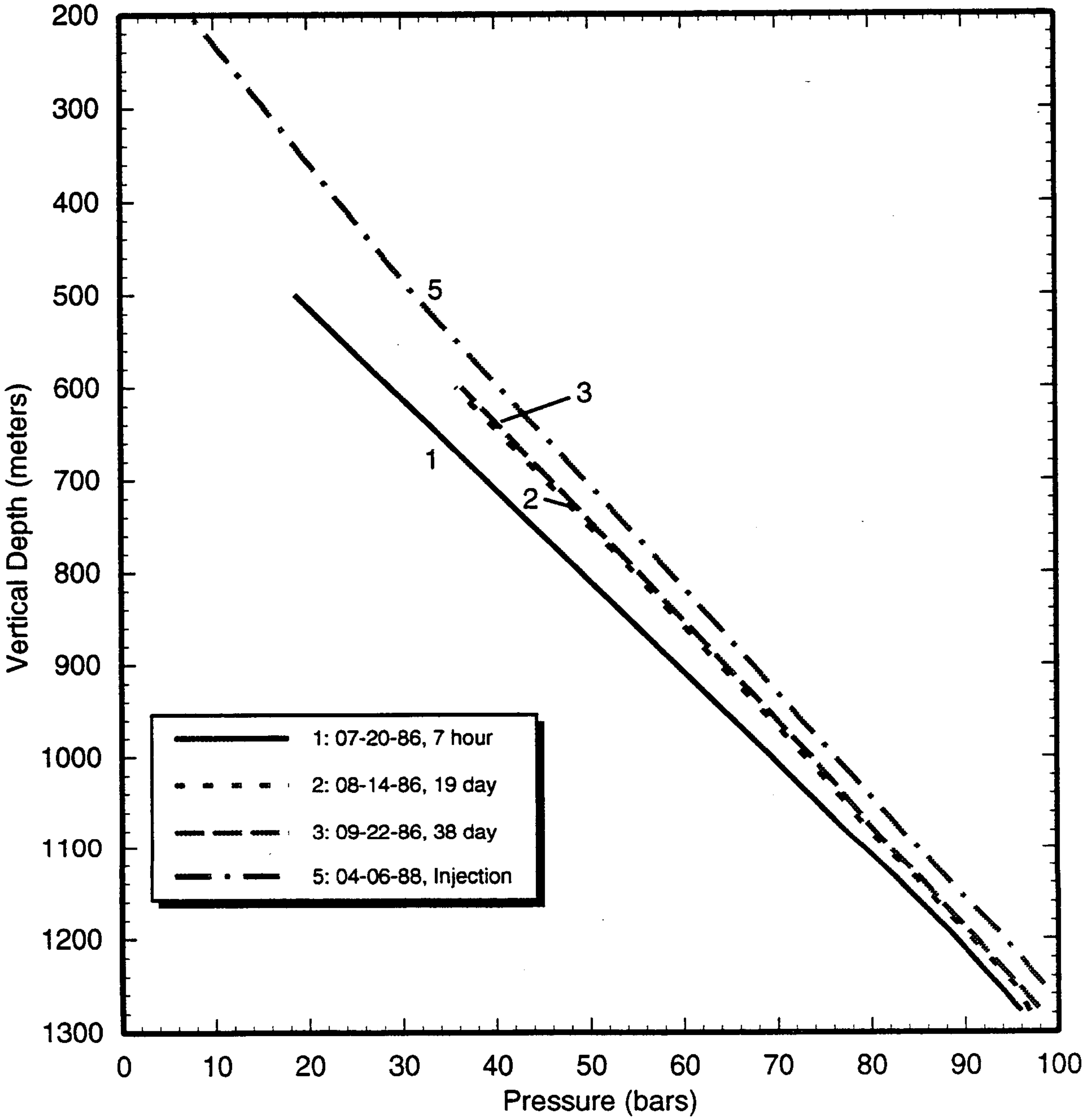

Figure 3.49. Pressure surveys in well TT-10.

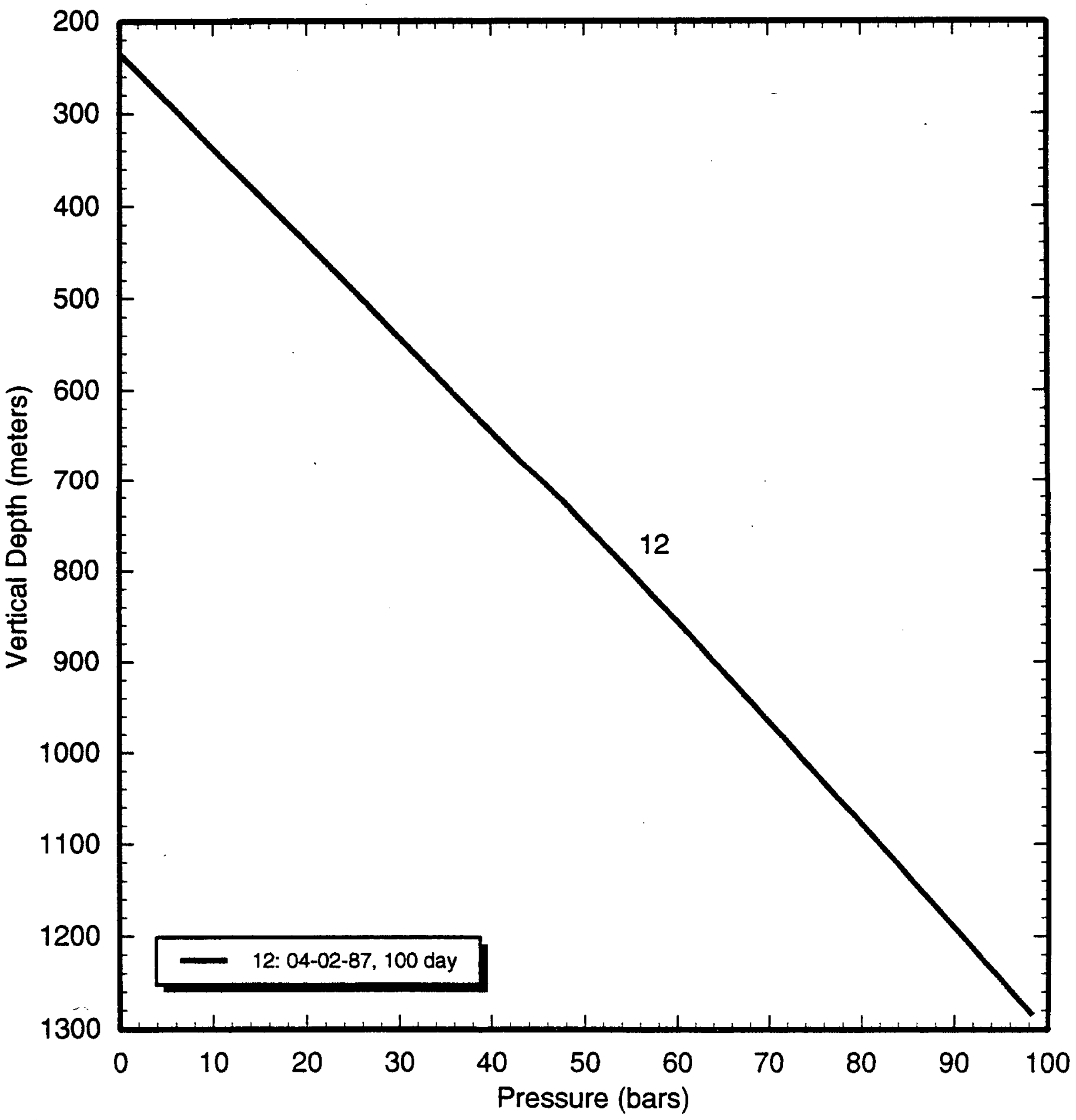

Figure 3.50. Pressures computed from water level and temperature data in well TT-10.

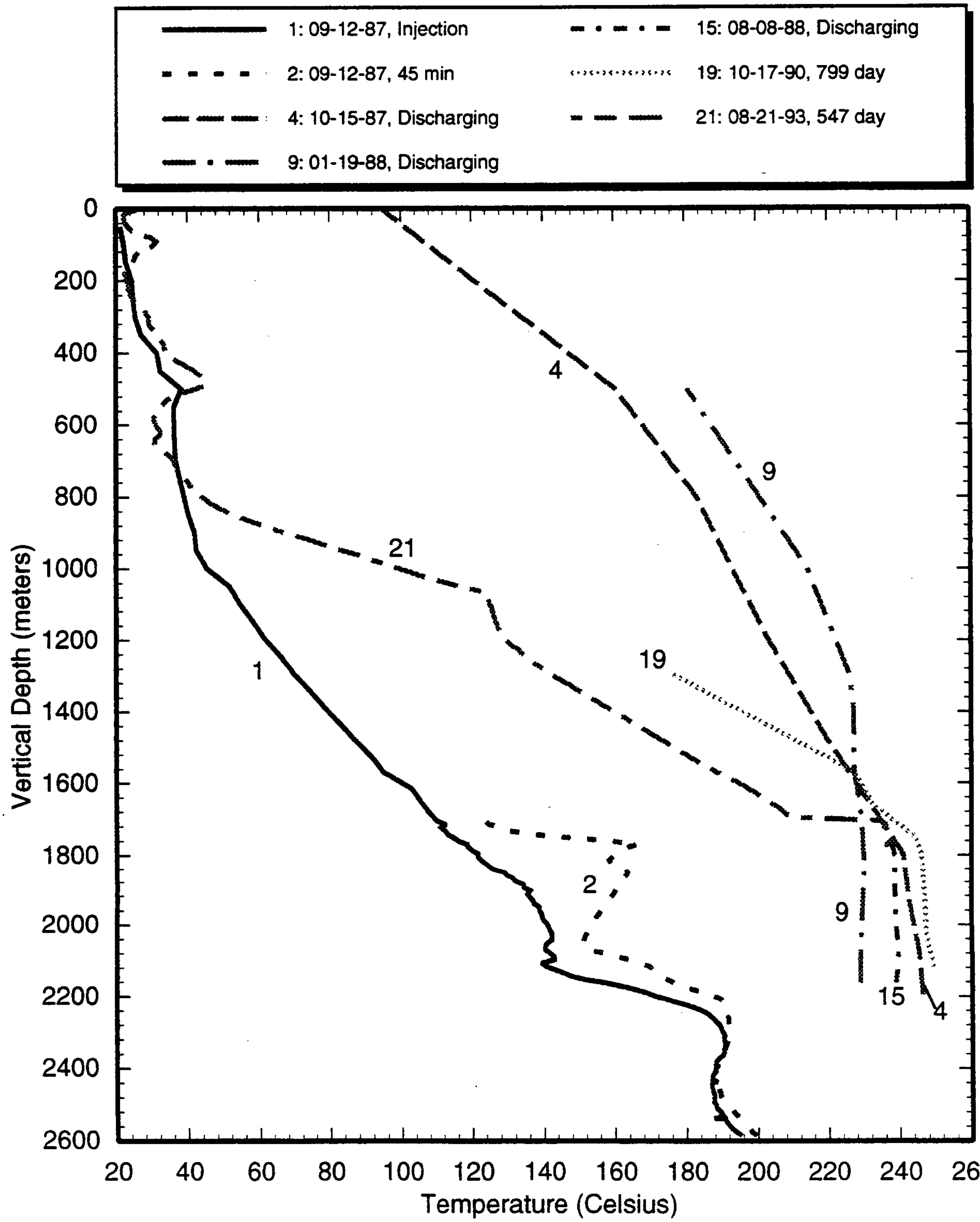

Figure 3.51. Temperature surveys in well TT-13S.

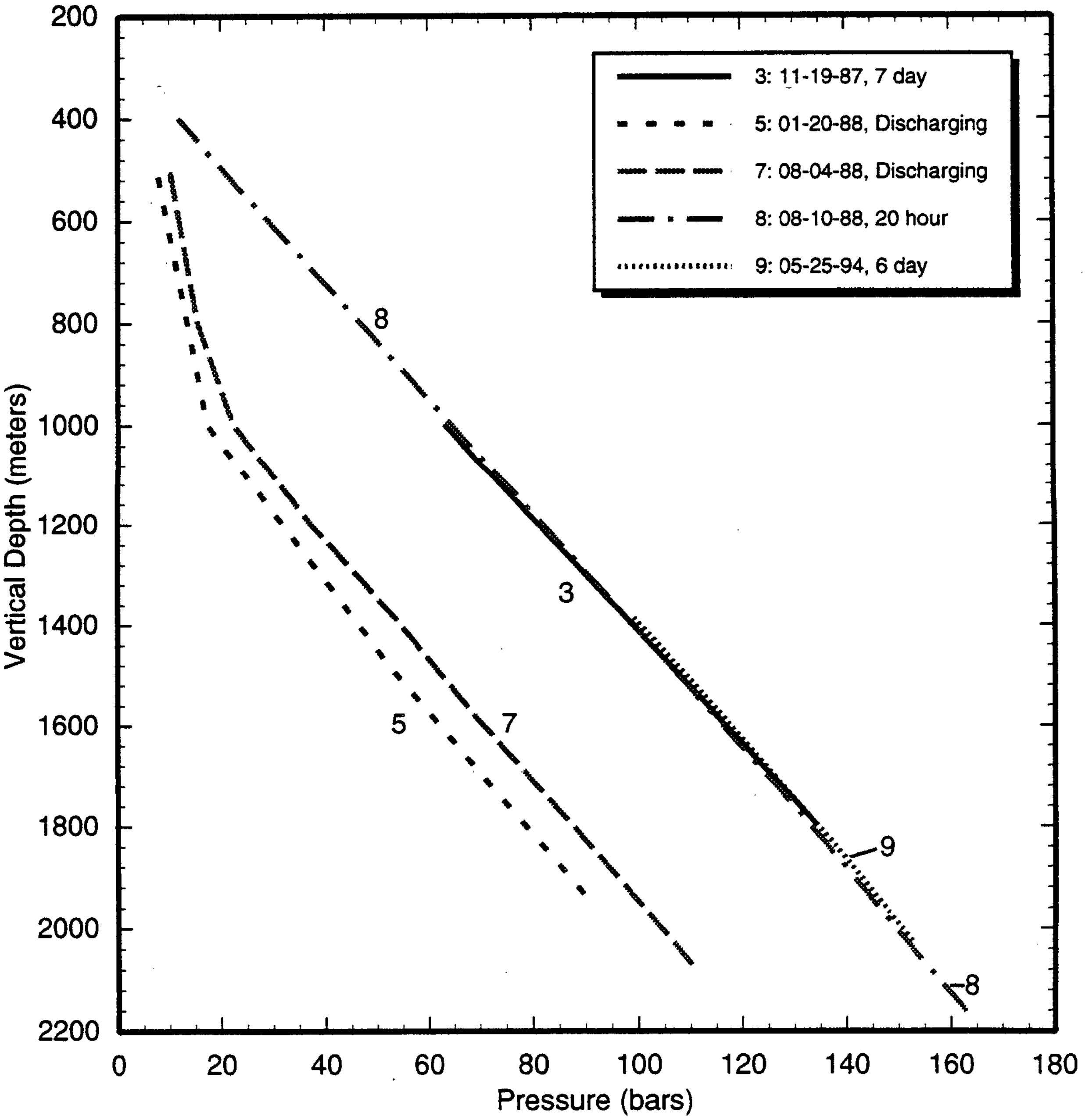

Figure 3.52. Pressure surveys in well TT-13S.

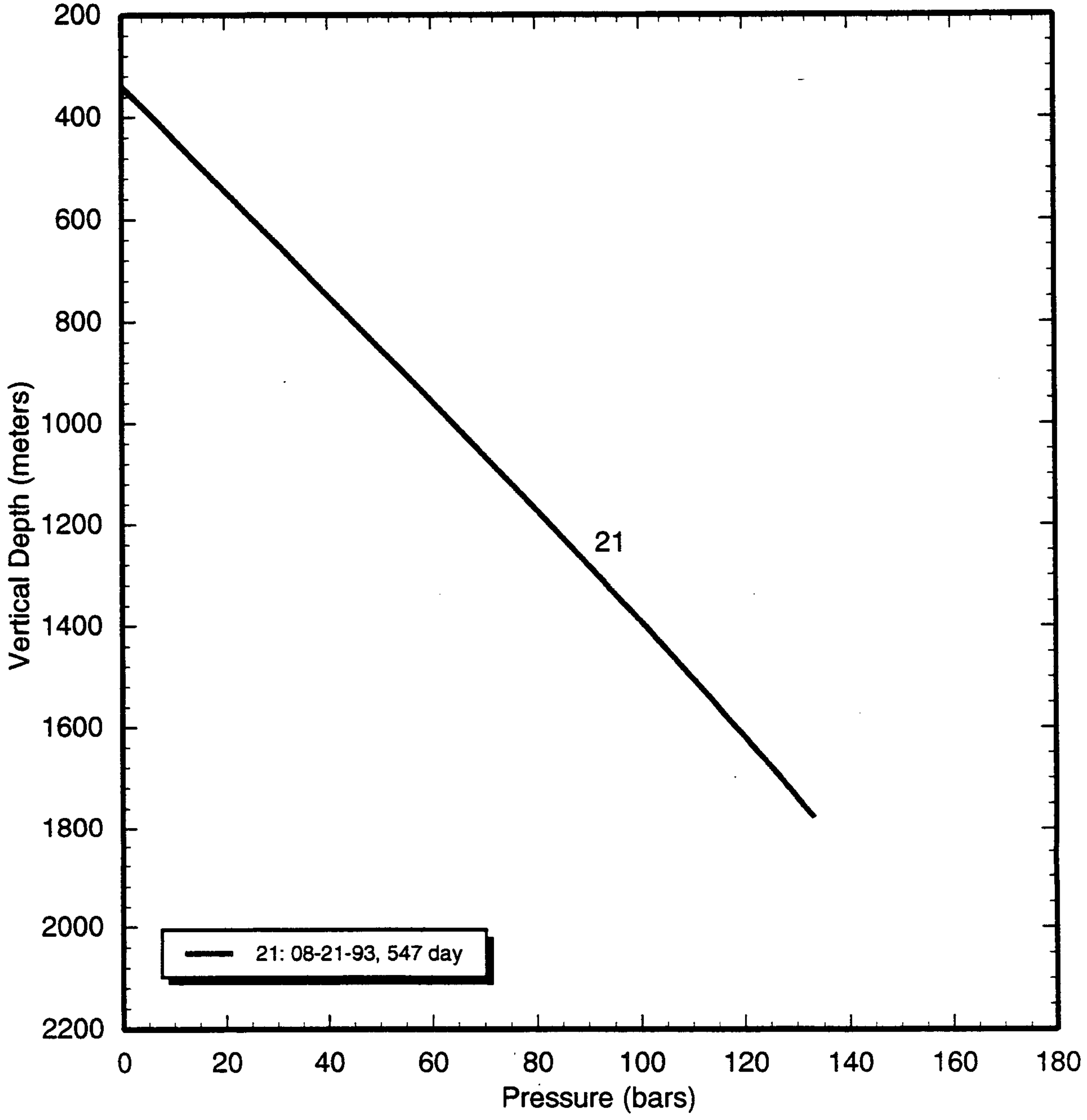

Figure 3.53. Pressures computed from water level and temperature data in well TT-13S.

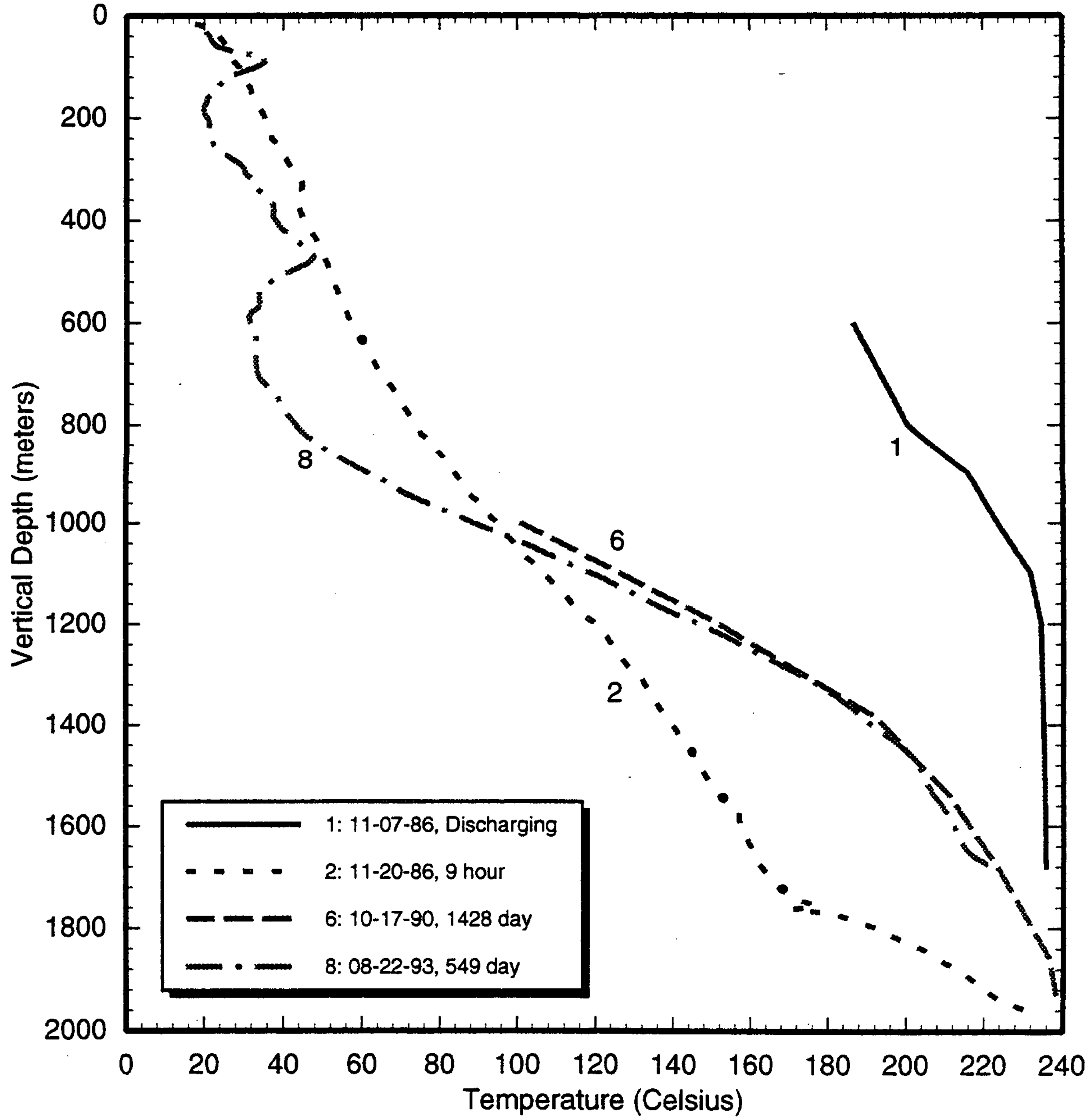

Figure 3.54. Temperature surveys in well TT-14R.

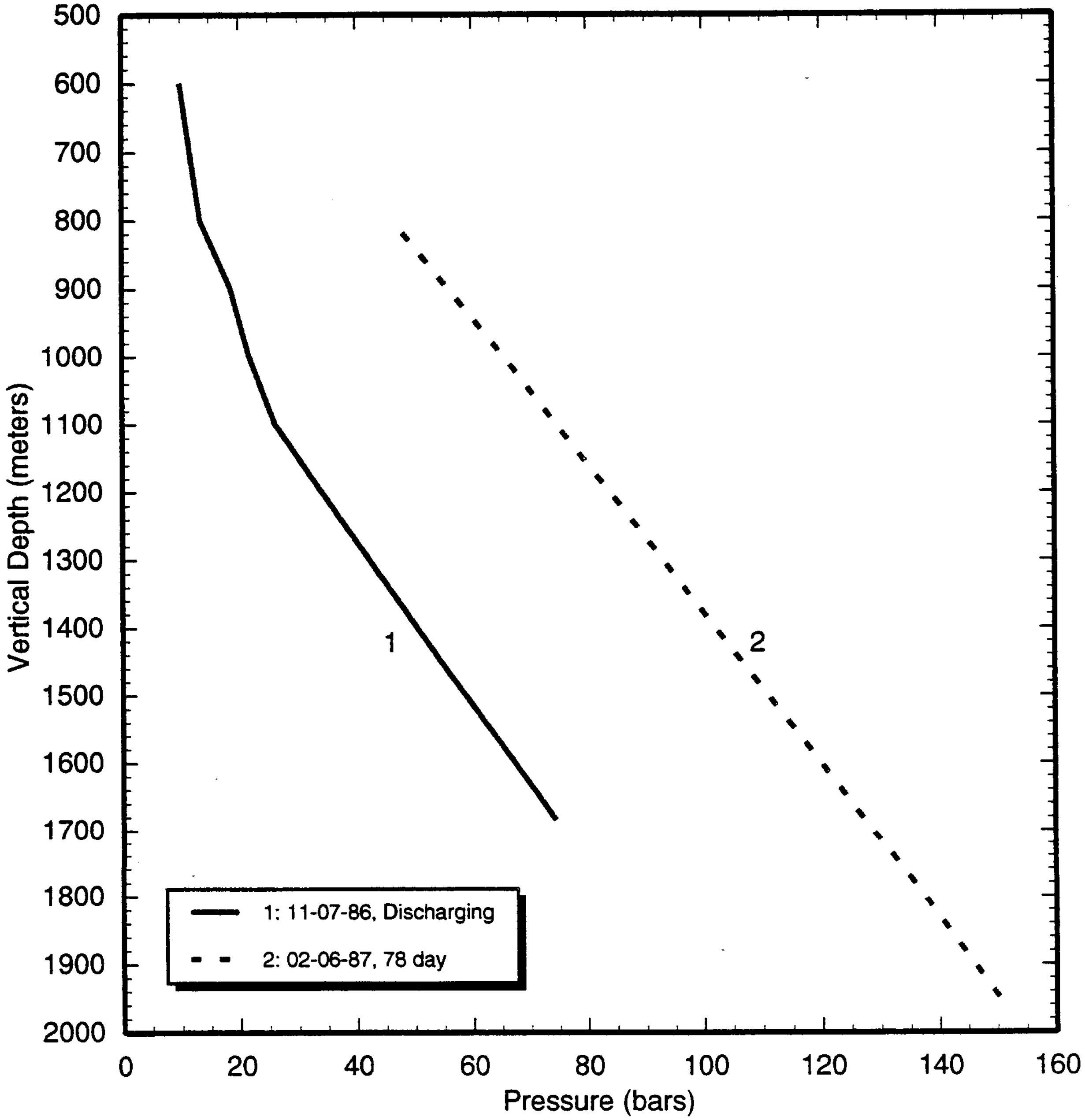

Figure 3.55. Pressure surveys in well TT-14R.

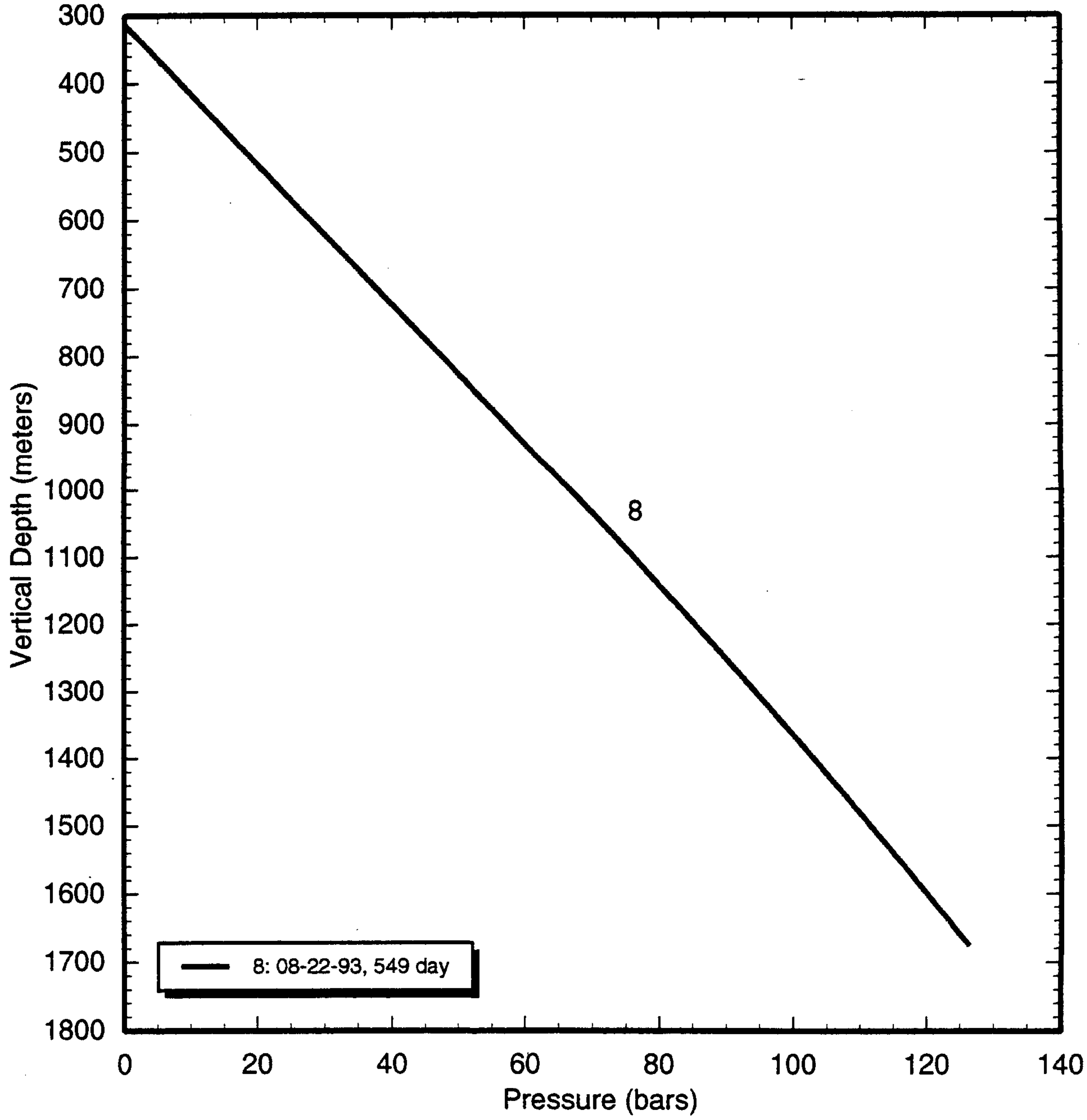

Figure 3.56. Pressures computed from water level and temperature data in well TT-14R.

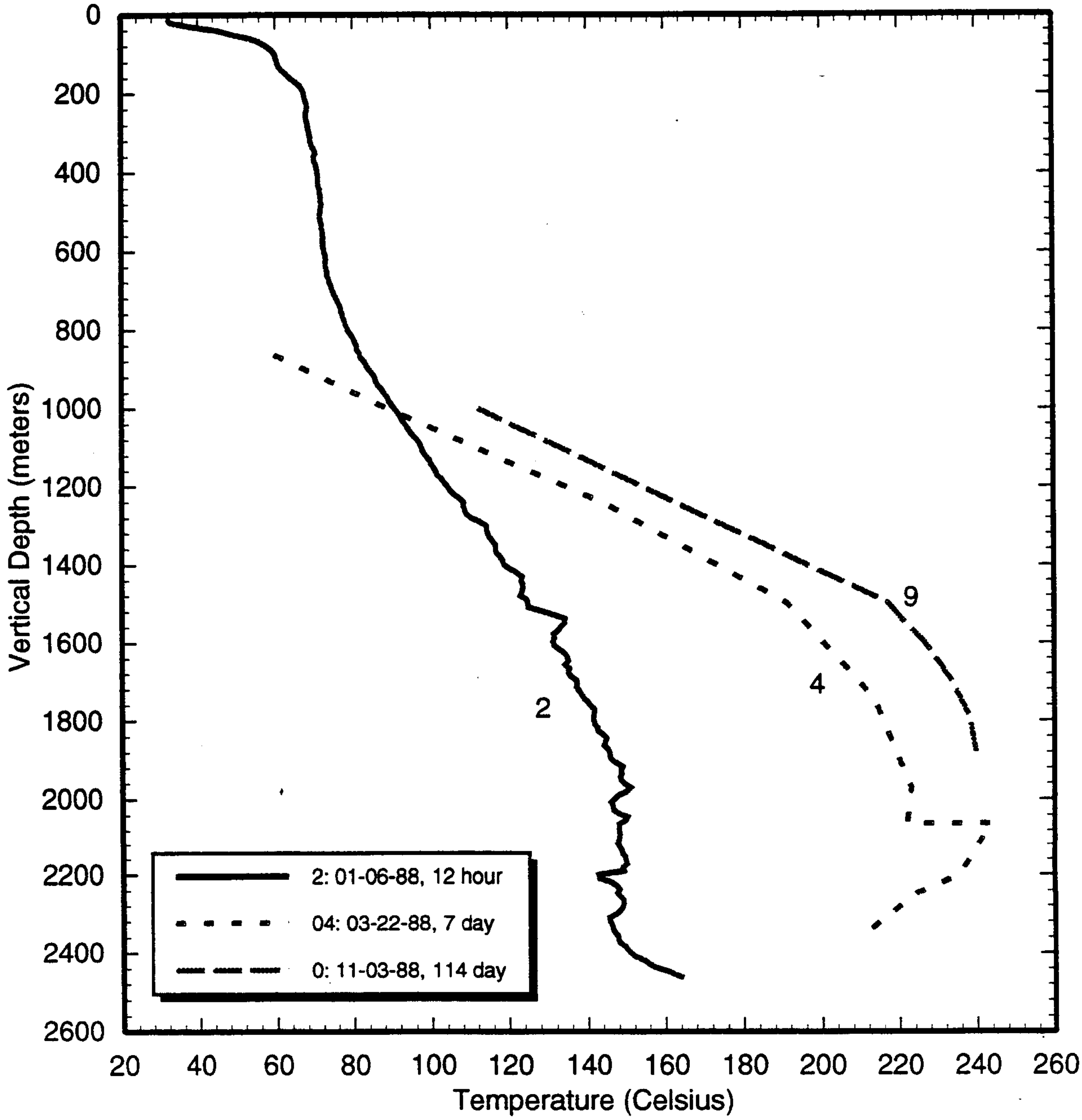

Figure 3.57. Temperature surveys in well TT-16.

Available pressure surveys for TT-16 are displayed in Figure 3.58; the pressure at 2300 m TVD (–1543.5 m ASL) is estimated (by extrapolation) to be 184.5 bars.

Well TT-16S

A temperature survey taken on February 6, 1989 during an injection test (Figure 3.59) shows a large change in temperature gradient at ~1740 m TVD; this identifies the major feedzone for well TT-16S. The isothermal zone below ~1500 m TVD in the shutin temperature profile of February 6, 1989 most likely represents the effects of well cooling as a result of mud circulation during drilling. The location of the feedzone at 1740 m TVD is confirmed by the temperature survey taken during the preliminary discharge test on February 16, 1989. The pressure (see Figure 3.60) and temperature surveys of February 16, 1989 imply the production of liquid water at a temperature of ~212°C. Later temperature surveys (see, e.g., temperature surveys of June 13, 1989 and October 18, 1990) indicate that the feedzone temperature may be considerably higher (~230°C). It is likely that the feedzone temperature had not fully recovered at the time of the February 1989 discharge test. The maximum temperature occurs towards bottomhole and is ~240°C.

A pressure profile computed from water level and temperature data recorded on February 6, 1989 is displayed in Figure 3.61. Extrapolating the computed pressure profile, the stable pressure at 1740 m TVD (–983.5 m ASL) is estimated to be ~131 bars.

Well TT-18

Well TT-18 was drilled from a pad northwest of well TT-19. A large (and continuous) circulation loss occurred below a depth of 1372 m MD (~1267 m TVD). The temperature survey of January 10, 1988 (Figure 3.62) shows an isothermal zone from 1290 m TVD to 1330 m TVD; an isothermal zone implies permeability at both of its end points. A cold zone is present below ~1300 m TVD in the temperature survey recorded on August 24, 1993; this cold zone is, however, absent in the temperature survey of January 23, 1989. It is possible that the temperature survey of August 24, 1993 was taken shortly after an injection test; the present authors do not, however, have any knowledge of such an injection test. In the absence of other data, it will be assumed that the principal feedzone for TT-8 is at ~1300 m TVD. A maximum temperature of ~160°C was recorded on January 23, 1989 at 1330 m TVD.

Several pressure surveys for TT-18 are shown in Figure 3.63. None of the available pressure surveys extends below a depth of ~875 m TVD. Because of the divergence between these pressure surveys, it is not possible to extrapolate measured pressures to estimate the feedzone pressure. A pressure profile computed from water level and temperature data is plotted in Figure 3.64; the pressure at 1300 m TVD (–636 m ASL) is 102.5 bars.

Well TT-19

Well TT-19 was completed with a 9-$^5/_8$ inch uncemented liner in a 12-$^1/_4$ inch hole from 564 m MD to 1411 m MD. The shoe of the 13-$^3/_8$ inch cemented casing is at 601.4 m MD (~601.3 m TVD). The temperature survey recorded on August 25, 1993 (Figure 3.65) shows a discontinuity in temperature gradient at ~570 m TVD (i.e., at about the top of the 9-$^5/_8$ inch uncemented liner). The discontinuity in temperature gradient at ~570 m TVD does not indicate a feedzone. In the uncemented part of the borehole, a total circulation loss was observed from ~1348 m TVD to ~1377 m TVD. In the absence of other data, it will be assumed that the principal feedzone for TT-19 is located at ~1350 m TVD. Wells TT-18, TT-19, TT-22 and TT-23 were used as injection wells during the long-term field-wide discharge test from November 1991 to February 1992. A bottomhole temperature of 90°C was recorded in well TT-19 on August 25, 1993 (Figure 3.65). Because of injection induced cooling in the wellbore, it is likely that the stable bottomhole temperature is higher than 90°C.

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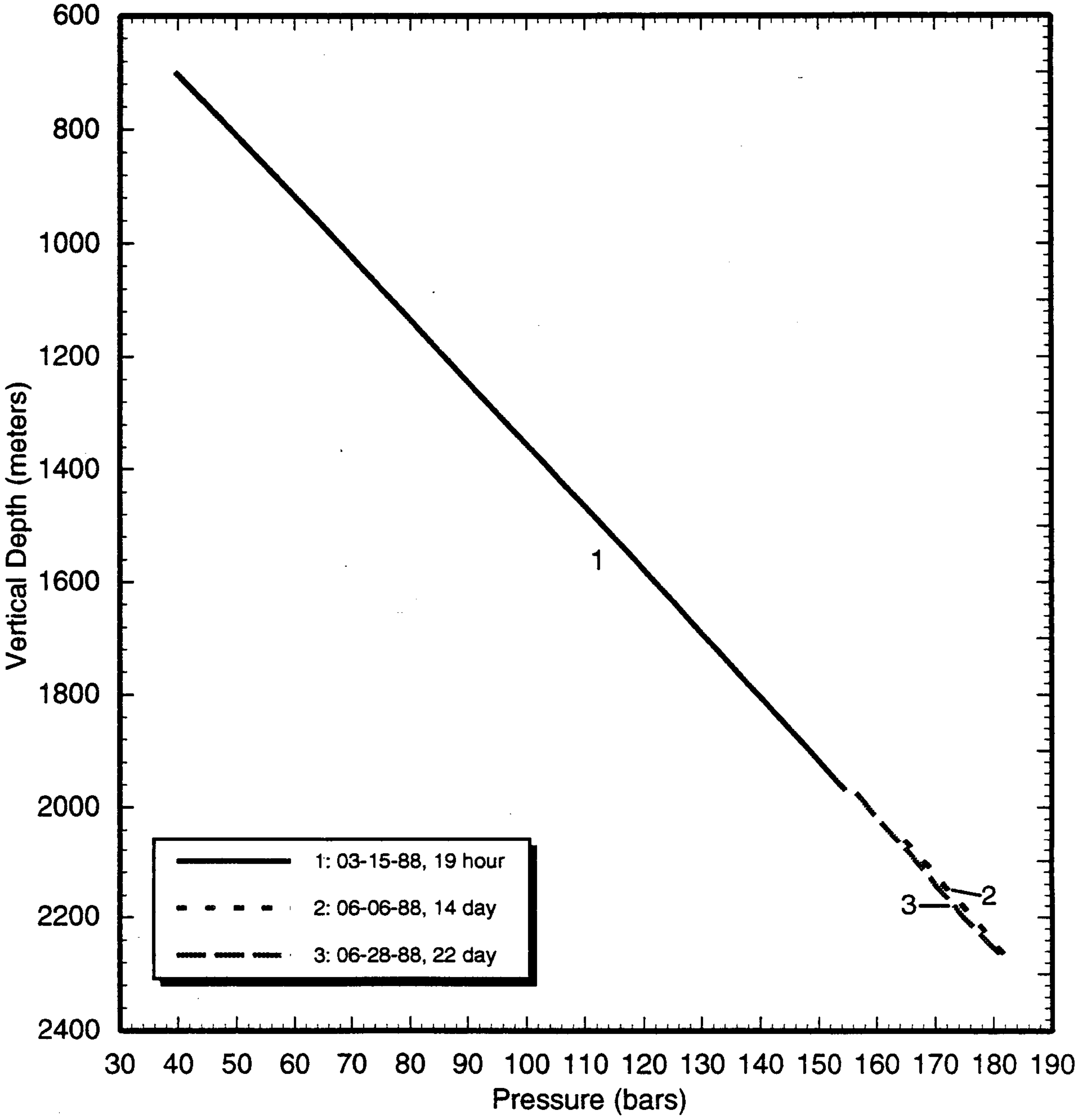

Figure 3.58. Pressure surveys in well TT-16.

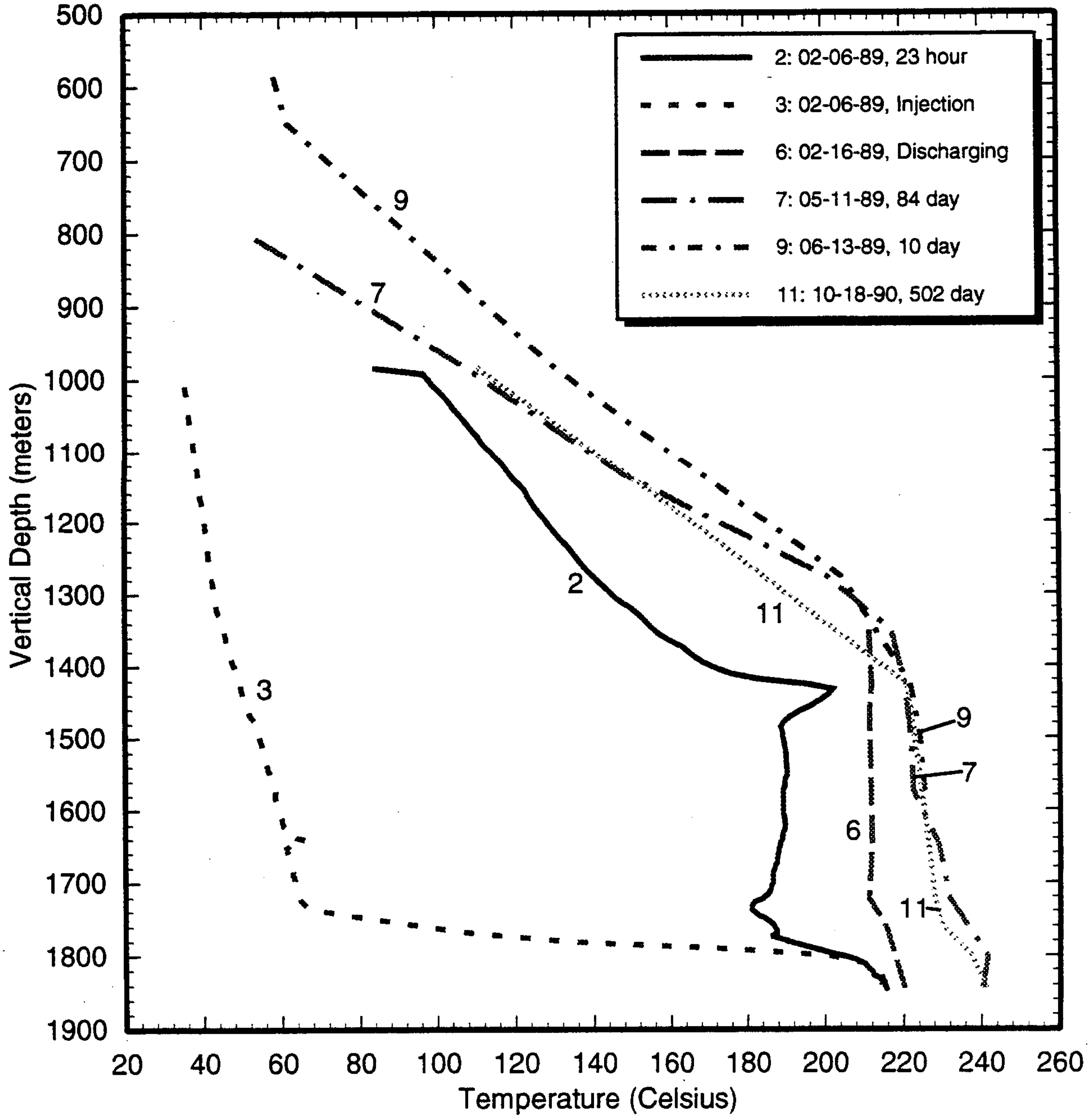

Figure 3.59. Temperature surveys in well TT-16S.

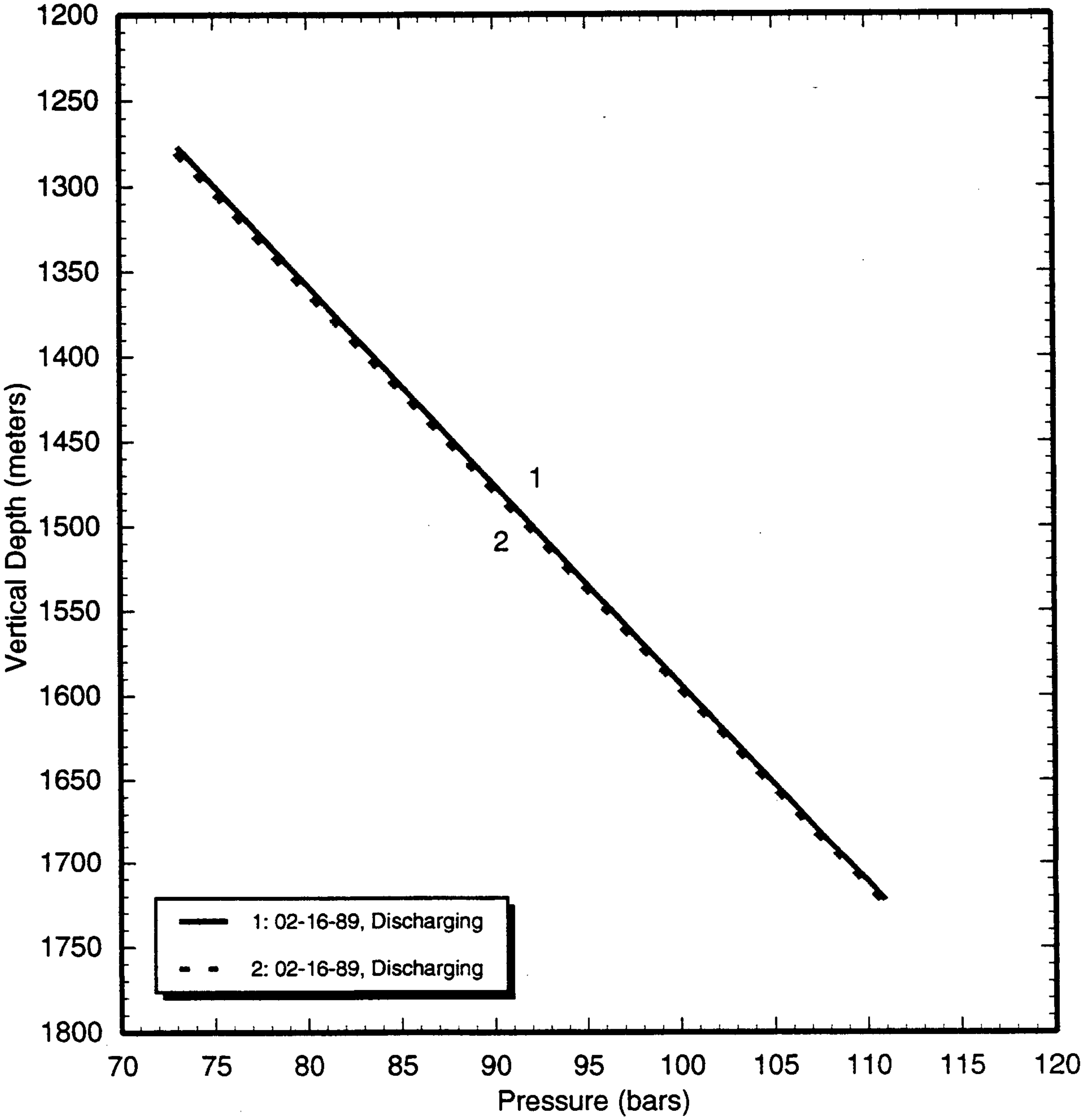

Figure 3.60. Pressure surveys in well TT-16S.

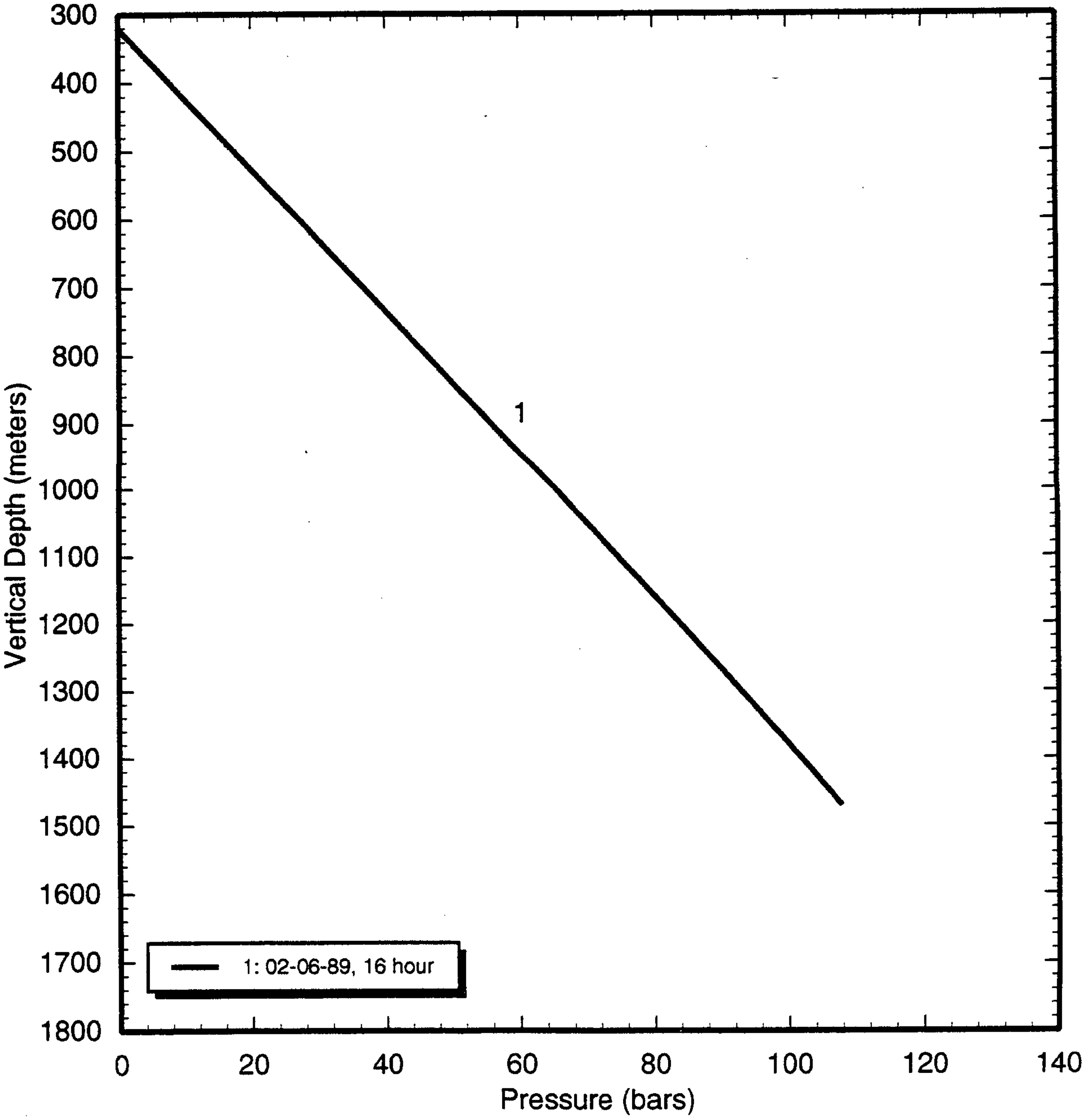

Figure 3.61. Pressures computed from water level and temperature data in well TT-16S.

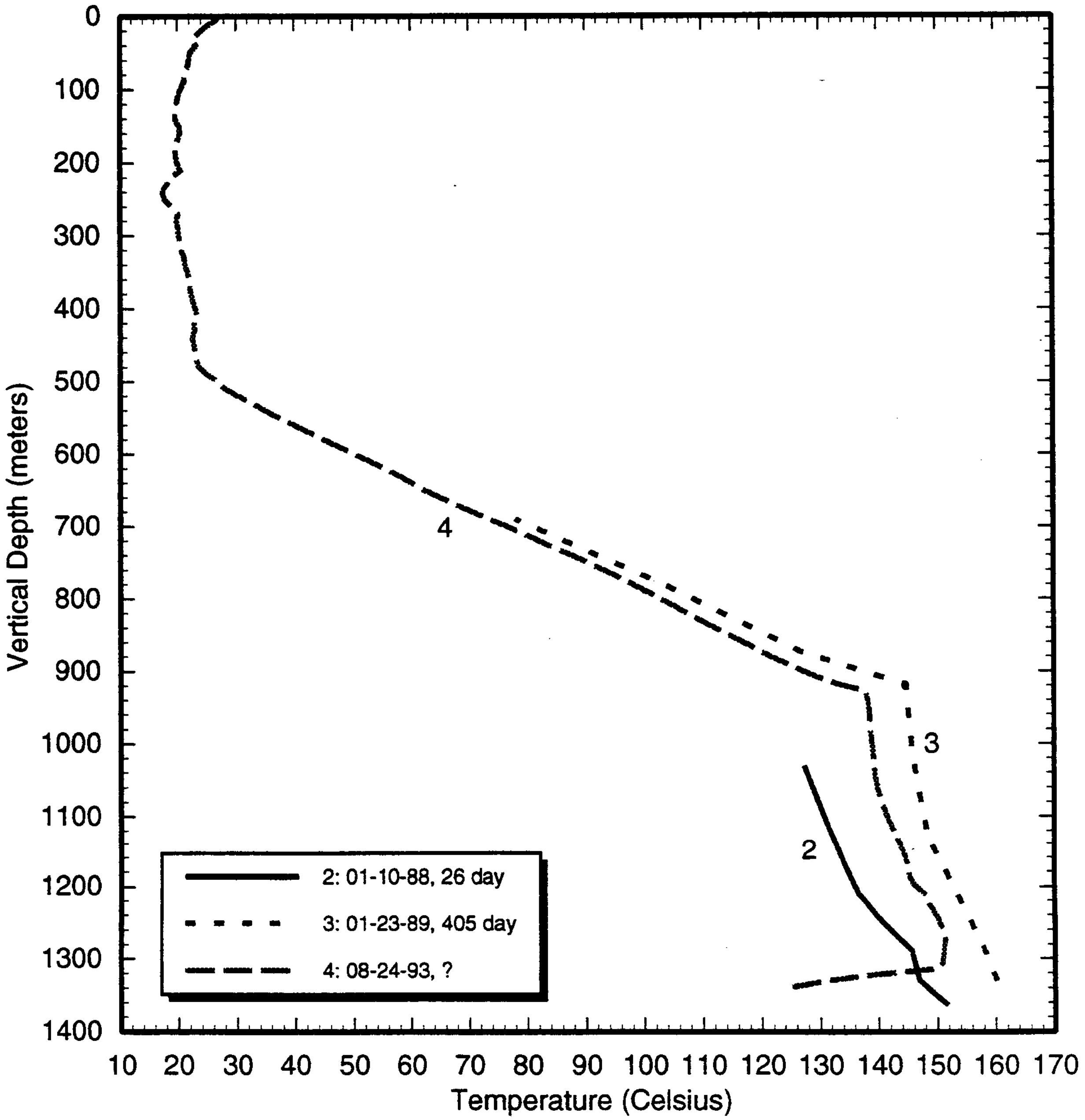

Figure 3.62. Temperature surveys in well TT-18.

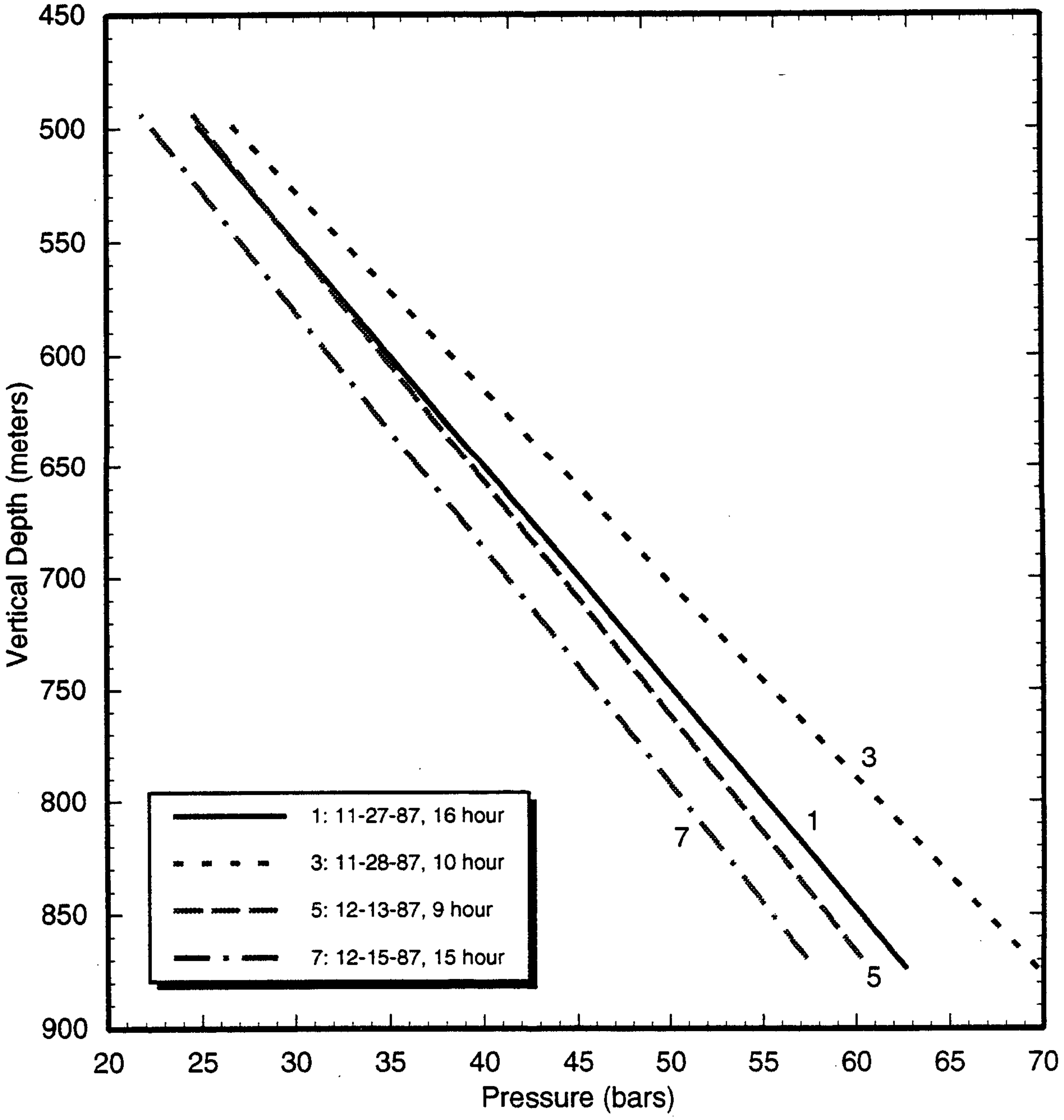

Figure 3.63. Pressure surveys in well TT-18.

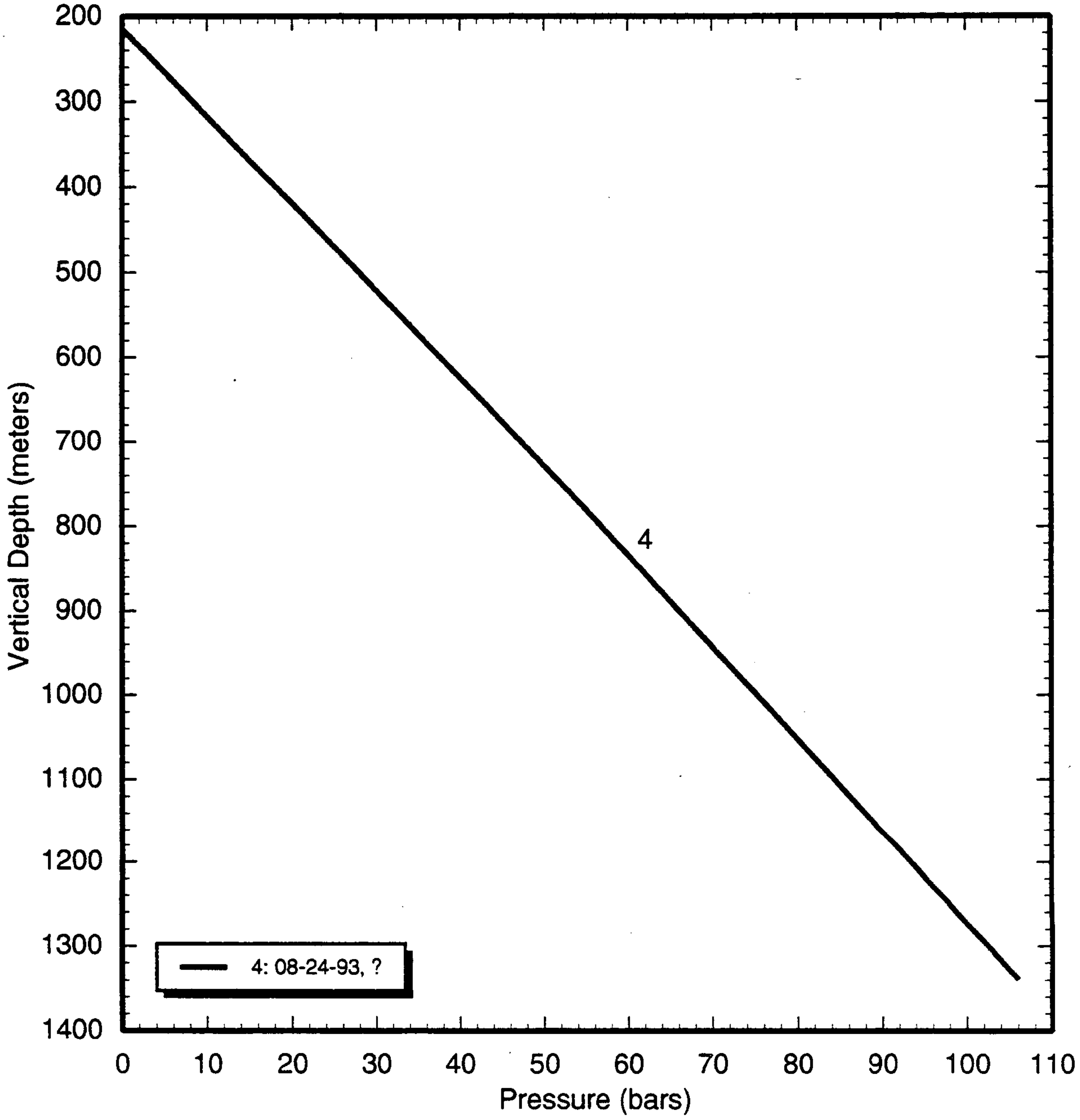

Figure 3.64. Pressure computed from water level and temperature data in well TT-18.

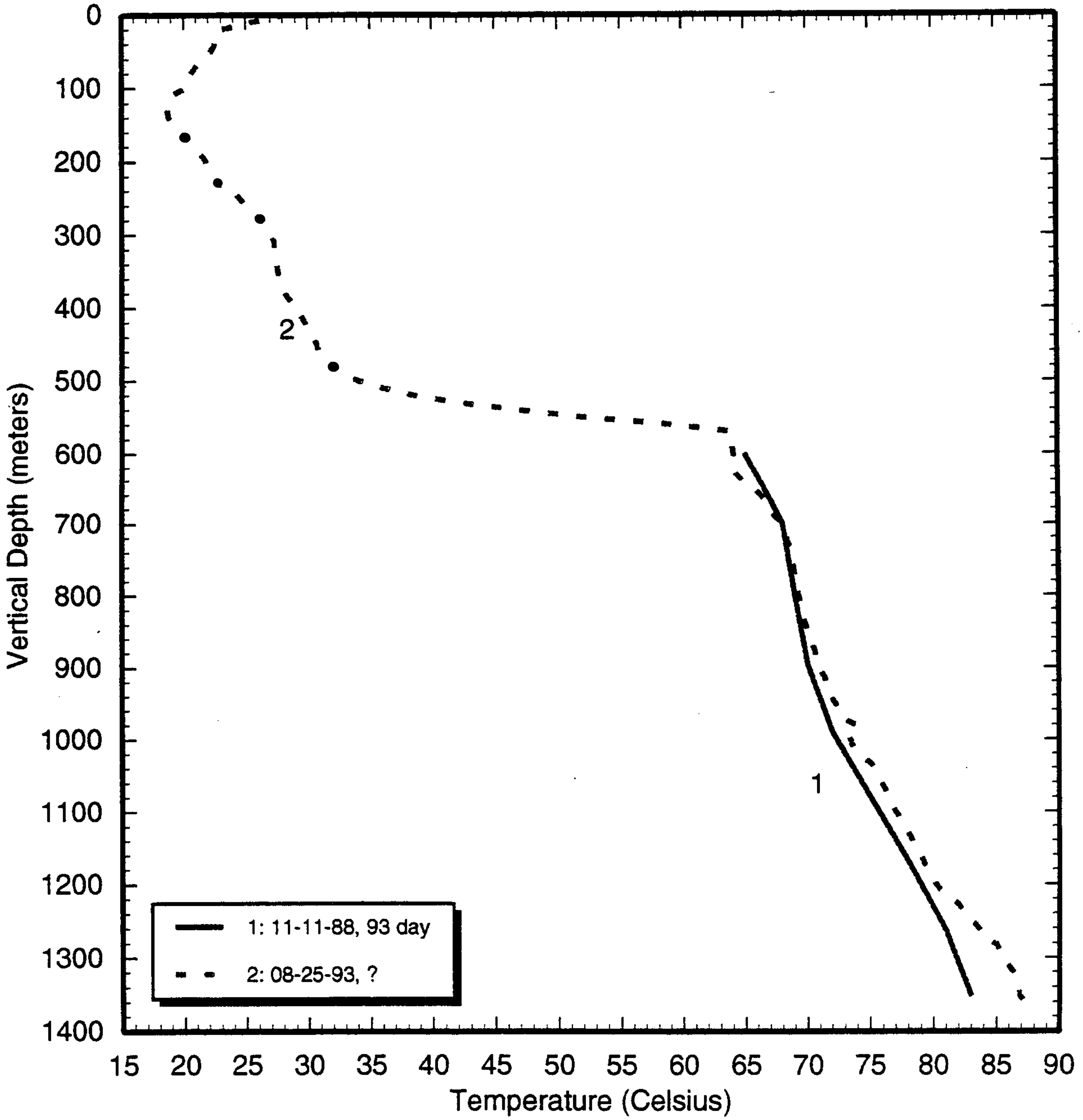

Figure 3.65. Temperature surveys in well TT-19.

Available pressure records for TT-19 are displayed in Figure 3.66. The pressure surveys do not extend below a depth of ~580 m TVD. Because of the divergence between the two pressure surveys in Figure 3.66, it is not feasible to extrapolate the measurements to estimate the feedzone pressure. A pressure profile computed from water level and temperature data is shown in Figure 3.67; the pressure at 1350 m TVD (–682.5 m ASL) is 107 bars.

Well TT-23

Well TT-23 was drilled from a location close to the wellhead for TT-19. A temperature survey taken during injection on September 15, 1988 (Figure 3.68) shows a sharp change in temperature gradient at ~1420 m TVD; this identifies the major feedzone for TT-23. The latter feedzone location is confirmed by the presence of a cold zone centered at 1420 m TVD in all other temperature surveys shown in Figure 3.68. A maximum temperature of ~160°C was recorded on August 25, 1993 at 1563 m TVD (bottom of temperature survey).

A pressure profile computed from water level and temperature data is plotted in Figure 3.69; the pressure at 1420 m TVD (–752.5 m ASL) is 113 bars.

3.2 Reservoir Pressures and Temperatures

In this subsection, we synthesize the results of Section 3.1 to deduce the pre-production subsurface pressure distribution in the Takigami geothermal reservoir. The feedpoint pressures for the various Takigami boreholes (Section 3.1) are listed in Table 3.2. For a reservoir system with good horizontal and vertical permeabilities, feedpoint pressure should principally depend upon feedpoint elevation. If a regional pressure gradient is present, then the feedpoint pressure will also exhibit a dependence on horizontal distance (measured with respect to some suitable origin). The Takigami feedpoint pressures are best fitted by a correlation of the form:

$$P = P_0 + aZ^*$$

where Z^* (equivalent or effective feedpoint elevation) is given by:

$$Z^* = Z + bX_E$$

Here Z denotes the actual feedpoint elevation (m ASL), and X_E is the distance (kilometers) to the east. For convenience, the origin for X_E is taken to be at 33°11′ latitude and 131°16′ longitude.

A least-squares procedure was used to determine the three unknowns a, b, and P_o. Results of the least-squares fit are:

$$P = 51.144 - 0.08651\, Z^*$$

$$Z^* = Z + 25.523\, X_E$$

where P is in bars (absolute); Z^* and Z are in m ASL (meters above seal level), and X_E is in kilometers. The root-mean-square error of the above fit is 1.66 bars. As can be seen from Figure 3.70, the least squares fit agrees closely with all of the pressure measurements.

The vertical pressure gradient in the Takigami Geothermal Field is 8.651 kPa/m and corresponds to a hydrostatic gradient at about 185°C. This implies fluid upflow in regions of the reservoir where temperature exceeds 185°C. The pressure fit also indicates that the pressure decreases to the east; the pressure gradient is ~2 bars/km. Thus, in the natural state there exists a regional flow to the east. The latter observation is in accord with the conceptual model of the Takigami Geothermal Field proposed by Idemitsu engineers (see Section 2).

The reservoir pressure extrapolates to atmospheric pressure (~1 bar) at

$$Z^* = Z + 25.523\, X_E = 579.6 \text{ m ASL}.$$

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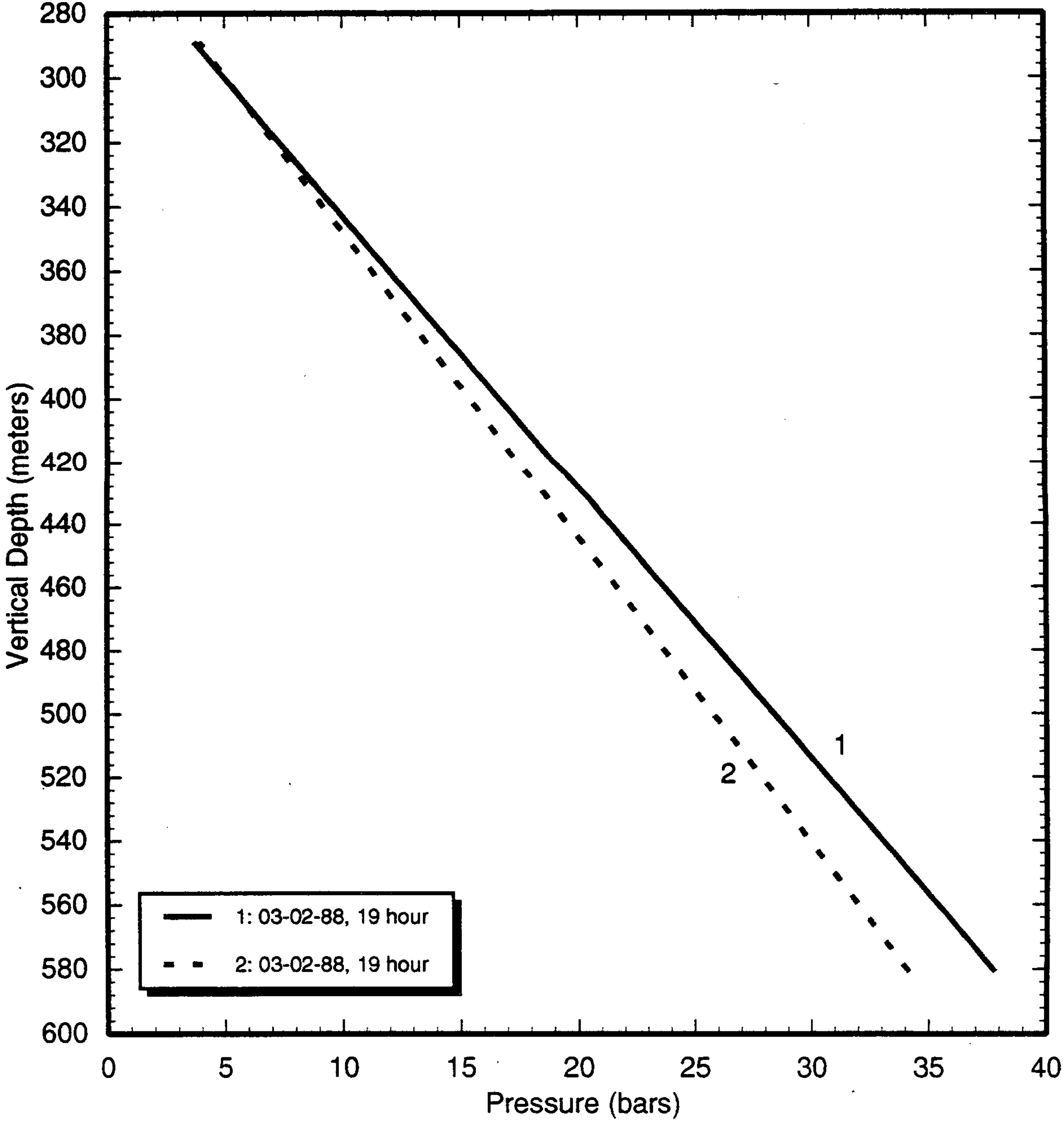

Figure 3.66. Pressure surveys in well TT-19.

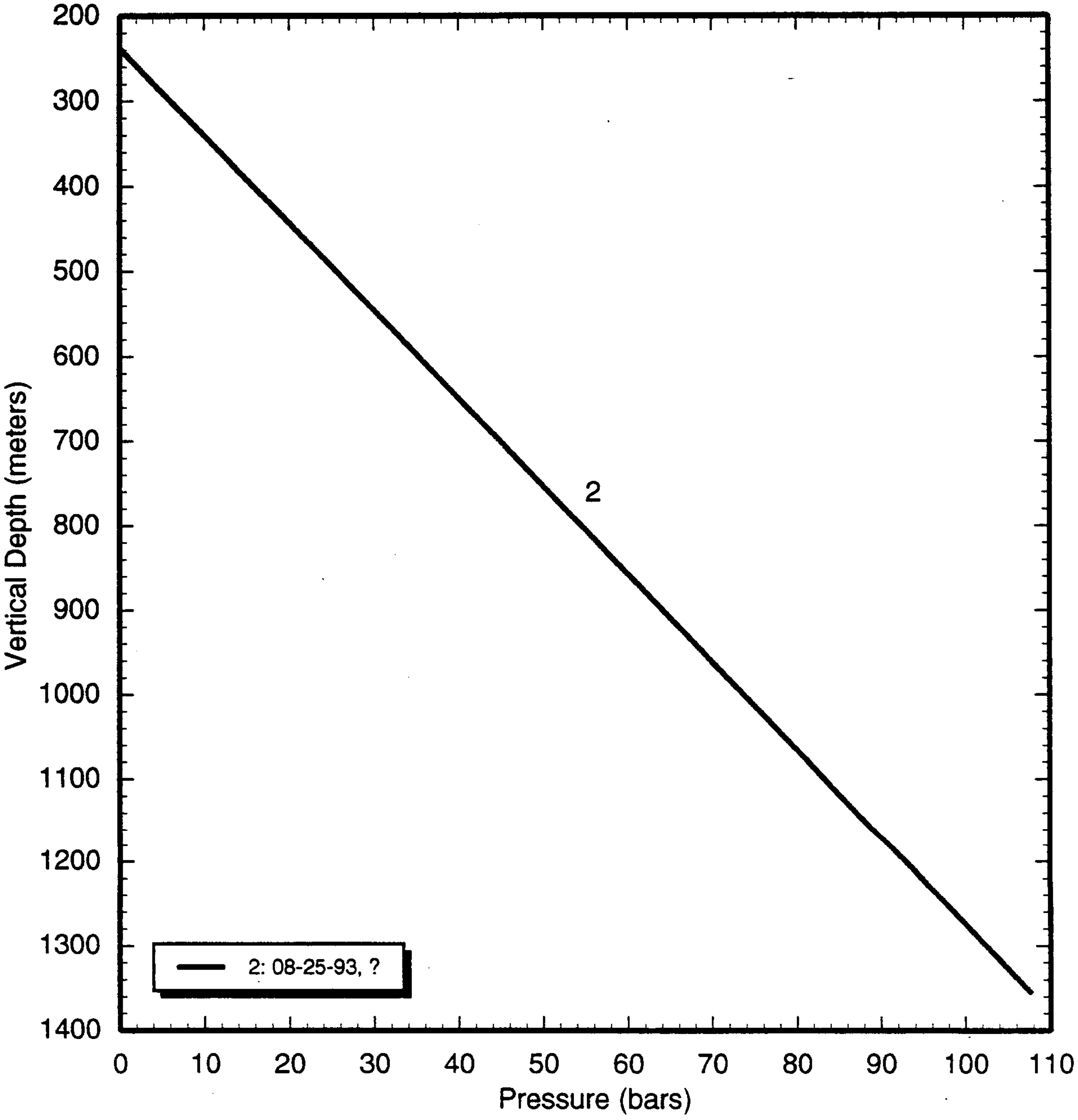

Figure 3.67. Pressures computed from water level and temperature data in well TT-19.

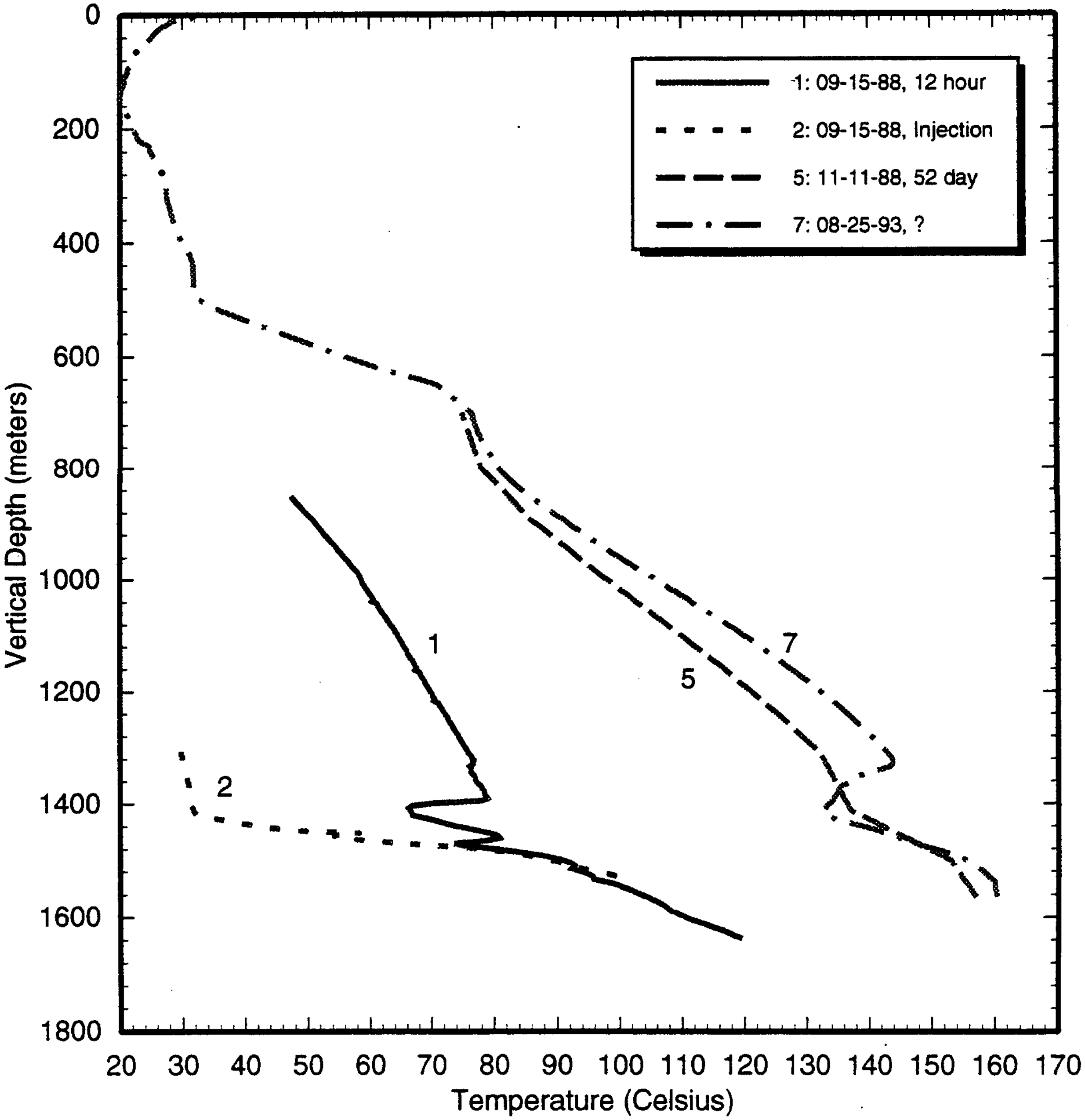

Figure 3.68. Temperature surveys in well TT-23.

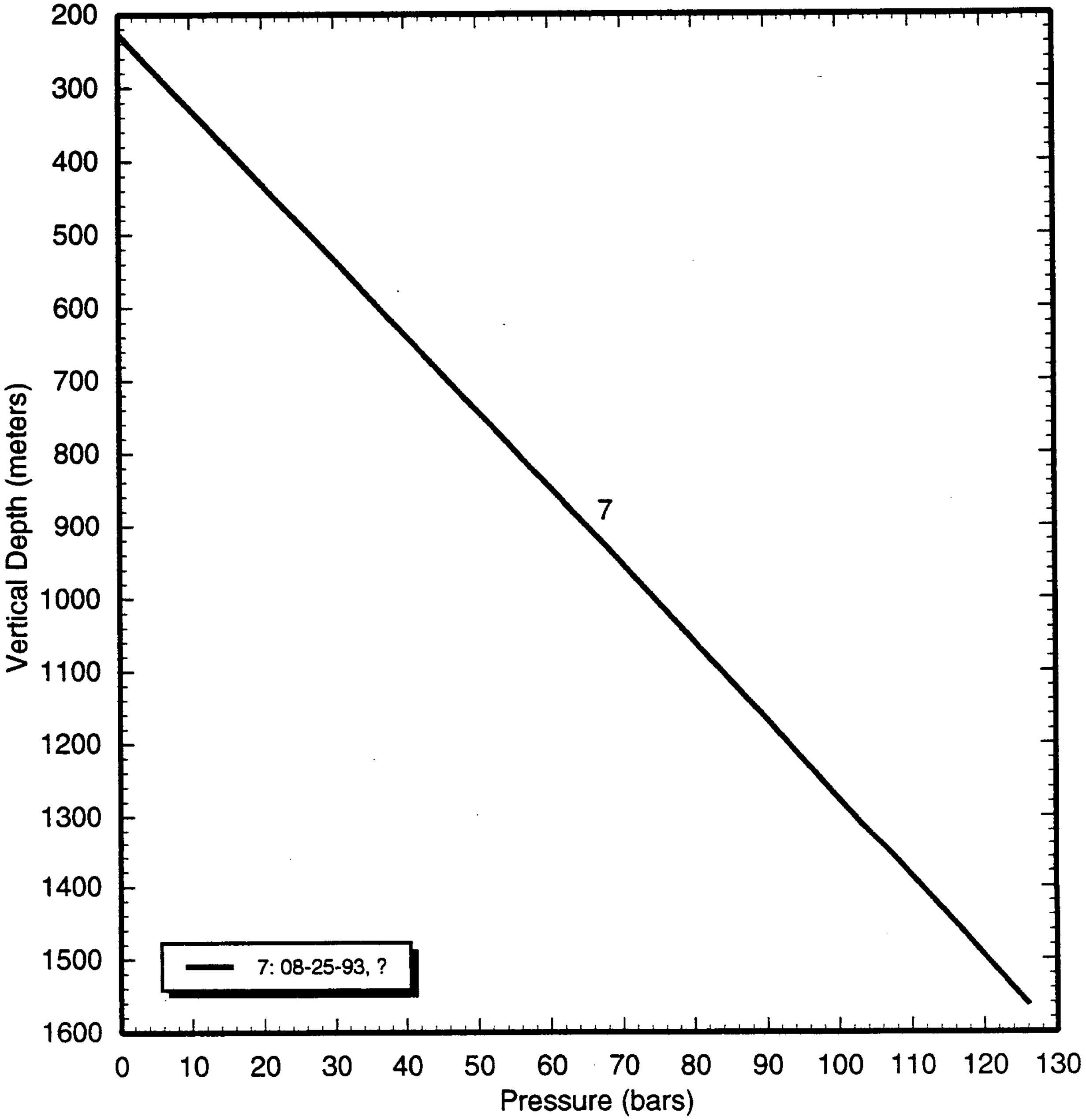

Figure 3.69. Pressure computed from water level and temperature data in well TT-23.

Table 3.2. Stable feedpoint pressures for Takigami boreholes. The feedpoint depth is measured with respect to the wellhead. The feedpoint co-ordinates are with respect to origin at 33°11′ latitude and 131°16′ longitude.

				Feedpoint Co-ordinates		
Borehole Name	**Wellhead Elevation (m ASL)**	**Feedpoint Depth (m TVD)**	**Feedpoint Elevation (m ASL)**	**(kmN)**	**(kmE)**	**Feedpoint Pressure (bars)**
NE-3	694	2275	-1581	3.523	1.094	186.5
NE-4	707	2230	-1523	2.943	0.315	185.5
NE-5(i2)	874	1180	-306	2.368	1.872	74
NE-5(i2)	874	1660	-786	2.377	1.908	115
NE-6(i2)	897	740	157	3.411	2.713	34
NE-6	897	1630	-733	3.411	2.713	110.5
NE-9	914	1115	-201	4.109	1.898	64
NE-10	832	1650	-818	2.047	0.919	122.5
NE-11	825.5	1340	-514.5	1.500	1.644	90
NE-11R	825.5	1850	-1024.5	1.541	1.855	134
TP-1	824.5	1820	-995.5	1.990	0.980	134
TT-1	708.5	2970	-2261.5	3.390	1.238	244
TT-2	708.5	1580	-871.5	3.226	1.434	122.5
TT-3	708.5	1880	-1171.5	3.532	1.201	149.5
TT-7	872.5	1070	-197.5	2.373	1.871	64.5
TT-8(i)	764	840	-76	2.802	1.606	55.5
TT-8S1(i)	764	1050	-286	2.810	1.597	70.5
TT-8S3	764	1870	-1106	2.965	1.367	142.5
TT-10	700	1275	-575	4.266	1.232	98
TT-13S	824.5	2100	-1275.5	1.733	0.710	158
TT-14R	824.5	1730	-905.5	1.786	0.624	131.5
TT-16	756.5	2300	-1543.5	2.512	0.545	184.5
TT-16S	756.5	1740	-983.5	2.233	1.302	131
TT-18	664	1300	-636	4.684	0.981	102.5
TT-19	667.5	1350	-682.5	4.203	0.949	107
TT-23	667.5	1420	-752.5	4.583	0.868	113

(i), (i2): intermediate depth completions

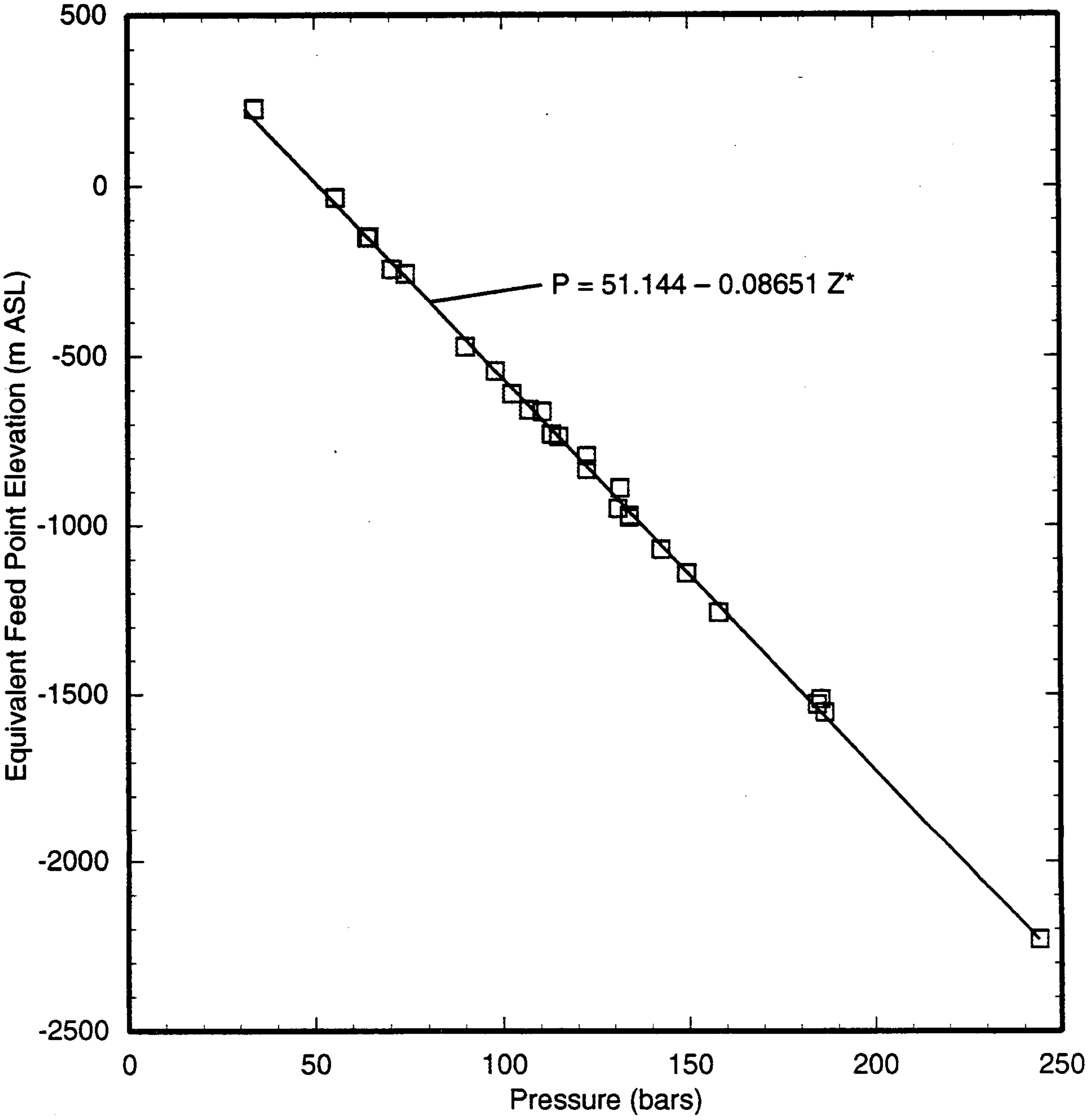

Figure 3.70. Correlation of feedzone pressure with equivalent feedpoint elevation for Takigami boreholes.

The nominal piezometric surface thus varies from 579.6 m ASL at $X_E = 0$ to 503.0 m ASL at $X_E = 3$ km. An examination of Table 3.2 reveals that the nominal piezometric surface lies substantially below the local ground surface in the drilled area.

The stable feedzone temperatures for Takigami boreholes are listed in Table 3.3. The highest temperatures (240°C to 250°C) at Takigami are observed in boreholes (NE-4, NE-10, TT-13S, TT-14R, TT-16, TT-16S) located in the southwestern parts of the Takigami Geothermal Field. The temperatures decline rather rapidly to the north and the east of Takigami boreholes NE-4 and TT-16S. Temperature inversions are seen in boreholes NE-2R, NE-5, NE-11R, TT-1, TT-8S3 and TT-16; all of these boreholes are located to the north or to the east of the group of high-temperature boreholes (NE-4, NE-10, TT-13S, TT-14R, TT-16 and TT-16S). A temperature inversion generally indicates an outflow zone. It is likely that the hot fluid source for the Takigami Geothermal Field is located in the southwestern part of the field; the hot fluid rises to about −1300 m ASL and then flows laterally to the east and to the north.

The reservoir temperatures and pressures at Takigami are such that the reservoir fluid is single-phase liquid. Stable feedzone pressures for Takigami boreholes exceed the saturation pressures (corresponding to stable feedzone temperature) by a substantial amount (see Table 3.4); the reservoir fluid in the natural state is far removed from the saturation line for pure water. Furthermore, production from Takigami boreholes is unlikely to induce *in situ* boiling. The production-induced pressure drop will have to exceed (50 to 120) bars for *in situ* boiling to take place.

Table 3.3. Stable feedpoint temperatures for Takigami boreholes.

Borehole Name	Feedzone Elevation (m ASL)	Feedpoint Coordinates		Feedpoint Temp (Celsius)	Maximum Temperature and Location	
		(kmN)	(kmE)		(Celsius)	(m ASL)
NE-2R	-1054	2.839	1.182	180	198	-854.*
NE-3(i)	-986	3.523	1.094	192	-	-
NE-3	-1581	3.523	1.094	197	-	-
NE-4	-1523	2.943	0.315	244	-	-
NE-5(i1)	-206	2.369	1.867	209	-	-
NE-5(i2)	-306	2.368	1.872	205	-	-
NE-5	-786	2.377	1.908	185	214	-226.*
NE-6(i1)	197	3.411	2.713	192	195	147
NE-6	-733	3.411	2.713	186	-	-
NE-9	-201	4.109	1.898	185	-	-
NE-10	-818	2.047	0.919	220	250	-1330
NE-11	-514.5	1.500	1.644	196	-	-
NE-11R	-1024.5	1.541	1.855	187	213	-414.*
TP-1	-995.5	1.990	0.980	-	-	-
TT-1	-2261.5	3.390	1.238	202	215	-1490.*
TT-2	-871.5	3.226	1.434	205	-	-
TT-3	-1171.5	3.532	1.201	-	-	-
TT-7	-197.5	2.373	1.871	>206.	217	-242
TT-8(i)	-76	2.802	1.606	180	-	-
TT-8S1(i)	-286	2.810	1.597	162	-	-
TT-8S3	-1106	2.965	1.367	214	224	-856.*
TT-10	-575	4.266	1.232	168	-	-
TT-13S	-1275.5	1.733	0.710	236	245	?
TT-14R	-905.5	1.786	0.624	236	240	-1136
TT-16	-1543.5	2.512	0.545	215	245	-1304.*
TT-16S	-983.5	2.233	1.302	230	240	-1093
TT-18	-636	4.684	0.981	160	-	-
TT-19	-682.5	4.203	0.949	90	-	-
TT-23	-752.5	4.583	0.868	-	160	-896

*Denotes depth for temperature inversion in the borehole.

Table 3.4. Comparison of saturation pressure (corresponding to stable feedzone temperature) with stable feedzone pressure for Takigami boreholes.

Borehole Name	Feedzone Elevation (m ASL)	Feedpoint Temperature (Celsius)	Feedpoint Pressure (bars)	Saturation Pressure (bars)
NE-3	-1581	197	186.5	14.6
NE-4	-1523	244	185.5	35.9
NE-5(i2)	-306	205	74	17.2
NE-5	-786	185	115	11.2
NE-6	-733	186	110.5	11.5
NE-9	-201	185	64	11.2
NE-10	-818	220	122.5	23.2
NE-11	-514.5	196	90	14.3
NE-11R	-1024.5	187	134	11.7
TT-1	-2261.5	202	244	16.2
TT-2	-871.5	205	122.5	17.2
TT-7	-197.5	206	64.5	17.6
TT-8(i)	-76	180	55.5	10.0
TT-8S1(i)	-286	162	70.5	6.5
TT-8S3	-1106	214	142.5	20.6
TT-10	-575	168	98	7.5
TT-13S	-1275.5	236	158	31.2
TT-14R	-905.5	236	131.5	31.2
TT-16	-1543.5	215	184.5	21.0
TT-16S	-983.5	230	131	28.0
TT-18	-636	160	102.5	6.2

Section 4

Injection and Production Tests

Injection tests have been performed on seven (7) slim holes and sixteen (16) large-diameter wells at Takigami. It is a standard practice at Takigami to perform a short (a few minutes to a few hours) injection test either prior to or soon after the drilling and completion of a borehole. A typical injection test at Takigami consists of injecting cold water into a borehole at a fixed rate and simultaneously monitoring pressure downhole. In several cases, injection was performed using two or more different rates. During the injection tests, the downhole pressure tool (Kuster gauges), in many cases, was placed substantially above the feedzone depth. Because of wellbore cooling due to injection of cold fluid, the measured change in pressure (= flowing pressure – static pressure prior to injection) at the gauge depth (gauge depth << feedzone depth) will underestimate the change in pressure at the feedzone depth. The discrepancy in rates of pressure change at the gauge and feedzone depths will decline with continued injection. After the injection of a few wellbore volumes (say 2 or 3), the temperature in the depth interval between the gauge and feedzone depths should approach a stable value; hence, the rates of pressure change at the two depths will be similar.

After the cessation of cold water injection, the wellbore will heat up with time. This heat up should be much slower than the wellbore cooling due to injection of cold water. For the latter reason, it is preferable to use the shutin pressure at the end of the injection test to estimate the pressure change at the feedzone depth. The injectivity index (II) is defined as follows:

$$\mathrm{II} = \frac{M}{P_{flowing} - P_{static}} \qquad (4.1)$$

where M is the injection rate (single rate test), $P_{flowing}$ is the flowing pressure (at gauge depth) during cold water injection, and P_{static} is the shutin pressure at the gauge depth. For multi-rate injection tests, Equation (4.1) can be rewritten as follows:

$$\mathrm{II} = \frac{\Delta M}{\Delta P} \qquad (4.2)$$

where $\Delta M / \Delta P$ is the slope of the straight-line fit to the multi-step injection rate versus injection pressure (at gauge depth) data.

The determination of injectivity indices for individual Takigami boreholes is described in Section 4.1. The injectivity data are summarized in Table 4.1. For several Takigami boreholes (*e.g.*, NE-5, NE-6, TT-7, TT-18), the computed injectivity indices are very large; the measured downhole pressure change in these cases is rather small (less than 1 bar). The Kuster gauges used in Takigami tests have a resolution of 0.1 bars. Furthermore, the two Kuster tools (tools 29651 and 29652) used in most of the tests gave pressures that differed from each other by as much as 0.5 bar. Because of gauge placement and inherent limitations of Kuster tools (resolution, accuracy) used at Takigami, the computed injectivity indices for high-permeability boreholes may be in substantial error.

Seven (7) slim holes and nine (9) large-diameter wells have been discharged at one time or another. All of the Takigami boreholes produce from liquid feedzones. As part of the discharge tests, the characteristic output curves (*i.e.*, mass and enthalpy versus wellhead pressure) were also obtained; these characteristic test data are discussed in Section 5. With the exception of one (1) slim hole (NE-2R) and one (1) large-diameter well (TT-1) downhole pressure and temperature surveys were run during the discharge tests of various Takigami boreholes. These pressure and temperature surveys are used to calculate the productivity indices for the Takigami boreholes in Section 4.1. Productivity Index, PI, is defined as follows:

Continued on page 4-4

Table 4.1. Injectivity Indices for Takigami Boreholes.

Borehole Name	Open Hole Diameter (mm)	Feedzone Depth (mTVD)	Test Date	Pressure Gauge Depth (m TVD)	Injectivity Index (kg/s-bar)	Remarks
NE-4	79	2230	01-28-86	2198	0.22	Static pressure measured 01-27-87.
NE-5(i1)	98	1080	02-12-85	990	12	Analysis by Idemitsu.
			02-17-85	1050	20	Analysis by Idemitsu.
NE-5(i2)	98	1180	02-26-85	1110	28	Analysis by Idemitsu. Hole depth ~1229 m TVD.
NE-5	79	1660	05-19-85	1399	1.7	
NE-6 (i1)	100	700	02-11-85	650	4.0	Analysis by Idemitsu.
NE-6 (i2)	100	740	03-17-85	740*	6.9	*Pressure gradient survey.
NE-6	81	1630	04-24-85	1390	0.36	
NE-9	60	1115	02-21-86	1126	0.09	
NE-10	79	1650	12-09-85	1641	0.17	
NE-11	100	1340	09-07-86	867	0.55	
NE-11R	100	1850	12-25-86	1375	2.7	
TP-1	216	1820	11-14-93	1716	1.1	Two-rate test.
TT-1	216	2970	11-16-83	2649	0.58	
TT-2	216	1580	01-21-84	1550	25	Two-rate test.
TT-3	216	1880	04-12-84	1489	0.19	
TT-7	216	1070	08-22-86	898	24	Static pressure measured prior to test.
			03-14-91	945	110	Two pressure gauges; maximum pressure change ~0.2 bars.
TT-8(i)	311	840	08-25-86	800	10	Analysis by Idemitsu.
			09-03-86	800	14	Analysis by Idemitsu.
TT-8S1(i)	311	1050	10-04-86	800	7.5	Analysis by Idemitsu.
TT-8S3	216	1870	05-03-87	1494	1.3	
			06-16-87	1494	1.7	After fracturing.
			06-18-87	1494	2.3	After second fracturing.
			06-20-87	1494	2.3	After third fracturing.
			06-21-87	1494	2.3	
TT-10	159	1275	07-20-86	1190	21	Pressure change ~0.8 bars.
			07-26-86	1190	47	Pressure change ~ 0.5 bars.
			04-06-88	1275*	16	*Pressure gradient survey; 2 gauges.

Table 4.1. Injectivity Indices for Takigami Boreholes (continued).

Borehole Name	Open Hole Diameter (mm)	Feedzone Depth (m TVD)	Test Date	Pressure Gauge Depth (m TVD)	Injectivity Index (kg/s-bar)	Remarks
TT-13S	216	2100	11-19-87	1796	0.98	
			12-22-87	1796	3.4	After six days of hot water injection.
			01-06-88	1796?	2.1	
			01-28-88 to 01-31-88	1796?	1.9→ 3.6	During the three-day injection test, the injection pressure declined by ~12 bars.
			07-22-88	1778	4.0	
TT-14R	216	1730	11-03-86	?	2.0	Analysis by Idemitsu.
TT-16	311	2300	02-05-88	1970	0.40	
			03-15-88	1970	0.15	
			06-06-88	2264	0.13	
			06-28-88	2264	0.11	
TT-16S	216	1740	01-29-89	1724	1.4	Two-rate test.
TT-18(i)	159	1300	12-15-87	869	23	Hole depth ~1360 m TVD. Maximum pressure change ~0.3 bars.
TT-19(i)	311	1350	03-02-88	581	5.0	Hole depth ~1362 m TVD.
TT-23	216	1420	09-19-88	1282	11	Two-rate test.

(i) = intermediate depth
(i1) = intermediate depth 1
(i2) = intermediate depth 2

$$\mathrm{PI} = \frac{M}{P_{ns} - P_{fp}}$$

where M is the mass discharge rate, P_{ns} is the stable (static) feedzone (or gauge depth) pressure and P_{fp} is the flowing feedzone (or gauge depth) pressure. The static feedzone (or gauge depth) pressure was estimated from shutin pressure surveys (or temperature and water level data) discussed in Section 3. The flowing pressures were obtained from the pressure surveys in the discharging boreholes. The productivity indices for the Takigami boreholes are summarized in Table 4.2.

A limited amount of pressure fall off (following injection tests), pressure buildup (following discharge tests), and pressure interference data for some of the Takigami boreholes have been made available by Idemitsu; these data may be analyzed to obtain formation transmissivity. Because of funding limitations, the authors did not attempt to analyze these pressure transient data.

4.1 Injectivity and Productivity Indices

Injection rates for Takigami boreholes are usually given as volume injection rates (m^3/s or liters/s). For present purposes, it suffices to assume that the density of injected water is 1000 kg/m^3; therefore, a volume flow rate of 1 liter/s equals a mass flow rate of 1 kg/s.

Slim Hole NE-3

Slim hole NE-3 was discharged for several days in January and February 1983. The slim hole produces from a liquid feedzone (temperature ~197°C) at 2275 m TVD. Pressure surveys in the discharging well were run on January 27, 1983 (survey depth: 1800 m TVD), January 28, 1983 (survey depth: 1995 m TVD), and February 9, 1983 (survey depth: 1995 m TVD). There is something wrong with the pressure survey recorded on January 27, 1983; the pressures in the discharging borehole (above 1800 m TVD) are greater than these recorded under shutin conditions on December 29, 1982. By way of contrast, the pressure surveys of January 28, 1983 and February 9, 1983 imply a small pressure drop ($\leq$ 2 bars) compared to the shutin pressure survey of December 29, 1982. Using the pressure surveys of January 28, 1983 and February 9, 1983, the productivity index for NE-3 is estimated to be 3.4 (± 0.2) kg/s-bar.

Slim Hole NE-4

An injectivity test was run on slim hole NE-4 on January 28, 1986. During the injection test, the pressure gauge was set at ~2198 m TVD (*i.e.*, about 30 meters above the feedzone at 2230 m TVD). The flowing pressure at 2198 m TVD was 206.8 bar. Using an injection rate of 4.92 kg/s and a static pressure of 184.4 bars (pressure measured on January 27, 1986), the injectivity index is estimated to be 0.22 kg/s-bar.

Slim hole NE-4 was discharged on two separate occasions (January 16–20, January 25–27) in 1986. The slim hole produced a single-phase liquid (temperature ~244°C) from a feedzone at ~2230 m TVD. The stable feedzone pressure is 185.5 bars. Two pressure surveys were run in the discharging borehole on January 18, 1986 and January 27, 1986; these pressure data yield rather low (0.05 and 0.08 kg/s-bar) values for the productivity index. As a matter of fact, NE-4 has the lowest productivity index of all the boreholes discharged at Takigami.

Slim Hole NE-5(i1)

Both discharge and injection tests were performed on slim hole NE-5 after the borehole had been drilled to a depth of ~1109 m TVD. The principal feedzone for NE-5(i1) is located at 1080 m TVD.

Two injection tests were run in slim hole NE-5(i1). For the February 12, 1985 test, injection rate was (13.5 to 38.1) kg/s, and the pressure gauge was set at 990 m TVD (*i.e.*, 90 meters above the feedzone).

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Table 4.2. Productivity Indices for Takigami Boreholes.

Borehole Name	Open Hole Diameter (mm)	Feedzone Depth (mTVD)	Test Date	Total Flow Rate (kg/s)	Static Pressure (bars)	Flowing Pressure (bars)	Productivity Index (kg/s-bar)	Remarks
NE-3	101	2275	01-28-83 02-09-83	5.01 6.41	163.2*	161.8* 161.2*	3.6 3.2	*Pressure at 2000 mTVD. Static pressure measured 12/29/82.
NE-4	79	2230	01-18-86 01-27-86	2.89 3.03	185.5	130.0 149.8	0.05 0.08	
NE-5(i1)	98	1080	02-16-85	10.2	?	66.1	?	Hole depth ~1109 m TVD
NE-5(i2)	98	1180	03-16-85 03-17-85	8.64	74.2	74.0 73.5	43 12	Static pressure measured 03-19-85. Hole depth ~1426 m TVD.
NE-6 (i1)	100	700	02-14-85	7.44	?	31.7	?	Hole depth ~ 764 m TVD.
NE-6 (i2)	100	740	03-14-85 03-15-85	7.03	34.2	33.6 33.9	12 23	Hole depth ~1403 m TVD. Static pressure measured 03-17-85.
NE-11	100	1340	09-16-86	5.17	90.0	82.9	0.73	Static pressure measured 09-07-86.
NE-11R	100	1850	02-18-87	3.46	135.2	134.3	3.8	Static pressure measured 02-19-87.
TT-2	216	1580	06-03-84	63.9	122.5	116.7	11	Static pressure measured 08-23-93.
TT-7	216	1070	08-29-86	129.	64.5	59.6	26	Static pressure measured 08-20-93; flowing pressure extrapolated below 700 m TVD.
TT-8(i)	311	840	08-31-86	54.4	55.5	48.6	7.9	Hole depth ~854 m TVD. Static pressure measured 08-29-86.
TT-8S1(i)	311	1050	10-07-86	27.2	70.5	68.0	11	Hole depth ~1215 m TVD. Flowing pressure extrapolated below 800 m TVD. Static pressure measured 10-09-86.
TT-8S3	216	1870	06-23-87 04-06-88	48.1 51.7	142.5	127.0 116.0	3.1 2.0	Flowing pressure extrapolated below 1494 m TVD.
TT-13S	216	2100	01-20-88 01-21-88 08-04-88	48.1 49.4 48.9	158.0	103.5 101.5 112.6	0.88 0.87 1.1	Flowing pressure extrapolated below 1933 m TVD. Flowing pressure extrapolated below 1796 m TVD.
TT-14R	216	1730	11-07-86	77.8	131.5	78.2	1.5	Test conducted prior to installation of 7-inch uncemented liner.
TT-16S	216	1740	02-16-89	15.3	131.0	112.3	0.82	Feedzone temperature had not fully recovered at the time of the test.

(i) = intermediate depth
(i1) = intermediate depth 1
(i2) = intermediate depth 2

During the injection test performed on February 17, 1985, the pressure gauge was set at 1050 m TVD, and the injection rate was 38.0 kg/s. Pressure data from these injection tests were not made available to the authors. Injectivity index values listed in Table 4.1 for NE-5(i1) were computed by Idemitsu engineers.

Slim hole NE-5(i1) was briefly discharged on February 15 and February 16, 1985. The borehole produced from a liquid feedzone (temperature ~209°C) at 1080 m TVD. The flowing pressure at 1080 m TVD (as measured on February 16, 1985) is 66.1 bars. It appears that no pressure surveys in the shutin well were taken either before or after the February 1985 discharge test. The absence of stable pressure data makes it impossible to compute a productivity index for NE-5(i1). The flowing feedzone pressure recorded on February 16, 1985 is actually higher than the stable feedzone pressure (~65 bars) estimated from a fit to the Takigami pressure data (Section 3); this implies a large productivity index for NE-5(i1).

Slim Hole NE-5(i2)

Slim hole NE-5 was discharged for approximately two days in mid-March 1985 after the borehole had been drilled to ~1426 m TVD. During the March 1985 discharge test, NE-5(i2) produced from a liquid feedzone (temperature ~205°C) at ~1180 m TVD. No injection tests were performed on the 1426 m TVD borehole. An injection test was, however, run on February 26, 1985 with a borehole depth of ~1229 m TVD. Since the borehole depth on February 26, 1985 was greater than 1180 m TVD (*i.e.*, feedzone depth for the March 1985 discharge test), the injection test of February 26, 1985 may be used to estimate the injectivity index for NE-5(i2).

During the injection test of February 26, 1985, the Kuster tool was set at ~1110 m TVD (*i.e.*, 70 meters above the feedzone), and the injection rate varied between 25.6 kg/s and 50 kg/s. Pressure data for this injection test were not made available to the authors. The injectivity index for NE-5(i2) (Table 4.1), computed by Idemitsu engineers, is 28 kg/s-bar.

During the March 1985 discharge test, two pressure surveys were run in NE-5(i2). Both of these pressure surveys indicated a rather small pressure drop (0.2 to 0.7 bars) at the feedzone. Because of the small pressure change, individual productivity index values listed in Table 4.2 may not be too reliable, howeer, the average of the two values, 27.5 kg/s-bar, is essentially the same as the injectivity index.

Slim Hole NE-5

A single injection test (three hours in duration) was run on the completed borehole on May 19, 1985. The Kuster tool was placed at ~1399 m TVD (*i.e.*, about 260 meters above the feedzone), and the injection rate was 4.17 kg/s. After the injection test, a shutin pressure of 89.9 bars was recorded at the gauge depth. Using an injection pressure of 92.3 bars, the injectivity index for NE-5 is estimated to be 1.7 kg/s-bar. The injectivity index for the completed borehole is much smaller than that for NE-5(i1) and NE-5(i2).

Slim Hole NE-6(i1)

Injection and discharge tests were performed on NE-6 after the borehole had been drilled to ~764 m TVD. During the injection test carried out on February 11, 1985, the pressure tool was set at 650 m TVD (*i.e.*, 50 meters above the feedzone at 700 m TVD); the injection rate was (4.64 to 23.2) kg/s. Pressure data for the February 1985 injectivity test have been analyzed by Idemitsu engineers; the injectivity index is estimated to be 4.0 (±0.7) kg/s-bar.

Slim hole NE-6(i1) was discharged for about 36 hours on February 14 and 15, 1985. A pressure survey run in the discharging well on February 14, 1985 indicated a pressure of 31.7 bars at the feedzone depth. Unfortunately, the absence of a shutin pressure profile for NE-6(i1) renders it impossible to compute a productivity index. The flowing feedzone pressure (31.7 bars) is higher than the stable feedzone pressure obtained from a fit to the Takigami feedzone pressures (Section 3); this implies that production from NE-6(i1) is accompanied by little or no pressure drop. It is thus likely that NE-6(i1) has a rather large productivity index.

Slim Hole NE-6(i2)

Both discharge and injection tests were performed on slim hole NE-6 after the borehole had been drilled to a vertical depth of ~1403 m TVD. A pressure survey run while injecting cold water (injection rate ~8.33 kg/s) indicated a pressure of 35.4 at the feedzone depth (740 m TVD). Using a shutin pressure of 34.2 bars (measured on March 17, 1985), the injectivity index is 6.9 kg/s-bar.

During the three-day discharge test carried out in March 1985 (March 14–17), pressure surveys were run in the discharging well on March 14 and March 15, 1985. Both of the latter pressure surveys imply that production from NE-6(i2) was accompanied by a small pressure drop (0.6 bars on March 14 and 0.3 bars on March 15). Because of the small magnitude of the pressure drop and problems with gauge resolution/calibration (see introduction to Section 4), we do not attach any significance to the difference in the computed values for the productivity index (Table 4.2).

Slim Hole NE-6

Despite repeated attempts, it proved impossible to discharge slim hole NE-6. A brief (30 minutes in duration) injection test (injection rate = 3.33 kg/s) was performed on April 24, 1985. The pressure gauge was set at 1390 m TVD (*i.e.*, about 240 meters above the feedzone at 1630 m TVD); the flowing pressure at gauge depth was 100.6 bars. Using a static pressure of 91.4 bars (measured after the injection test), the injectivity index is estimated to be 0.36 kg/s-bar. The latter injectivity index value is only a small fraction of the injectivity (productivity) indices for NE-6(i1) and NE-6(i2).

Slim Hole NE-9

An injection test (injection rate: 3.47 kg/s) was performed on slim hole NE-9 on February 21 and 22, 1986 with the Kuster tool set at 1126 m TVD (*i.e.*, 11 meters below the feedzone at 1115 m TVD). During the injection phase, the pressure at gauge depth was 102.8 bars. By comparison with stable feedzone pressure (Section 3), the static pressure at 1126 m TVD is ~65.0 bars. The calculated injectivity index for NE-9 (Table 4.1) is rather small (~0.09 kg/s-bar).

Slim Hole NE-10

An injection test was performed on the completed slim hole NE-10 on December 9, 1985 with the Kuster pressure gauge set at 1641 m TVD (*i.e.*, 9 meters above the feedzone at 1650 m TVD). The cold water injection rate during the latter test was 5.0 kg/s. The pressure (at gauge depth) during the injection phase was ~153.3 bars. By comparison with the stable feedzone pressure (Section 3), the static pressure at 1641 m TVD is ~123 bars. The injectivity index for NE-10 is, therefore, ~0.17 kg/s-bar.

Slim Hole NE-11

The injectivity test of September 7, 1986 was performed with the Kuster pressure tool set at ~867 m TVD (*i.e.*, about 500 meters above the feedzone at 1340 m TVD). Cold water was injected at a rate of 9.0 kg/s for 30 minutes; the injection pressure (at gauge depth) was 62.6 bars. Using a post-injection shutin pressure of 46.3 bars (The pre-injection shutin pressure at gauge depth was 47.9 bars.), the injectivity index for NE-11 is computed as 0.55 kg/s-bar.

Slim hole NE-11 was discharged for about seven days (September 12–19) in September 1986. A pressure survey run in the discharging well (discharge rate ~5.17 kg/s) on September 16, 1986 gave a pressure of 82.9 bars at 1340 m TVD. With a stable feedzone pressure of 90 bars (Section 3), the productivity index for NE-11 is estimated as 0.73 kg/s-bar.

Slim Hole NE-11R

During the injection test performed on December 25, 1986, the Kuster pressure tool was set at ~1375 m TVD, *i.e.*, about 500 meters above the feedzone at 1850 m TVD. Cold water was injected at a rate of 9.0 kg/s for 30 minutes; the injection pressure at gauge depth was 95.3 bars. Using the post-test static pressure of 92.0 bars (The pre-test static pressure was 92.3 bars.), the injectivity index for NE-11R is obtained as 2.7 kg/s-bar.

Slim hole NE-11R was discharged for about eighteen days in February 1987. A pressure survey run in the borehole on February 18, 1987 indicated a pressure of 134.3 bars at 1850 m TVD. With a discharge rate of 3.46 kg/s and a static pressure of 135.2 bars (survey made in shutin hole on February 19, 1987), the productivity index for NE-11R is estimated as 3.8 kg/s-bar.

Large-Diameter Well TP-1

A two-rate injection test (total injection time ~3 hours) was performed on November 14, 1993 with two Kuster pressure tools set at ~1716 m TVD (*i.e.*, about 100 meters above the feedzone at 1820 m TVD). The pressure (average of two Kuster gauges) and injection rate data are displayed in Figure 4.1. The injectivity index for well TP-1 is ~1.1 kg/s-bar.

Large-Diameter Well TT-1

During an injection test performed on November 16–17, 1983, the Kuster pressure tool was set at ~2649 m TVD, *i.e.*, about 300 meters above the feedzone at 2970 m TVD. The shutin and flowing pressures (at gauge depth) were 211.9 and 233.8 bars, respectively. With an injection rate of 12.8 kg/s, the injectivity index for TT-1 is computed as 0.58 kg/s-bar.

Well TT-1 was discharged briefly (total discharge time < 2 days) prior to the injection test on November 16, 1983. The well would discharge only at wellhead pressures less than 0.5 bars (gauge). No downhole pressure surveys were carried out in the discharging well. Although it is not possible to compute a productivity index for TT-1, the inability to discharge TT-1 at wellhead pressures greater than 0.5 bars (gauge) is consistent with its poor injectivity.

Production Well TT-2

A two-rate injection test for TT-2 was performed on January 21, 1984 after the well had been drilled to a depth of ~1607 m TVD. The pressure gauge was set at 1550 m TVD. The total injection period was less than one hour; injection at the higher of the two rates (~46.7 kg/s) was carried out for only eight minutes. Pressure versus injection rate data are displayed in Figure 4.2; the injectivity index for TT-2 is about 25 kg/s-bar.

During a discharge test in June 1984, a pressure survey was run on June 3, 1984. The flowing feedzone pressure was 116.7 bars. With a total discharge rate of 63.9 kg/s and a stable feedzone pressure of 122.5 bars (Section 3), the productivity index for TT-2 is computed to be ~11 kg/s-bar.

Injection Well TT-3

An injection test was performed on the completed borehole on April 12, 1984. During the four-hour injection test, the injection rate was 5.17 kg/s. The Kuster tool was set at ~1489 m TVD, *i.e.*, about 400 meters above the feedzone at 1880 m TVD. The static pressure (prior to test ?) at gauge depth was 114.7 bars. With an injection pressure (at gauge depth) of 142.6 bars, the injectivity index for TT-3 is 0.19 kg/s-bar.

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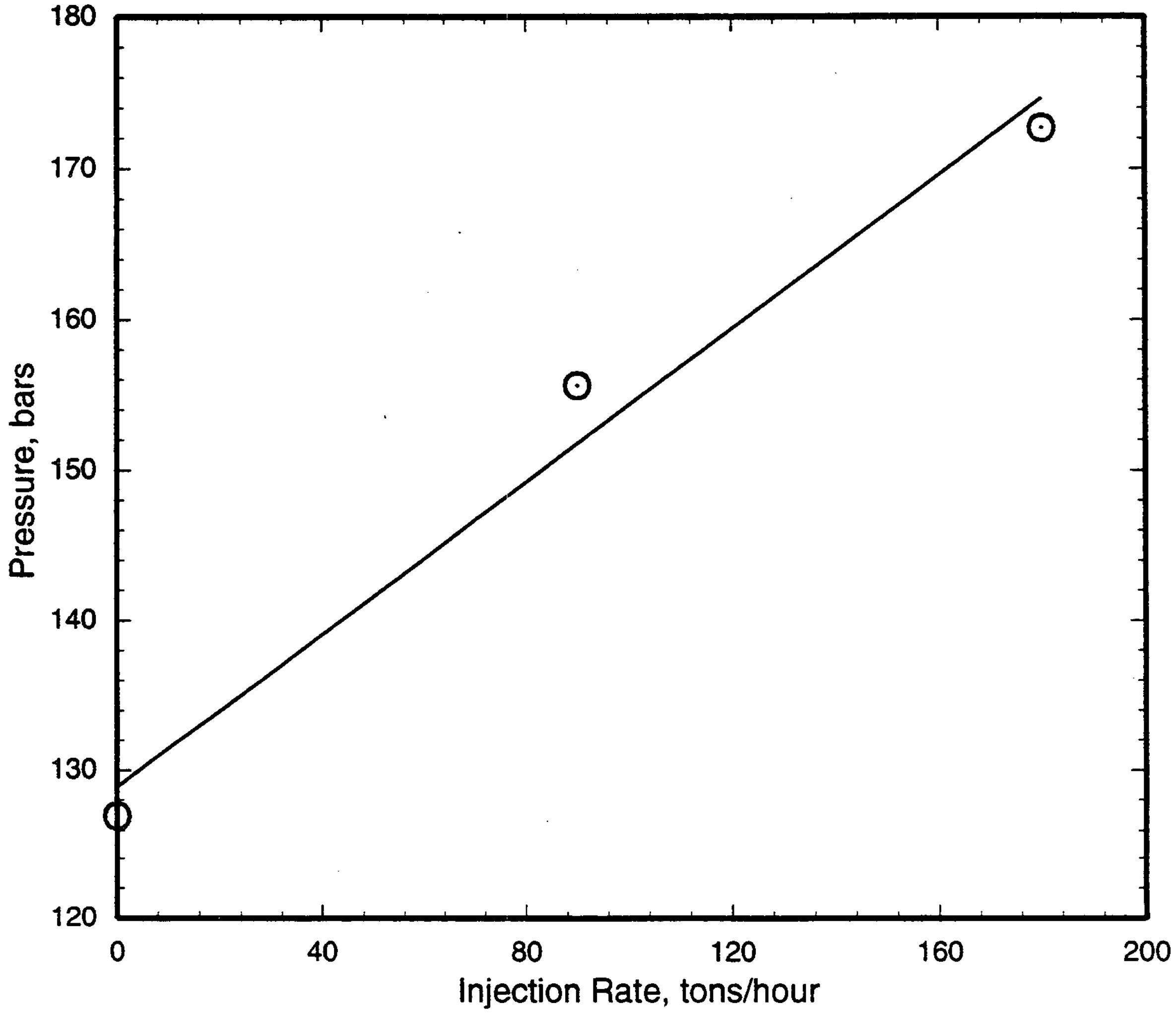

Figure 4.1 Injectivity test for well TP-1 performed on November 14, 1993. Two Kuster pressure tools were set at ~1716 m TVD.

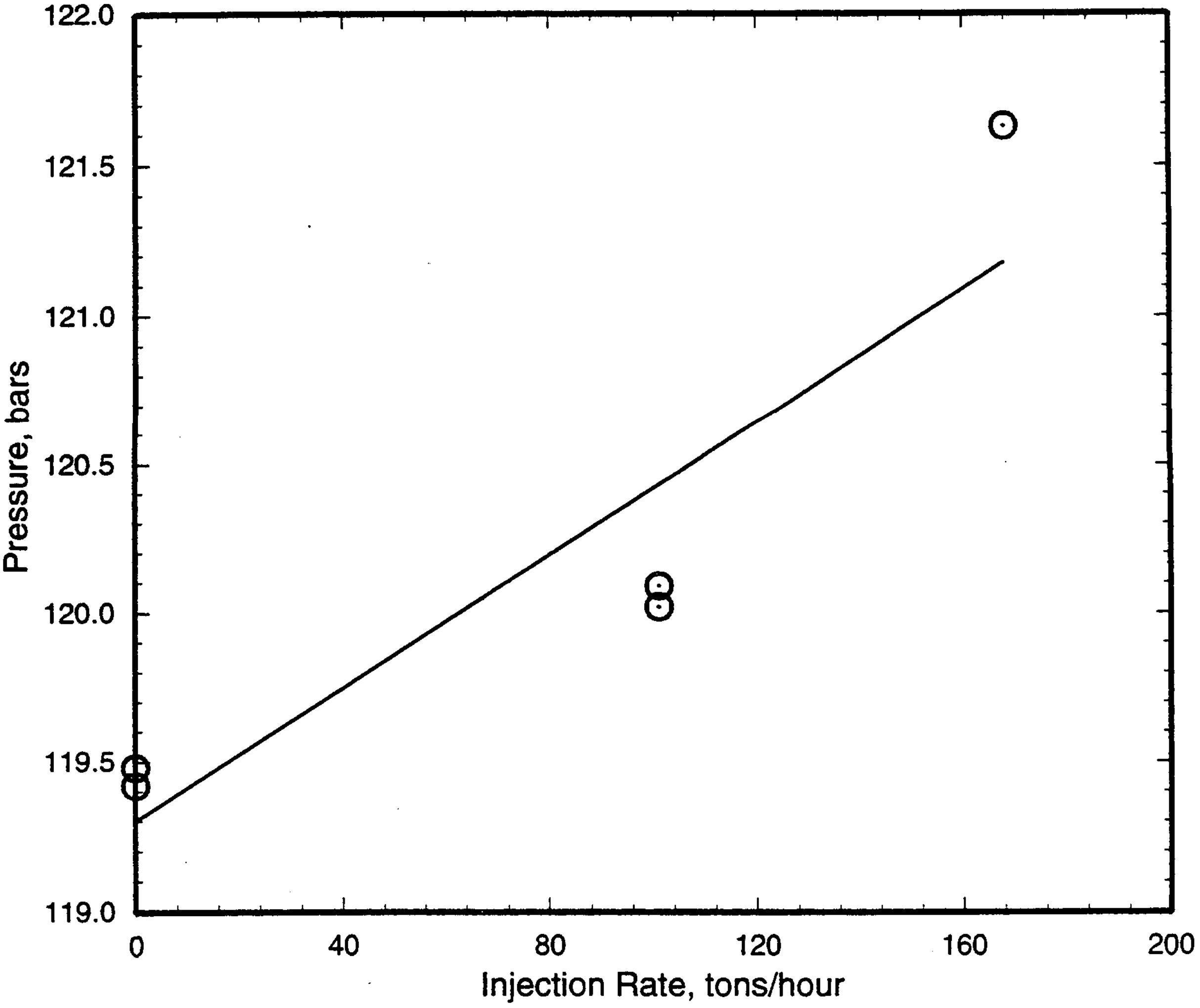

Figure 4.2 Injectivity test for production well TT-2 performed on January 21, 1984. The pressure tool was set at ~1550 m TVD.

Production Well TT-7

TT-7 is the most productive well at Takigami. During a 30-minute injection test on August 22, 1986, a Kuster tool was set at 898 m TVD. The injection rate and pressure were 33.3 kg/s and 47.9 bars, respectively. The pre- and post-test static pressures (at gauge depth) were 46.5 bars and 47.4 bars, respectively. Using the pre-test static pressure value of 46.5 bars, the injectivity index is obtained as 24 kg/s-bar. The latter value for the injectivity index represents a lower bound in that the use of post-test static pressure yields a value of 67 kg/s-bar.

An additional injection test was performed on March 14, 1991 with two Kuster tools set at 948 m TVD (*i.e.*, ~120 meters above the feedzone at 1070 m TVD). Cold water was injected at a rate of 21.4 kg/s for 30 minutes; the injection rate was then increased to 35.8 kg/s for another 30 minutes. The injection pressure (average of two gauges) was identical (52.5 bars) for both the injection rates. The injection pressure is lower than the reported pre-injection pressure of 52.8 bars. The post-injection pressure was 52.3 bars; thus, the maximum change in pressure was 0.2 bars. Using an injection rate of 21.4 kg/s (*i.e.*, the smaller of the two rates), the injectivity index is estimated to be at least 110 kg/s-bar.

During the preliminary discharge test (August 1986) of TT-7, a pressure survey was run to a depth of ~699 m TVD. Extrapolating the single-phase (liquid) part of the measured pressure profile, the flowing feedzone pressure is obtained as 59.6 bars. The static feedzone pressure (see Section 3) is 64.5 bars. With a discharge rate of 129 kg/s, the productivity index for TT-7 is computed as 26 kg/s-bar. The latter value for the productivity index is not too different from that (30 kg/s-bar) obtained from a numerical simulation (Section 5.2) of the various discharge tests of well TT-7.

Large-Diameter Well TT-8

Injection and production tests were performed on well TT-8 in August and September 1986 after the borehole had been drilled to a depth of ~854 m TVD. During injection tests on August 25, 1986 (injection rate ~10 kg/s) and September 3, 1986 (injection rate ~14.2 kg/s), the Kuster tool was set at 800 m TVD (*i.e.*, ~40 meters above the feedzone at 840 m TVD). Detailed pressure data for these tests have not been made available to the authors. The injectivity indices listed in Table 4.1 were calculated by Idemitsu engineers.

A short term (< 48 hours) production test was performed with $4^1/_2$-inch drilling pipe in the borehole from 15:00 LT August 31, 986 to 13:00 LT September 2, 1986. The discharge rate was ~54.4 kg/s. A pressure survey was run in the discharging well on August 31, 1986 to a depth of ~791 m TVD; extrapolating the measured pressures, the flowing feedzone pressure is estimated to be ~48.6 bars. Assuming a stable feedzone pressure of 55.5 bars, the productivity index is computed to be 7.9 kg/s-bar.

Large-Diameter Well TT-8S1

After the borehole had been drilled to a depth of ~1213 m TVD, both injection and discharge tests were performed in October 1986. During the injection test on October 4, 1986, the Kuster gauge was set at a depth of 800 m TVD (*i.e.*, 250 meters above the feedzone at 1050 m TVD). The injection rate was 50.8 kg/s. The pressure data have been analyzed by Idemitsu engineers; the injectivity index is 7.5 (±1.9) kg/s-bar.

A short term discharge test was performed from October 5, 1986 to October 9, 1986 with $4^1/_2$-inch drill pipe in the borehole. Downhole pressure surveys were recorded on October 5, October 6 and October 7, 1986. The pressure survey of October 6 was taken during airlift. There is something wrong with the pressure survey of October 5 since the measured pressure gradient is less than the hydrostatic gradient. The pressure survey of October 7, 1986 was measured to a depth of 800 m TVD; extrapolating the data, the flowing pressure at 1050 m TVD is ~68.0 bars. The static feedzone pressure (see Section 3) is 70.5 bars. Using a discharge rate of 27.2 kg/s, the productivity index is ~11 kg/s-bar.

Production Well TT-8S3

During the preliminary injection test on May 3, 1987, two Kuster tools were set at ~1494 m TVD. Cold water was injected at a rate of 33.3 kg/s for 61 minutes; the injection pressure was 131.4 bars. With a static pressure (measured after the test) of 106.7 bars, the injectivity index is 1.3 kg/s-bar. In an attempt to enhance injectivity, several fracturing operations were carried out in June 1987. Injectivity index apparently increased to 2.3 kg/s-bar after the first two attempts at fracturing (Table 4.1, and Figures 4.3 and 4.4). No additional enhancement in injectivity index (see Table 4.1 and Figures 4.5 and 4.6) was obtained with further attempts at stimulating the well.

Flowing pressure surveys were recorded during discharge tests in April 1987, June 1987 and April 1988. The pressure survey of April 30, 1987 was run during air lift; these data are not useful for determining the productivity index. Pressure survey of June 23, 1987 (discharge rate ~48.1 kg/s) was run to a depth of 1494 m TVD; extrapolating the data, the flowing feedzone pressure is estimated to be 127.0 bars. The static pressure at 1870 m TVD (feedzone depth) is 142.5; therefore, the productivity index (as obtained from June 23, 1987 survey) is 3.1 kg/s-bar. The pressure survey of April 6, 1988 indicated a flowing feedzone pressure of 116.0 bars. With the measured discharge rate of 51.7 kg/s, the productivity index (April 1988 test) is ~2.0 kg/s-bar. It is perhaps worth noting here that the measured feedzone temperature (190°C) on June 23, 1987 was substantially less than that (214°C) recorded on April 6, 1988. Since the June 23, 1987 pressure survey was run shortly after cold water injection tests, it is likely that the feedzone temperature had not fully recovered at the time of this (June 1987) temperature survey.

Injection Well TT-10

Two short-term injection tests of well TT-10 were performed on July 20, 1986 (injection rate ~16.9 kg/s) and July 26, 1986 (injection rate ~23.3 kg/s) with the pressure toolset at 1190 m TVD (*i.e.*, about 85 meters above the feedzone at 1275 m TVD). The injection and static (prior to test) pressures for the July 20, 1986 test were 89.0 bars and 88.2 bars, respectively; these data yield an injectivity index of 21 kg/s-bar. For the July 26, 1986 test, the injection and static (after the test) pressures were 88.1 bars and 87.6 bars, respectively; the injectivity index is, therefore, ~47 kg/s-bar.

An additional injectivity test (injection rate ~41.7 kg/s) was undertaken on April 6, 1988; during this test, a pressure gradient survey was run using two pressure tools. The flowing feedzone pressure (average of two pressure gauges) was 100.6 bars. With a stable feedzone pressure of 98.0 bars (see Section 3), the injectivity index is computed as 16 kg/s-bar.

Production Well TT-13S

Both short (a few hours) and long-term (several days) injection tests have been performed on well TT-13S. Three short-term multi-rate injection tests were performed on November 19, 1987, December 22, 1987 and January 6, 1988 (see Figures 4.7–4.9); the injectivity index computed from these tests varied from a low of 0.98 kg/s-bar (November 19, 1987) to a high of 3.4 kg/s-bar (December 22, 1987). Interestingly, the December 1987 injectivity test was performed after hot water had been injected into TT-13S for about six(6) days.

A three (3) day injectivity test was carried out towards the end of January 1988 (Table 4.1). During the latter test, the injection rate was held more or less constant (~50 kg/s); the injection pressure (at gauge depth), however, decreased from 155.0 bars

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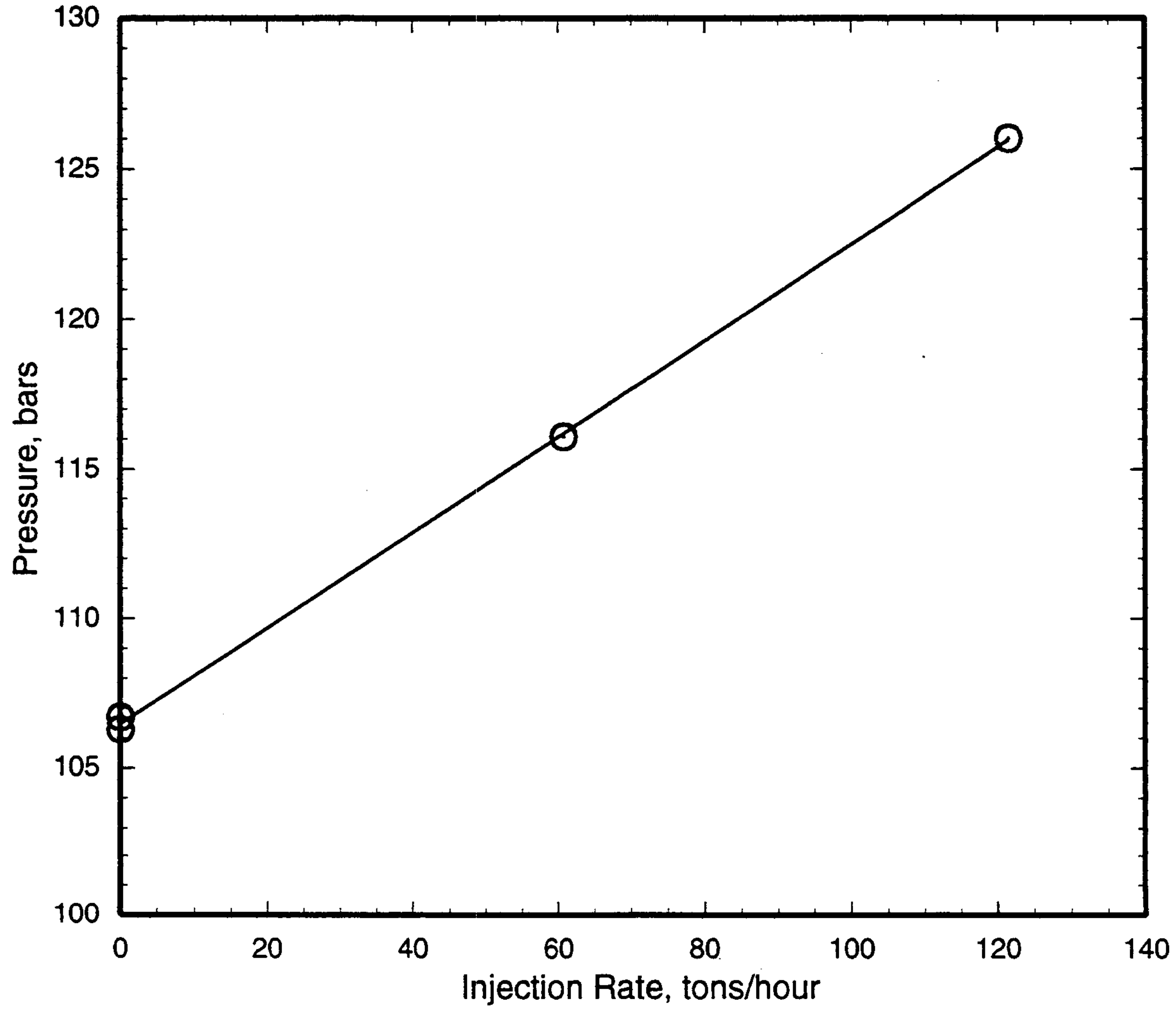

Figure 4.3. Injectivity test for production well TT-8S3 performed on June 16, 1987. Two pressure tools were set at ~1494 m TVD.

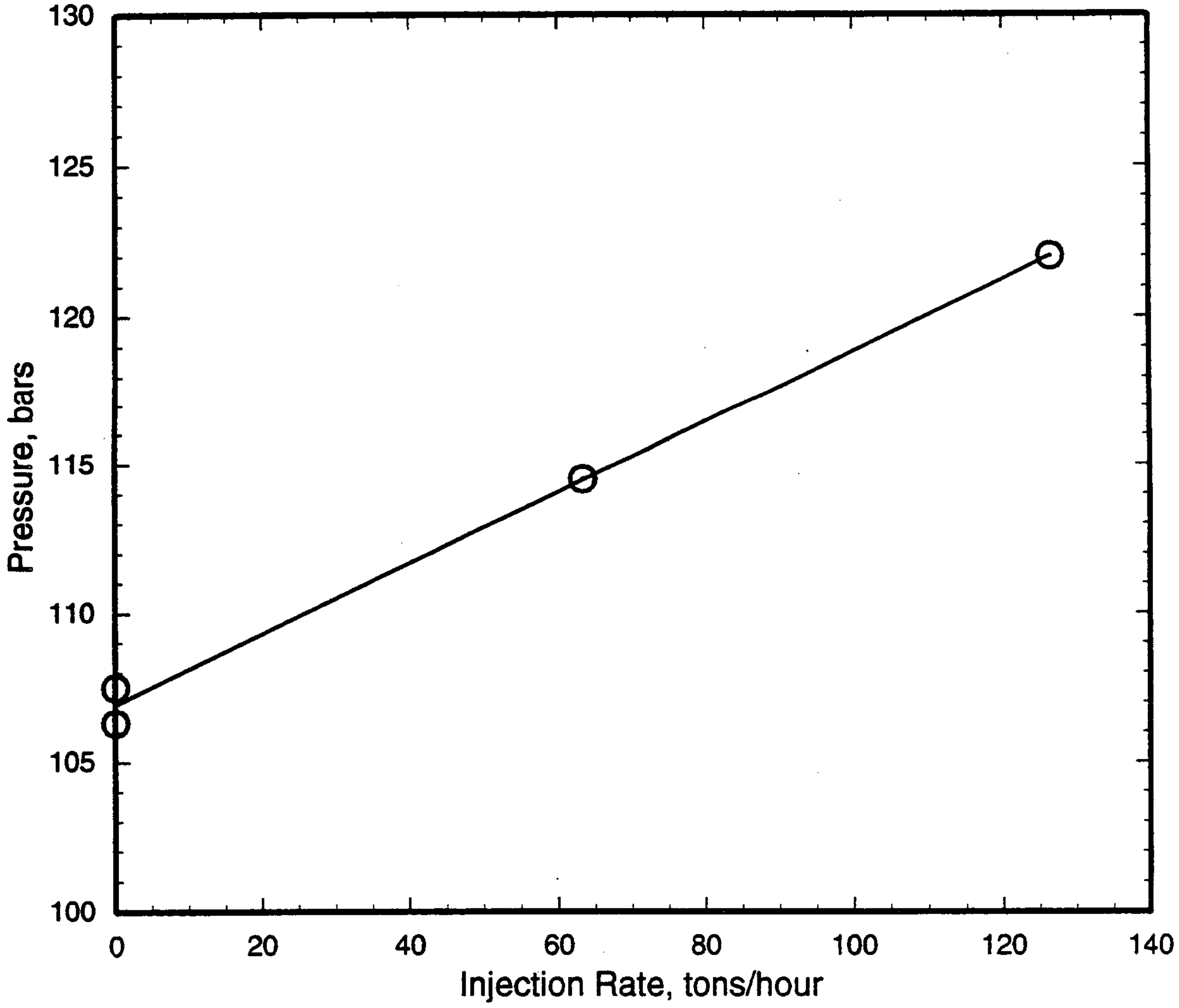

Figure 4.4. Injectivity tet for production well TT-8S3 performed on June 18, 1987. Two pressure tools were set at ~1494 m TVD.

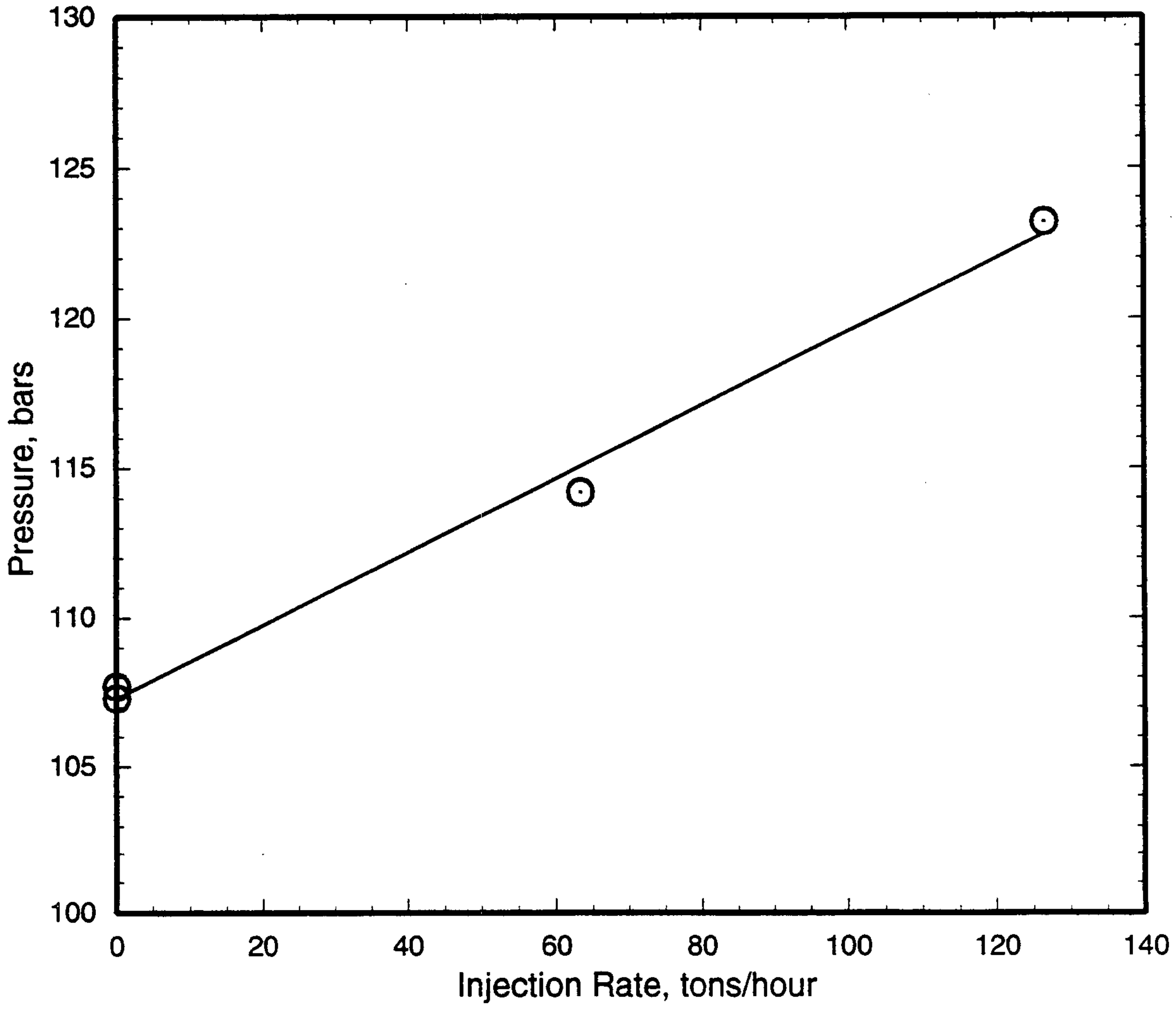

Figure 4.5. Injectivity test for production well TT-8S3 performed on June 20, 1987. The pressure tool was set at ~1494 m TVD.

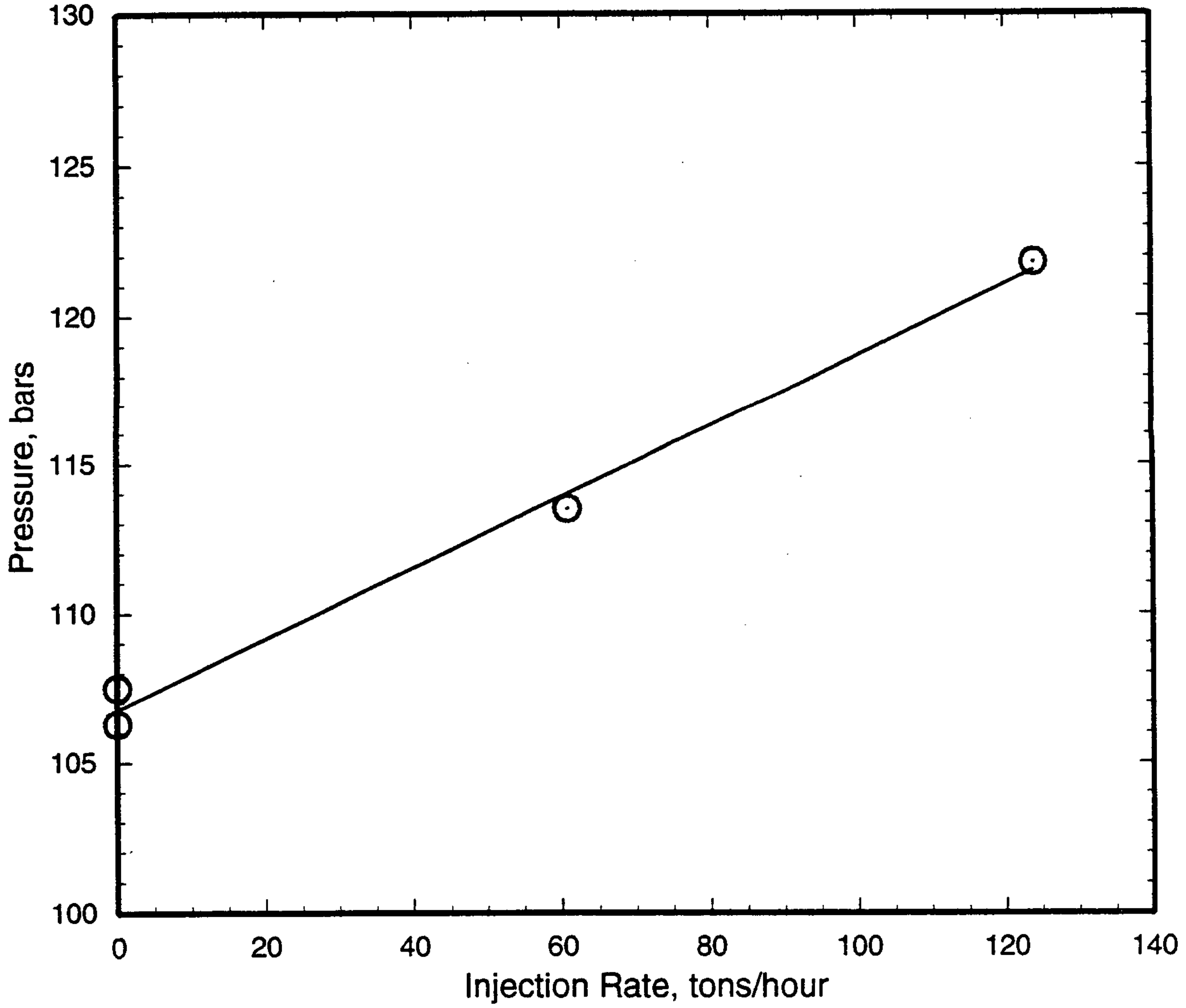

Figure 4.6. Injectivity test for production well TT-8S3 performed on June 21, 1987. Two pressure tools were set at ~1494 m TVD.

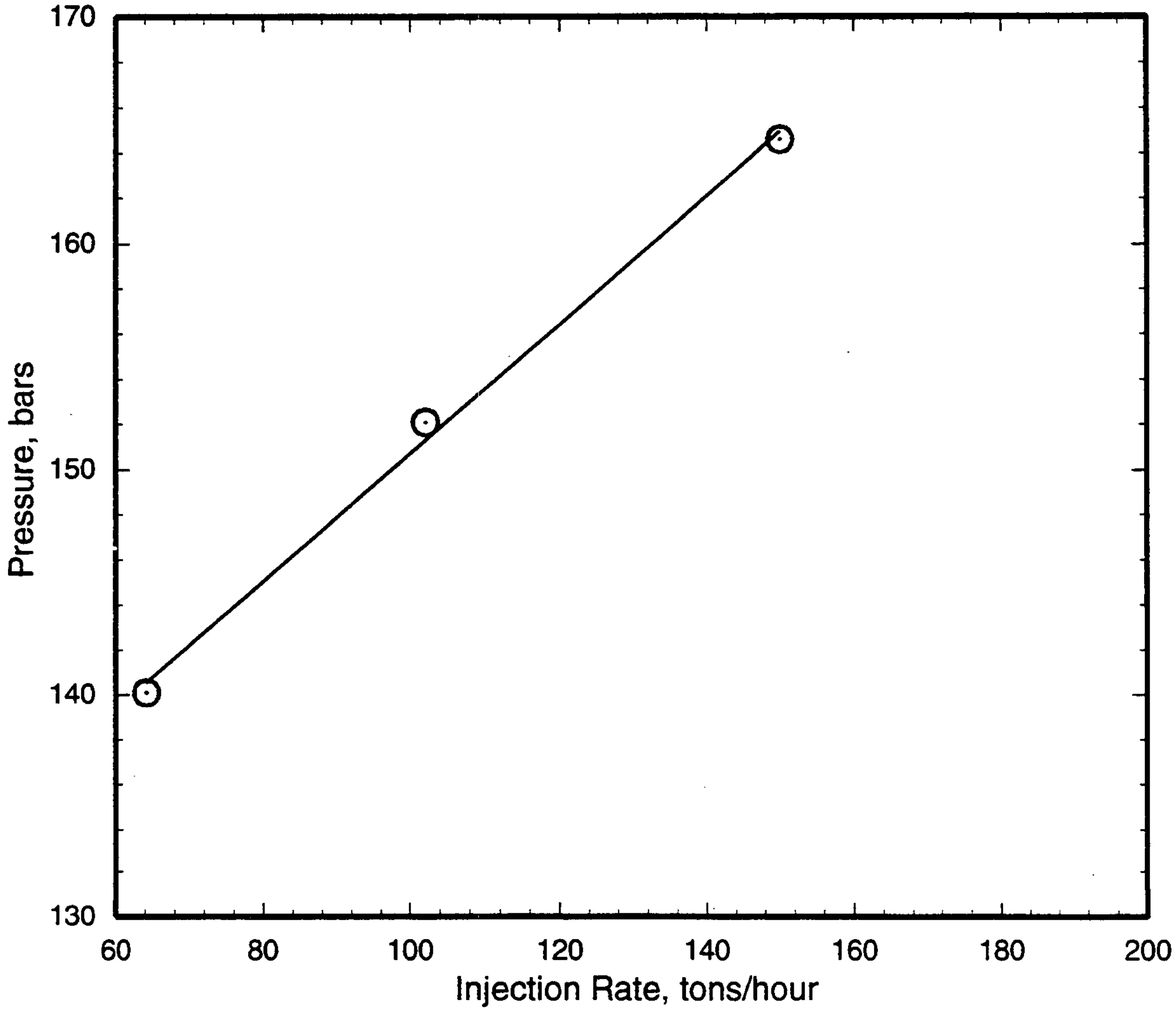

Figure 4.7. Injectivity test for production well TT-13S performed on November 19, 1987. The Kuster tool was set at 1796 m TVD.

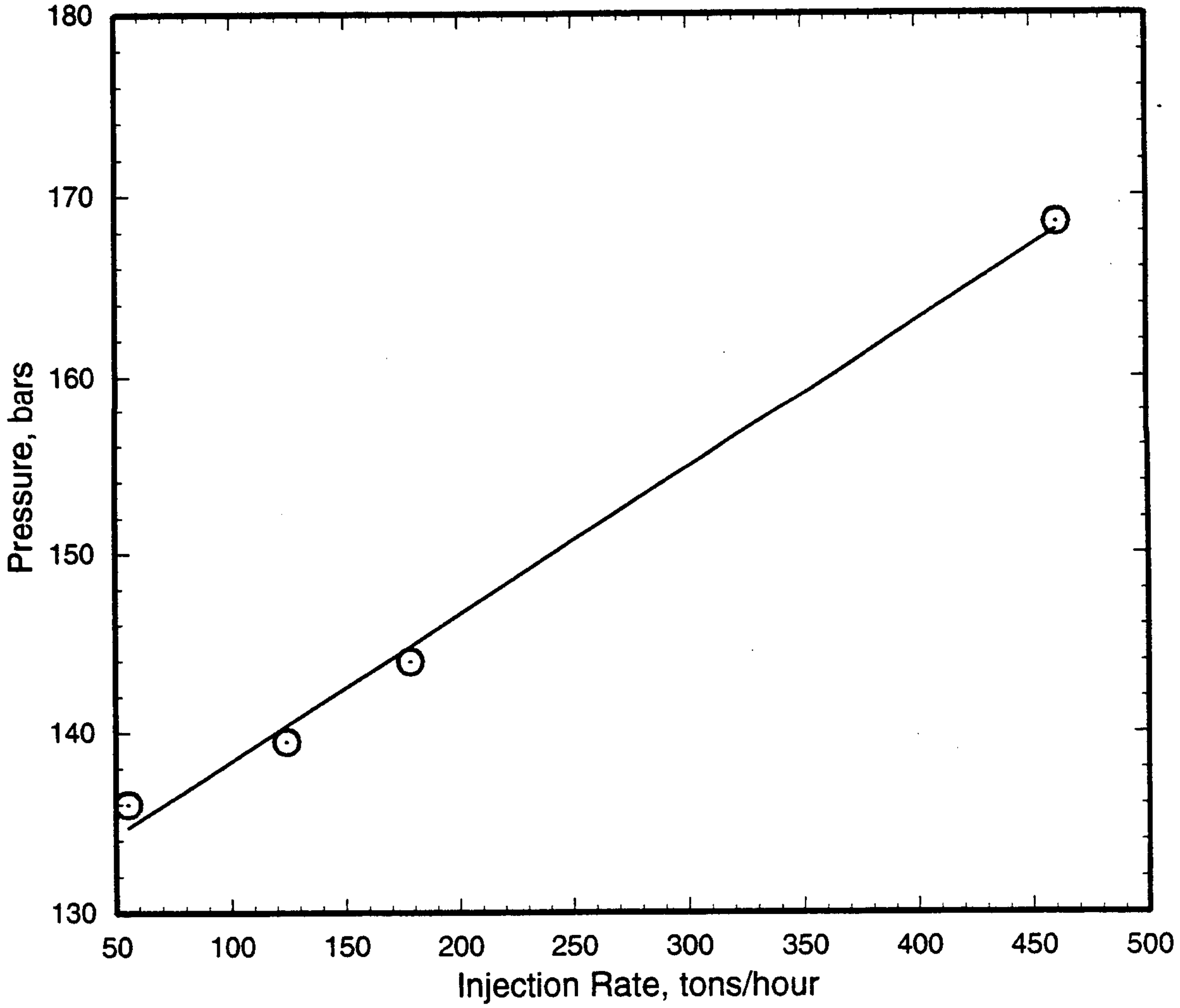

Figure 4.8. Injectivity test for production well TT-13S performed on December 22, 1987. The Kuster tool was set at 1796 m TVD.

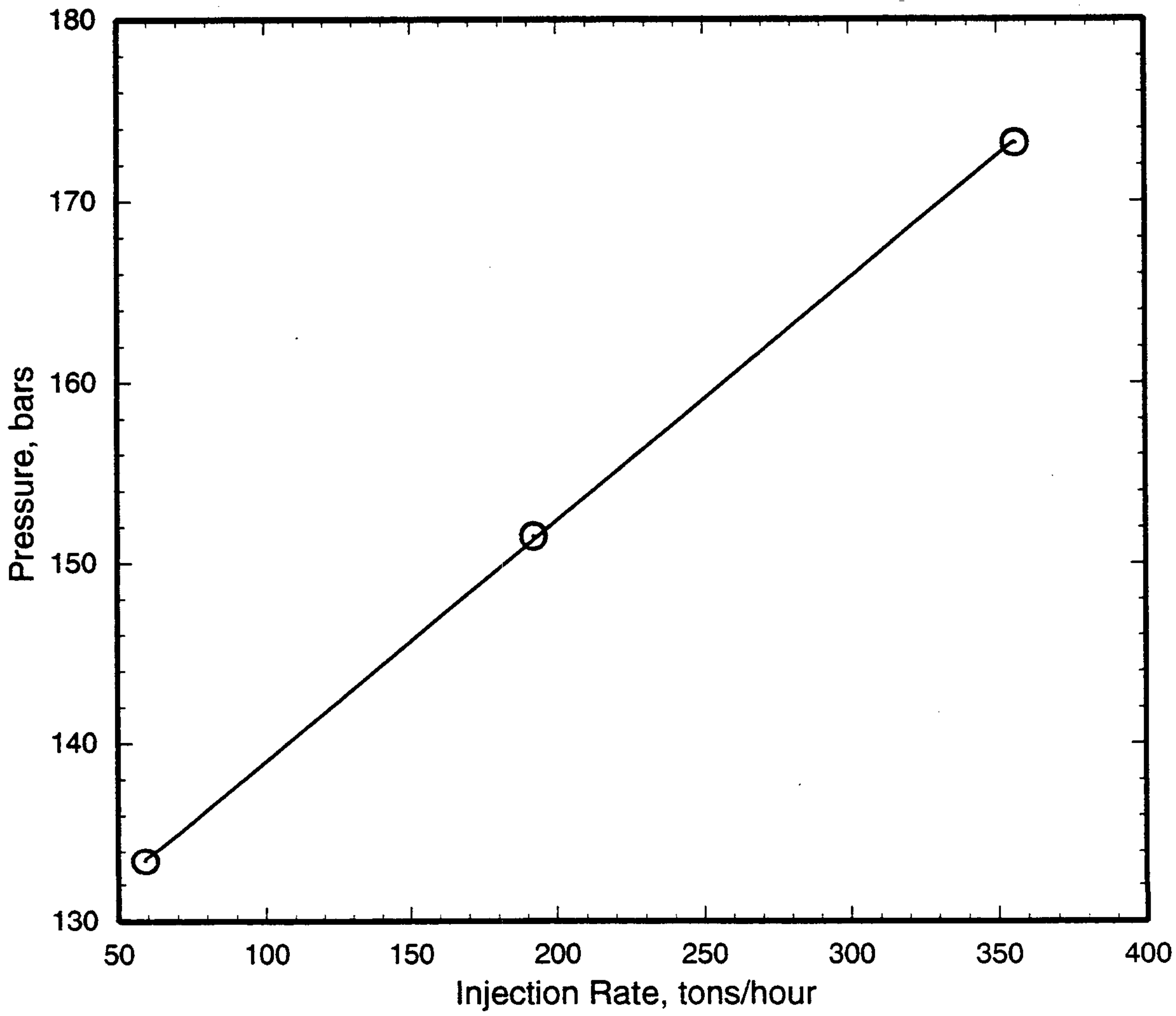

Figure 4.9. Injectivity test for production well TT-13S performed on January 6, 1988. The Kuster tool was set at 1796 m TVD (?).

(at the start of the test) to 143.2 bars (at the end of the test). The static pressure (at gauge depth) prior to the test was 129.2 bars. These data imply that the injectivity index increased substantially (from 1.9 kg/s-bar to 3.6 kg/s-bar) during the course of the injection test.

An additional short-term (30 minutes) injection test was run on July 22, 1988 with the pressure tool set at 1778 m TVD. The injection rate and pressure were 30.6 kg/s and 138.0 bars, respectively. With a static pressure (post-test) of 130.3 bars, the injectivity index is 4.0 kg/s-bar.

Four pressure surveys are available for the discharging well. The pressure survey of October 15, 1987 extends to a depth of only ~1479 m TVD; all the pressure measurements were made in the two-phase part of the borehole. Consequently, these pressure data cannot be extrapolated to obtain the feedzone pressure (feedzone depth = 2100 m TVD) and to compute the productivity index. The reported discharge rates on January 20, 1988 and January 21, 1988 were 48.1 kg/s and 49.4 kg/s, respectively; the corresponding flowing feedzone pressures (extrapolated from measurements) were 103.5 bars and 101.5 bars, respectively. The static feedzone pressure is 158.0 bars (Section 3). The productivity index values (0.88 kg/s-bar and 0.87 kg/s-bar) obtained from January 20, 1988 and January 21, 1988 tests are virtually identical. The pressure survey of August 4, 1988 was carried out to a depth of ~2070 m TVD; the flowing feedzone pressure was ~112.6 bars. With a discharge rate of 48.9 kg/s, the productivity index for the August 1988 test is computed to be 1.1 kg/s-bar. Downhole temperature surveys in the discharging well imply that the feedzone temperatures had not fully recovered at the time of the January 1988 tests. Consequently, it is possible that the August 1988 test provides a better measure of the productivity index for well TT-13S.

Production Well TT-14R

Both injection and discharge tests were performed on well TT-14R in early November 1986 prior to the installation of the 7-inch liner. A short-term injectivity test (injection rate ~25.8 kg/s) was carried out on November 3, 1986; pressure data from this test have not been made available to the authors. The injectivity index, computed by Idemitsu engineers, is 2.0 kg/s-bar.

A downhole pressure survey was run in the discharging well (discharge rate ~77.8 kg/s) to a depth of 1683 m TVD; extrapolating the data, the flowing feedzone pressure is estimated as ~78.2 bars. Using a static feedzone pressure of 131.5 bars (Section 3), the productivity index for TT-14R is 1.5 kg/s-bar.

Large-Diameter Well TT-16

A long-term (four days?) injection test (injection rate ~9.44 kg/s) was performed in February 1988 with the Kuster gauge set at 1970 m TVD (*i.e.*, about 330 meters above the feedzone at 2300 m TVD). The injection pressure was 192.7 bars. A shutin pressure of 169.0 bars was recorded four hours after stopping cold water injection. By comparison with feedzone pressure (184.5 bars at 2300 m TVD), it appears that the measured shutin pressure (169.0 bars) does not represent a stable value; therefore, the calculated injectivity index (0.40 kg/s-bar) is not reliable.

Subsequent short-term injection tests performed on March 15, 1988, June 6, 1988 and June 28, 1988, yield similar values (0.15, 0.13 and 0.11 kg/s-bar) for the injectivity index. For the March 15, 1988 test (injection rate ~4.00 kg/s), the pressure tool was set at 1970 m TVD; the static (prior to test) and injection pressures were 154.7 bars and 181.3 bars, respectively. The pressure gauge was set at 2264 TVD for both the June 6, 1988 and June 28, 1988 tests. For the June 6, 1988 test (injection rate ~3.89 kg/s), the static (prior to test) and injection pressures were 181.8 bars and 211.1 bars, respectively. The injection rate during the June 28, 1988 test was 2.67 kg/s; the static and injection pressures were 181.0 bars and 206.2 bars, respectively. The three short-term injection tests imply that well TT-16 has poor injectivity (~0.1 kg/s-bar); for this reason, Idemitsu decided to use the upper part of TT-16 to drill a new well (TT-16S).

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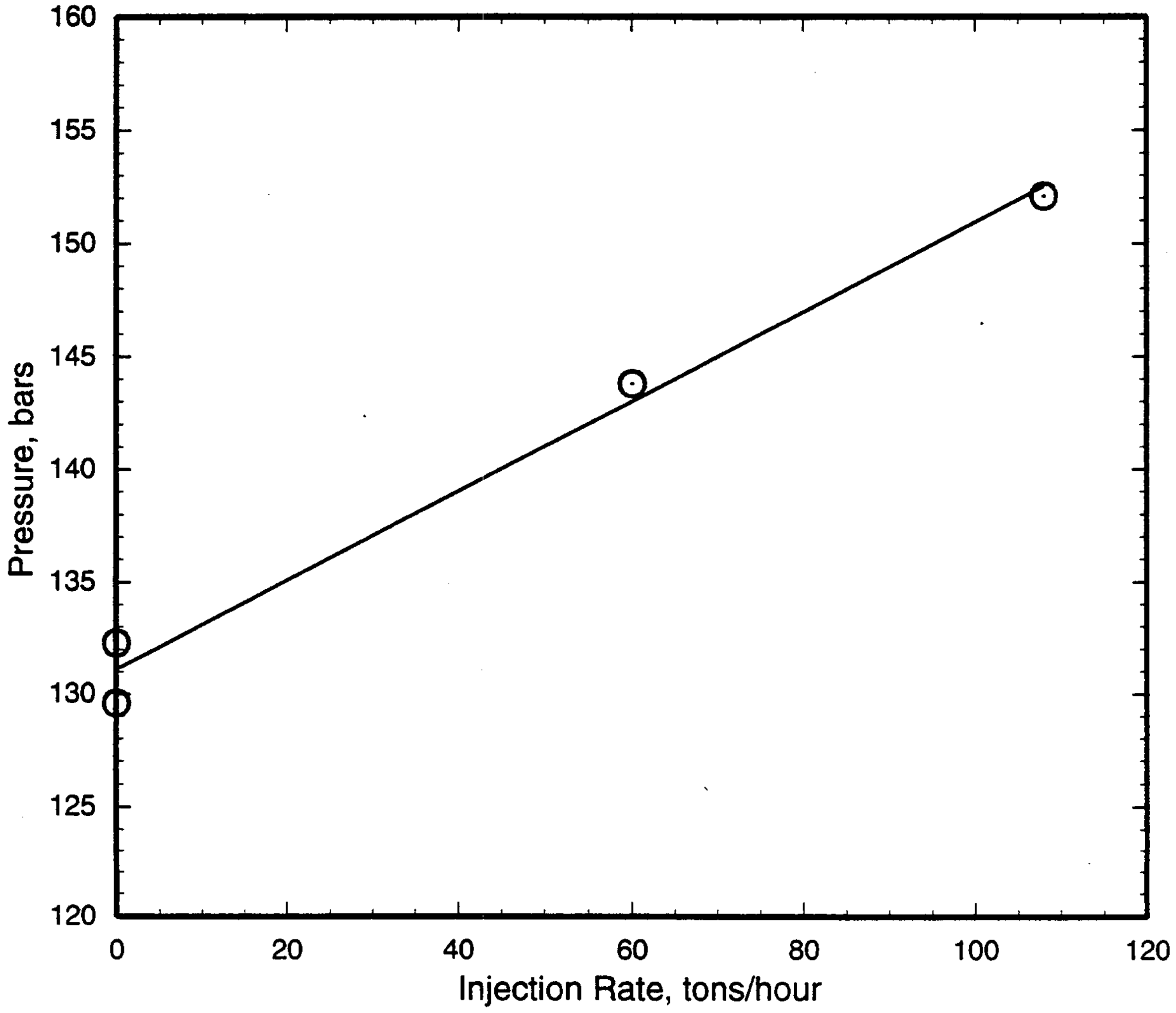

Figure 4.10. Injectivity test for production well TT-16S performed on January 29, 1989. Two Kuster gauges were set at ~1724 m TVD; plotted pressures represent the average of the two gauges.

Production Well TT-16S

A two-rate injection test was performed on January 29, 1989 with two Kuster tools set at 1724 m TVD (*i.e.*, 16 meters above the feedzone at 1740 m TVD). The slope of the pressure versus injection rate data (Figure 4.10) implies that the injectivity index for TT-16S is 1.4 kg/s-bar.

During the preliminary discharge test on February 16, 1989, a downhole pressure survey was run with two Kuster tools; the flowing feedzone pressure (average of two gauges) was 112.3 bars. The discharge rate was 15.3 kg/s. With a stable feedzone pressure of 131.0 bars, the productivity index is 0.82 kg/s-bar. As remarked in Section 3, at the time of the February 1989 test, the feedzone temperature had not recovered fully. The discharge rate from the well increased substantially (from 15.3 kg/s to ~25.0 kg/s) during later discharge tests. It is, therefore, likely that the February 1989 data yield too low an estimate of the productivity index for well TT-16S.

Injection Well TT-18

An injection test was performed on December 15, 1987 after the borehole had been drilled to 1485 m MD (the final well depth was 1500 m MD). During the 30-minute injection test, two Kuster tools were set at 869 m TVD (*i.e.*, about 330 meters above the feedzone at 1300 m TVD). The injection rate and pressure were 6.75 kg/s and 57.3 bars, respectively. With a static (pre-test) pressure of 57.0 bars, the injectivity index is computed as 23 kg/s-bar. Because of gauge location, short test duration (~30 minutes), and small pressure change (~0.3 bars), the computed injectivity index for TT-18 (23 kg/s-bar) is not considered to be reliable.

Injection Well TT-19

A short-term (total injection time = 25 minutes) injection test was run on March 2, 1988 after the borehole had been drilled to ~1362 m TVD (the final hole depth is ~1377 m TVD). Two Kuster tools were set at a depth of ~581 m TVD (*i.e.*, about 800 meters above the feedzone at 1350 m TVD). The injection pressure and injection rate were 40.4 bars and 22.2 kg/s, , respectively. Using a pre-test static pressure of 36.0 bars, the injectivity index is computed as 5.0 kg/s-bar. Because of the short test duration and shallow gauge location, it is likely that the actual injectivity index for TT-19 is lower than 5.0 kg/s-bar.

Injection Well TT-23

A two-rate injection test (total injection time = 3 hours) was performed on September 19, 1988. Two Kuster gauges were set at ~1282 m TVD, *i.e.*, about 140 meters above the feedzone at 1420 m TVD. The injection pressure and flow rate data are shown in Figure 4.11; these data imply that the injectivity index for TT-23 is ~11 kg/s-bar.

4.2 Comparison of Productivity and Injectivity Indices

Discharge capacity of a geothermal borehole is principally determined by pressure losses associated with flow (1) in the reservoir rocks, and (2) in the wellbore. Given mass flow rate and feedzone pressure and flowing enthalpy, equations governing mass and energy transport in the wellbore may be solved to obtain the wellhead conditions (pressure and flowing enthalpy). At present, two-phase fluid flow in the wellbore (a common condition in geothermal wells) is not amenable to rigorous analytical treatment; instead, empirical correlations for flowing steam quality, friction factor and heat loss must be used. Unfortunately, utilization of different empirical correlations does not always lead to comparable results. Despite the uncertainties associated with the modeling of two-phase flow in geothermal wells, the available correlations are adequate for computing a first approximation to the pressure losses in the wellbore.

Ignoring pressure transient effects, the flow resistance (or pressure losses) of the reservoir rock can be characterized by the productivity index.

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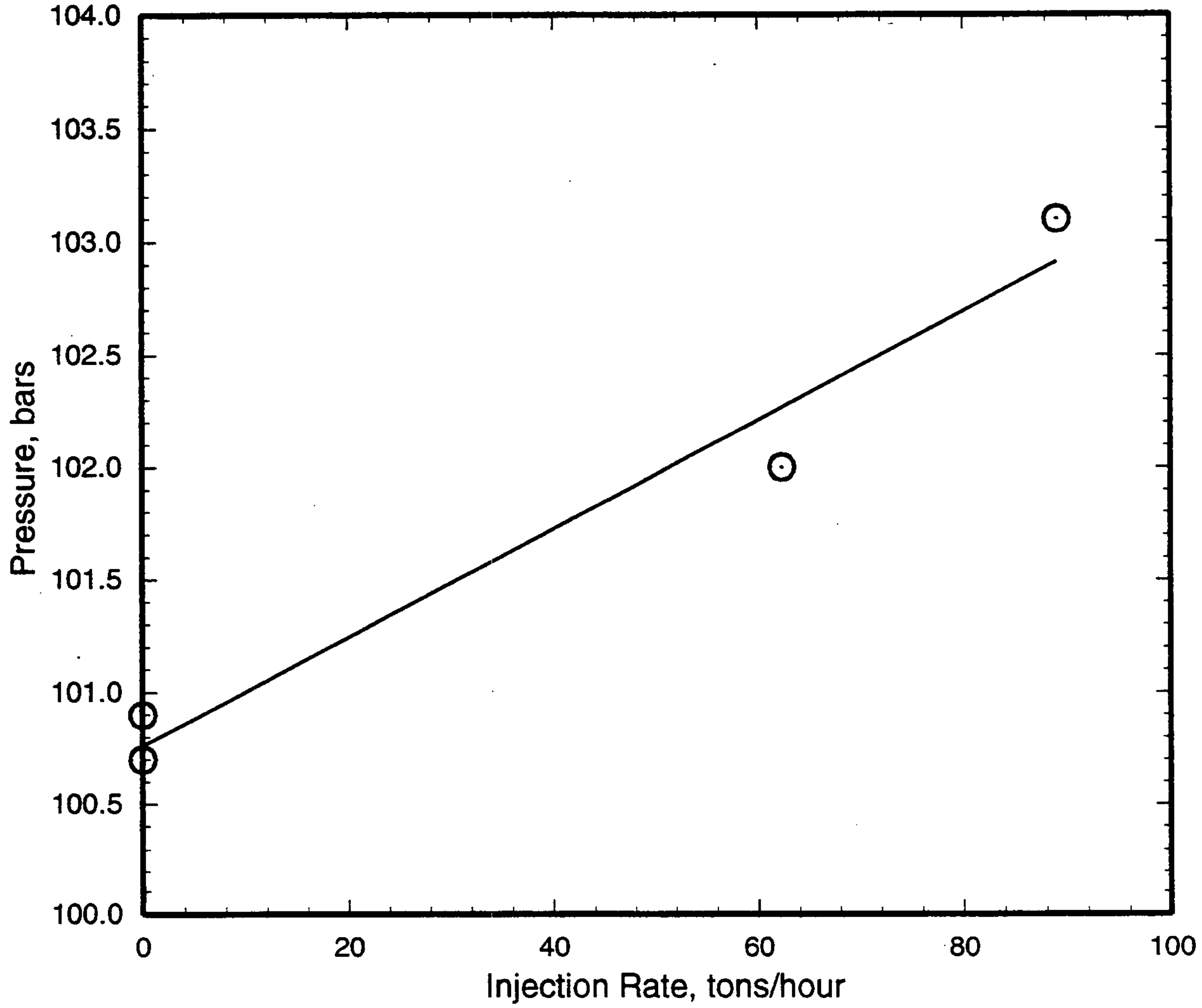

Figure 4.11. Injectivity test for injection well TT-23 performed on September 19, 1988. Two Kuster tools were set at 1282 m TVD.

Prediction of the mass output of a large-diameter well based on discharge data from a slim hole requires, among other things, a relationship between productivity index and borehole diameter.

Because of the increased importance of frictional and heat losses in small-diameter boreholes, it is often difficult to discharge slim holes. There is, however, no problem with performing injection tests (and determining injectivity index) on slim holes. If a relationship can be established between injectivity and productivity indices, then it should be possible to use injection tests on slim holes to predict the probable discharge characteristics of large-diameter wells.

Based on theoretical considerations, Pritchett (1993) and Hadgu, *et al.* (1994) have suggested that the productivity (or injectivity) index should exhibit only a weak dependence on borehole diameter. The productivity and injectivity indices for Takigami boreholes (see Tables 4.1, 4.2) do not exhibit any systematic dependence on borehole diameter. The latter result is in agreement with the results for Sumikawa boreholes, but is at variance with the injectivity/productivity indices for Oguni boreholes (Garg and Combs, 1995; Garg, *et al.*. 1995a,b). Unlike Takigami and Sumikawa boreholes, both the productivity and injectivity indices for Oguni boreholes display a strong dependence on borehole diameter. Garg, *et. al.* (1995a) ascribed the apparent variation of productivity/injectivity indices with borehole diameter to differences in drilling techniques (*i.e.*, core drilling versus rotary drilling). Most of the Oguni slim holes were drilled with complete loss of circulation fluid (dilute bentonite based mud). In contrast with Oguni slim holes, drilling fluid circulation was maintained for Sumikawa slim holes and for rotary drilled large-diameter wells at Oguni and Sumikawa. Garg, *et al.* (1995a) suggested that in the Oguni Geothermal Field, core drilling may have caused greater formation plugging than that resulting from rotary drilling. Like the Oguni slim holes, most of the slim holes at Takigami were also drilled with a complete loss of circulation. The Takigami productivity/injectivity data, however, indicate that core drilling (with complete circulation loss) did not result in any impairment of borehole injectivity/productivity. The contradictory trends in the relationship between productivity/injectivity indices and borehole diameter at the Oguni and Takigami Geothermal Fields indicate that enhanced formation plugging in boreholes drilled with coring rigs may not be a pervasive phenomenon. Data from additional geothermal fields would be useful to characterize enhanced formation plugging in core-drilled slim holes.

Both productivity and injectivity indices are available for five slim holes and eight large-diameter wells at Takigami (Table 4.3). Productivity and injectivity indices for Takigami boreholes are cross-plotted in Figure 4.12. For comparison purposes, data for Oguni and Sumikawa boreholes with liquid feedzones are also shown in Figure 4.12. Like the Sumikawa and Oguni Geothermal boreholes with liquid feedzones, the productivity and injectivity indices for Takigami boreholes are equal to first order. The latter result is especially significant in that the inability to discharge slim holes does not necessarily render the use of slim holes to predict the behavior of large-diameter wells impractical. In the absence of discharge testing and the resultant productivity index, the injectivity index may be used to characterize the flow resistance of reservoir rocks, and to compute (in conjunction with a wellbore flow simulator) the probable discharge characteristics of large-diameter geothermal wells.

Table 4.3. Comparison of Productivity and Injectivity Indices for Takigami Boreholes.

Borehole Name	Open Hole Diameter (mm)	Feedzone Depth (m TVD)	Injectivity Index (kg/s-bar)	Productivity Index (kg/s-bar)	Remarks
NE-4	79	2230	0.22	0.08	Productivity Index of 01-27-86
NE-5(i2)	98	1180	28	28	Productivity Index: average of two values
NE-6(i2)	100	740	6.9	18	Productivity Index: average of two values
NE-11	100	1340	0.55	0.73	
NE-11R	100	1850	2.7	3.8	
TT-2	216	1580	25	11	
TT-7	216	1070	24	26	Injectivity Index of 08-22-86
TT-8(i)	311	840	12	7.9	Injectivity Index: average of two values
TT-8S1(i)	311	1050	7.5	11	
TT-8S3	216	1870	2.3	2.6	Productivity Index: average of two values. Injectivity Index: after second fracturing.
TT-13S	216	2100	3.2	0.94	Productivity Index: average of three values. Injectivity Index: average of 12/22/87, 01/06/88, 07/22/88
TT-14R	216	1730	2.0	1.5	
TT-16S	216	1740	1.4	0.82	

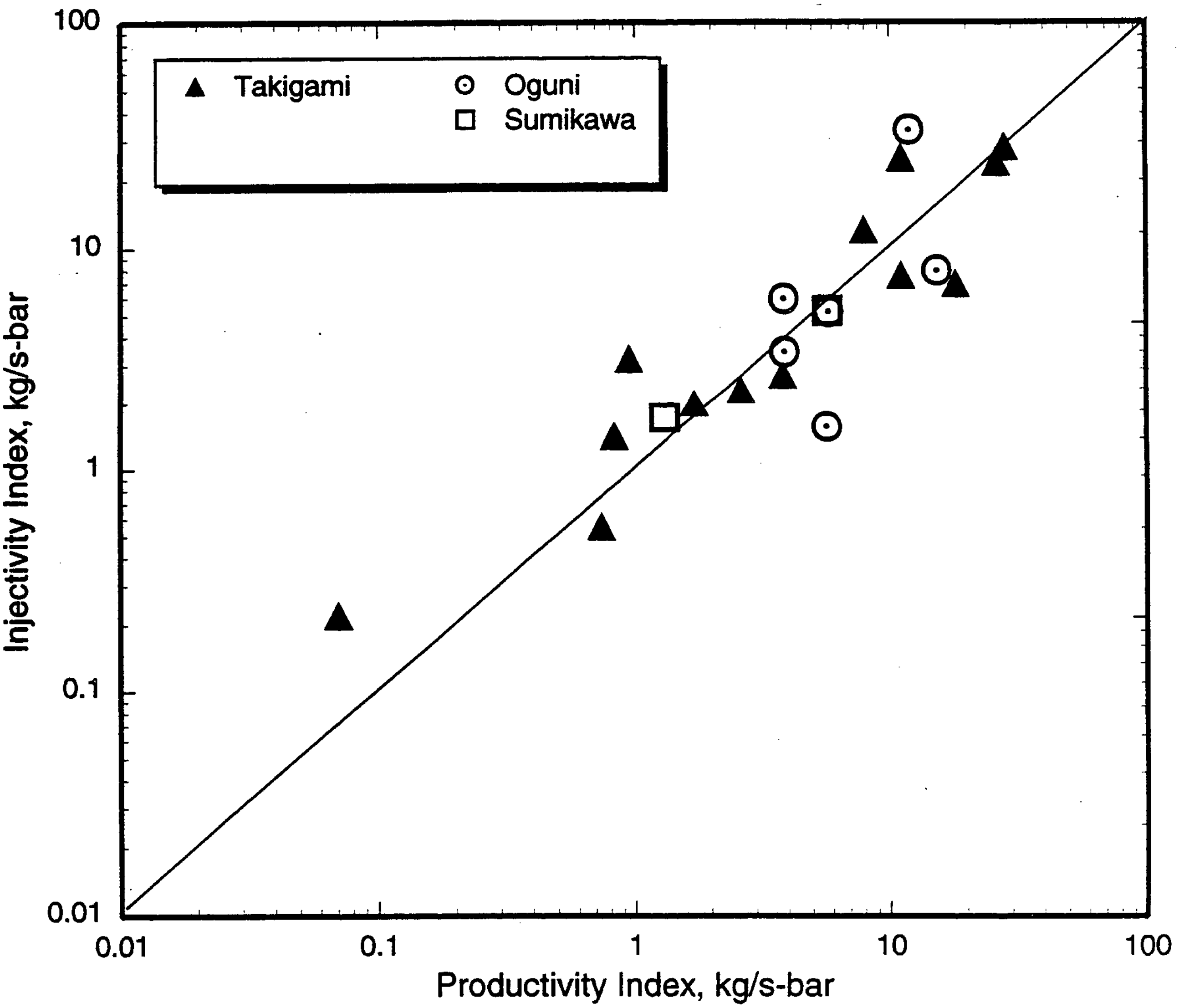

Figure 4.12. Productivity Index versus Injectivity Index for Takigami (▲) boreholes. For comparison, data for Oguni (⊙) and Sumikawa (☐) boreholes with liquid feedzones are also shown.

Section 5

Discharge Capacity and Borehole Diameter

5.1 Characteristic Tests

A total of seven slim holes (NE-2R, NE-3, NE-4, NE-5, NE-6, NE-11, and NE-11R) and nine large-diameter wells (TT-1, TT-2, TT-7, TT-8, TT-8S1, TT-8S3, TT-13S, TT-14R, and TT-16S) have been discharged. Several boreholes (NE-3, NE-5, NE-6, TT-8 and TT-8S1) were discharged at intermediate depths (*i.e.*, prior to reaching target depth). The discharge data are required to define the characteristic output curves (*i.e.*, mass and enthalpy versus wellhead pressure). Wellhead enthalpy measurements and downhole pressure/temperature surveys indicate that all of the Takigami boreholes produce from liquid feedzones; production does not induce *in situ* boiling. The mass output curves for the various Takigami boreholes are shown in Figures 5.1 through 5.19; tables of the data are given in Appendix B. The measured maximum discharge rates for the various Takigami boreholes are presented in Table 5.1. Since large-diameter wells TT-8 and TT-8S1 were tested with the 4-$^1/_2$ inch drill pipe in the borehole, the discharge rates for these wells listed in Table 5.1 were restricted and, therefore, are most likely on the low side. In the following discussion, we will not further consider discharge data for the latter two boreholes (TT-8 and TT-8S1).

To determine the fluid carrying capacity of geothermal boreholes of varying sizes, Pritchett (1993) conducted numerical simulations assuming that (1) boreholes are of uniform size, (2) pressure losses in the formation are negligible, and (3) boreholes produce from a liquid feedzone. Based on these numerical simulations, Pritchett (1993) found that the maximum discharge rate of a borehole, M_{max}, increases at a rate somewhat greater than the square of borehole diameter, *i.e.*,

$$M_{\text{max}} = M_0\left(\frac{d}{d_0}\right)^{2+n} \qquad n > 0$$

$$= M^*\left(\frac{d}{d_0}\right)^{n}$$

Here M_{max} (M_0) is the discharge rate of a borehole with internal diameter d (d_0). The area-scaled discharge rate M^* is defined as follows:

$$M^* = M_0\left(\frac{d}{d_0}\right)^2$$

The value of n may be expected to vary with feedzone conditions (depth, pressure, temperature, gas content) and well completion (uniform or non-uniform internal diameter). For the conditions assumed by Pritchett (feedzone depth = 1500 m, pressure = 80 bars, single phase liquid at 250°C, uniform borehole diameter), n is approximately equal to 0.56. In a similar theoretical study, Hadgu, *et al.* (1994) have considered single-phase (liquid) adiabatic flow (no heat loss) up a wellbore and suggest that n equals 0.62.

Garg *et al.* (1995b) have examined production data from slim holes and large-diameter wells in three geothermal fields (Oguni, Japan; Sumikawa, Japan; and Steamboat Hills, U.S.A.) to determine the effect of borehole diameter on the discharge rate. For boreholes with liquid feedzones in these three geothermal fields, the "scaled maximum discharge rate" provides a reasonable estimate of the maximum discharge rate of large-diameter geothermal wells based on discharge data from slim holes.

The "area-scaled" and "scaled maximum ($n = 0.56$)" discharge rates for the Takigami slim holes are compared with measured discharge rates for large-diameter wells at Takigami in Table 5.2. The average discharge rate for large-diameter wells is significantly greater than the average "scaled maximum" discharge rate computed from slim hole data. The latter result is at variance with the data for Oguni, Sumikawa and Steamboat Hills Geothermal Fields. For these three geothermal fields, "scaled maximum" discharge rate provides an upper bound on the average measured discharge rate for large-diameter wells.

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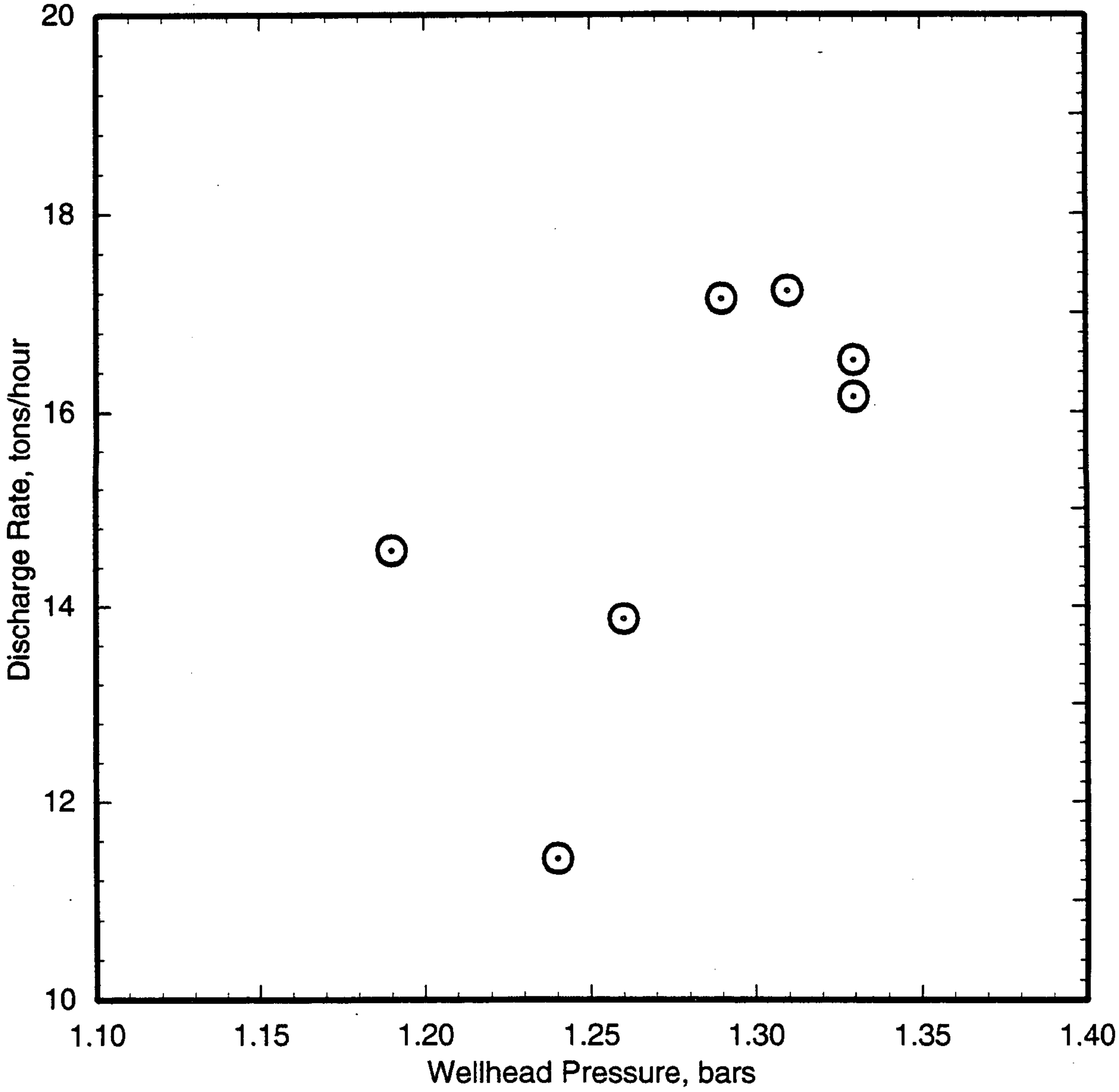

Figure 5.1. Discharge rate versus wellhead pressure for slim hole NE-2R (November and December 1982).

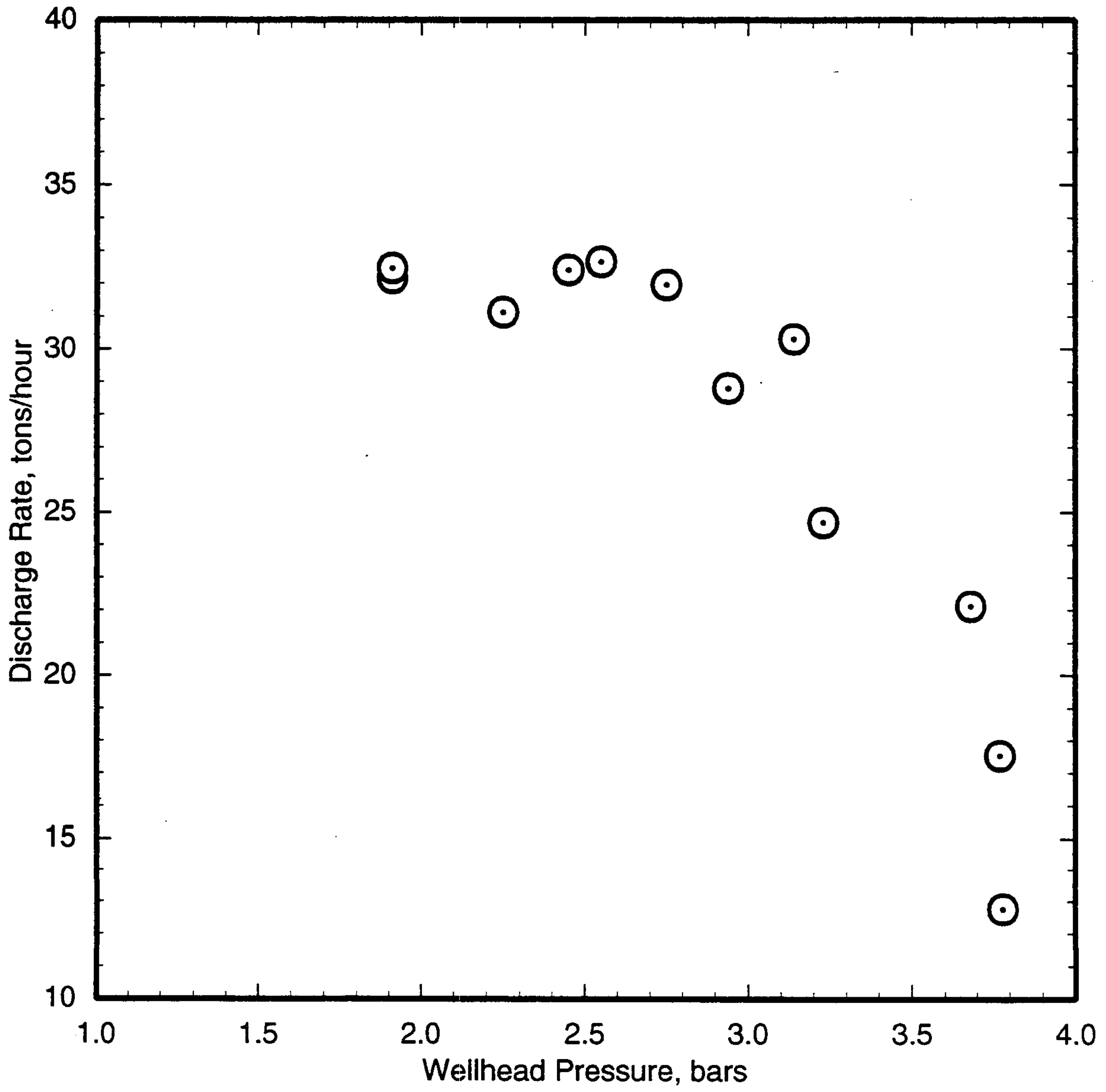

Figure 5.2. Discharge rate versus wellhead pressure for intermediate depth slim hole NE-3(i) (October 1982). The hole depth at the time of the test was ~1689 m TVD.

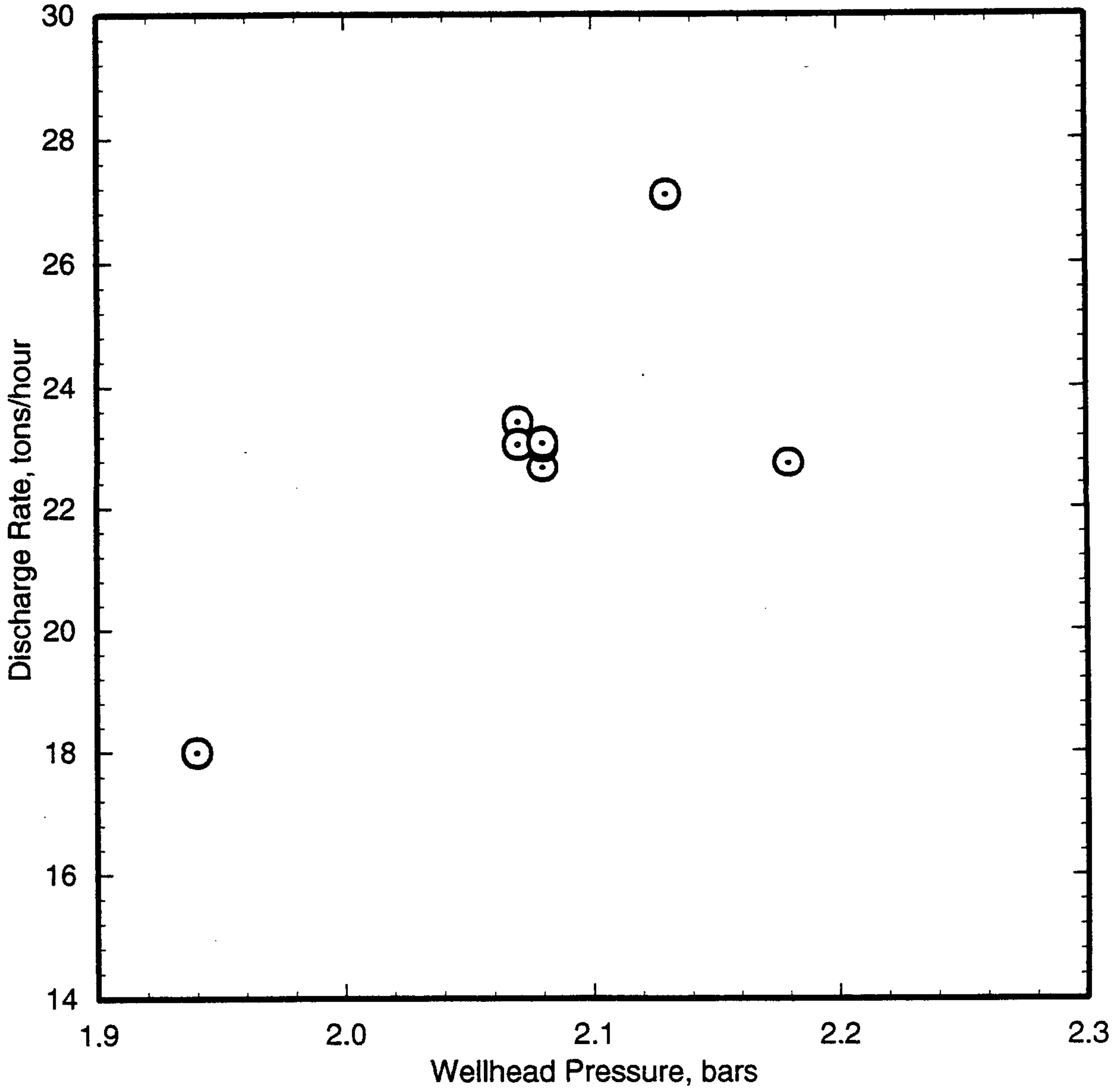

Figure 5.3. Discharge rate versus wellhead pressure for slim hole NE-3 (January and February 1983).

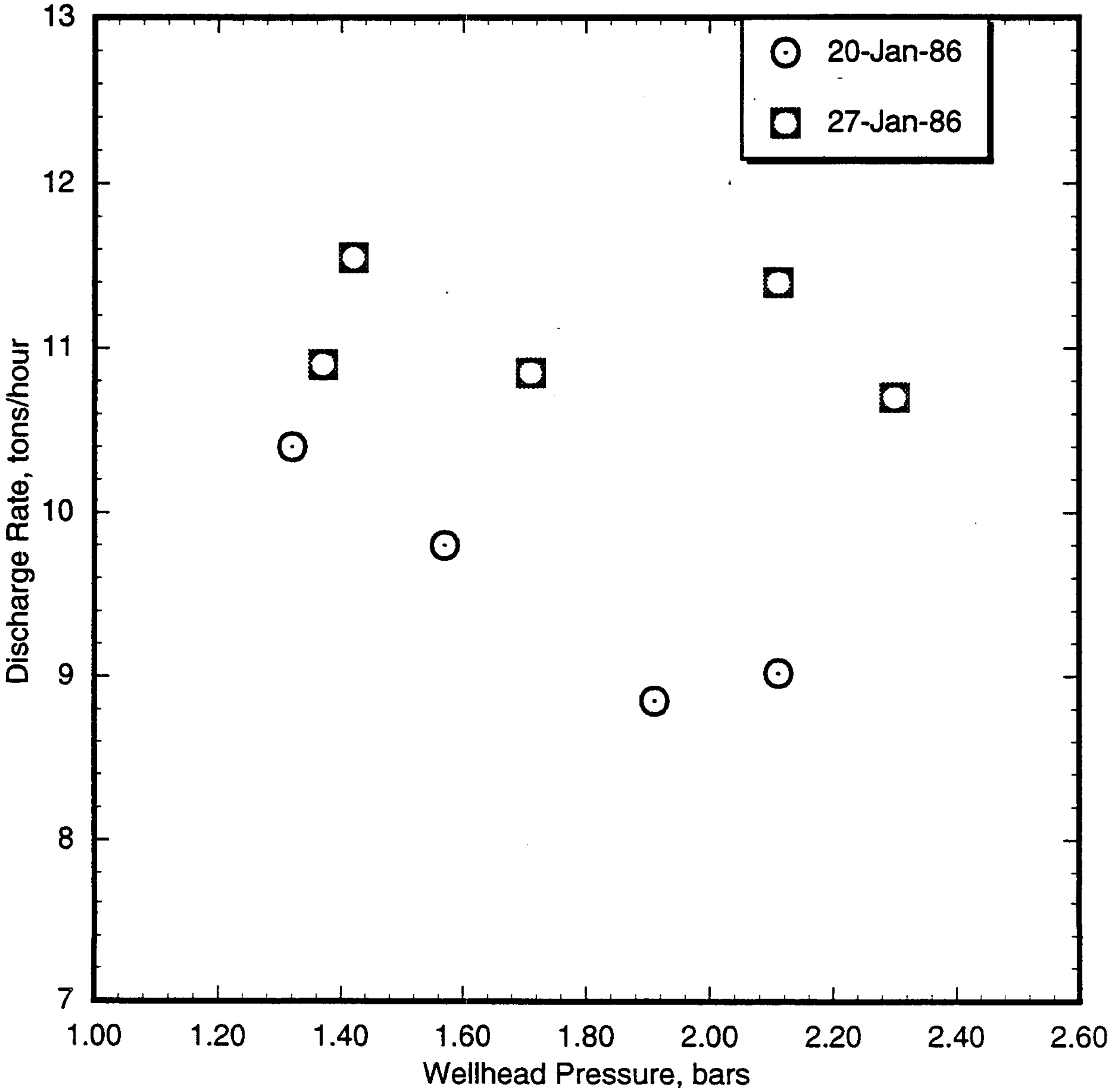

Figure 5.4. Discharge rate versus wellhead pressure for slim hole NE-4 (January 1986).

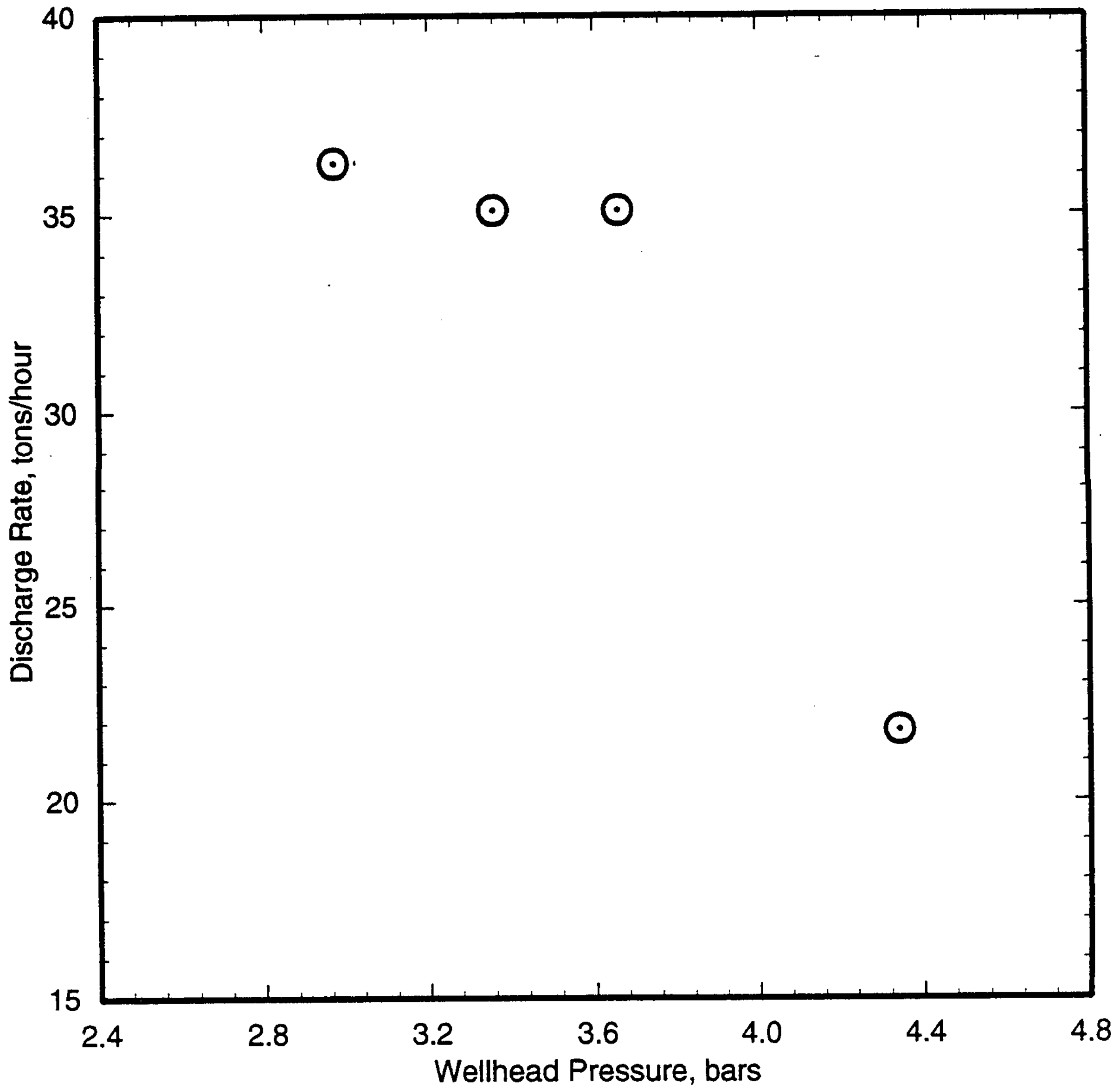

Figure 5.5. Discharge rate versus wellhead pressure for intermediate depth slim hole NE-5(i1) (February 1985). The hole depth at the time of the test was 1109.5 m TVD.

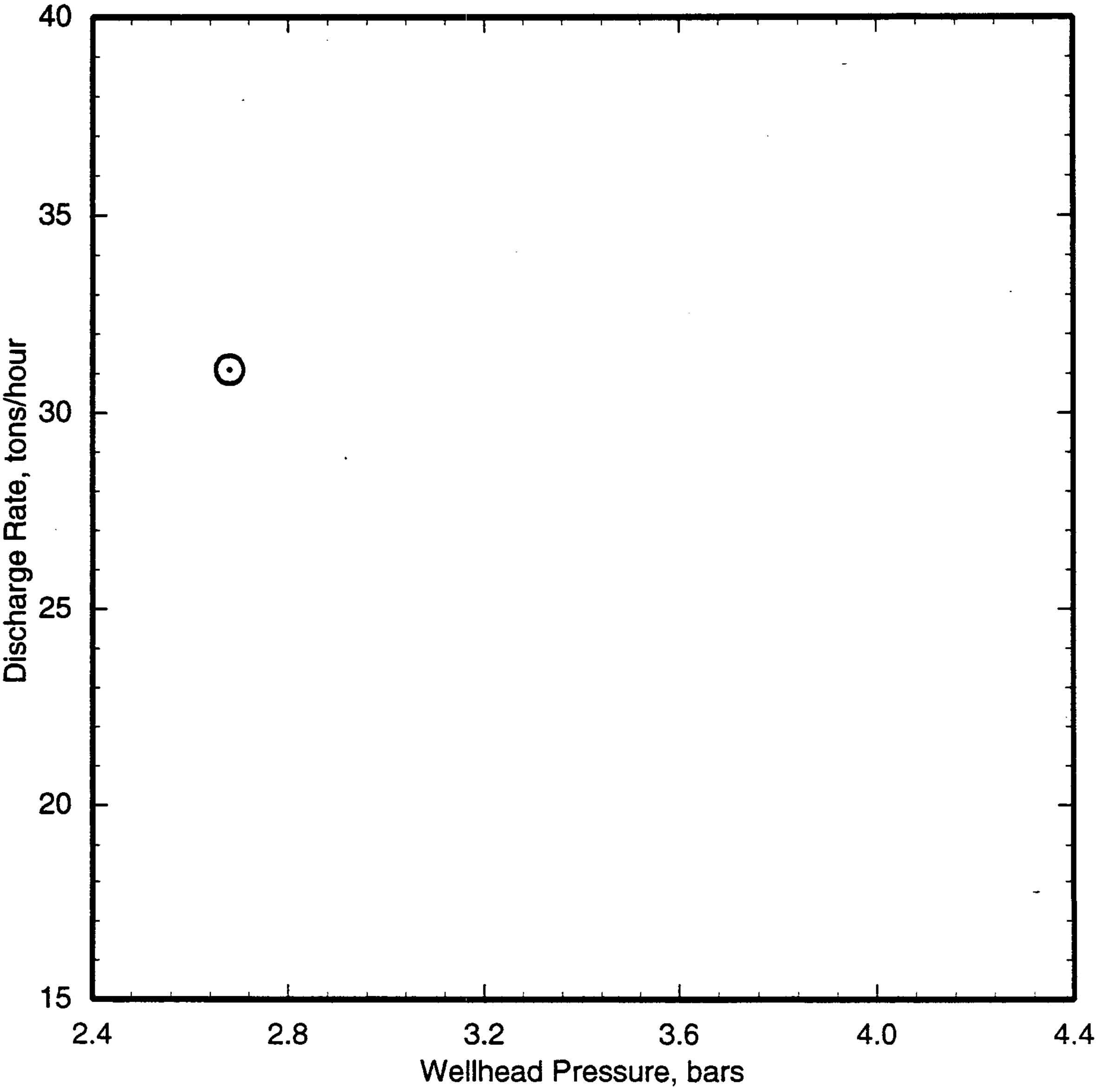

Figure 5.6. Discharge rate versus wellhead pressure for intermediate depth slim hole NE-5(i2) (March 1985). The hole depth at the time of the test was 1426.4 m TVD.

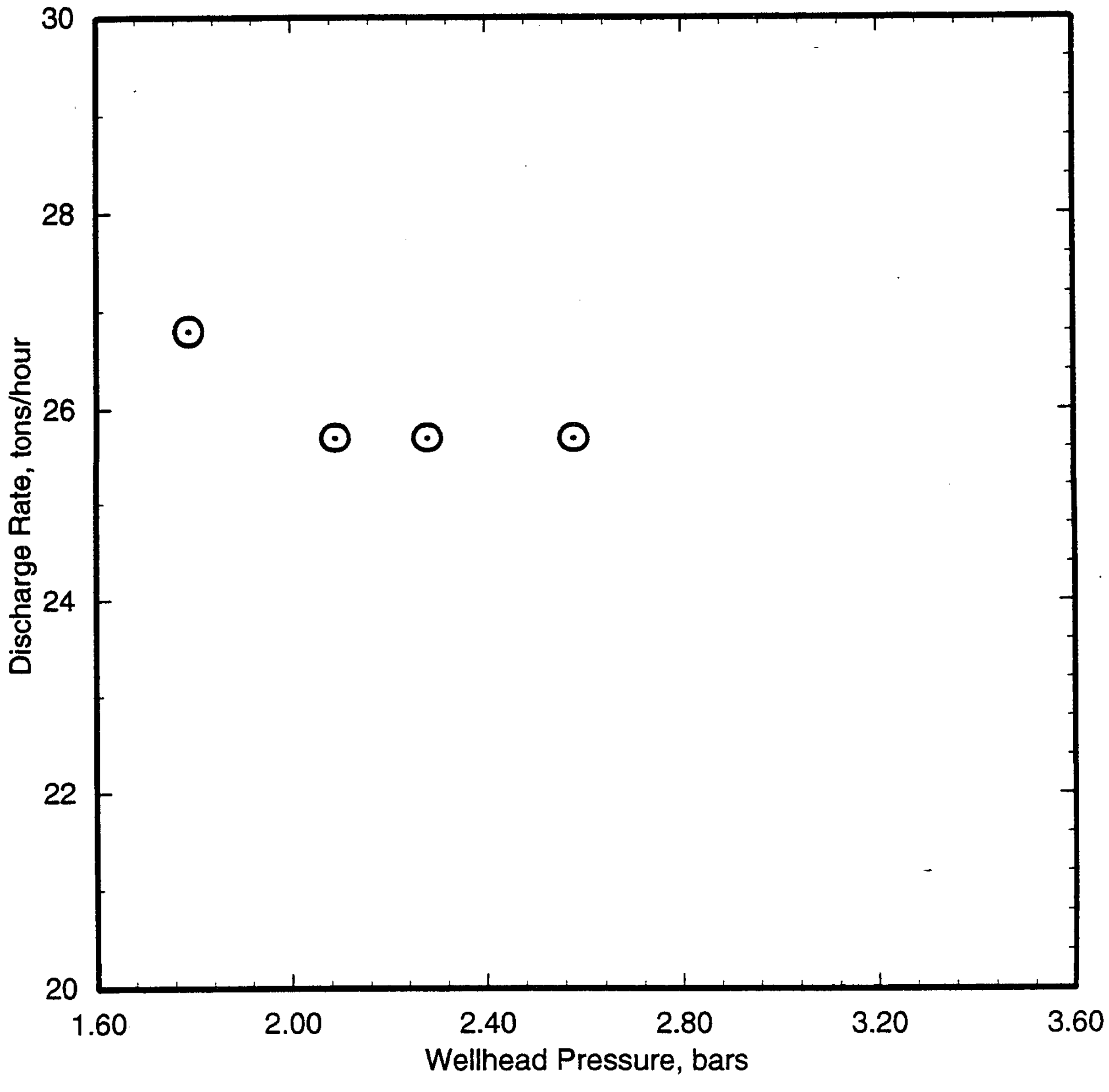

Figure 5.7. Discharge rate versus wellhead pressure for intermediate depth slim hole NE-6(i1) (February 1985). The hole depth at the time of the test was 763.5 m TVD.

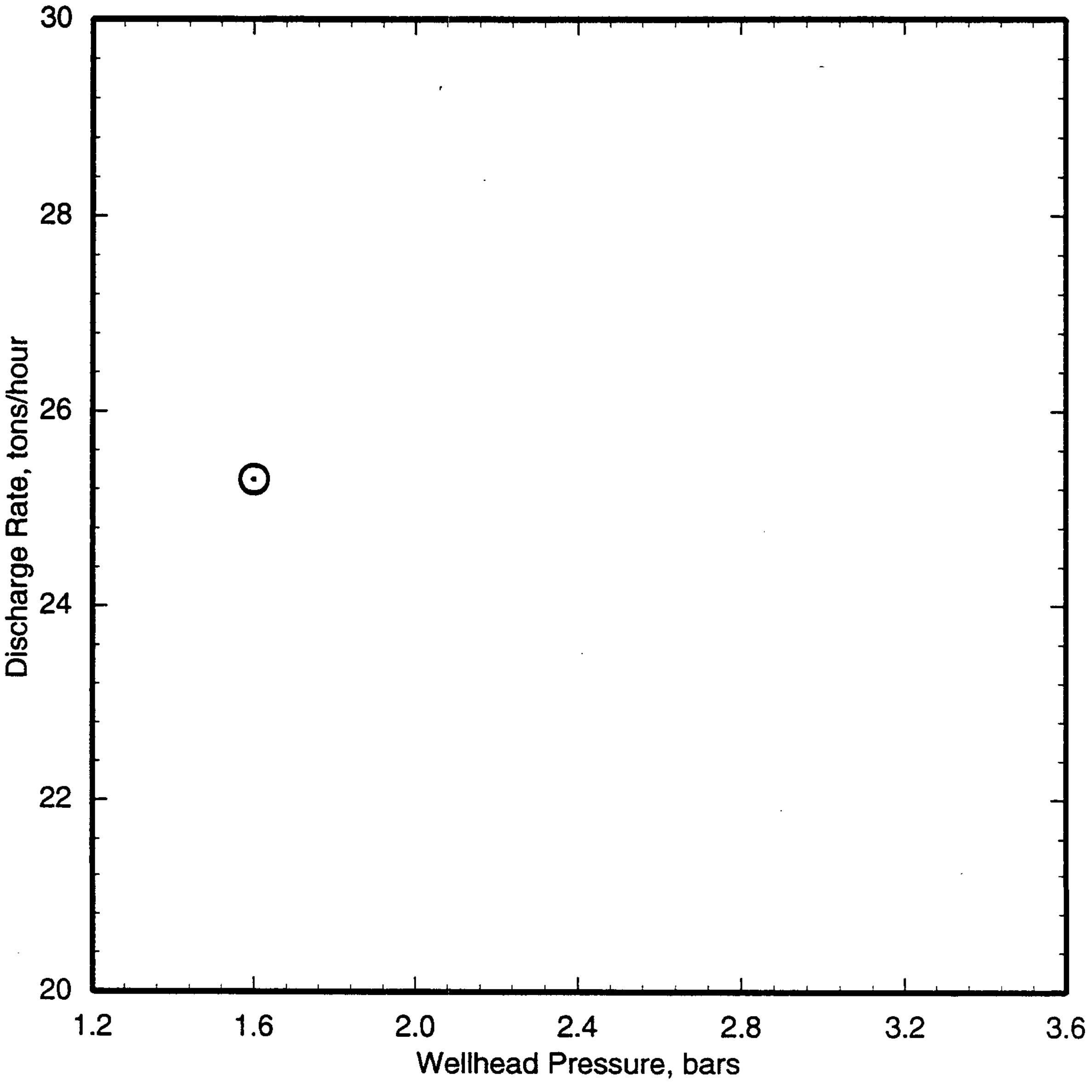

Figure 5.8. Discharge rate versus wellhead pressure for intermediate depth slim hole NE-6(i2) March 1985). The hole depth at the time of the test was 1403.0 m TVD.

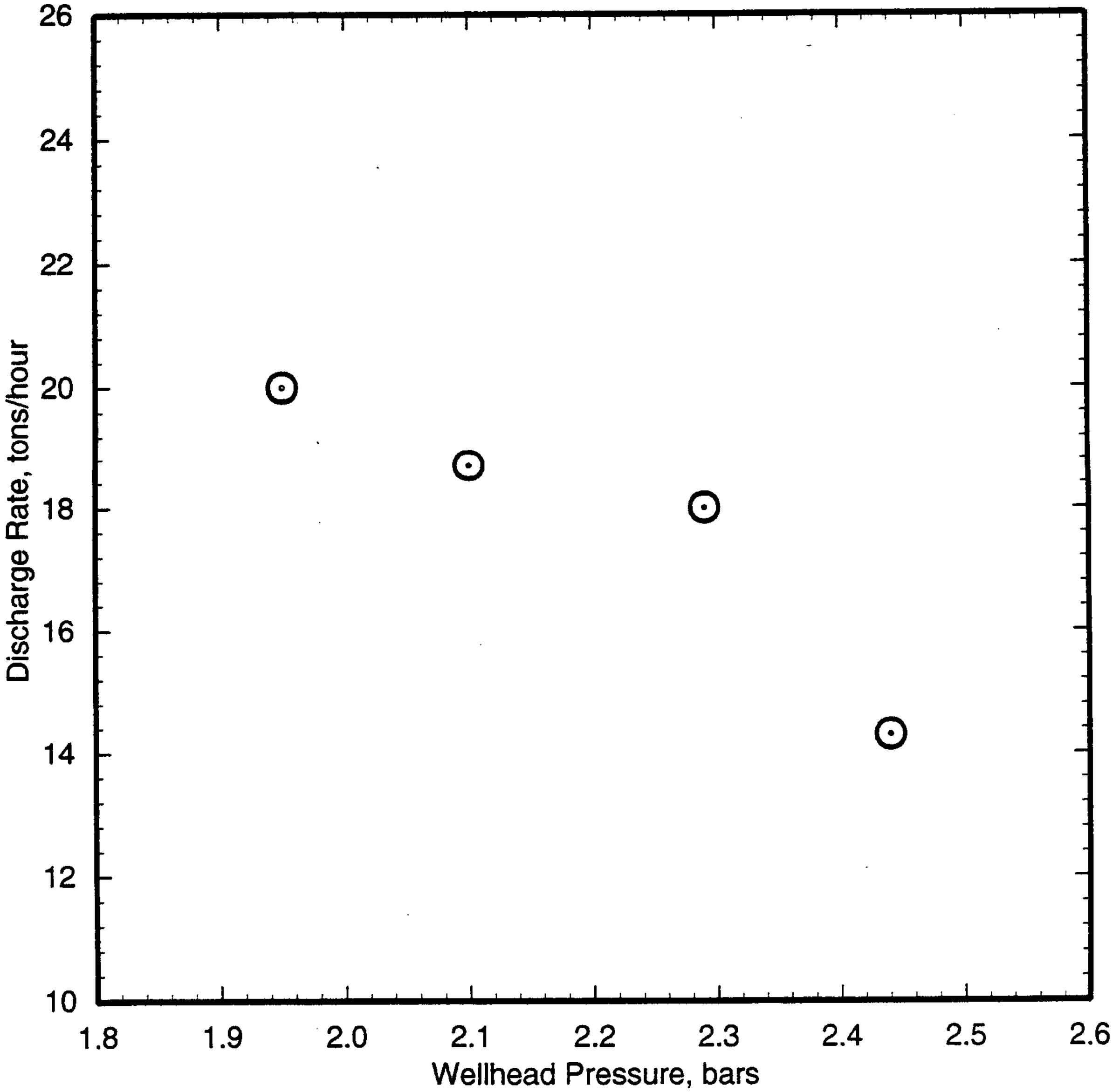

Figure 5.9. Discharge rate versus wellhead pressure for slim hole NE-11 (September 1986).

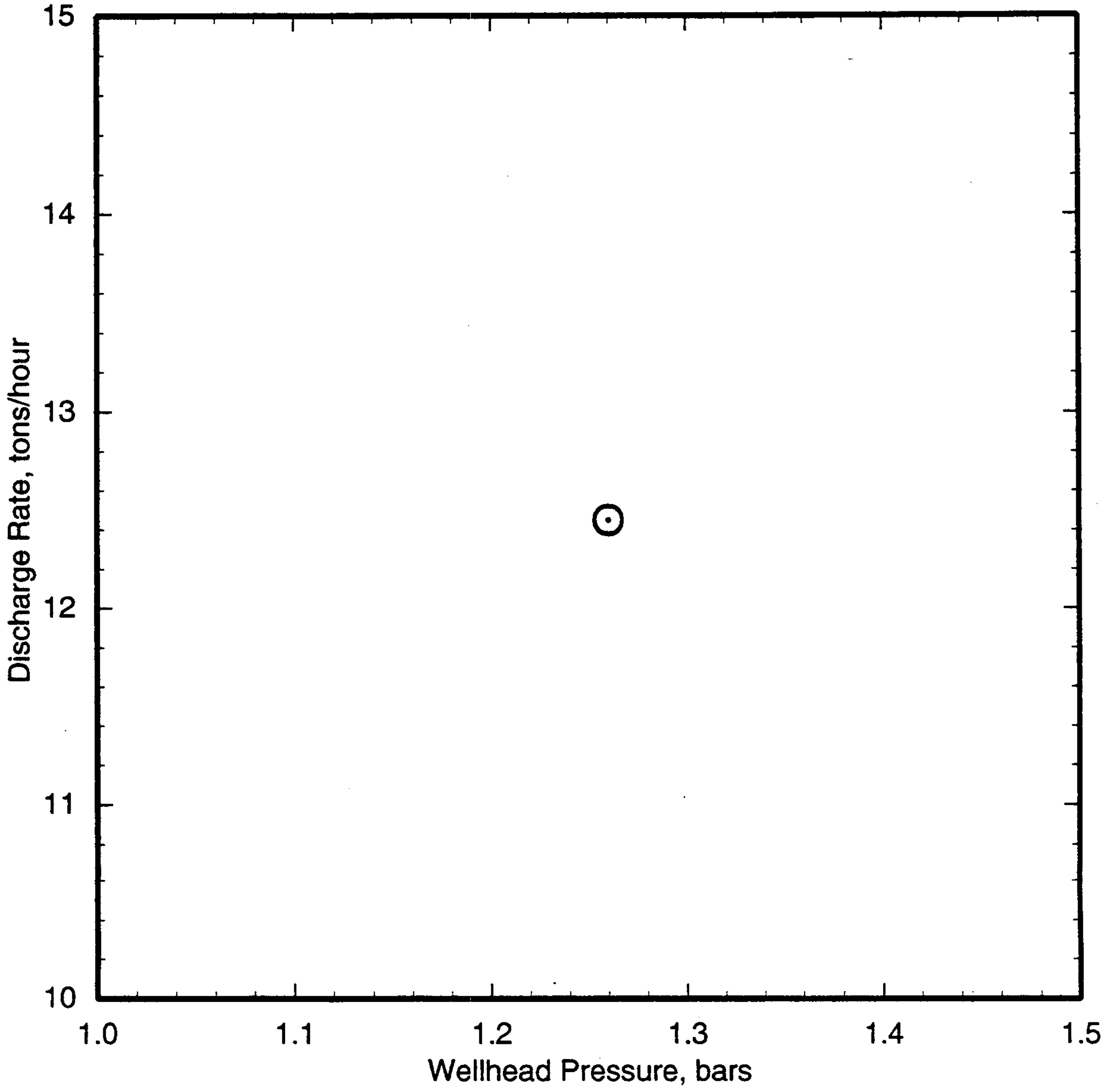

Figure 5.10. Discharge rate versus wellhead pressure for slim hole NE-11R (February 1987).

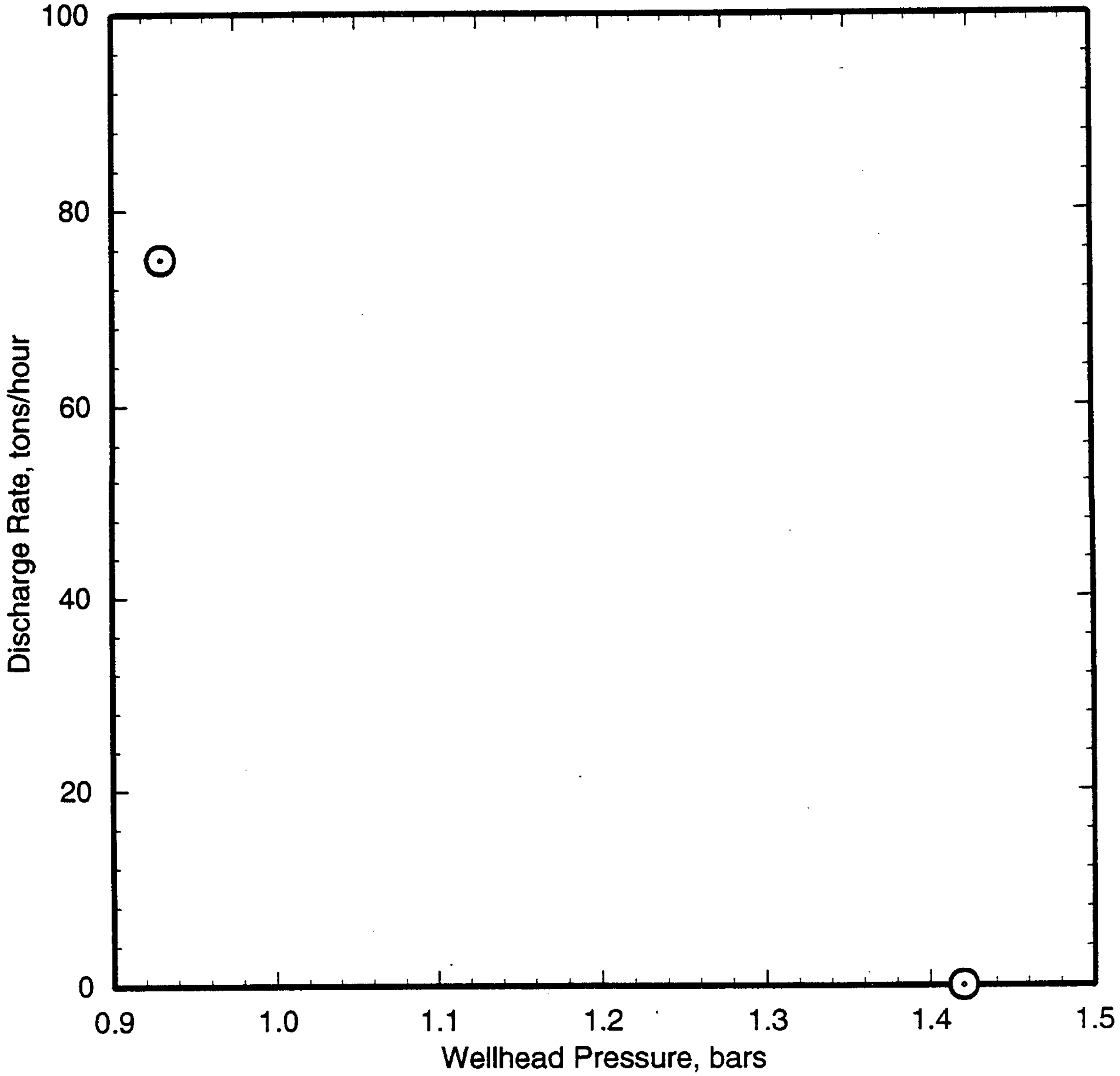

Figure 5.11. Discharge rate versus wellhead pressure for large-diameter well TT-1 (November 1983).

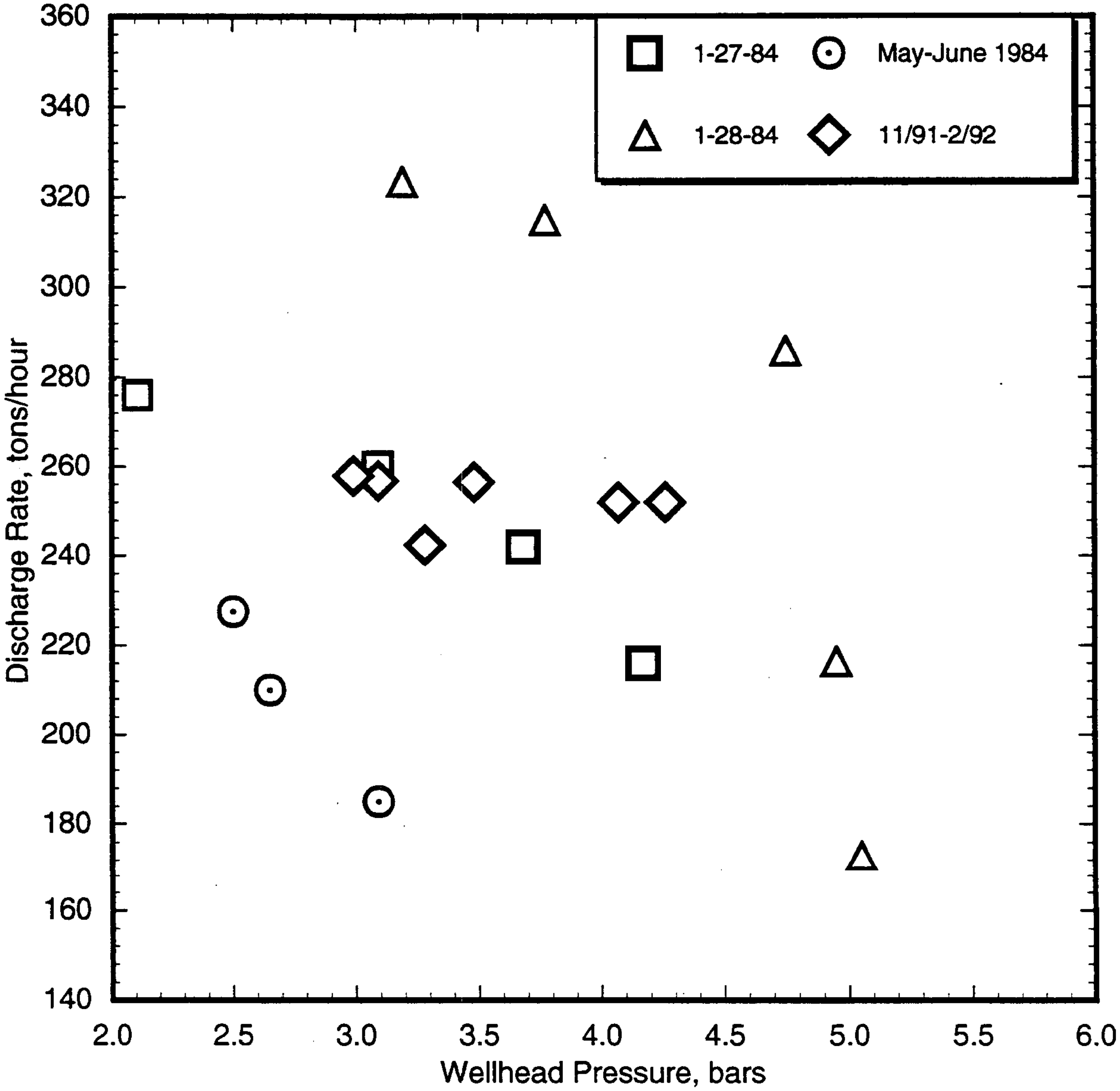

Figure 5.12. Discharge rate versus wellhead pressure for large-diameter production well TT-2 (January 1984, May–June 1984, November 1991–February 1992).

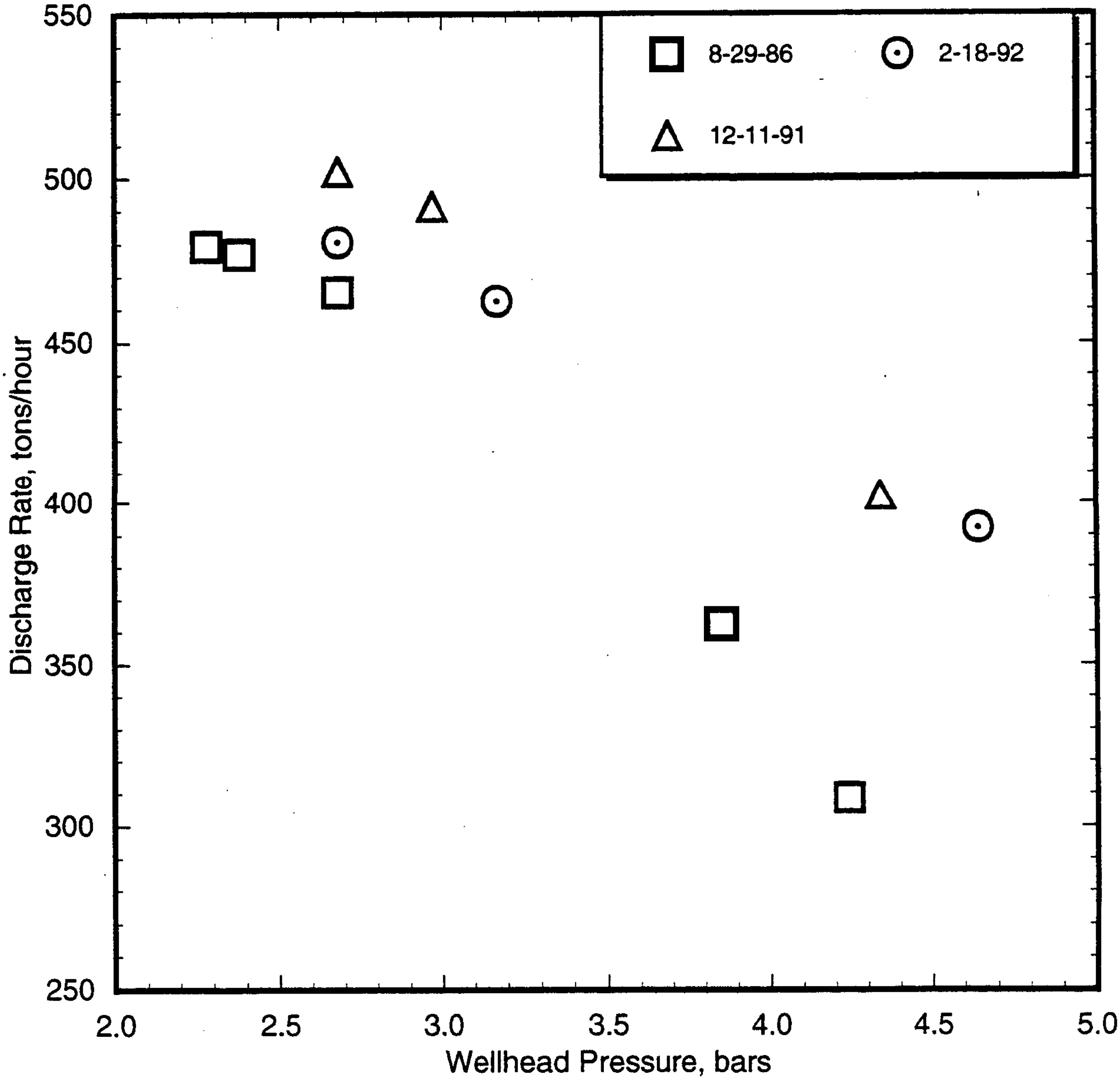

Figure 5.13. Discharge rate versus wellhead pressure for large-diameter production well TT-7 (August 1986, December 1991 and February 1992).

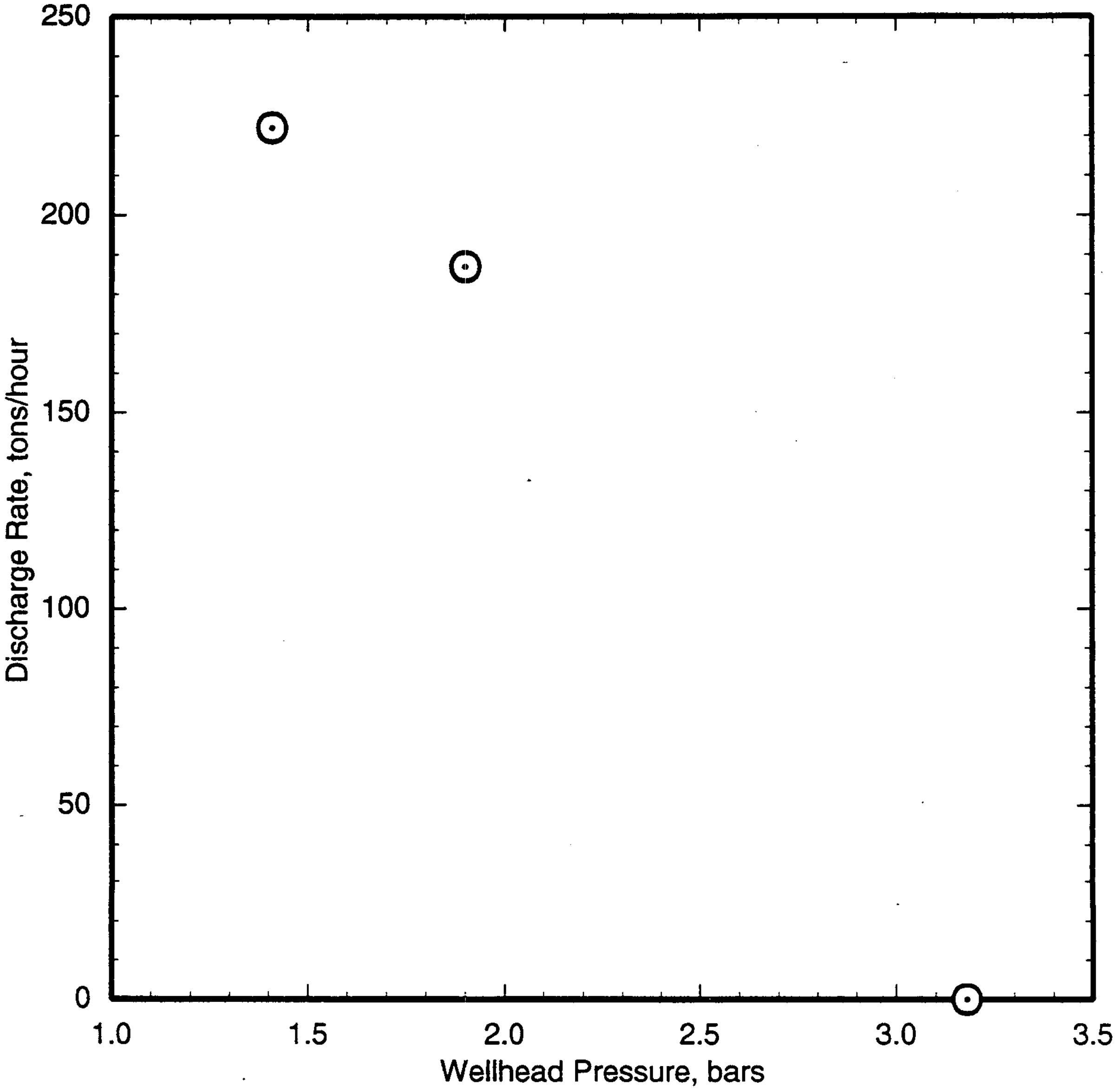

Figure 5.14. Discharge rate versus wellhead pressure for intermediate depth large-diameter well TT-8(i) (August 1986). The borehole depth at the time of the test was 854.2 m TVD. The discharge test was performed with 4-$^1/_2$ inch drill pipe in the borehole.

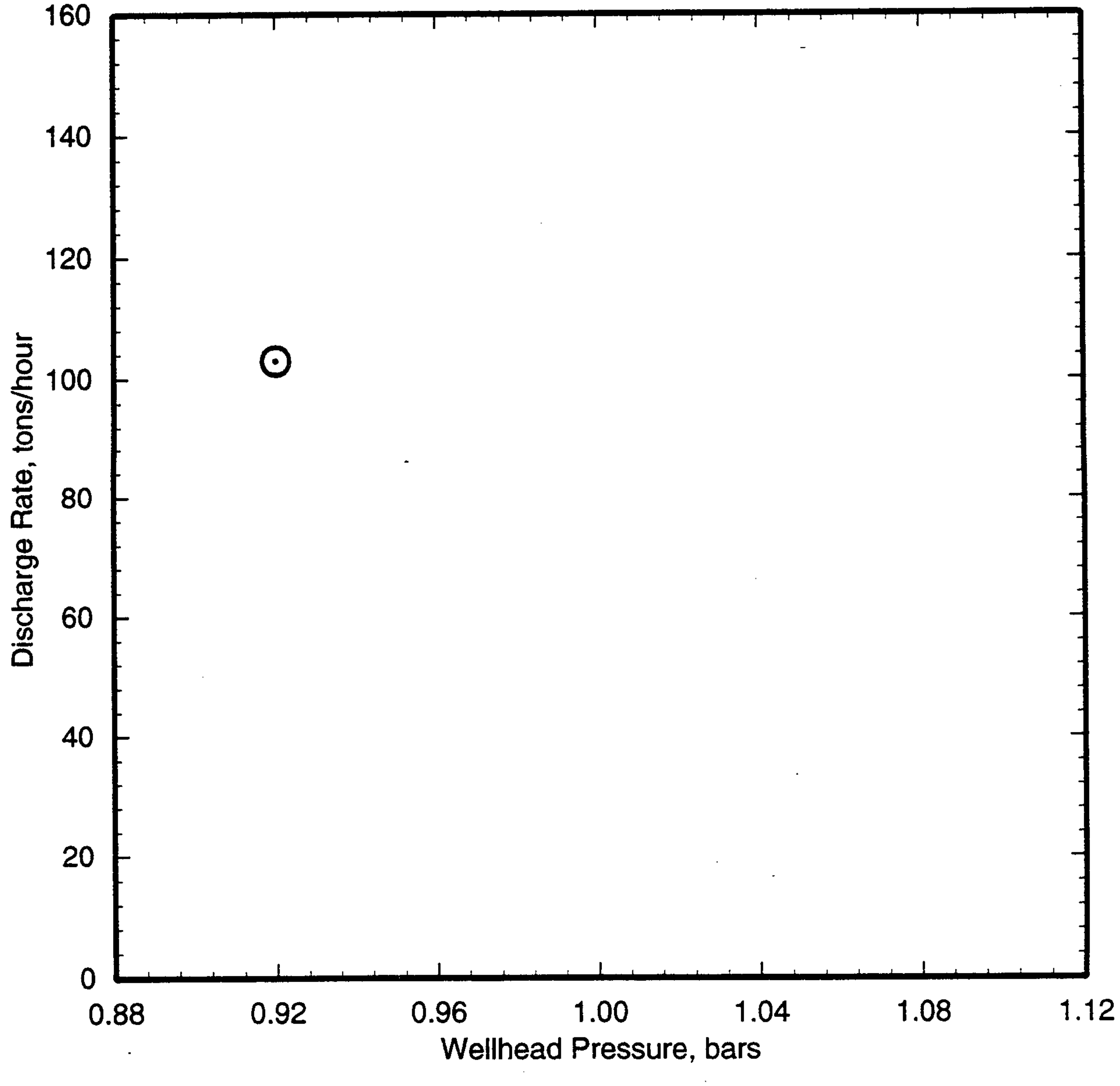

Figure 5.15. Discharge rate versus wellhead pressure for intermediate depth large-diameter well TT-8S1(i) (October 1986). The borehole depth at the time of the test was 1212.6 m TVD. The discharge test was performed with 4-$^{1}/_{2}$ inch drill pipe in the borehole.

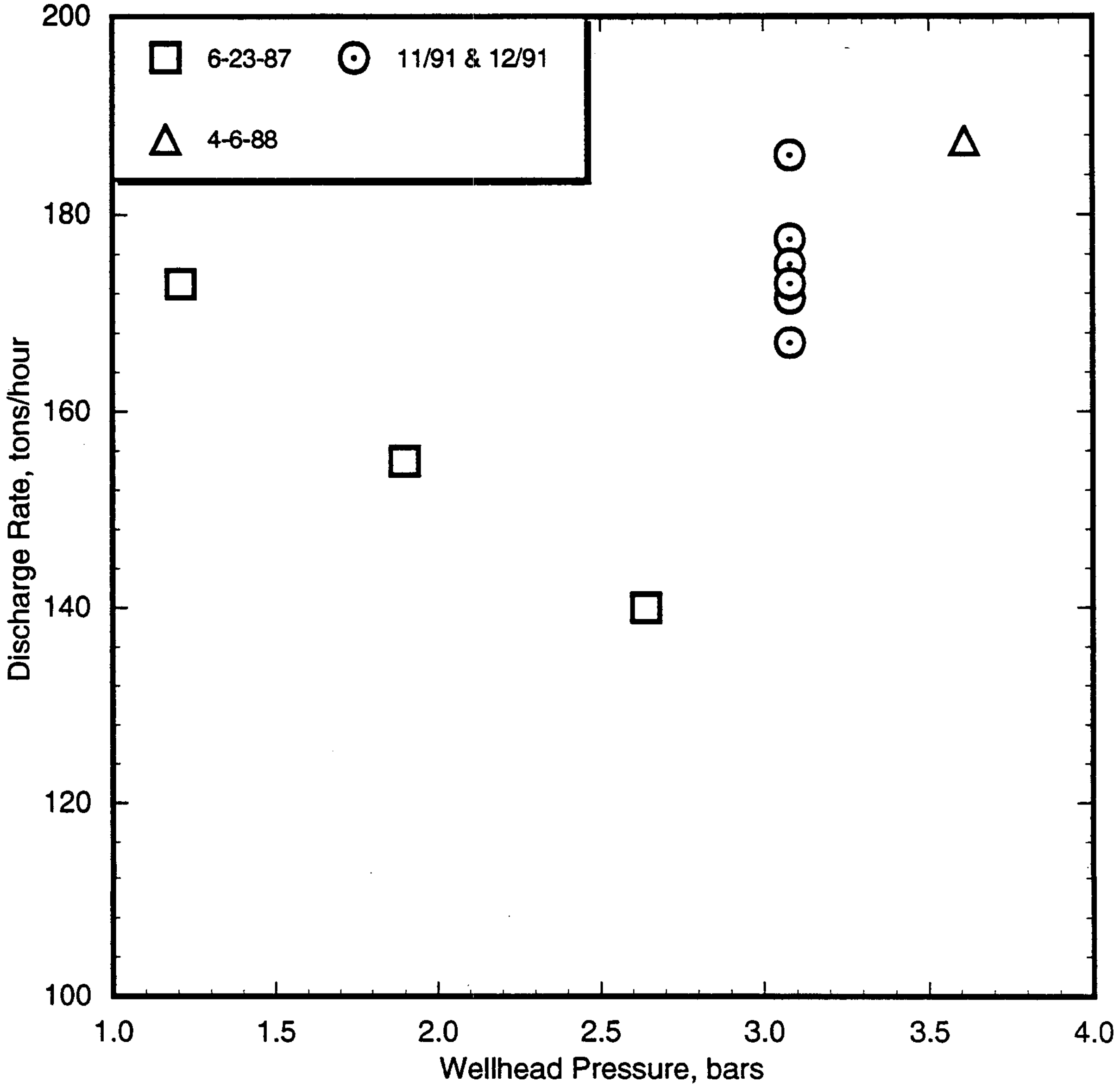

Figure 5.16. Discharge rate versus wellhead pressure for large-diameter production well TT-8S3 (June 1987, April 1988, November–December 1991).

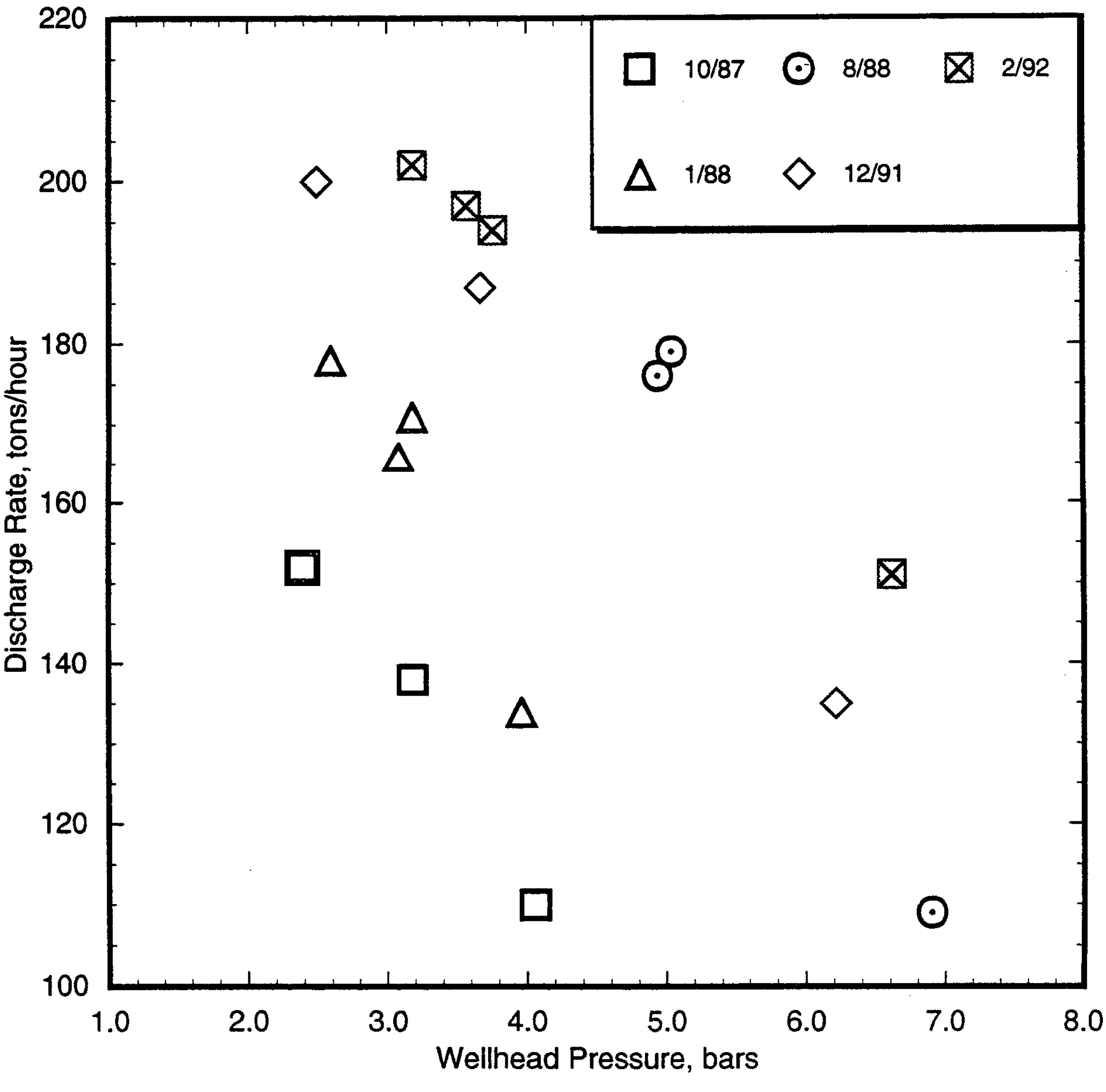

Figure 5.17. Discharge rate versus wellhead pressure for large-diameter production well TT-13S (October 1987, January 1988, August 1988, December 1991, and February 1992).

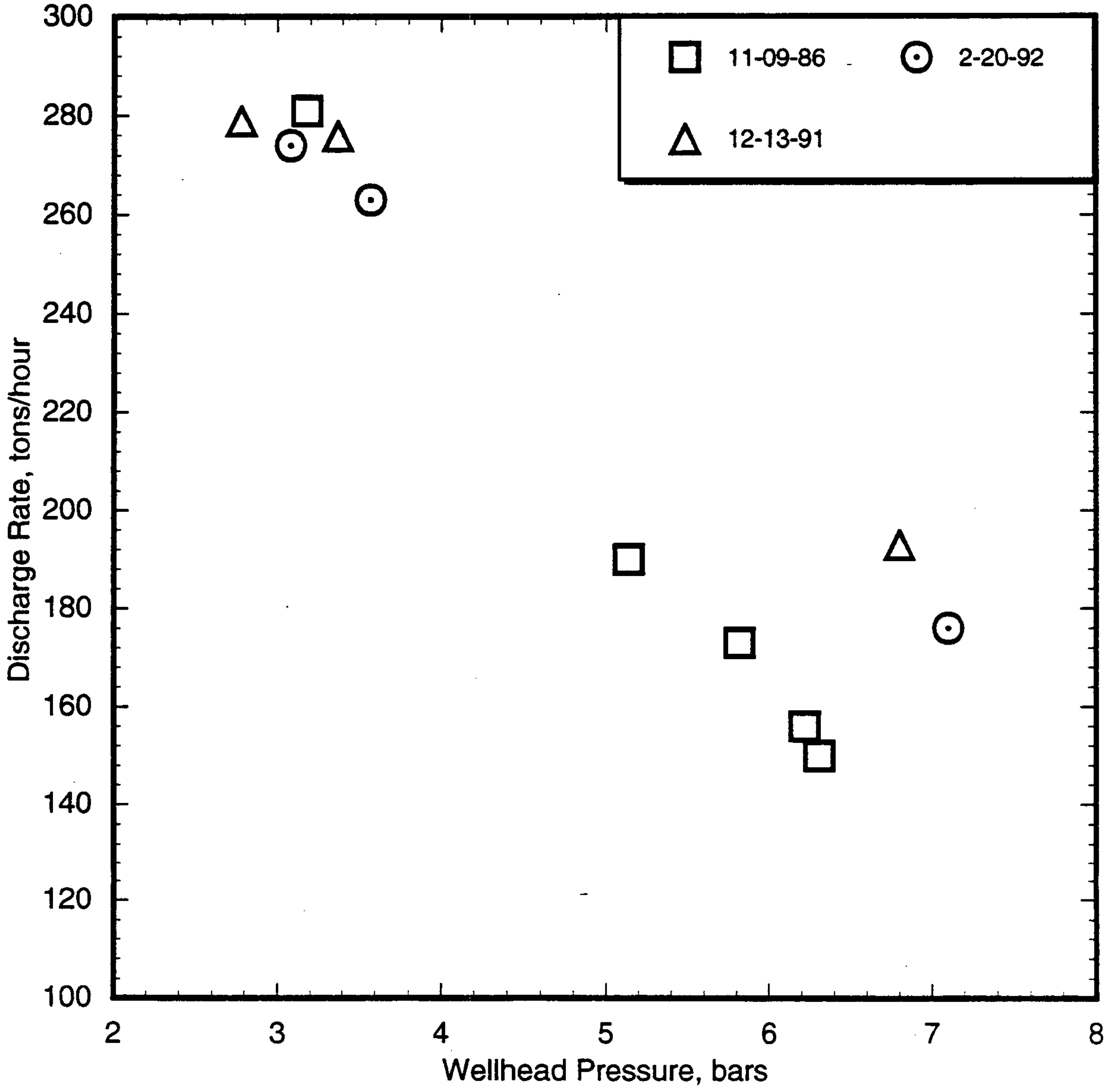

Figure 5.18. Discharge rate versus wellhead pressure for large-diameter production well TT-14R (November 1986, December 1991, and February 1992).

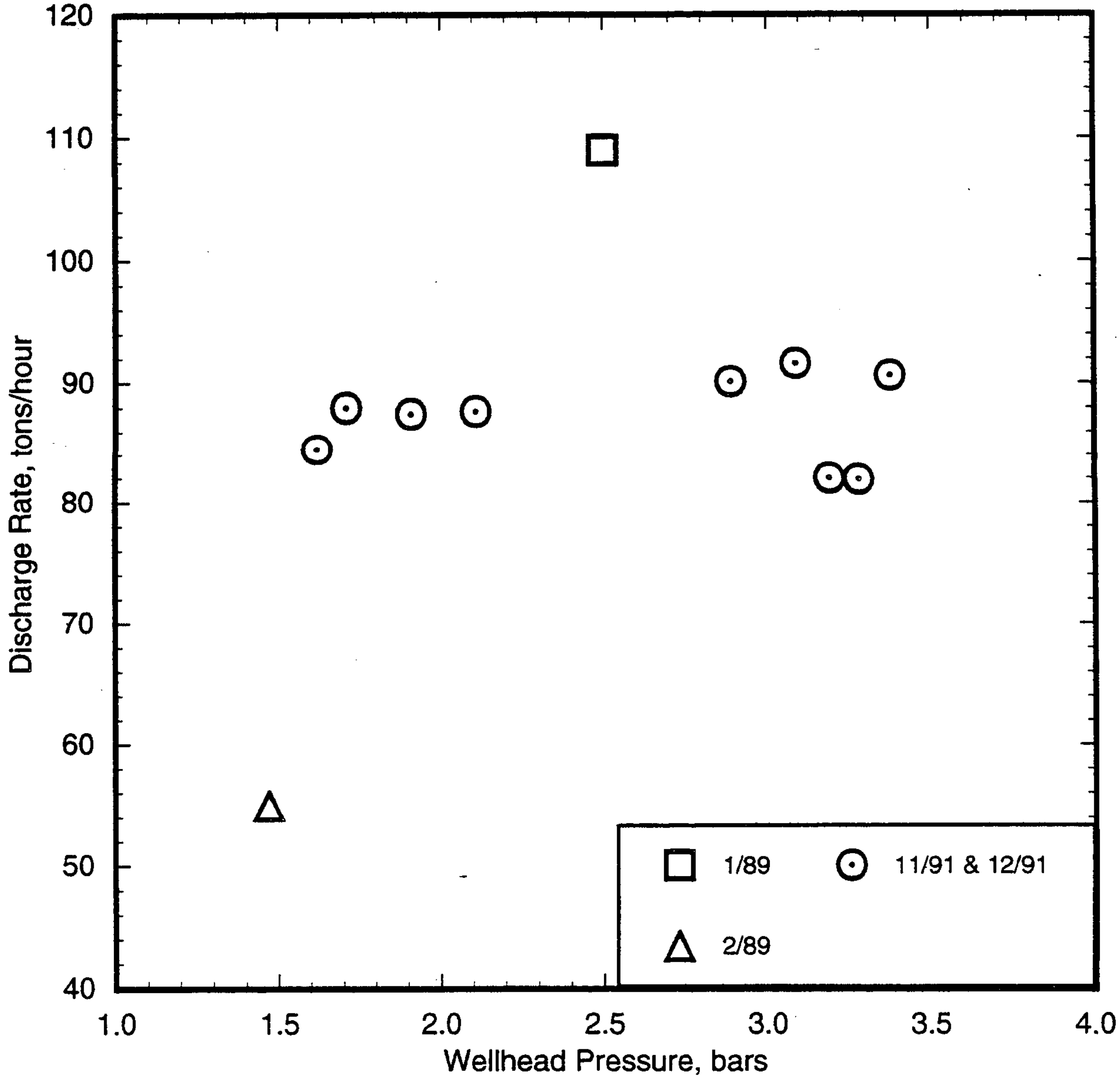

Figure 5.19. Discharge rate versus wellhead pressure for large-diameter production well TT-16S (January 1989, February 1989, November 1991, and December 1991).

Table 5.1. Measured maximum discharge rates for Takigami boreholes.

Borehole Name	Total Borehole Depth (m TVD)	Bottom of Cemented Casing (m TVD)	Open Hole Diameter (mm)	Feedzone Depth (m TVD)	Feedzone Temp. (Celsius)	Maximum Discharge Rate (tons/hr)
NE-2R	2010.0	1685.6	79	1800	180	17
NE-3(i)	1688.8?	1675.0	101	1680	192	32
NE-3	2303.1	1675.0	101	2275	197	23
NE-4	2243.3	1379.8	79	2230	244	11
NE-5(i1)	1109.5	996.9	98	1080	209	36
NE-5(i2)	1426.4	996.9	98	1180	205	31
NE-6(i1)	763.5	685.0	100	700	192	26
NE-6(i2)	1403.0	685.0	100	740	187	25
NE-11	1381.6	868.2	100	1340	196	20
NE-11R	1889.3	1377.3	100	1850	187	12
TT-1	3001.4	1624.2	216	2970	202	75
TT-2	1608.6	1553.3	216	1580	205	260
TT-7	1108.9	949.4	216	1070	215	490
TT-8(i)	854.2	822.3	311	840	180	220
TT-8S1(i)	1212.6	822.3	311	1050	162	100
TT-8S3	1875.9	1555.1	216	1870	214	180
TT-13S	2582.3	1724.7	216	2100	236	200
TT-14R	1960.6	1690.5	216	1730	236	280
TT-16S	1849.5	1316.6	216	1740	230	90

Table 5.2. Measured and predicted discharge rates for Takigami boreholes.

Borehole Name	**Open Hole Diameter (mm)**	**Measured Discharge (tons/hr)**	**M^* Area Scaled Discharge $^+$ (tons/hr)**	**M_{max} Scaled Maximum Discharge $^{++}$ (tons/hr)**
NE-2R	79	17	127	223
NE-3(i)	101	32	146	224
NE-3	101	23	105	161
NE-4	79	11	82	144
NE-5(i1)	98	36	175	272
NE-5(i2)	98	31	151	234
NE-6(i1)	100	26	121	187
NE-6(i2)	100	25	117	180
NE-11	100	20	93	144
NE-11R	100	12	56	86
Average (NE-2R to NE-11R)			118	186
TT-1	216	75		
TT-2	216	260		
TT-7	216	490		
TT-8S3	216	180		
TT-13S	216	200		
TT-14R	216	280		
TT-16S	216	90		
Average		225		

$^+$Area Scaled Discharge Rate = Measured Discharge Rate × $(216/\text{well diameter in mm})^2$

$^{++}$Scaled Maximum Discharge Rate = Measured Discharge Rate × $(216/\text{well dia. in mm})^{2.56}$

Most large-diameter wells at Oguni and at Sumikawa geothermal fields are completed with a 9-5/8 inch (internal diameter ≈ 224 mm) cemented casing and a 8-1/2 inch (≈ 216 mm) open hole (In some cases, the open hole is lined with a 7-inch uncemented liner.). Thus, most Oguni and Sumikawa large-diameter wells have a more or less uniform internal diameter (≈ 22 cm), and satisfy one of the key assumptions (*i.e.*, uniform wellbore diameter) made by Pritchett in his analysis.

By way of contrast, Takigami large-diameter wells have non-uniform internal diameter. Most large-diameter production wells at Takigami are completed with 13-3/8 inch cemented casing (internal diameter ≈ 318 mm) in the upper part, 9-5/8 inch cemented casing (internal diameter ≈ 224 mm) in the middle part, and 8-1/2 inch open hole (internal diameter ≈ 216 mm) in the lower part of the borehole. For well TT-7, the diameter of the cemented casing in the upper part of the borehole is 16 inches (internal diameter ≈ 381 mm). The Takigami production wells do not have uniform internal diameters; therefore, we do not expect Pritchett's scaling rule to apply to Takigami boreholes.

To explore the relationship between the discharge capacity of slim holes and large-diameter Takigami wells, it is necessary to numerically simulate the production characteristics of large-diameter, non-uniform diameter, Takigami wells. The numerical parameters derived from a fit to actual production data (for large-diameter wells) can then be used to calculate the probable discharge rate for a uniform-diameter (*i.e.*, an Oguni/Sumikawa type) well. Lack of a productivity index for well TT-1. and the presence of drill pipe in wells TT-8(i) and TT-8S1(i) makes it impossible to perform meaningful numerical simulations for these three wells. However, numerical simulations for all other large-diameter Takigami wells (TT-2, TT-7, TT-8S3, TT-13S, TT-14R and TT-16S) are presented in Subsection 5.2.

5.2 Mathematical Modeling of Fluid Flow in Takigami Boreholes

To model the flow characteristics of Takigami boreholes, the wellbore computer simulation program WELBOR (Pritchett, 1985) was employed. The WELBOR code treats the steady flow of water and/or steam up a borehole. The user provides parameters describing the well geometry (inside diameter and angle of deviation with respect to vertical along the hole length), a stable formation temperature distribution with depth, and an "effective thermal conductivity" representing the effects of conductive heat transfer between the fluid in the wellbore and the surrounding rock formation. Values must also be specified for the flowing feedpoint pressure (or alternately stable feedpoint pressure and productivity index) and enthalpy (or alternately temperature for wells producing from a single-phase liquid zone). Since all the existing Takigami boreholes produce from liquid feedzones, the feedzone fluid state can be prescribed by stable feedzone pressure, productivity index, and feedzone temperature.

In WELBOR, the frictional pressure gradient is treated using Dukler's correlation (Dukler *et al.*, 1964) and a user prescribed roughness factor. The relative slip between the liquid and gas phases is treated using a modified version of the Hughmark liquid holdup correlation (Hughmark, 1962). The slippage rate may vary between the value given by the Hughmark correlation and no slip at all, according to the value of a user-supplied holdup parameter which varies between zero (no slip) and unity (Hughmark). For all of the calculations presented in this subsection, the Hughmark correlation was used.

Given the downhole (usually at feedzone depth) values for mass flow, pressure and temperature (or flowing enthalpy for wells producing from a two-phase zone), the WELBOR code can be used to compute the conditions along the wellbore and at the wellhead (pressure, flowing enthalpy, *etc.*). The principal parameters that may be varied to match the measured conditions in the wellbore and at the wellhead are (1) holdup parameter, (2) effective thermal conductivity and (3) interior roughness factor. As mentioned earlier, for the Takigami boreholes, it was not necessary to vary the holdup parameter, and the Hughmark correlation was employed in all cases. Numerical experimentation revealed that several of the Takigami slim holes are simply incapable of transmitting the reported discharge rates to the wellhead; it is likely that a part of the flow is diverted to the annulus (bad cement?) behind the casing. For the latter boreholes, the diameter of the cemented section was taken to be a free parameter.

For both the slim holes and large-diameter production wells at Takigami, WELBOR was used to match the downhole pressure/temperature profiles and the results of characteristic tests. The model parameters derived from fits to actual discharge test data (for both the slim holes and large-diameter production wells) were used to calculate the discharge characteristics of an "Oguni/Sumikawa type" well (9-$^5/_8$ inch cemented casing with an internal diameter of 224 mm, and a 216 mm open hole). Detailed results of these calculations follow.

Slim Hole NE-3

The principal feedzone for slim hole NE-3 is located at 2275 m TVD. No pressure/temperature surveys in the discharging well were run below a depth of 2000 m TVD; therefore, the pressure data at 2000 m TVD were used to determine the productivity index for slim hole NE-3. The stable pressure at 2000 m TVD is 163.2 bars; using the flowing pressure recorded on February 9, 1983, the productivity index is estimated to be ~3.2 kg/s-bar (see Section 4).

The well geometry is as follows:

Measured Depth (meters)	Vertical Depth (meters)	Angle with Vertical (degrees)	Internal Diameter (cm)
0.0–1675.0	0.0–1675.0	0.00	10.4
1675.0–2000.0	1675.0–2000.0	0.00	10.1

The stable formation temperature was approximated by the following temperature distribution using linear interpolations between tabulated points:

Vertical Depth (meters)	Temperature (Celsius)
0	20
500	50
1000	155
1600	190
2000	196

The flowing temperature (*i.e.*, temperature of the liquid in the discharging well) at 2000 m TVD is 194°C.

The characteristic test data (*i.e.*, discharge rate versus wellhead pressure, Figure 5.20) and downhole profiles (Figures 5.21 and 5.22) recorded during a discharge test in early 1983 were fitted using the following two alternate sets of parameter values:

Model I:
Effective Thermal Conductivity, $K = 1.0$ W/m-°C
Roughness Factor, $\varepsilon = 0.36$ mm

Model II:
Effective Thermal Conductivity, $K = 3.6$ W/m-°C
Roughness Factor, $\varepsilon = 0.00$ mm

Neither of the above two models provides a totally satisfactory fit to the temperature profile. Model I yields a good fit in the single-phase region (below ~300 meters); however, the fit in the two-phase region (above 300 meters) is unsatisfactory. Model II on the other hand gives a good fit in the two-phase region and a poor fit in the upper part of the single-phase region. Attempts to improve the fit to temperature data using other parameter (K, ε) values were not successful. As far as the characteristic test data (Figure 5.20) are concerned, Model II yields a superior fit than Model I. Accordingly, Model II was used for purposes of calculating the discharge

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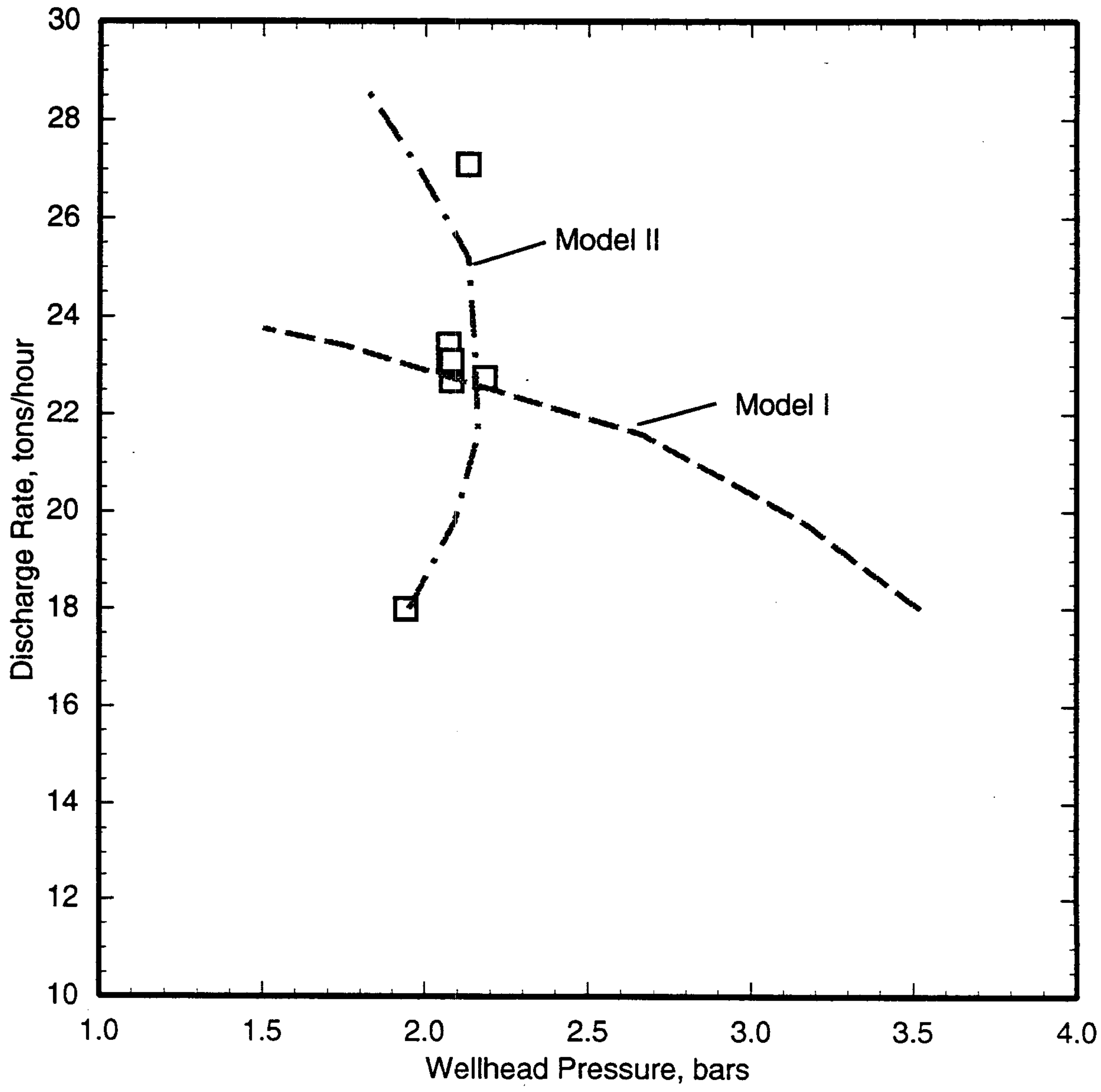

Figure 5.20. Discharge rate versus wellhead pressure for slim hole NE-3 (January and February 1983). The dashed lines are the computed characteristic curves.

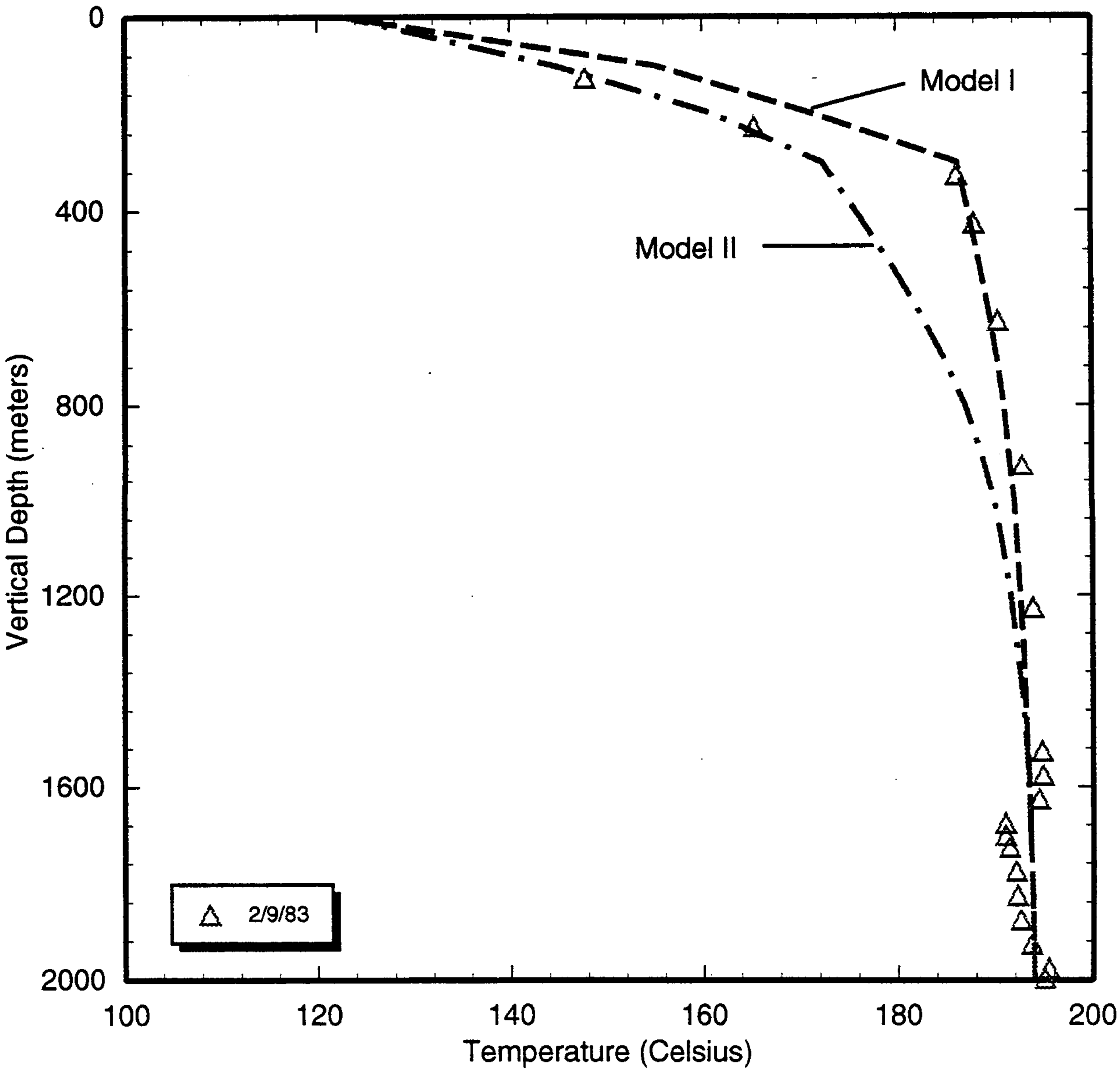

Figure 5.21. Temperature profile recorded in discharging NE-3 on February 9, 1983. The dashed lines are the computed temperature profiles.

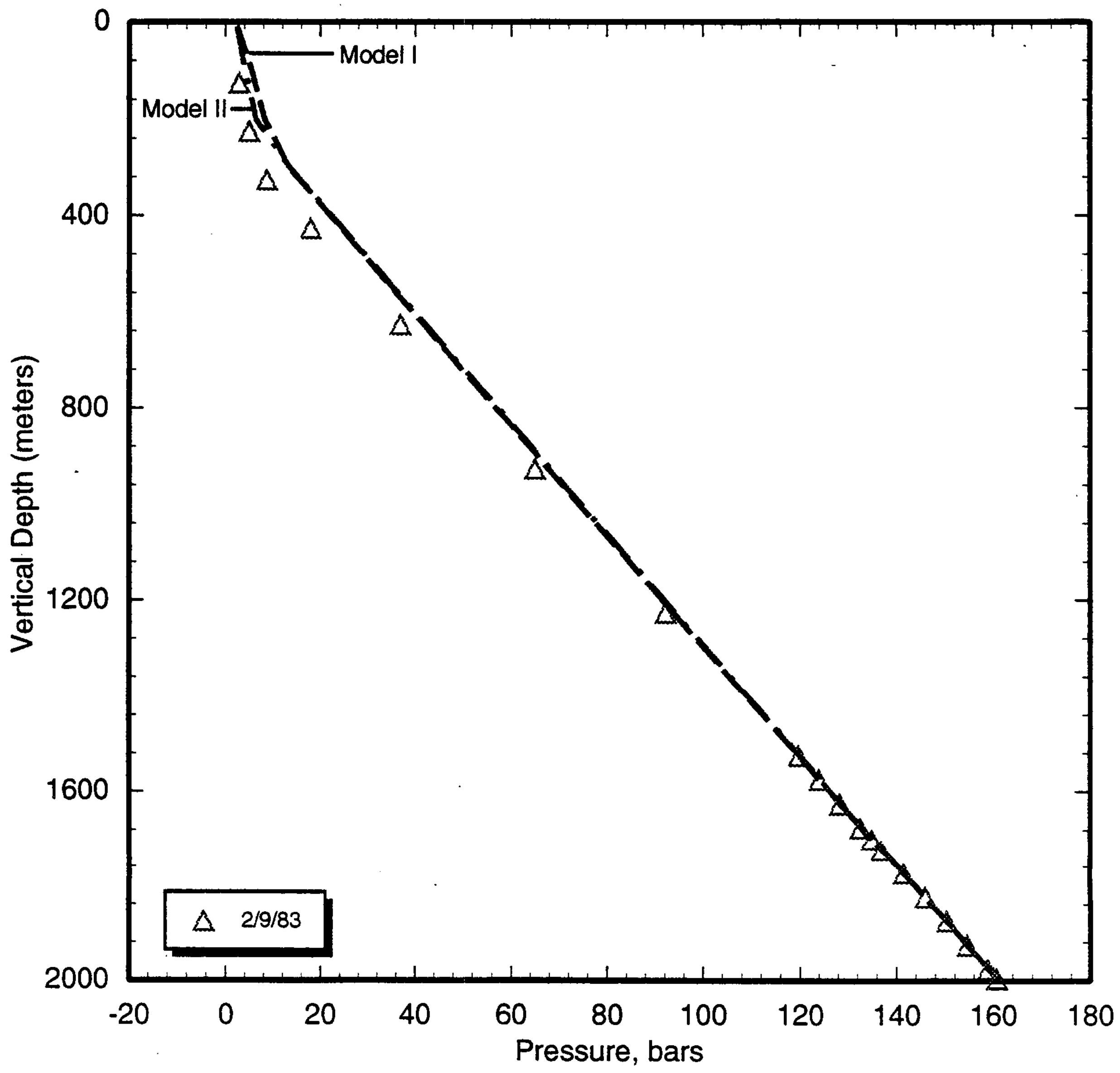

Figure 5.22. Pressure profile recorded in discharging NE-3 on February 9, 1983. The dashed lines are the computed pressure profiles.

characteristics of a hypothetical "Oguni/Sumikawa type" well with the following geometry:

Measured Depth (meters)	Vertical Depth (meters)	Angle with Vertical (degrees)	Internal Diameter (cm)
0.0–1675.0	0.0–1675.0	0.00	22.44
1675.0–2275.0	1675.0–2275.0	0.00	21.59

The stable feedzone (2275 m TVD) pressure and temperature are 186.5 bars and 194°C, respectively. The remaining parameters for the hypothetical well (*i.e.*, productivity index, roughness parameter, effective thermal conductivity) are taken to be the same as those for the slim hole (Model II).

The computed discharge characteristics for the hypothetical "Oguni/Sumikawa type" well are displayed in Figure 5.23; the maximum discharge rate is ~168 tons/hour. The latter value for the discharge rate is not too different from the scaled maximum discharge rate (~151 tons/hour) given in Table 5.2.

Slim Hole NE-4

The principal feedzone for NE-4 is located at 2230 m TVD. The stable feedzone pressure and flowing temperature (as determined from the temperature survey of January 18, 1986) are 185.5 bars and 247°C, respectively. After cold water injection and well cleaning on January 21–22, 1986, a discharge test was performed on January 27, 1986. The feedzone temperature of 236°C during the latter discharge test is 11°C lower than that recorded during the discharge test on January 18, 1986. It is likely that feedzone temperature had not fully recovered at the time of the discharge test on January 27, 1986. In the following, only the pressure and temperature surveys recorded on January 18, 1986 will be considered. The productivity index for NE-4 as obtained from the pressure survey of January 18, 1986 is ~0-.052 kg/s-bar.

The well geometry is as follows:

Measured Depth (meters)	Vertical Depth (meters)	Angle with Vertical (degrees)	Internal Diameter (cm)
0.0–1456.8	0.0–1348.8	22.20	10.1
1456.8–2392.6	1348.8–2230.0	19.67	7.9

The stable formation temperature was approximated by the following temperature distribution using linear interpolations between tabulated data:

Vertical Depth (meters)	Temperature (Celsius)
0	20
600	50
1400	200
2230	247

The characteristic test data taken during the two January 1986 discharge tests (Figure 5.24) and downhole profiles (Figures 5.25 and 5.26) of January 18, 1986 were fitted using the following two alternate models:

Model I:
Roughness Factor, $\varepsilon = 0.0$ mm
Effective Thermal Conductivity, $K = 2.6$ W/m-°C

Model II:
Roughness Factor, $\varepsilon = 0.2$ mm
Effective Thermal Conductivity, $K = 2.0$ W/m-°C

Model I provides a somewhat better fit to the downhole pressure/temperature data (Figures 5.25 and 5.26). The characteristic test data are, however, better approximated by Model II.

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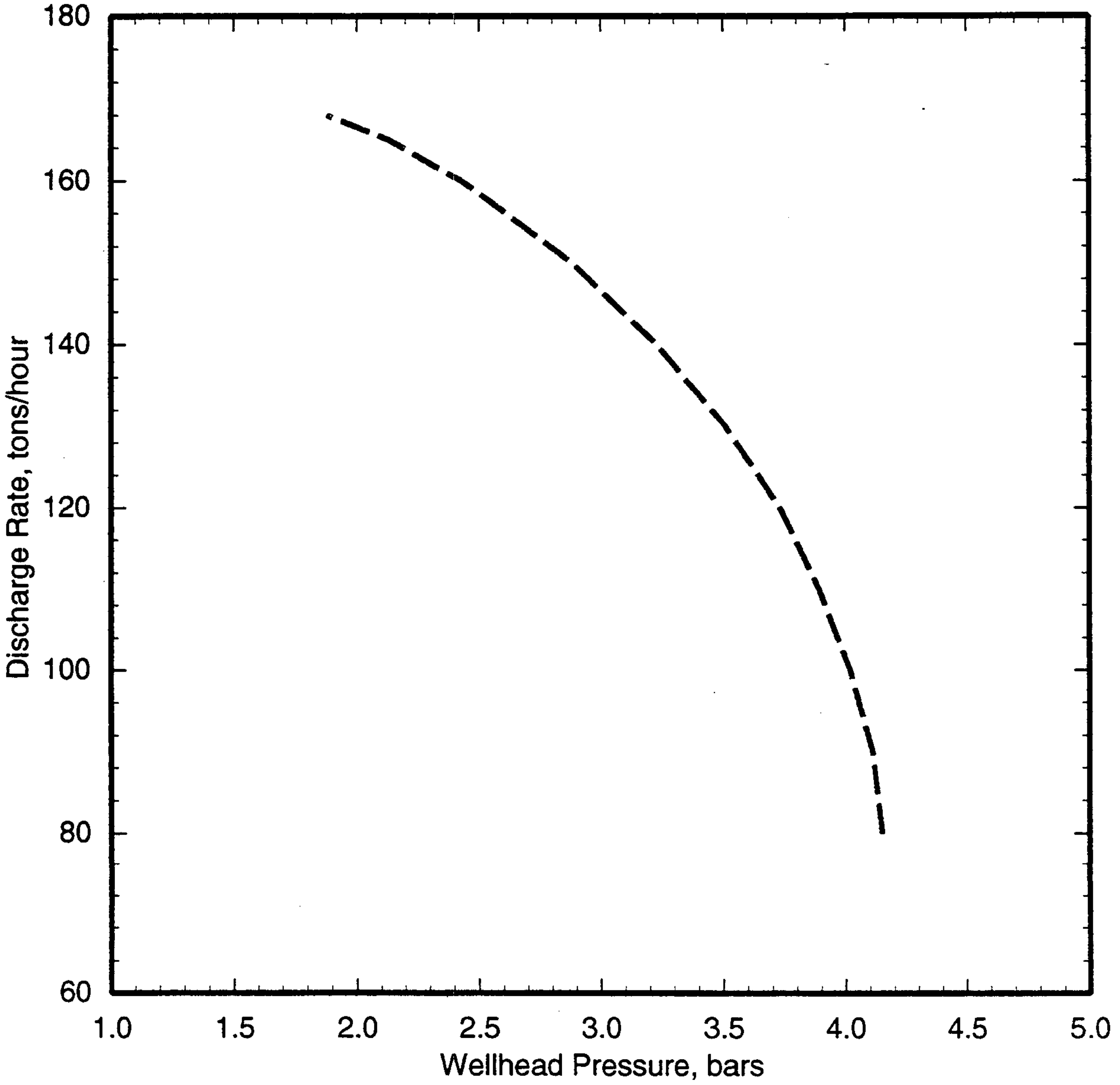

Figure 5.23. Computed discharge characteristics for the hypothetical "Oguni/Sumikawa type" well using model parameters for slim hole NE-3.

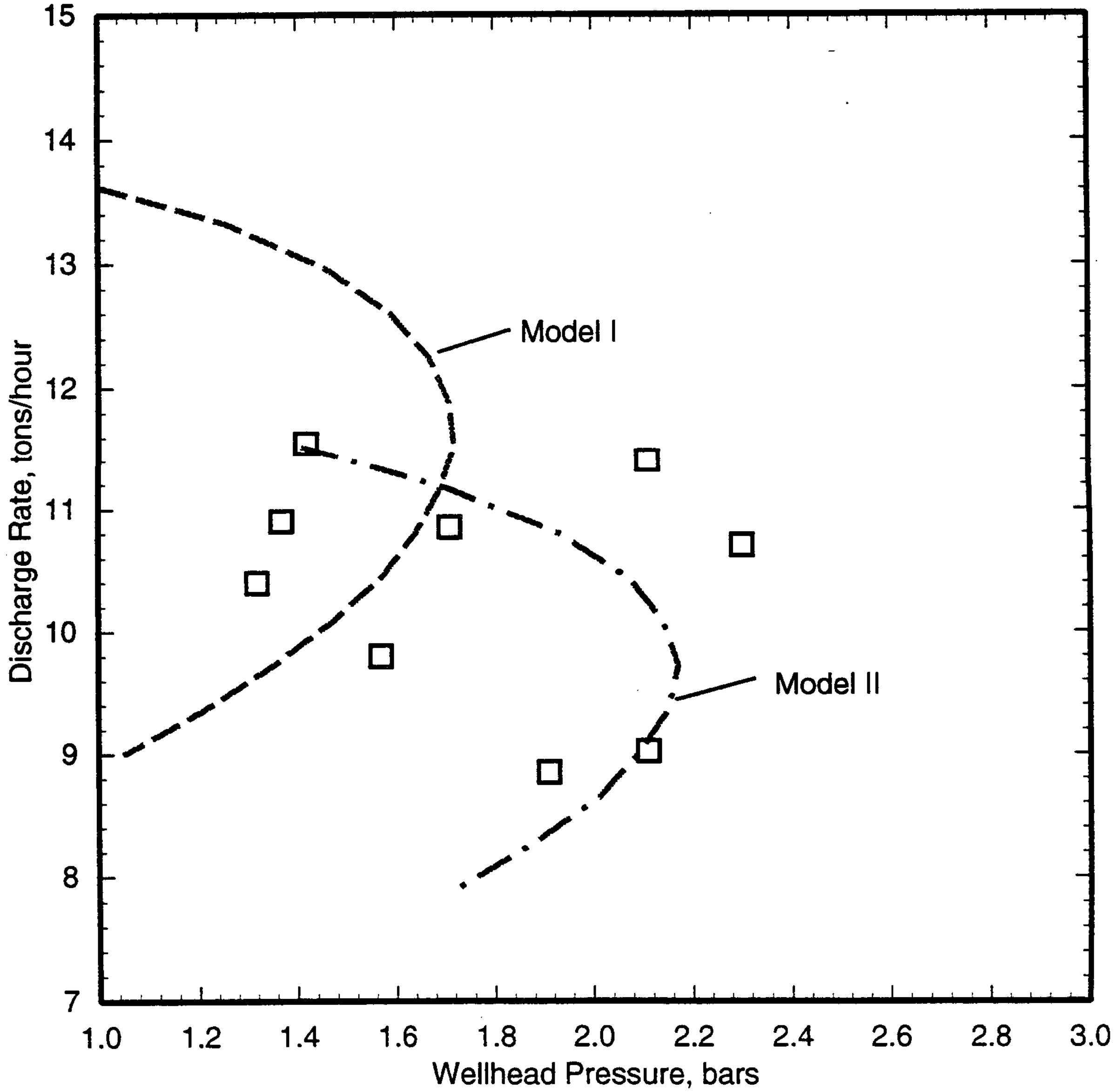

Figure 5.24. Discharge rate versus wellhead pressure for slim hole NE-4 (January 1986). The dashed lines are the computed characteristic curves.

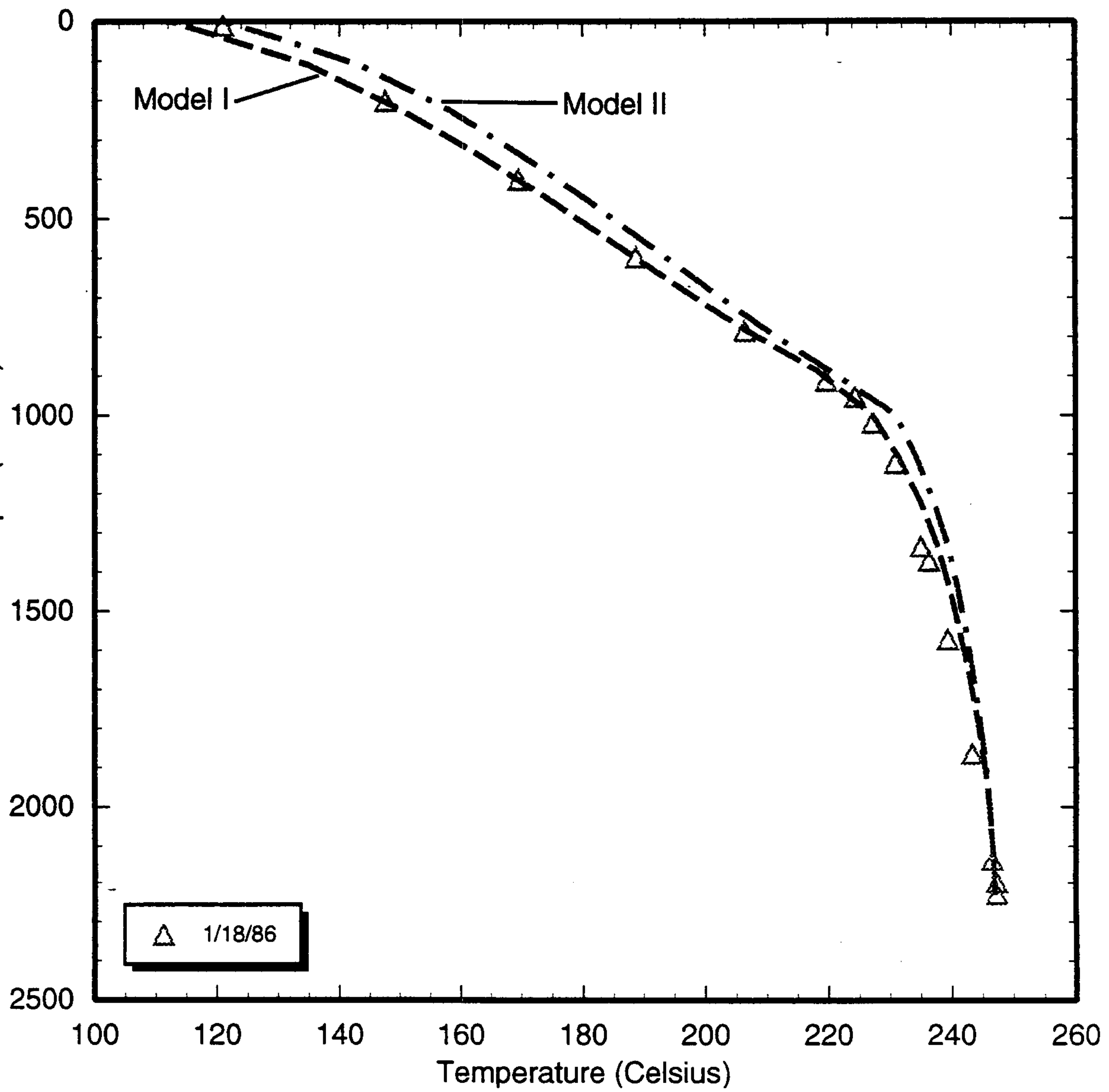

Figure 5.25. Temperature profile recorded in discharging NE-4 on January 18, 1986. The dashed lines are the computed temperature profiles.

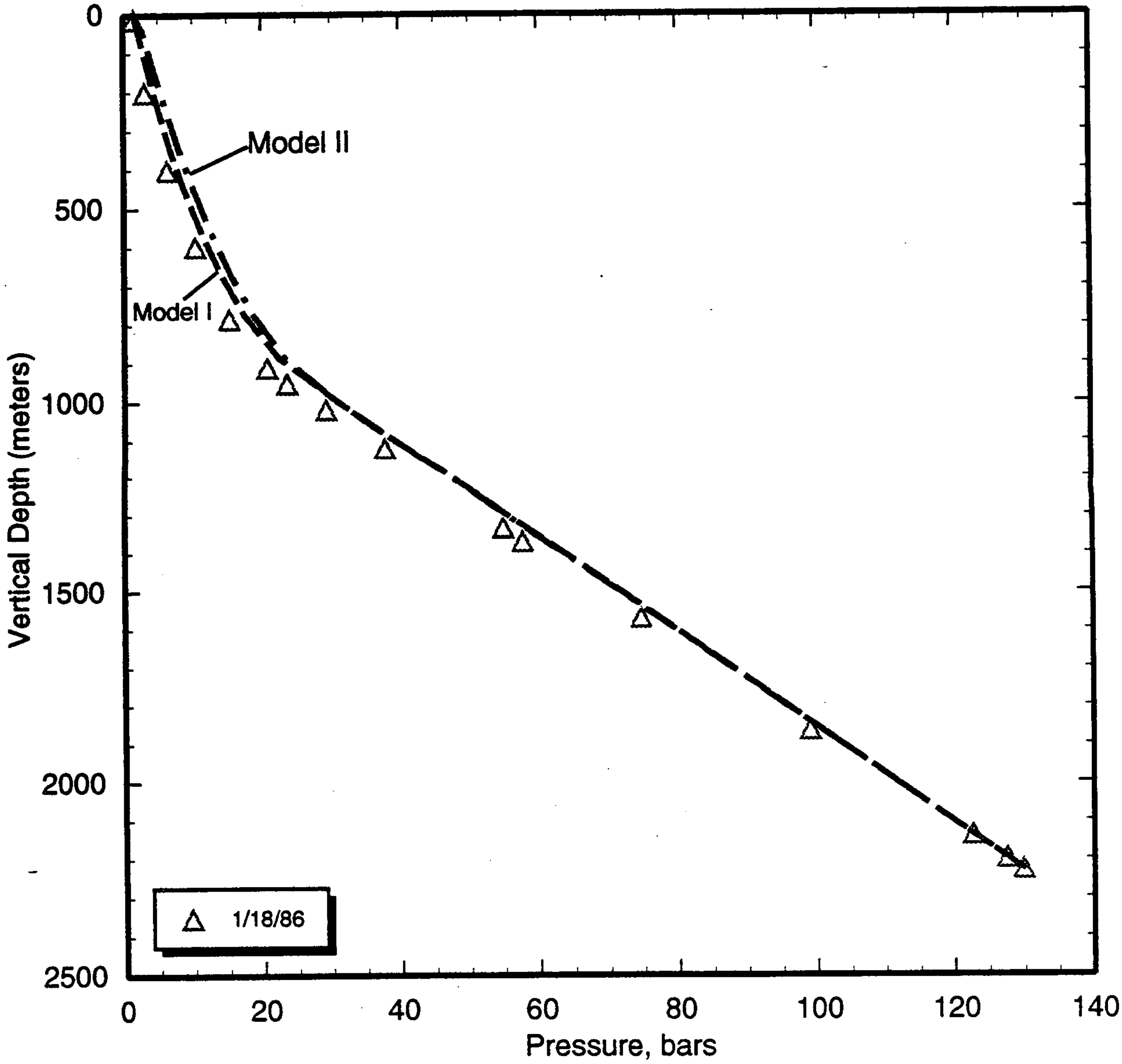

Figure 5.26. Pressure profile recorded in discharging NE-4 on January 18, 1986. The dashed lines are the computed pressure profiles.

Model II parameters (K, ε) were used to calculate the discharge characteristics of the following hypothetical "Oguni/Sumikawa type" well:

Measured Depth (meters)	Vertical Depth (meters)	Angle with Vertical (degrees)	Internal Diameter (cm)
0.0–1456.8	0.0–1348.8	22.20	22.44
1456.8–2392.6	1348.8–2230.0	19.67	21.59

The computed discharge characteristics for the hypothetical well are shown in Figure 5.27. The maximum computed discharge rate of ~18 tons/hour is only a small fraction of the scaled maximum discharge rate (144 tons/hour) given in Table 5.2. The very small productivity index for NE-4 causes most of the pressure drop to take place in the formation. Since the pressure drop in the wellbore is a small fraction of the total pressure drop (*i.e.*, the pressure drop between the reservoir and the wellhead), increasing the borehole diameter does not lead to a large increase in the discharge rate. Slim hole NE-4 is located close to the unsuccessful large-diameter well TT-16. Apparently, the western part of the Takigami Geothermal Field, which contains both NE-4 and TT-16, is characterized by poor productivity.

Slim Hole NE-5(i1)

The principal feedzone for slim hole NE-5(i1) is located at 1080 m TVD. Slim hole NE-5(i1) was briefly discharged on February 15 and 16, 1985. The flowing feedzone temperature and pressure, as measured on February 16, 1985, were ~209°C and 66.12 bars, respectively. As noted in Section 4, absence of shutin pressure data makes it impossible to compute a productivity index for NE-5(i1). For present purposes, it is assumed that the productivity index for NE-5(i1) can be approximated by the injectivity index (= 20 kg/s-bar) obtained from an injection test performed on February 17, 1985 (*i.e.*, after the production test). With $P_{flowing} = 66.12$ bars, $\dot{M} = 10.08$ kg/s, and $PI = 20$ kg/s-bar, the stable feedzone pressure is estimated to be ~66.62 bars.

The nominal well geometry for NE-5(i1) is as follows:

Measured Depth (meters)	Vertical Depth (meters)	Angle with Vertical (degrees)	Internal Diameter (cm)
0.0–997.0	0.0–996.9	0.81	10.4
997.0–1080.1	996.9–1080.0	0.00	9.8

Numerical experimentation showed that the above well geometry is incapable of transmitting the discharge rates measured during the February 1985 discharge test. It is likely that flow behind the casing is involved. Based on numerical experiments, the well geometry for NE-5(i1) was modified as follows:

Measured Depth (meters)	Vertical Depth (meters)	Angle with Vertical (degrees)	Internal Diameter (cm)
0.0–997.0	0.0–996.9	0.81	12.3
997.0–1080.1	996.9–1080.0	0.00	9.8

The effective diameter for the upper section must be at least 12.3 cm to accommodate the reported discharge rates.

The stable formation temperature was approximated by the following temperature distribution using linear interpolations between tabulated data:

Vertical Depth (meters)	Temperature (Celsius)
0	15
500	50
900	185
1080	210

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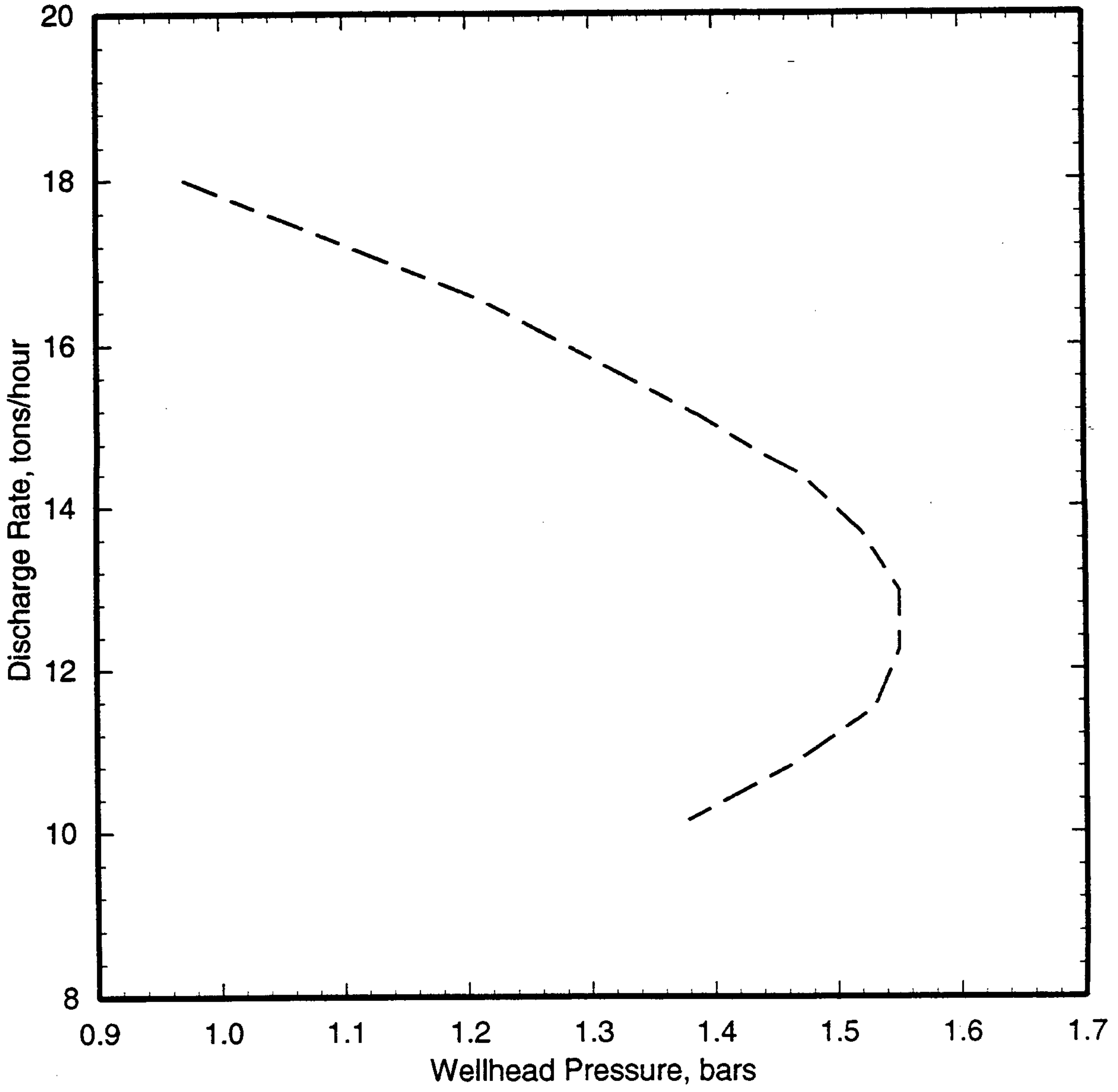

Figure 5.27. Computed discharge characteristics for the hypothetical "Oguni/Sumikawa type" well using model parameters for slim hole NE-4.

Except for the temperature at 1080 m TVD, the above temperature data are derived from temperatures recorded in nearby large-diameter production well TT-7.

The characteristic test data and downhole pressure/temperature profiles taken during the February 1985 test were simulated using the following model parameters:

Effective Thermal Conductivity, $K = 4$ W/m-°C
Roughness Factor, $\varepsilon = 0.00$ mm

The computed characteristic curves are shown for both the nominal and modified well geometries in Figure 5.28. The maximum discharge rate for the nominal geometry is ~7.6 kg/s (~27 tons/hour). The modified geometry curve closely approximates the three data points at high flow rates (~35 tons/hour); no attempt was made to modify the well parameters (geometry, K, ε) to match the single data point at ~20 tons/hour. Comparison between the computed and measured downhole temperature/pressure profiles is shown in Figures 5.29 and 5.30, respectively. Apparently, the downhole pressure/temperature profiles are insensitive to well geometry. Good agreement is obtained for both the nominal and modified well geometries.

The fitted model parameters (K, ε) for slim hole NE-5(i1) were employed to compute the discharge characteristics for the following hypothetical "Oguni/Sumikawa type" well:

Measured Depth (meters)	Vertical Depth (meters)	Angle with Vertical (degrees)	Internal Diameter (cm)
0.0–997.0	0.0–996.9	0.81	22.44
997.0–1080.1	996..9–1080.0	0.00	21.59

The computed discharge characteristics for the hypothetical well are displayed in Figure 5.31. The maximum computed discharge rate (~210 tons/hour) is about 20 percent smaller than the scaled maximum discharge rate (~272 tons/hour) given in Table 5.2; the difference between the two discharge rates is linked to flow behind the casing in NE-5(i1). Scaled maximum discharge rate calculation assumes a uniform internal diameter for the slim hole. Slim hole NE-5(i1) (modified geometry) does not meet this uniform diameter wellbore requirement.

Slim Hole NE-5(i2)

The principal feedzone for slim hole NE-5(i2) is located at 1180 m TVD. The stable feedzone pressure is ~74.2 bars. During a short-term discharge test (March 15, 1985 14:30 LT to March 17, 1985 22:00 LT), two pressure surveys were run in the borehole; the average flowing feedzone pressure was ~73.72 bars. Using the reported discharge rate of 31.1 tons/hour (~8.64 kg/s), the productivity index is estimated to be ~17 kg/s-bar (see also Section 4). The flowing feedzone temperature was ~205°C. The latter temperature is 4°C lower than that reported for NE-5(i1).

The nominal well geometry for NE-5(i2) is as follows:

Measured Depth (meters)	Vertical Depth (meters)	Angle with Vertical (degrees)	Internal Diameter (cm)
0.0–997.0	0.0–996.9	0.81	10.4
997.0–1180.3	996..9–1180.0	2.68	9.8

In common with slim hole NE-5(i1), the nominal well geometry for NE-5(i2) is incapable of supporting the reported discharge rate (8.64 kg/s). Apparently, part of the discharge takes place behind the casing. Numerical experimentation showed that the effective diameter for the upper section must be at least 12.3 cm (same as for NE-5(i1)) to accommodate the reported discharge rate. Accordingly, the well geometry for NE-5(i2) was modified as follows:

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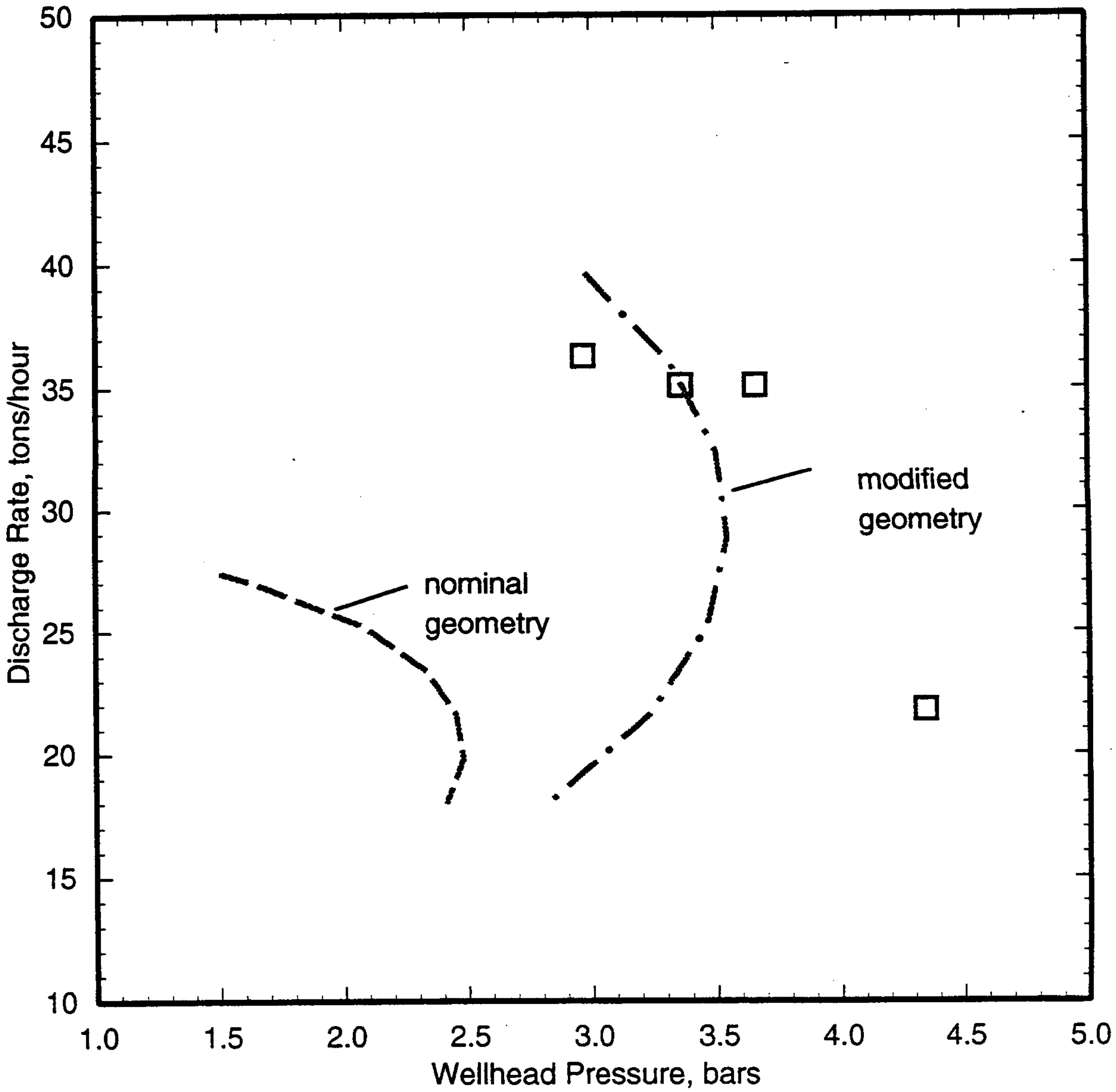

Figure 5.28. Discharge rate versus wellhead pressure for slim hole NE-5(i1) (February 15–16, 1985). The dashed lines are the computed characteristic curves.

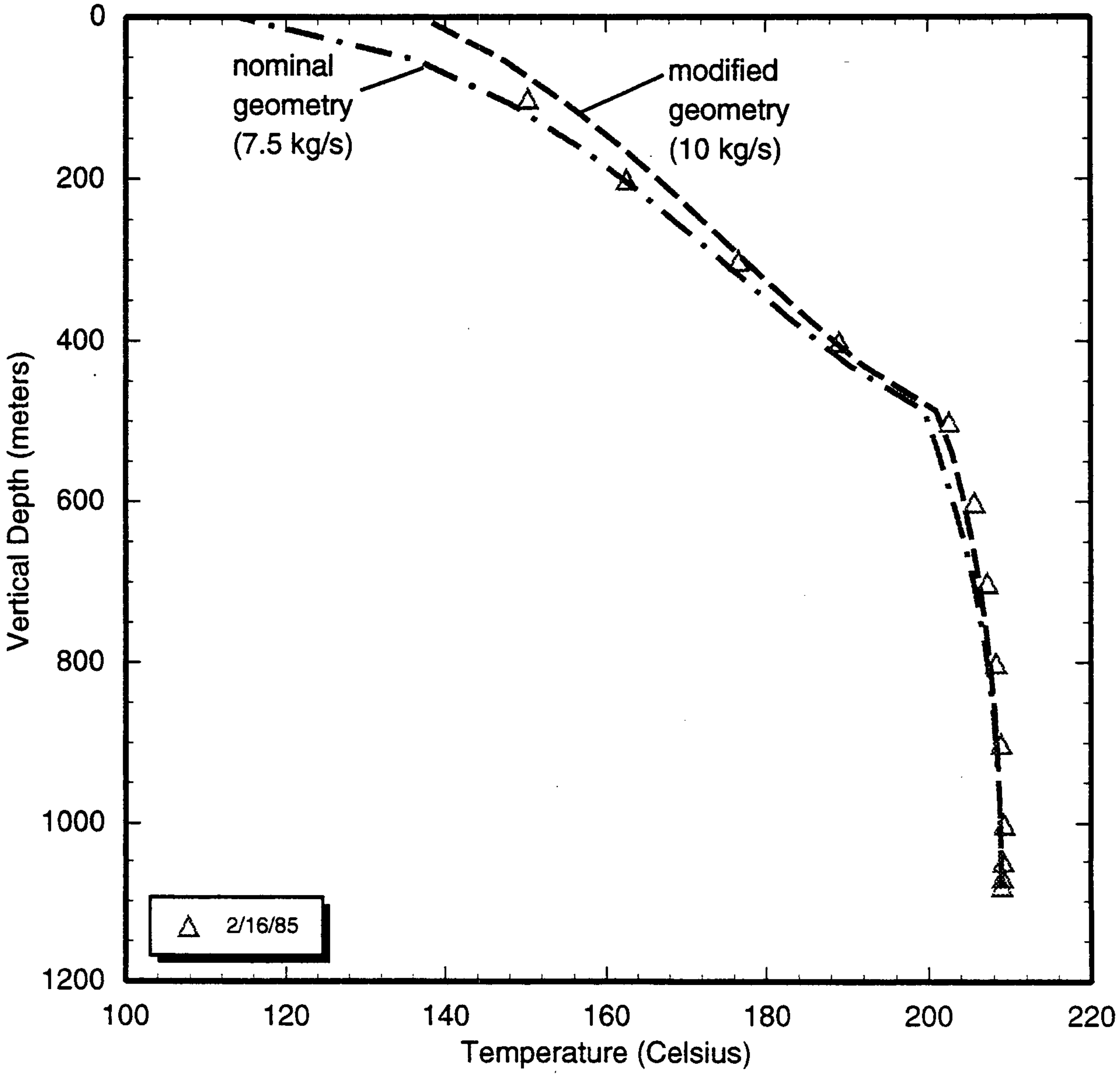

Figure 5.29. Temperature profile recorded in discharging NE-5(i1) on February 16, 1985. The dashed lines are the computed temperature profiles.

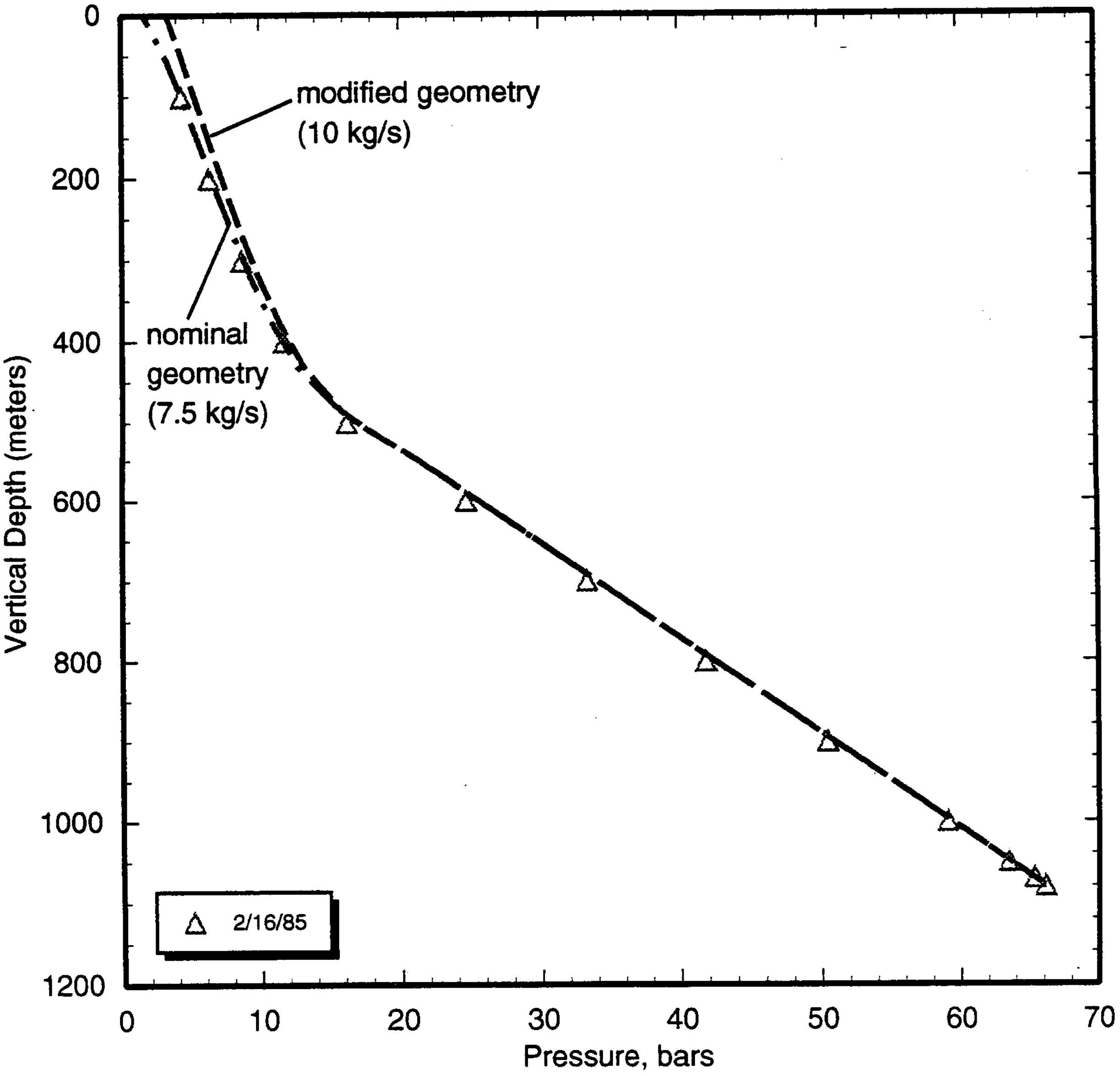

Figure 5.30. Pressure profile recorded in discharging NE-5(i1) on February 16, 1985. The dashed lines are the computed pressure profiles.

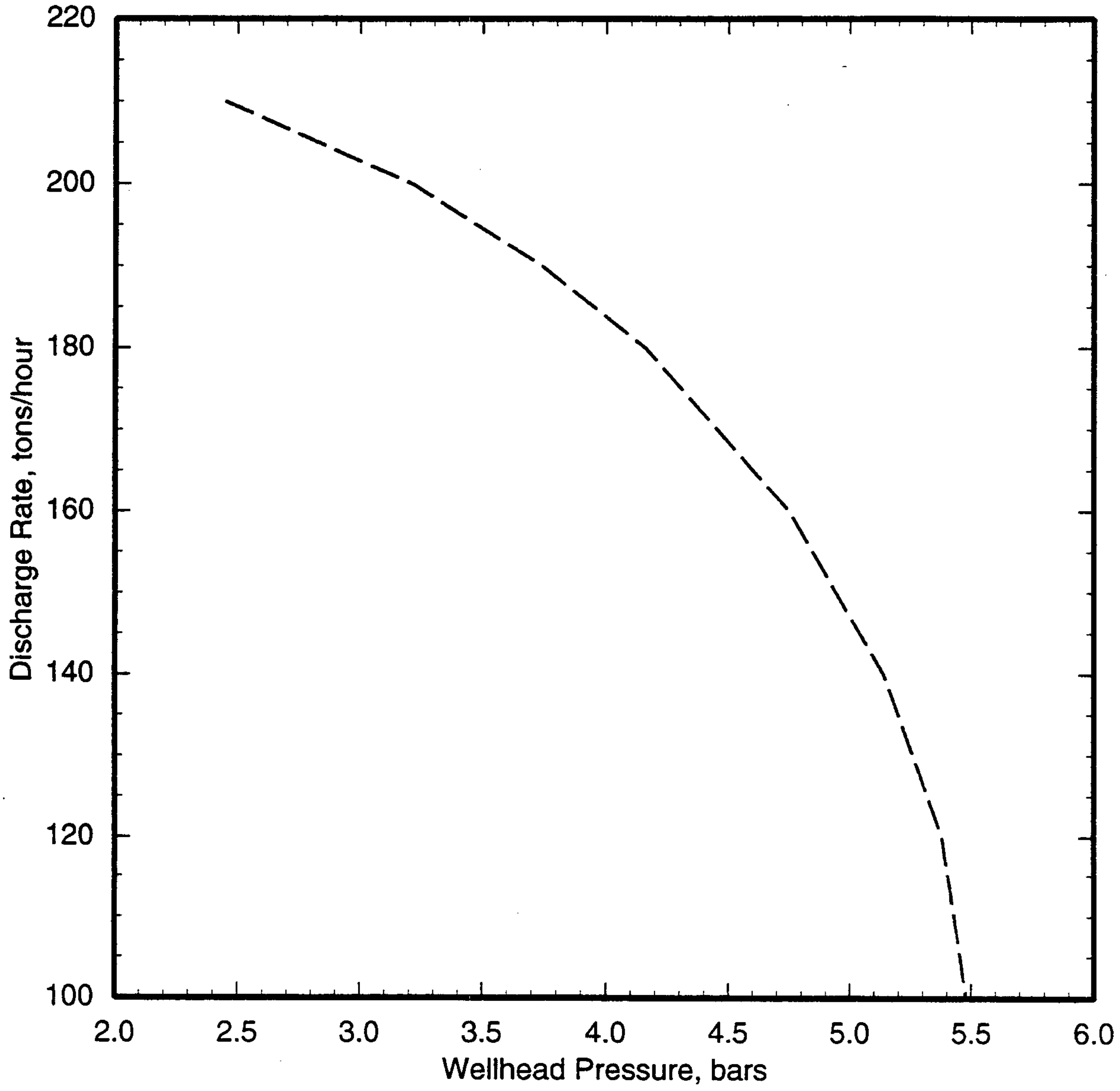

Figure 5.31. Computed discharge characteristics for the hypothetical "Oguni/Sumikawa type" well using model parameters for slim hole NE-5(i1).

Measured Depth (meters)	Vertical Depth (meters)	Angle with Vertical (degrees)	Internal Diameter (cm)
0.0–997.0	0.0–996.9	0.81	12.3
997.0–1180.3	996.9–1180.0	2.68	9.8

The stable formation temperature was approximated by the following temperature distribution using linear interpolations between tabulated data:

Vertical Depth (meters)	Temperature (Celsius)
0	15
500	50
900	185
1080	210
1180	205

Except for the temperature at 1180 meters, the above temperature distribution is identical with that assumed for slim hole NE-5(i1).

The characteristic test data and downhole pressure/temperature profiles taken during the March 1985 test were simulated using the following model parameters:

Effective Thermal Conductivity, $K = 4$ W/m-°C
Roughness Factor, $\varepsilon = 0.00$ mm

The computed characteristics curves for both the nominal and modified well geometries are shown in Figure 5.32. The maximum discharge rate for the nominal geometry is ~6.5 kg/s (23.4 tons/hour). Comparison between the computed and measured downhole temperature/pressure profiles is displayed in Figures 5.33 and 5.34, respectively. Good agreement is obtained for both the nominal and modified well geometries.

The model parameters (K, ε) for slim hole NE-5(i2) were employed to compute the discharge characteristics for the following hypothetical "Oguni/Sumikawa type" well:

Measured Depth (meters)	Vertical Depth (meters)	Angle with Vertical (degrees)	Internal Diameter (cm)
0.0–997.0	0.0–996.9	0.81	22.44
997.0–1180.3	996..9–1180.0	2.68	21.59

The computed discharge characteristics for the hypothetical well are shown in Figure 5.35. The maximum computed discharge rate (~188 tons/hour) is about 80 percent of the scaled maximum discharge rate (~234 tons/hour) given in Table 5.2.

Slim Hole NE-6(i1)

The principal feedzone for slim hole NE-6(i1) is located at 700 m TVD. The borehole was discharged for a brief period on February 14, and 15, 1985. The flowing feedzone temperature and pressure, recorded on February 14, 1985, were ~192°C and 31.7 bars, respectively. As remarked in Section 4, a lack of shutin pressure data makes it impossible to compute a productivity index for NE-6(i1). For present purposes, it is assumed that the productivity index for NE-6(i1) equals the injectivity index (~4 kg/s-bar) obtained on February 11, 1985. With $P_{flowing}$ ~31.7 bars, M ~7.44 kg/s, and PI ~4 kg/s-bar, the stable feedzone pressure is estimated as 33.6 bars.

The nominal well geometry for NE-6(i1) is as follows:

Measured Depth (meters)	Vertical Depth (meters)	Angle with Vertical (degrees)	Internal Diameter (cm)
0.0–684.0	0.0–684.0	0.00	10.4
684.0–700.0	684.0–700.0	0.00	10.0

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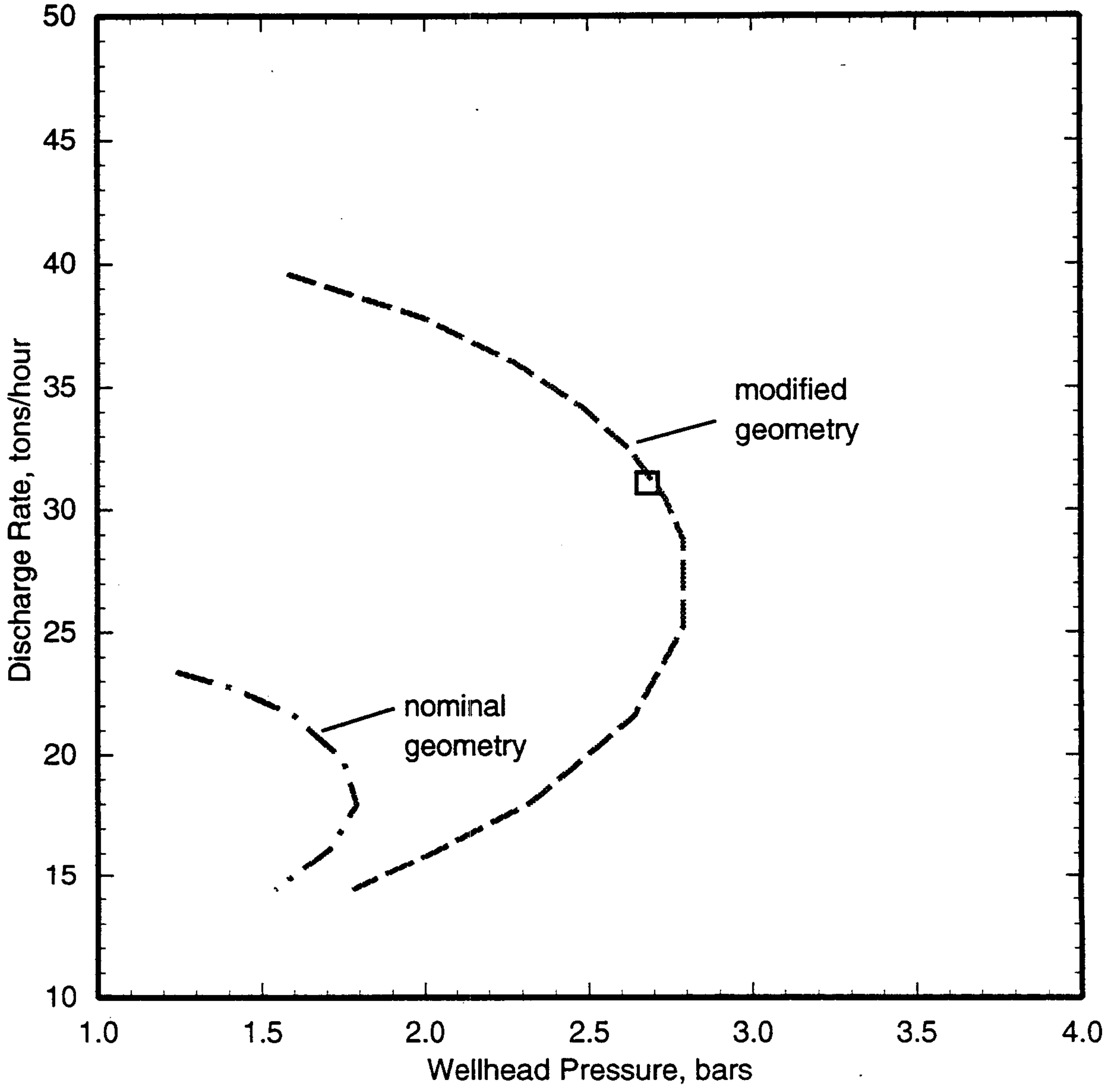

Figure 5.32. Discharge rate versus wellhead pressure for slim hole NE-5(i2) (March 15–17, 1985). The dashed lines are the computed characteristic curves.

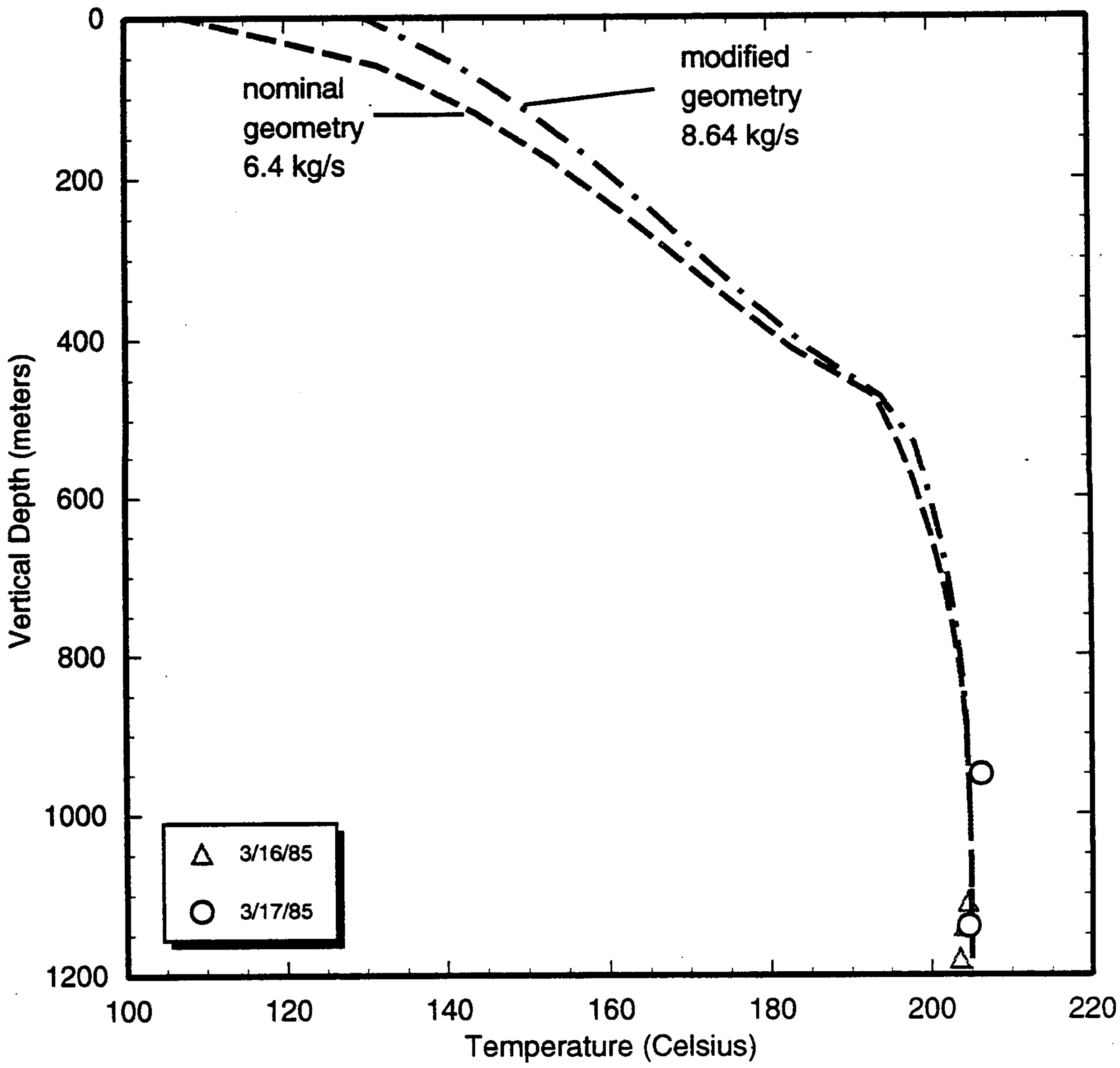

Figure 5.33. Temperature profiles recorded in discharging NE-5(i2) on March 16 and 17, 1985. The dashed lines are the computed temperature profiles.

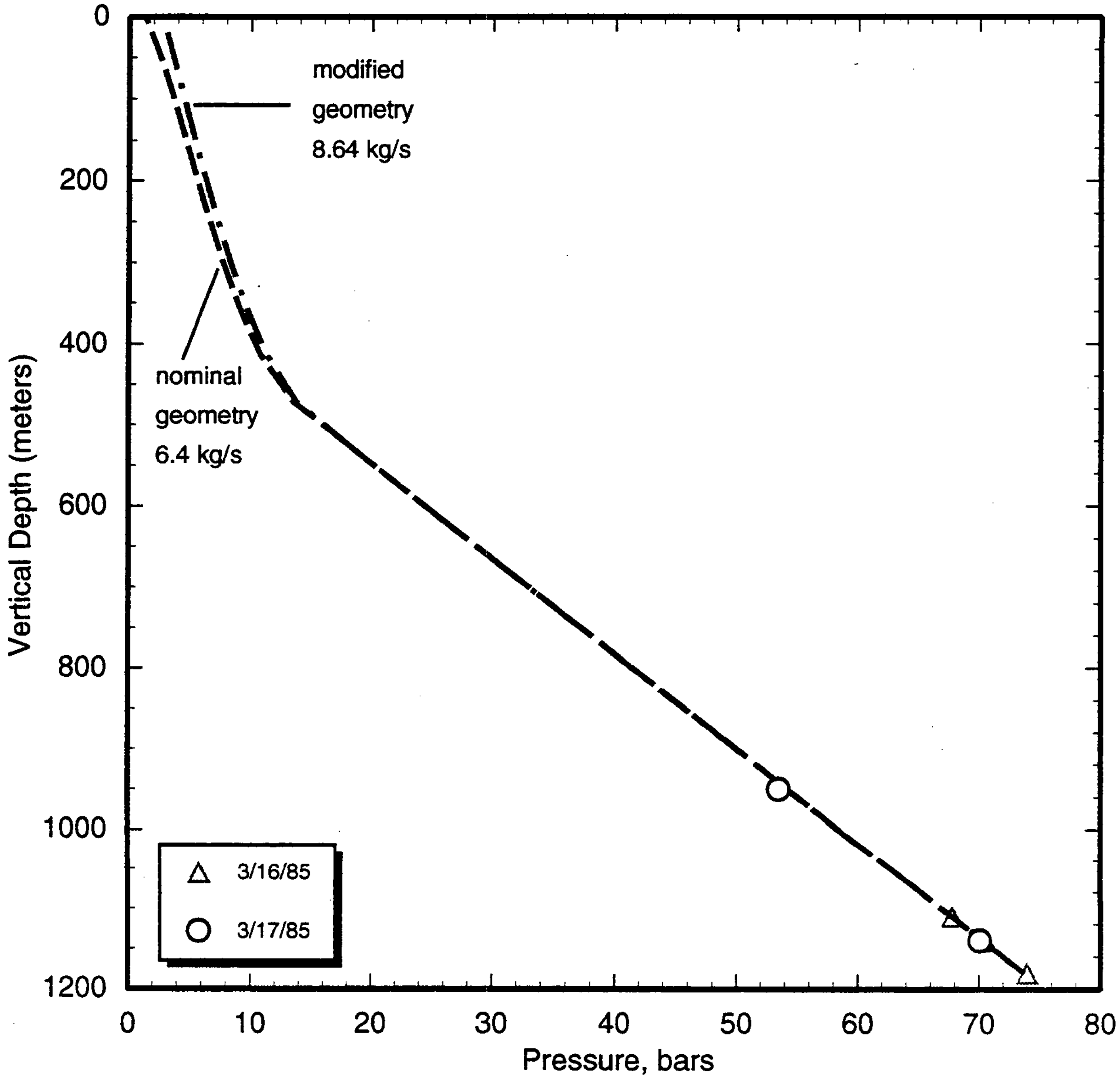

Figure 5.34. Pressure profiles recorded in discharging NE-5(i2) on March 16 and 17, 1985. The dashed lines are the computed pressure profiles.

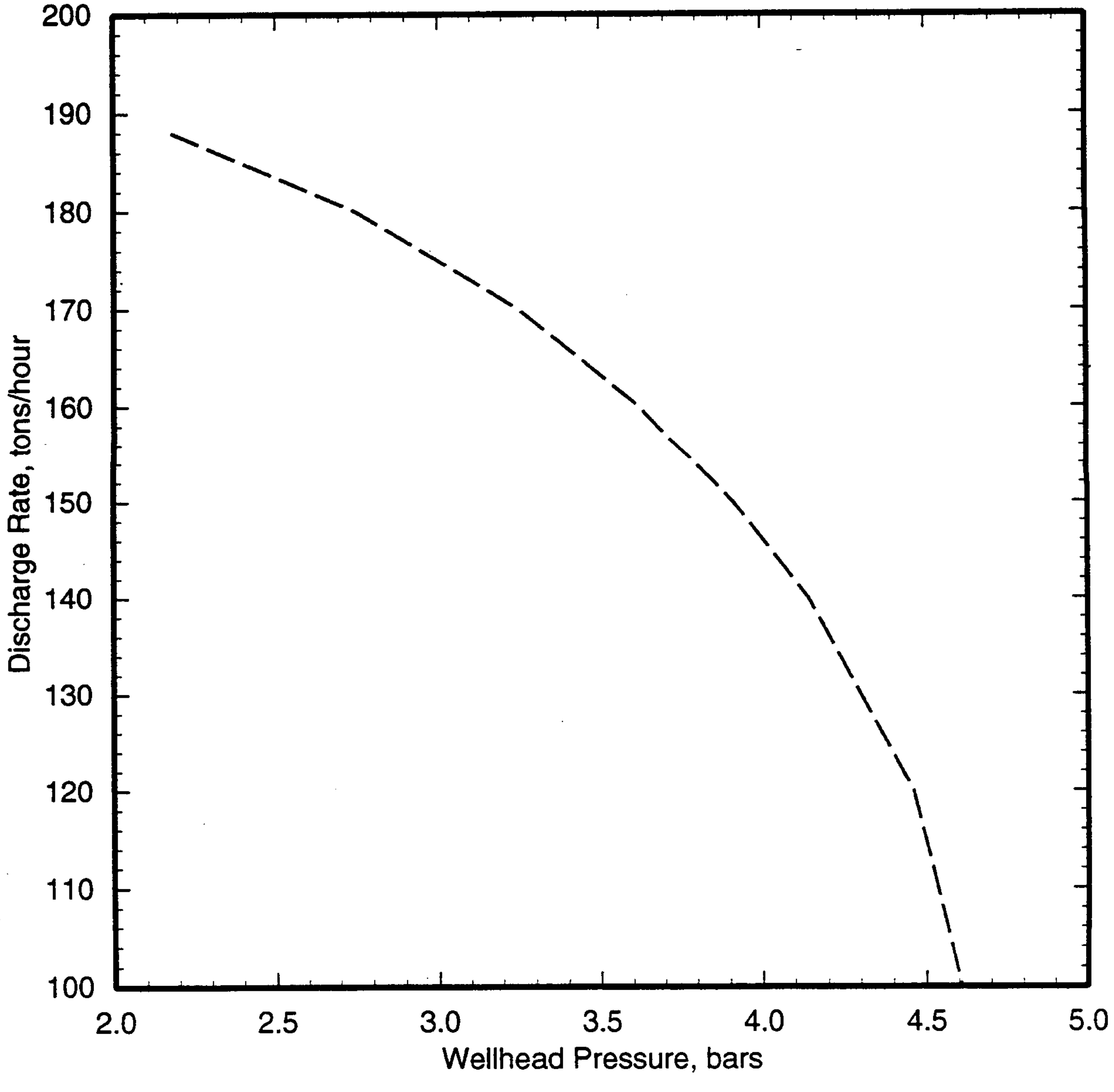

Figure 5.35. Computed discharge characteristics for the hypothetical "Oguni/Sumikawa type" well using model parameters for slim hole NE-5(i2).

The above well geometry is incapable of transmitting the reported discharge rates for the February 1985 test. Based on numerical experiments, the well geometry for NE-6(i1) was modified as follows:

Measured Depth (meters)	Vertical Depth (meters)	Angle with Vertical (degrees)	Internal Diameter (cm)
0.0–684.0	0.0–684.0	0.00	12.6
684.0–700.0	684.0–700.0	0.00	10.0

The effective diameter of the upper section must be at least 12.6 cm to accommodate the reported discharge rates.

The stable formation temperature was approximated by the following temperature distribution using linear interpolations between tabulated data:

Vertical Depth (meters)	Temperature (Celsius)
0	15
700	192

The characteristic test data and downhole pressure/temperature profiles taken during the February 1985 discharge test were simulated using the following model parameters:

Effective Thermal Conductivity, $K = 4$ W/m-°C
Roughness Factor, $\varepsilon = 0.00$ mm

The computed characteristic curve is compared with the measurements in Figure 5.36; considering the large scatter in measured pressure data, the agreement is satisfactory. Comparison between the computed and measured temperatures/pressures is shown in Figures 5.37 and 5.38, respectively. The agreement between measurements and calculated curves is good.

The model parameters (K, ε) for slim hole NE-6(i1) were employed to compute the discharge characteristics for the following hypothetical "Oguni/Sumikawa type" well:

Measured Depth (meters)	Vertical Depth (meters)	Angle with Vertical (degrees)	Internal Diameter (cm)
0.0–684.0	0.0–684.0	0.00	22.44
684.0–700.0	684.0–700.0	0.00	21.59

The computed discharge characteristics for the hypothetical well are plotted in Figure 5.39. The maximum computed discharge rate (~118 tons/hour) is about ~60 percent of the scaled maximum discharge rate (~187 tons/hour) given in Table 5.2. The difference between the two discharge rates (118 tons/hour versus 187 tons/hour) is linked to (1) a small productivity index and (2) flow behind the casing. Both of these factors cause the predicted discharge rate for the large-diameter well to be smaller than the scaled maximum discharge rate.

Slim Hole NE-6(i2)

The major feedpoint for slim hole NE-6(i2) is located at 740 m TVD. The stable feedzone pressure is ~34.2 bars. During a short-term discharge test in March 1985, two pressure surveys were run in the borehole on March 14 and 15, 1985; the average flowing feedzone pressure was ~33.74 bars. Using the reported discharge rate of 25.3 tons/hour (= 7.03 kg/s), the productivity index is ~15 kg/s-bar (see also Section 4). The flowing feedzone temperature in March 1985 was ~187.5°C. The latter temperature is ~4.5°C lower than that reported for NE-6(i1).

The nominal well geometry for NE-6(i2) is as follows:

Measured Depth (meters)	Vertical Depth (meters)	Angle with Vertical (degrees)	Internal Diameter (cm)
0.0–684.0	0.0–684.0	0.00	10.4
684.0–740.0	684.0–740.0	0.00	10.0

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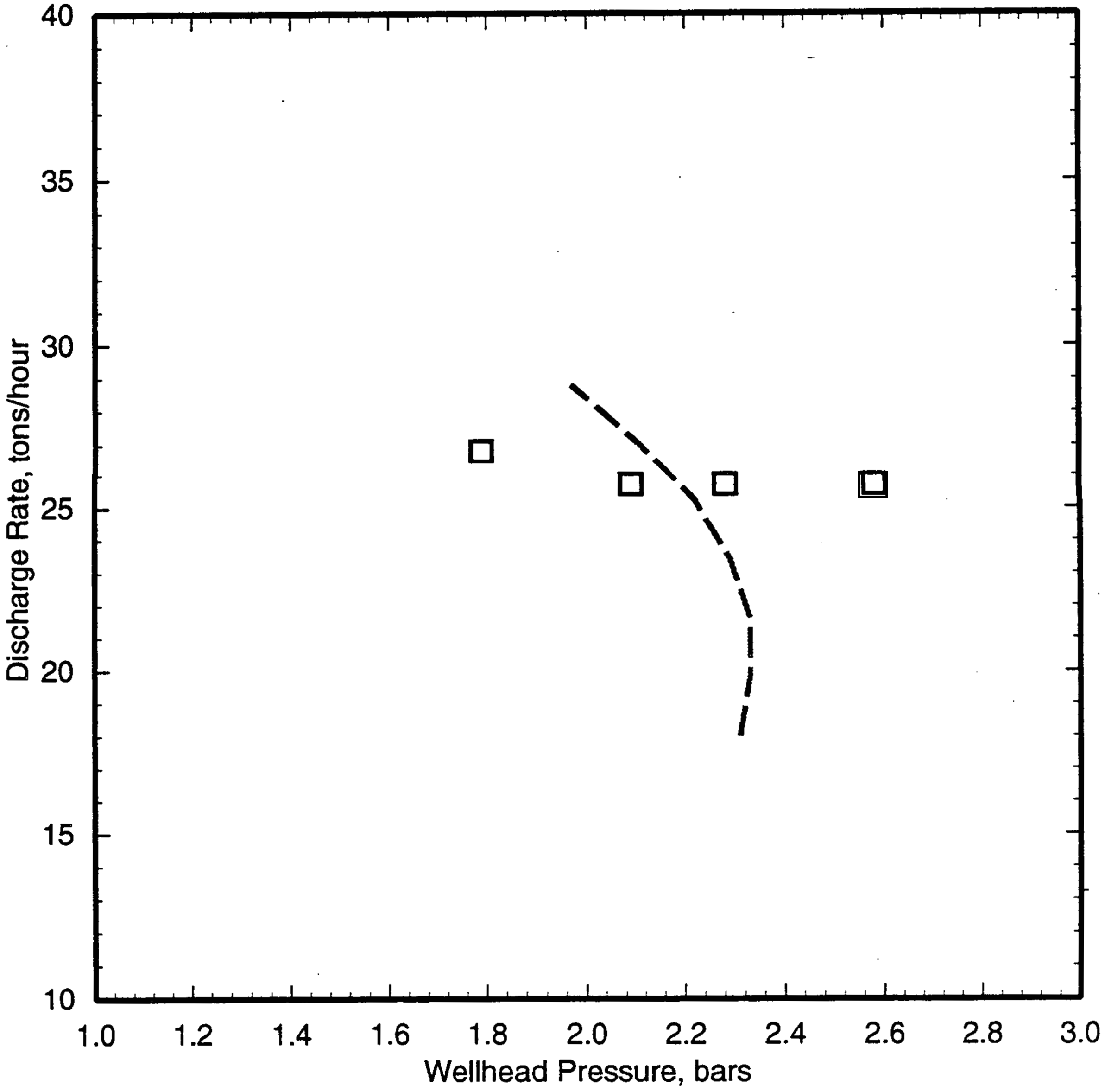

Figure 5.36. Discharge rate versus wellhead pressure for slim hole NE-6(i1) (February 14–15, 1985). The dashed line is the computed characteristic curve.

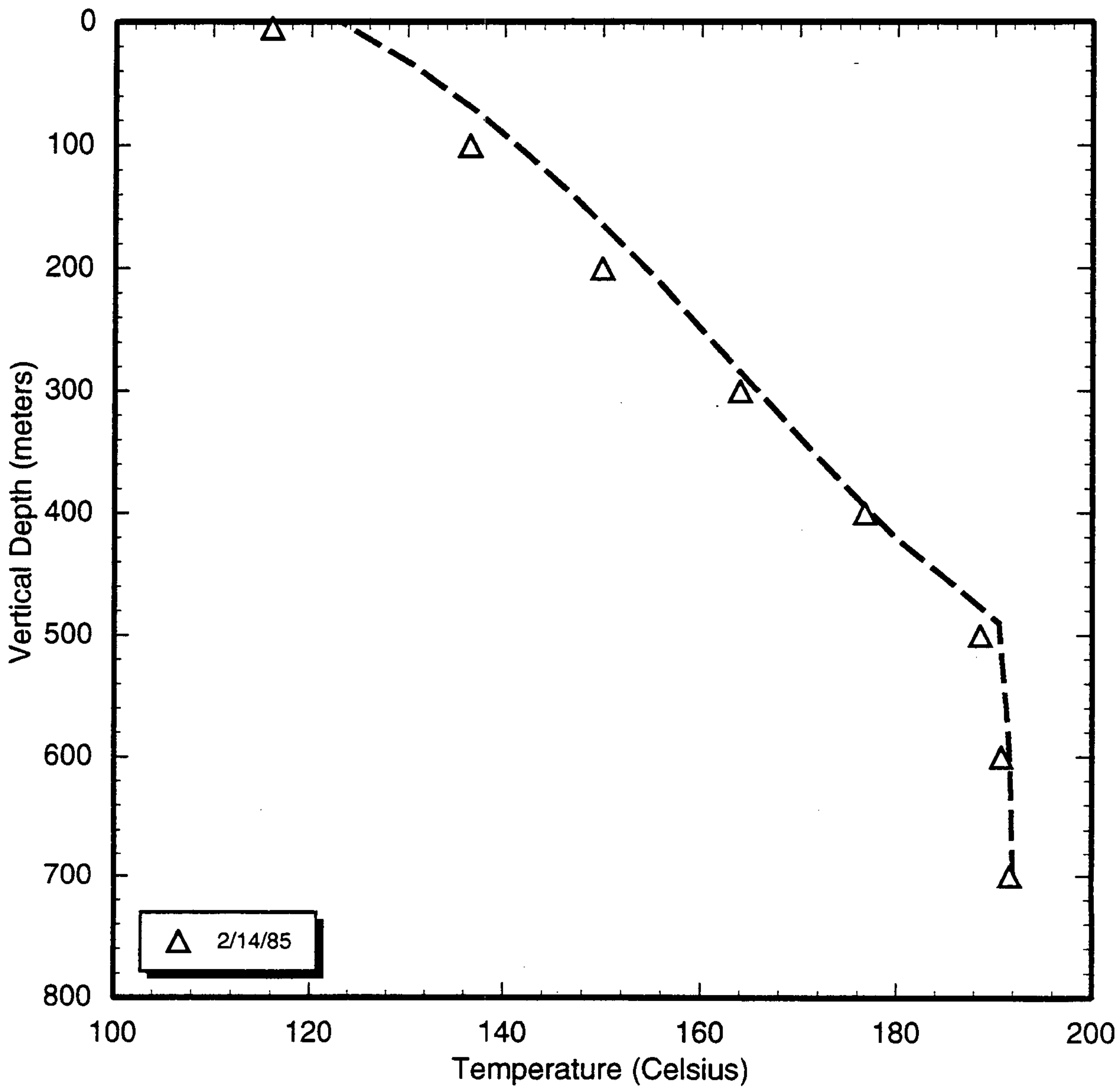

Figure 5.37. Temperature profile recorded in discharging NE-6(i1) on February 14, 1985. The dashed line is the computed temperature profile.

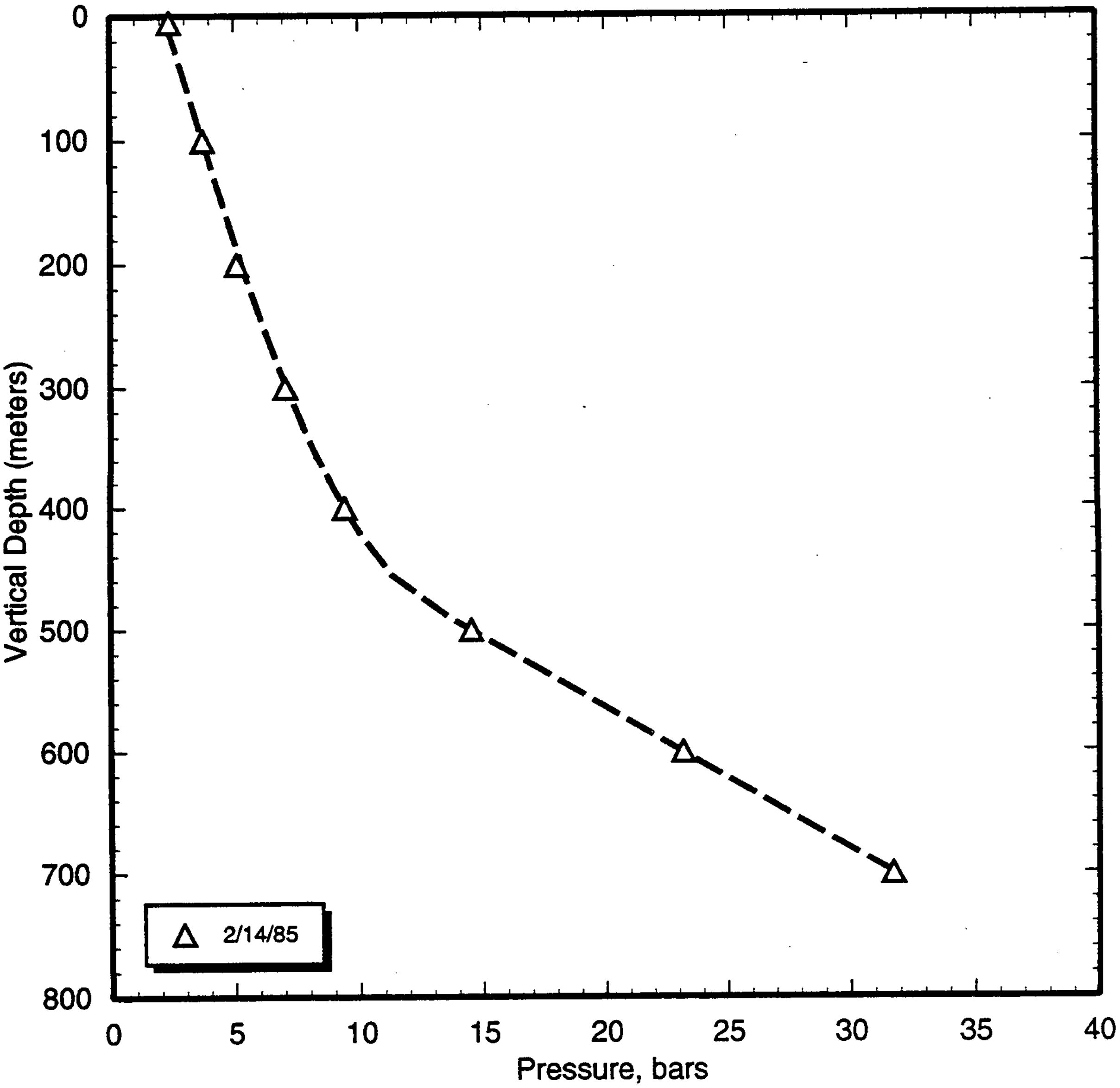

Figure 5.38. Pressure profile recorded in discharging NE-6(i1) on February 14, 1985. The dashed line is the computed pressure profile.

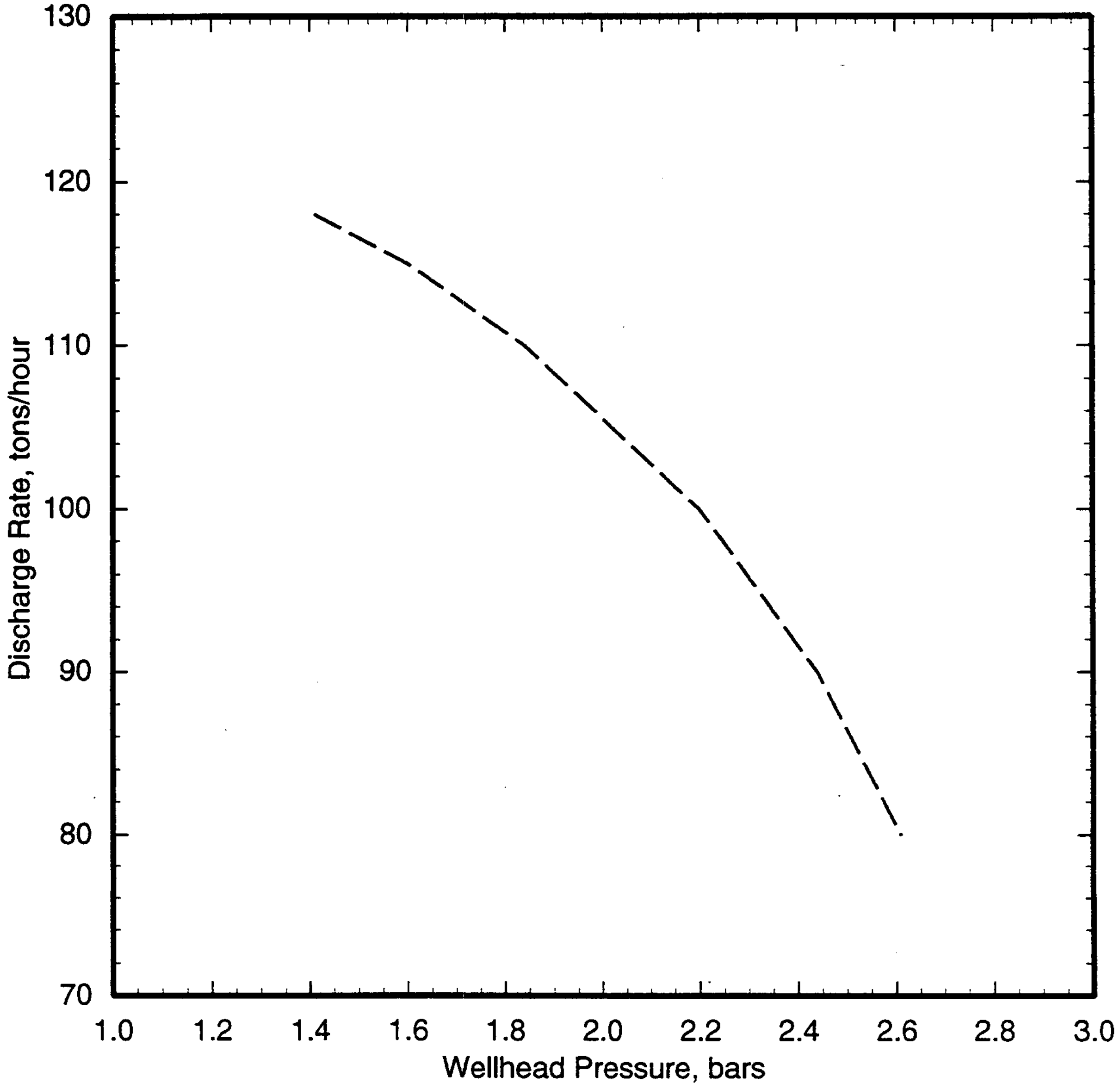

Figure 5.39. Computed discharge characteristics for the hypothetical "Oguni/Sumikawa type" well using model parameters for slim hole NE-6(i1).

The above well geometry for NE-6(i2) is incapable of transmitting the reported discharge rate (~7.03 kg/s) for NE-6(i2). Part of the discharge is apparently diverted behind the casing. Based on numerical experimentation, the well geometry was modified as follows:

Measured Depth (meters)	Vertical Depth (meters)	Angle with Vertical (degrees)	Internal Diameter (cm)
0.0–684.0	0.0–684.0	0.00	12.6
684.0–740.0	684.0–740.0	0.00	10.0

The diameter for the upper section must be increased to at least 12.6 cm (same as that for NE-6(i1)) to accommodate the reported discharge rate.

The stable formation temperature was approximated by the following temperature distribution using linear interpolations between tabulated data:

Vertical Depth (meters)	Temperature (Celsius)
0	15
740	187.5

The characteristic test data and downhole pressure/temperature profiles taken during the March 1985 test were simulated using the following model parameters:

Effective Thermal Conductivity, $K = 4$ W/m-°C
Roughness Factor, $\varepsilon = 0.00$ mm

The computed characteristic curve is compared with the single measurement in Figure 5.40. The measured wellhead pressure (Figure 5.40) is significantly greater than the computed value. There appears to be something wrong with the measured wellhead pressure value. Downhole temperature/pressure profiles display good agreement with the computed values (Figures 5.41 and 5.42). At shallow depths (200 to 400 meters), the computed pressures are somewhat greater than the measured values (Figure 5.42). Based on results shown in Figure 5.42, it is reasonable to expect that the measured wellhead pressure should be smaller than the computed pressure (and not the other way around).

The model parameters (K, ε) for slim hole NE-6(i2) were used to compute the discharge characteristics for the following hypothetical "Oguni/Sumikawa type" well:

Measured Depth (meters)	Vertical Depth (meters)	Angle with Vertical (degrees)	Internal Diameter (cm)
0.0–684.0	0.0–684.0	0.00	22.44
684.0–740.0	684.0–740.0	0.00	21.59

The computed discharge characteristics for the hypothetical well are shown in Figure 5.43. The maximum computed discharge rate (~116 tons/hour) is about 65 percent of the scaled maximum discharge rate (~180 tons/hour) given in Table 5.2.

Slim Hole NE-11

The major feedpoint for slim hole NE-11 is located at 1340 m TVD. The stable feedzone pressure and productivity index are 90 bars and 0.73 kg/s-bar, respectively. A short-term discharge test was performed in September 1986. Based on a downhole temperature survey in the discharging well, the flowing feedzone temperature is estimated to be ~197°C.

The nominal well geometry for NE-11 is as follows:

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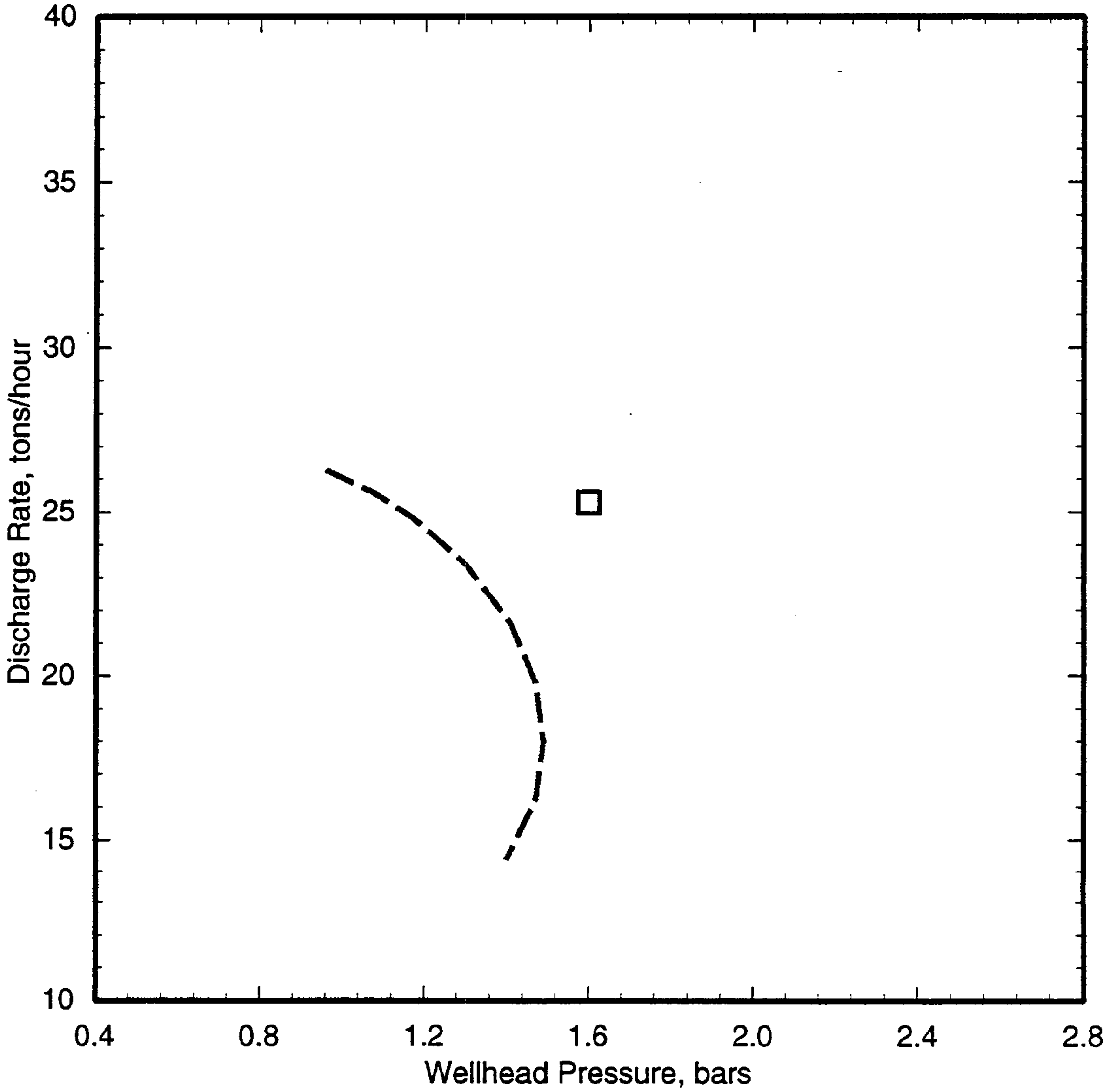

Figure 5.40. Discharge rate versus wellhead pressure for slim hole NE-6(i2) (March 14–17, 1985). The dashed line is the computed characteristic curve.

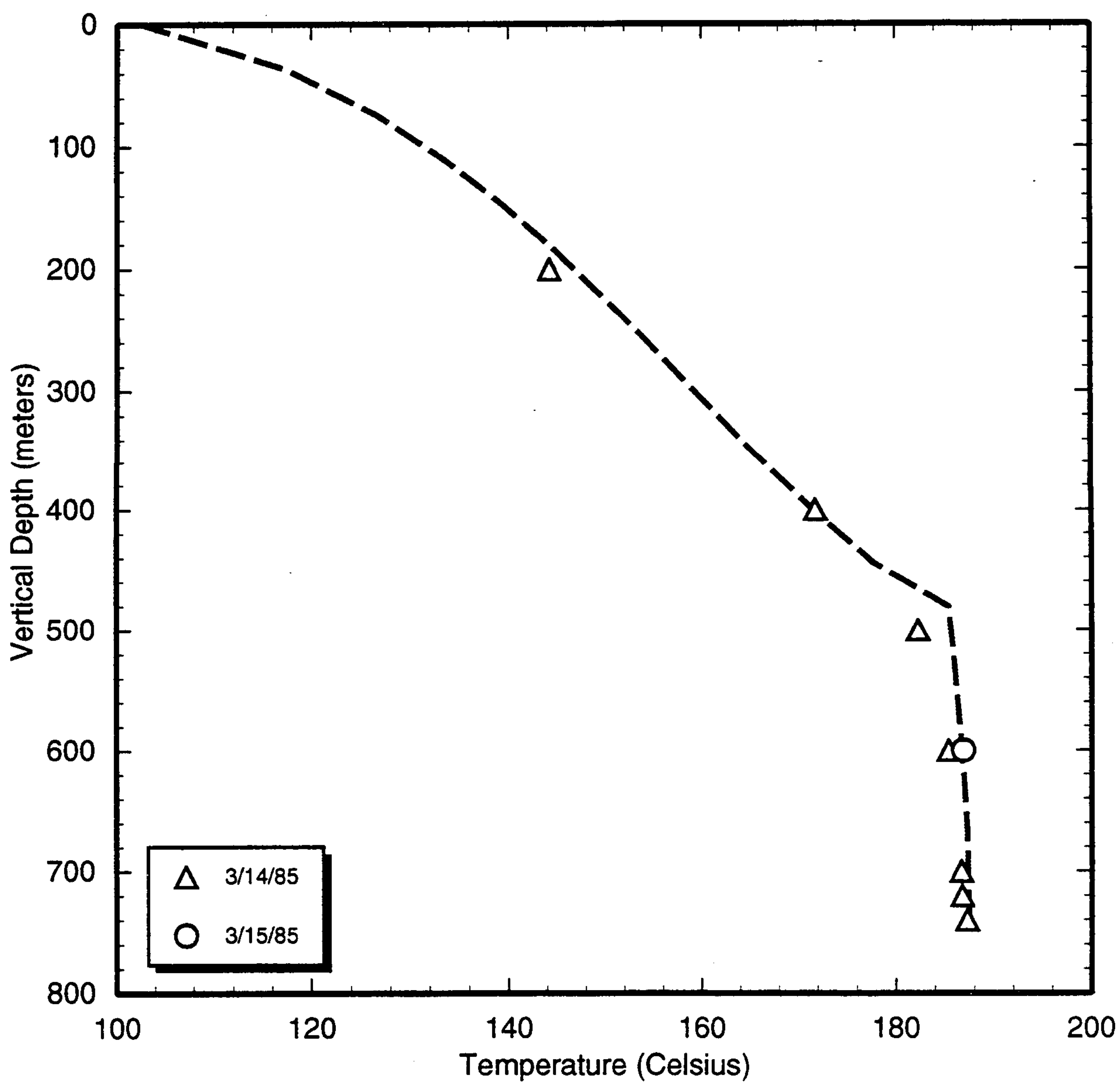

Figure 5.41. Temperature profiles recorded in discharging NE-6(i2) on March 14 and 15, 1985. The dashed line is the computed temperature profile.

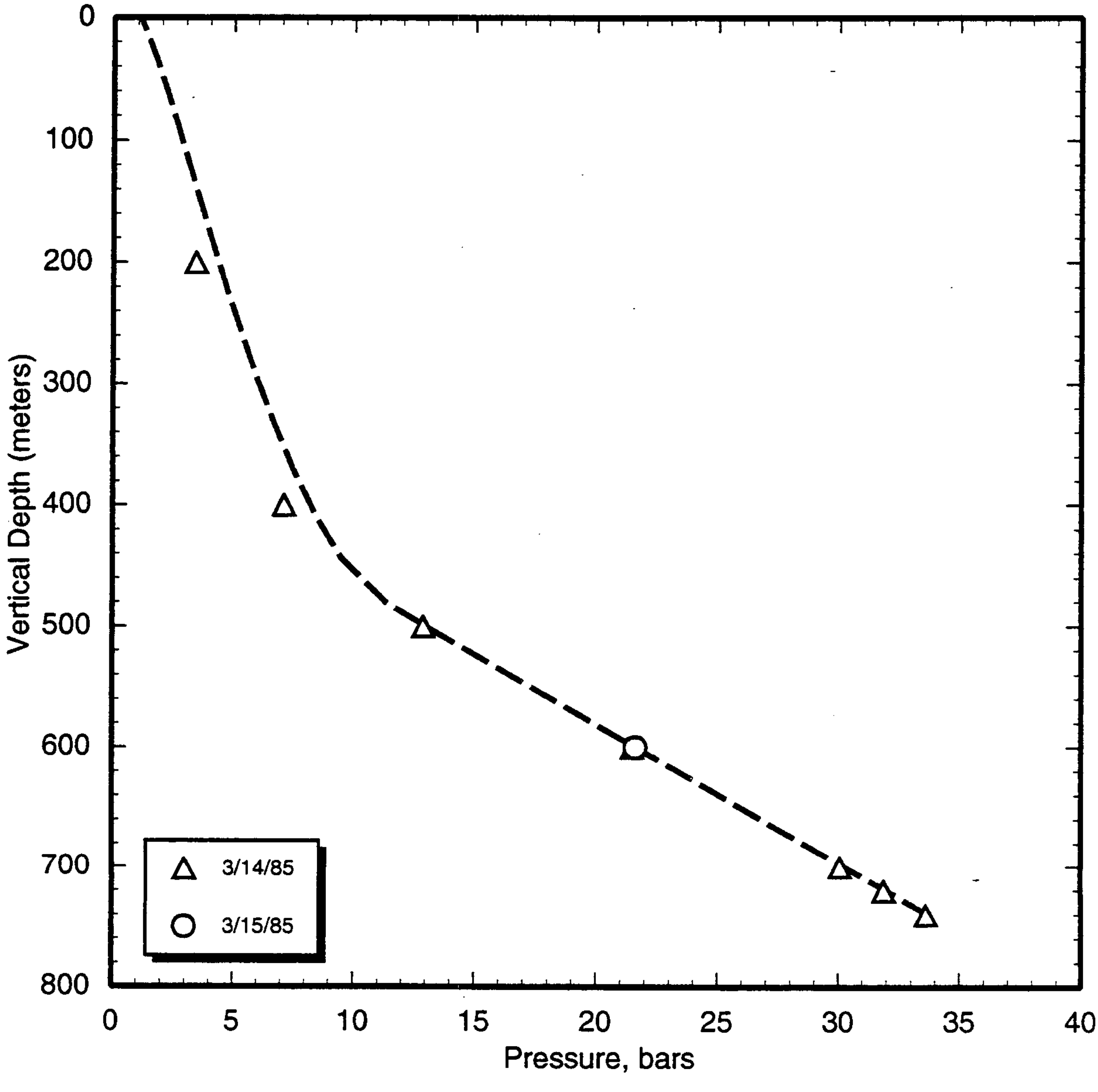

Figure 5.42. Pressure profiles recorded in discharging NE-6(i2) on March 14 and 15, 1985. The dashed line is the computed pressure profile.

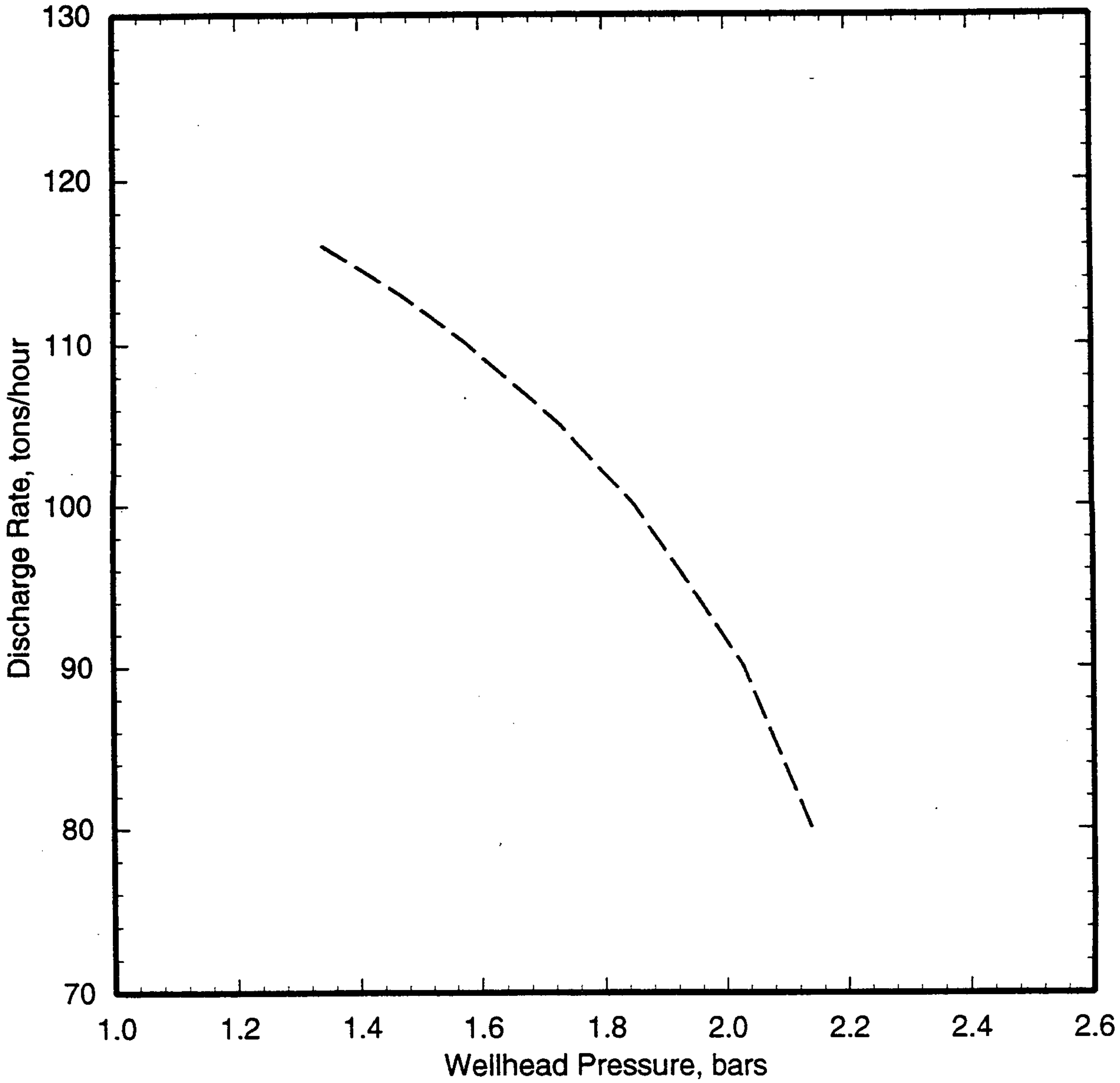

Figure 5.43. Computed discharge characteristics for the hypothetical "Oguni/Sumikawa type" well using model parameters for slim hole NE-6(i2).

Measured Depth (meters)	Vertical Depth (meters)	Angle with Vertical (degrees)	Internal Diameter (cm)
0.0–825.7	0.0–798.7	14.69	10.4
825.7–901.8	798.7–868.2	24.04	16.2
901.8–1404.5	868.2–1340.0	20.19	10.0

The above well geometry for NE-11 cannot transmit the reported discharge rates for NE-11. The effective diameter for the uppermost section must be increased to accommodate the measured discharge rates. Based on numerical experimentation, the well geometry was modified as follows:

Measured Depth (meters)	Vertical Depth (meters)	Angle with Vertical (degrees)	Internal Diameter (cm)
0.0–825.7	0.0–798.7	14.69	12.0
825.7–901.8	798.7–868.2	24.04	16.2
901.8–1404.5	868.2–1340.0	20.19	10.0

The stable formation temperature was approximated by the following temperature distribution using linear temperature interpolations between tabulated data:

Vertical Depth (meters)	Temperature (Celsius)
0	20
1240	215
1340	197

The characteristic test data and downhole pressure/temperature profiles taken during the September 1986 discharge test were simulated using the following model parameters:

Effective Thermal Conductivity, $K = 1$ W/m-°C
Roughness Factor, $\varepsilon = 0.025$ mm

The computed characteristic curve and downhole profiles are compared with the measurements in Figures 5.44 to 5.46; and the agreement is excellent.

The model parameters (K, ε) for slim hole NE-11 were used to compute the discharge characteristics for the following hypothetical "Oguni/Sumikawa type" well:

Measured Depth (meters)	Vertical Depth (meters)	Angle with Vertical (degrees)	Internal Diameter (cm)
0.0–825.7	0.0–798.7	14.69	22.44
825.7–901.8	798.7–868.2	24.04	22.44
901.8–1404.5	868.2–1340.0	20.19	21.59

The computed discharge characteristics for the hypothetical well are shown in Figure 5.47. The maximum computed discharge rate (~60 tons/hour) is only ~40 percent of the scaled maximum discharge rate (~144 tons/hour) given in Table 5.2. The large difference between the two discharge rates (60 tons/hour and 144 tons/hour) is due to the relatively small productivity index (0.73 kg/s-bar) for NE-11.

Slim Hole NE-11R

The principal feedpoint for slim hole NE-11R is located at 1850 m TVD. The stable feedzone pressure and productivity index are 135.2 bars and 3.8 kg/s-bar. During the discharge test performed in early 1987 (January 30, 1987–February 18, 1987), the flowing feedzone temperature was ~183.5°C. There are, however, indications (see Section 3) that the stable feedzone temperature may be somewhat higher (~187°C). In the following, a feedzone temperature of 183.5°C is used for matching the test data for NE-11R. Discharge characteristics for the hypothetical "Oguni/Sumikawa type" well are,

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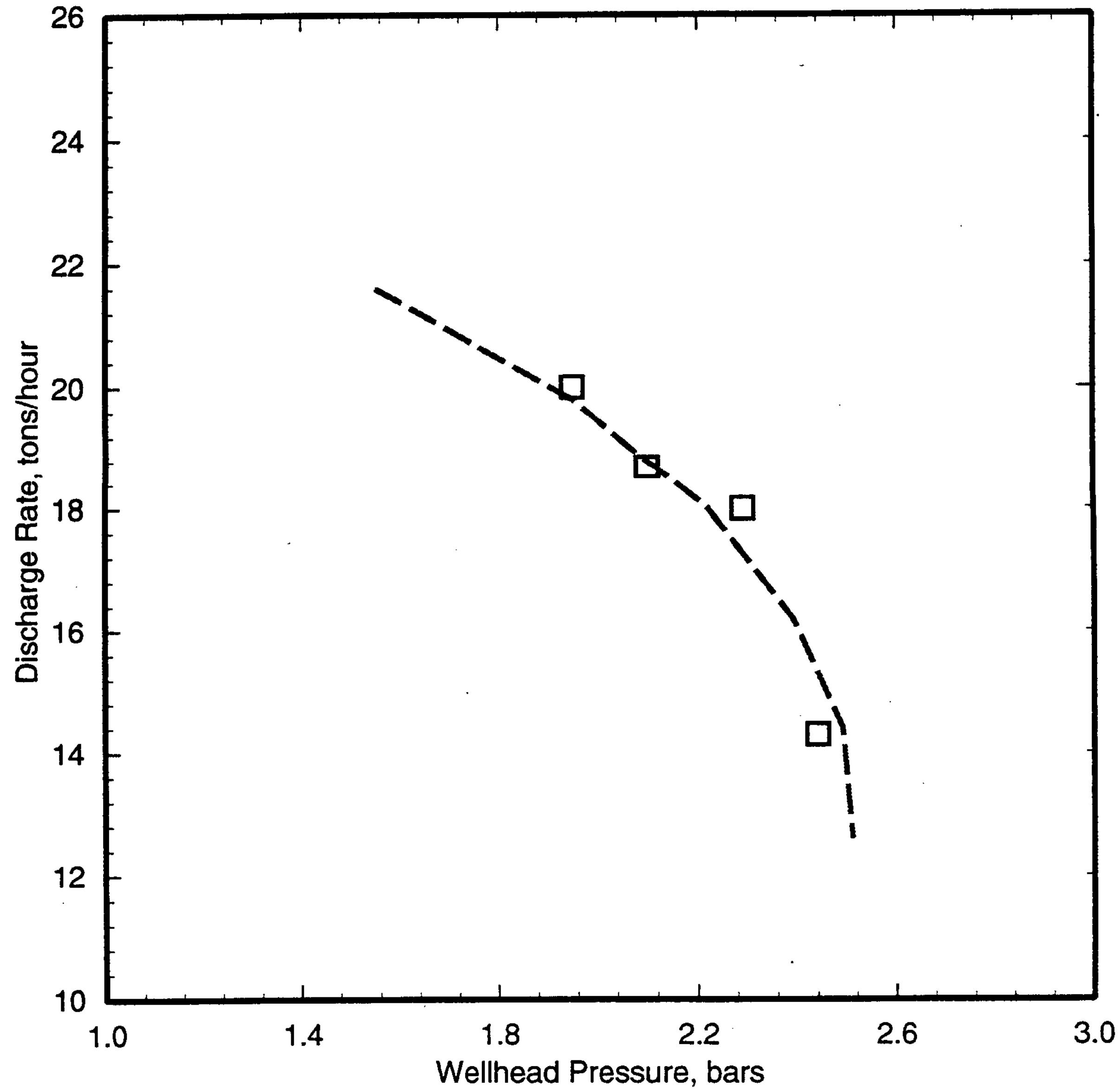

Figure 5.44. Discharge rate versus wellhead pressure for slim hole NE-11 (September 12–19, 1986). The dashed line is the computed characteristic curve.

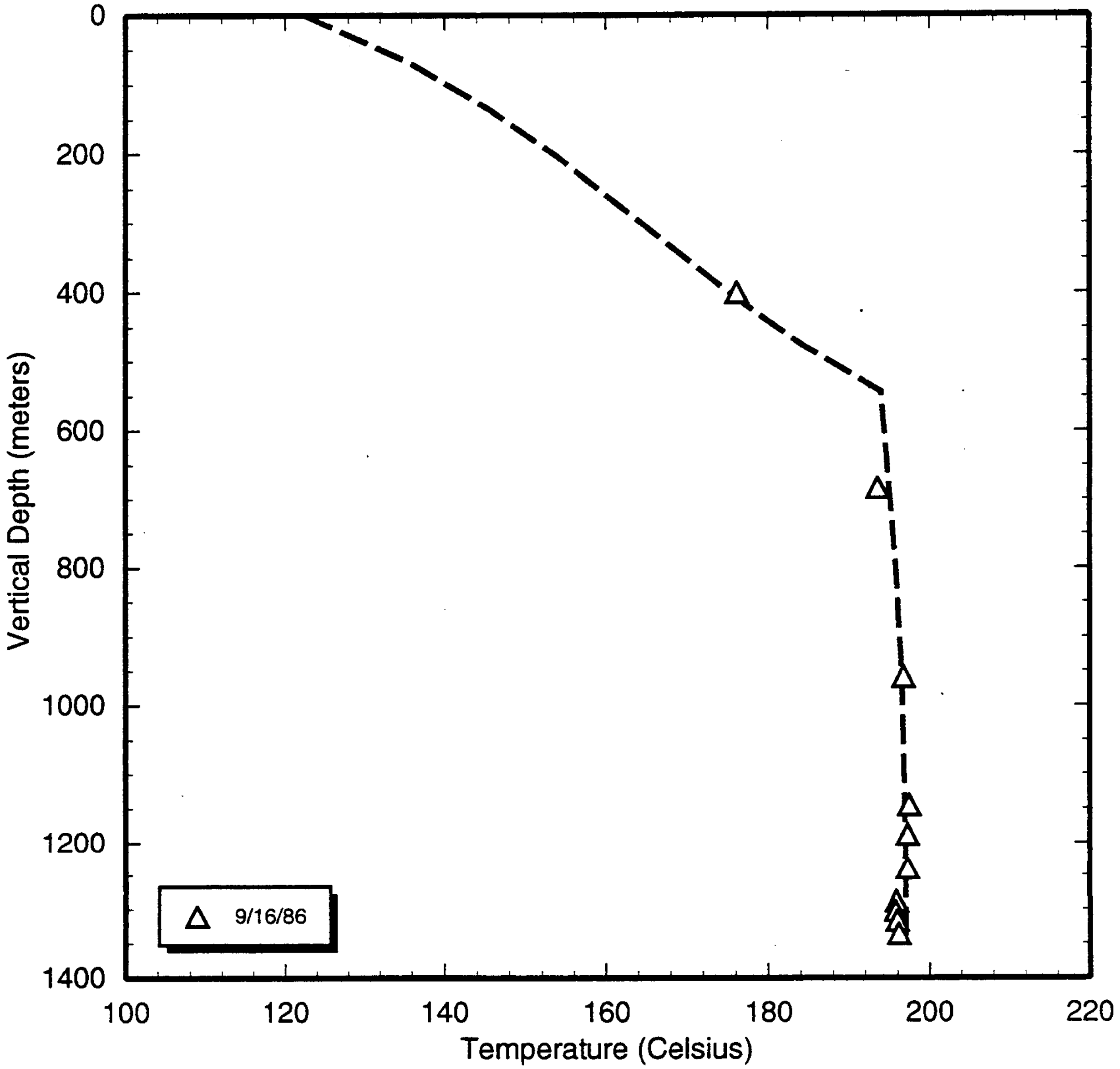

Figure 5.45. Temperature profile recorded in discharging NE-11 on September 16, 1986. The dashed line is the computed temperature profile.

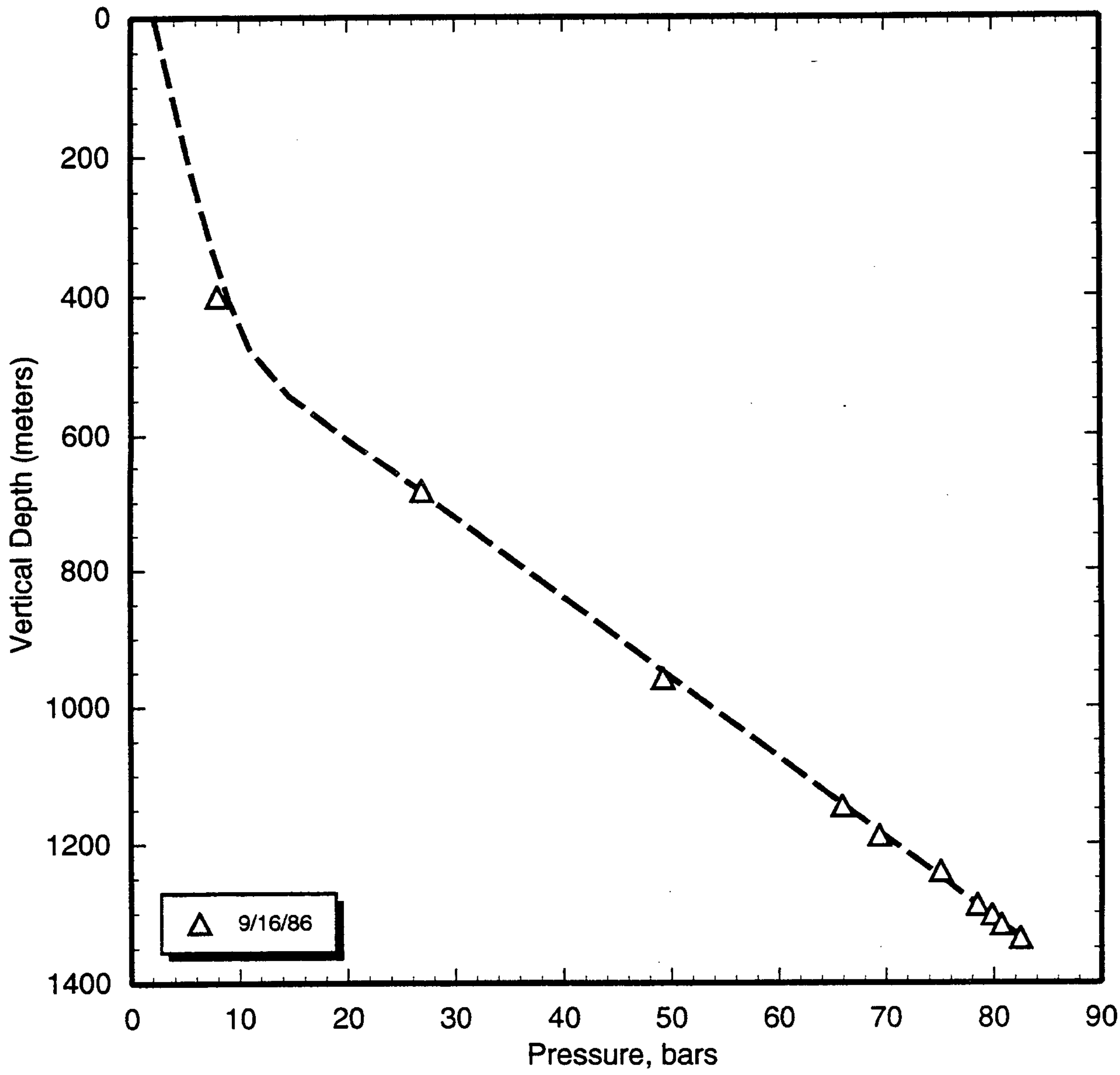

Figure 5.46. Pressure profile recorded in discharging NE-11 on September 16, 1986. The dashed line is the computed pressure profile.

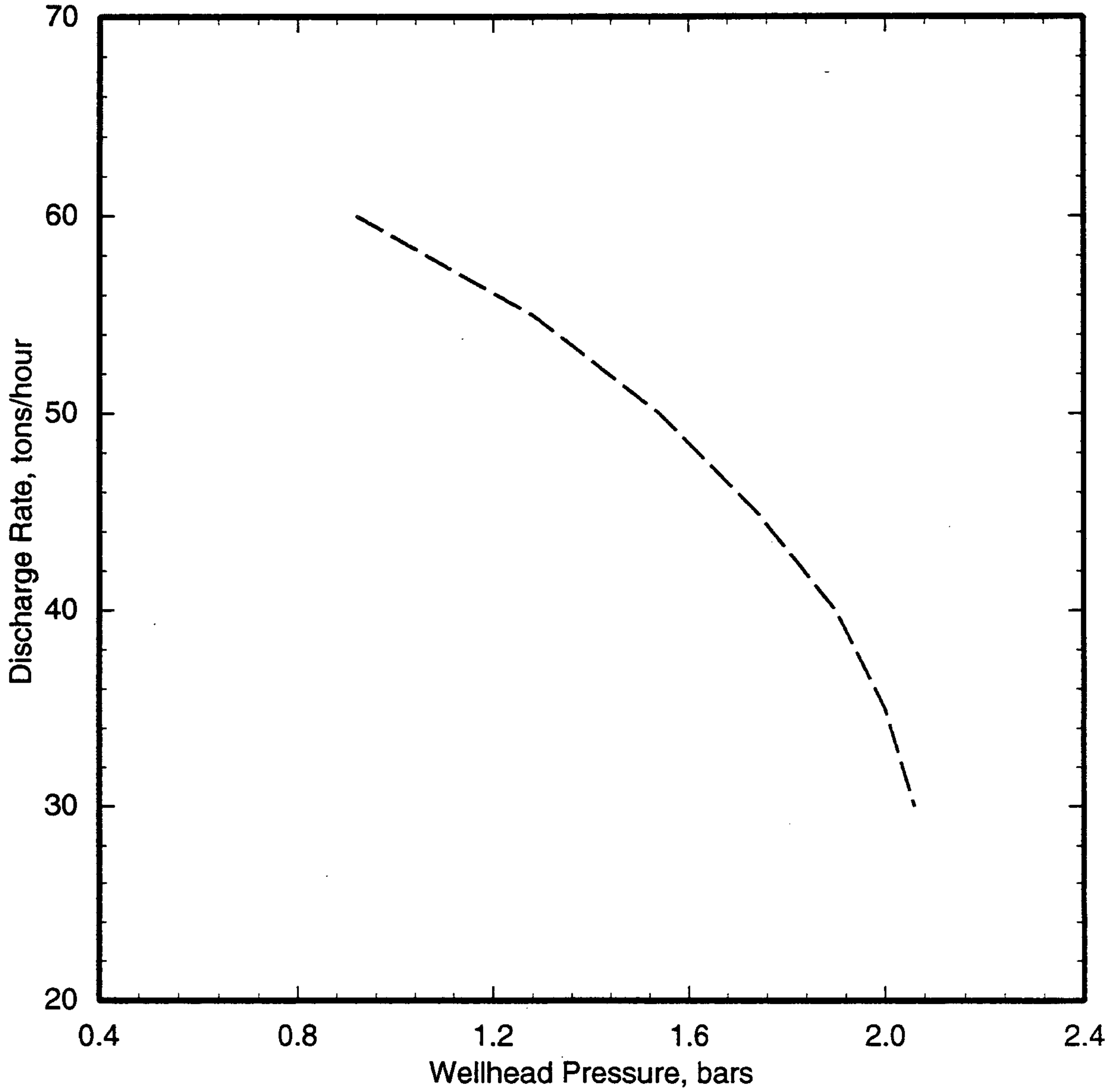

Figure 5.47. Computed discharge characteristics for the hypothetical "Oguni/Sumikawa type" well using model parameters for slim hole NE-11.

however, computed with a flowing feedzone temperature of 187°C.

The well geometry for NE-11R is as follows:

Measured Depth (meters)	Vertical Depth (meters)	Angle with Vertical (degrees)	Internal Diameter (cm)
0.0–1430.0	0.0–1357.1	18.37	10.4
1430.0–1958.3	1357.1–1850.0	21.09	10.0

The stable formation temperature was approximated by the following temperature distribution using linear temperature interpolations between tabulated data:

Vertical Depth (meters)	Temperature (Celsius)
0	20
1240	215
1420	187
1850	187

The characteristic discharge test data and downhole pressure/temperature profiles taken during the 1987 discharge test of NE-11R were simulated using the following model parameters:

Effective Thermal Conductivity, $K = 1$ W/m-°C
Roughness Factor, $\varepsilon = 0.00$ mm

The computed characteristic curve and downhole profiles are compared with the measurements in Figures 5.48 to 5.50. The downhole pressure measurements display excellent agreement with computed results. The temperature data at shallow depths lie somewhat below the computed curve. In the two-phase region prevailing at shallow depths, pressure and temperature are not independent; for pure water (assumed in WELBOR computations reported herein), pressure is a unique function of temperature. The disagreement between the computed and measured temperatures is most likely due to either the measurement errors or the presence of noncondensable gases in the discharge.

The model parameters (K, ε) for slim hole NE-11R were used to compute the discharge characteristics for the following hypothetical "Oguni/Sumikawa type" well:

Measured Depth (meters)	Vertical Depth (meters)	Angle with Vertical (degrees)	Internal Diameter (cm)
0.0–1430.0	0.0–1357.1	18.37	22.44
1430.0–1958.3	1357.1–1850.0	21.09	21.59

The computed discharge characteristics for the hypothetical well are shown in Figure 5.51. The maximum computed discharge rate (~103 tons/hour) is about 20 percent higher than the scaled maximum discharge rate given in Table 5.2.

Production Well TT-2

The principal feedzone for production well TT-2 is located at 1580 m TVD. The stable feedzone pressure and productivity index are ~122.5 bars and ~11 kg/s-bar, respectively. Characteristic test data are available from four different discharge tests (January 27, 1984; January 28, 1984; May 29–June 6, 1984; and November 1991–February 1992) of well TT-2. Discharge tests of January 27, 1984 and January 28, 1984 were performed with the drill pipe in the hole; these data will not be considered here. During the short-term discharge test (May 29–June 6, 1984), a pressure/temperature survey was run in the discharging well on June 3, 1984; the feedzone temperature was ~199°C. There are indications that the stable feedzone temperature is somewhat higher (~205°C).

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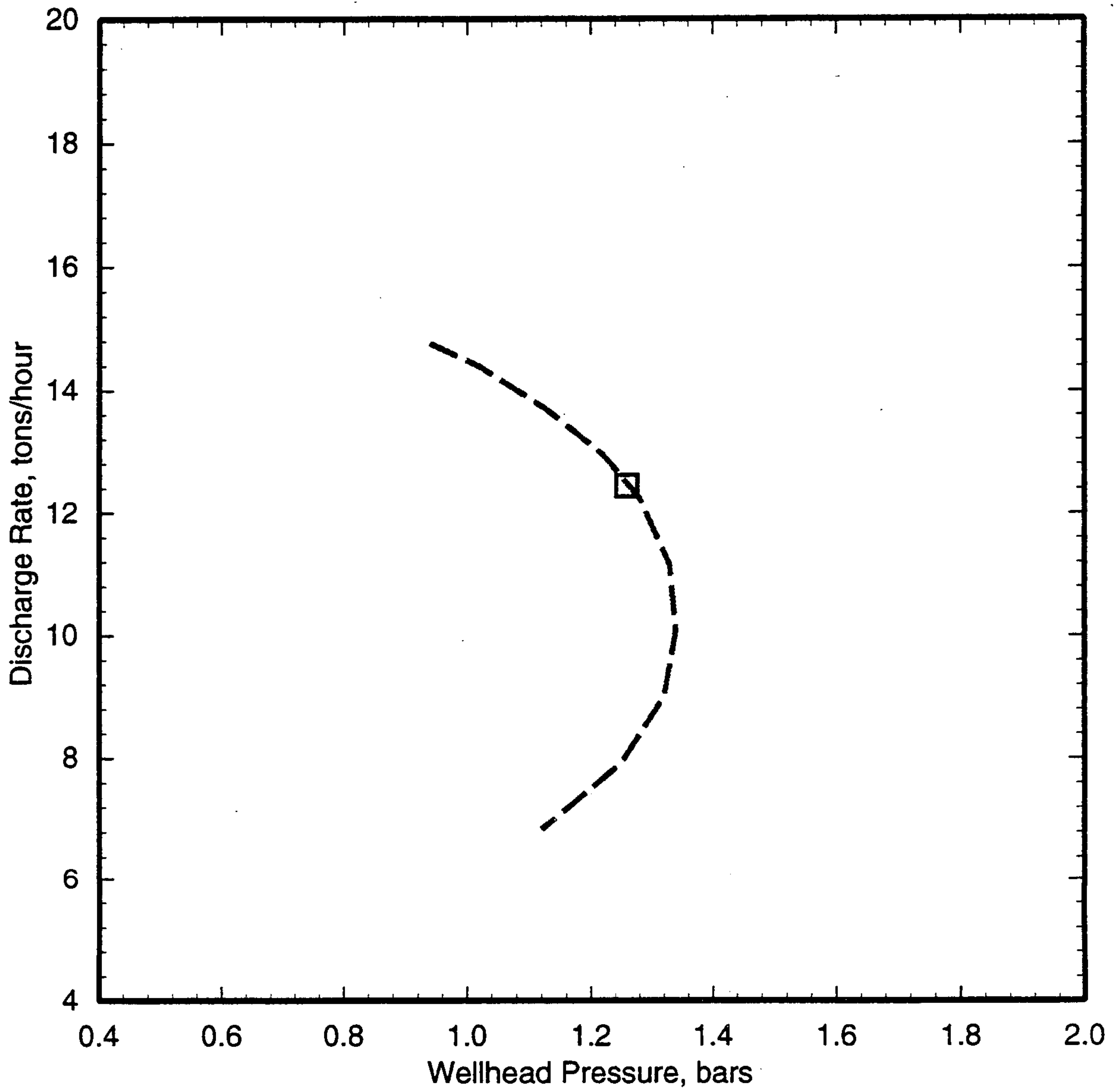

Figure 5.48. Discharge rate versus wellhead pressure for slim hole NE-11R (January 30, 1987–February 18, 1987). The dashed line is the computed characteristic curve.

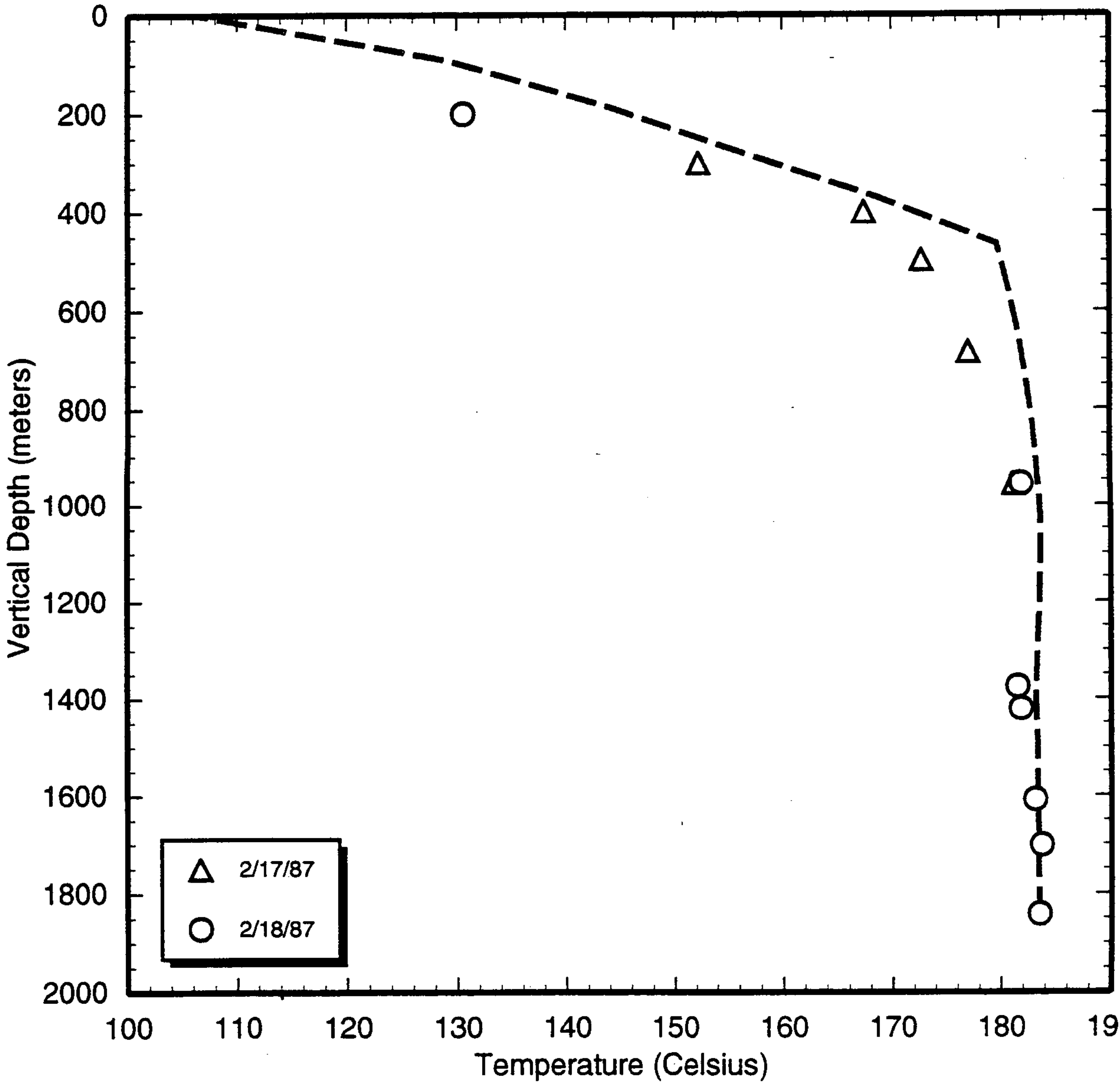

Figure 5.49. Temperature profiles recorded in discharging NE-11R on February 17 and February 18, 1987. The dashed line is the computed temperature profile.

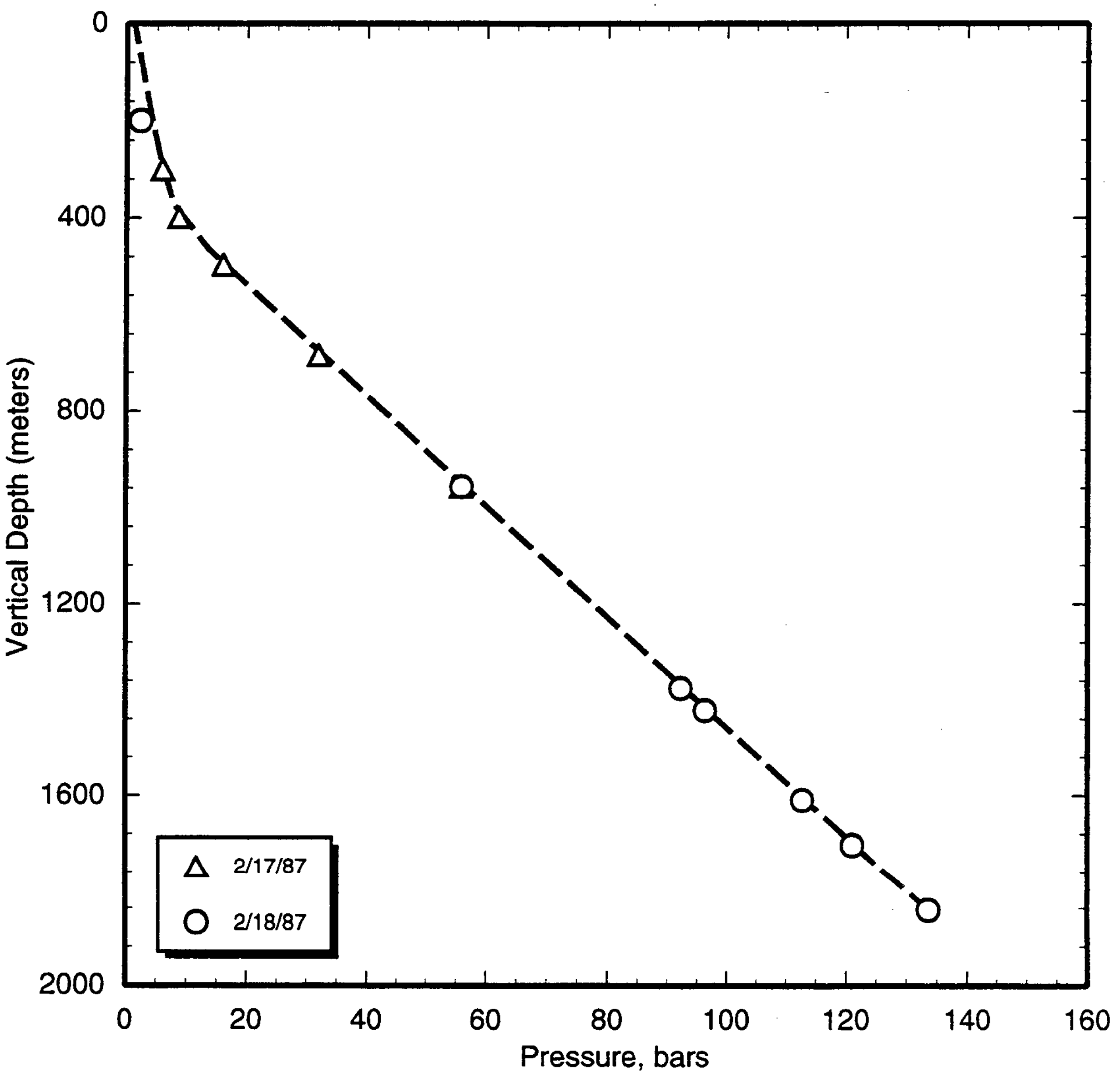

Figure 5.50. Pressure profiles recorded in discharging NE-11R on February 17 and February 18, 1987. The dashed line is the computed pressure profile.

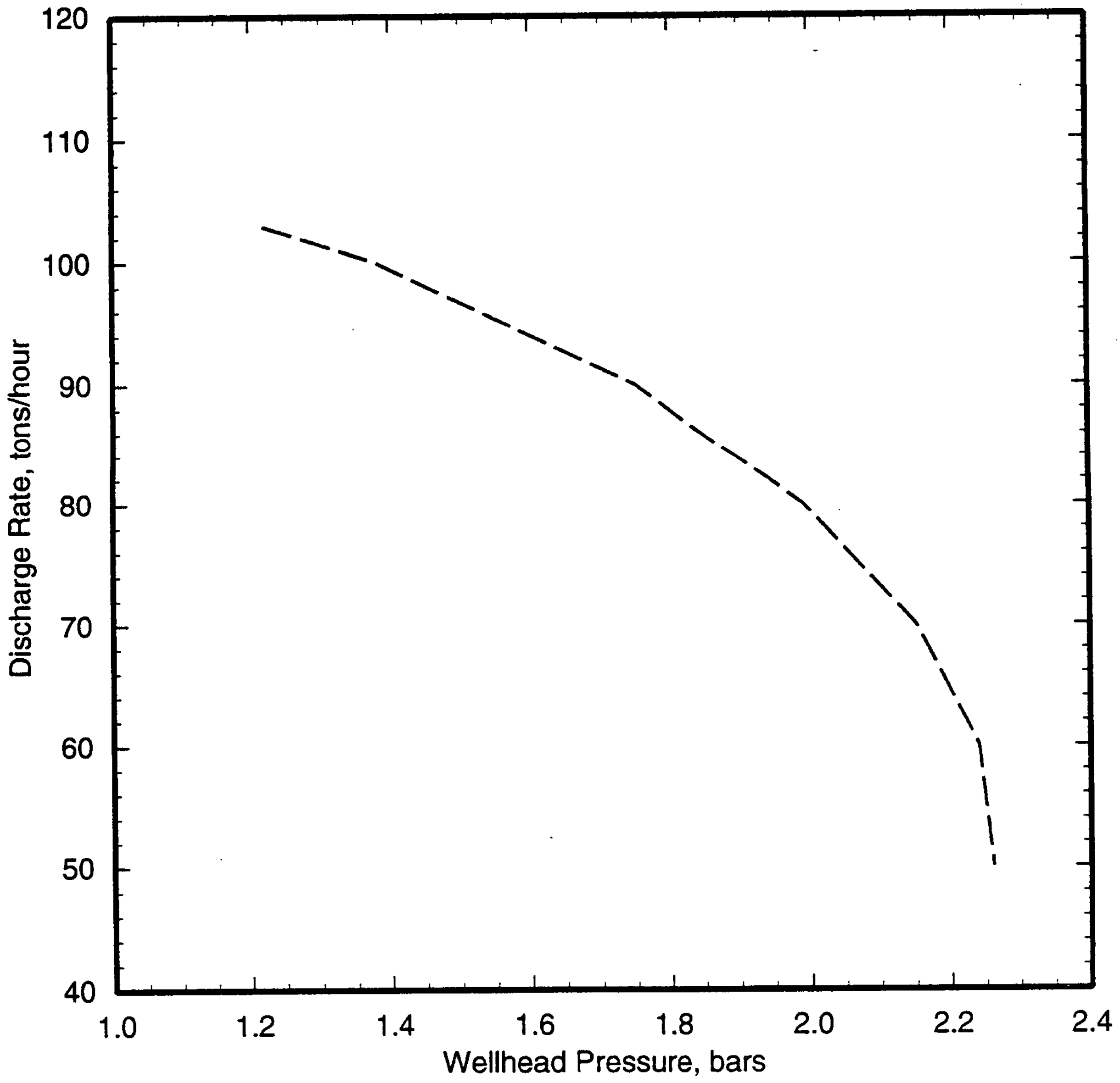

Figure 5.51. Computed discharge characteristics for the hypothetical "Oguni/Sumikawa type" well using model parameters for slim hole NE-11R.

The well geometry for TT-2 is as follows:

Measured Depth (meters)	Vertical Depth (meters)	Angle with Vertical (degrees)	Internal Diameter (cm)
0.0–795.3	0.0–795.0	1.57	31.79
795.3–1604.4	795.0–1553.3	20.41	22.44
1604.4–1635.0	1553.3–1580.0	29.24	21.59

The stable formation temperature was approximated by the following temperature distribution using linear interpolations between tabulated data:

Vertical Depth (meters)	Temperature (Celsius)
0	10
600	40
1000	150
1580	205

The characteristic test data and downhole pressure/temperature profiles recorded during the May–June 1984 short-term test were simulated using the following model parameters:

Flowing Feedzone Temperature, T_f = 199°C
Effective Thermal Conductivity, K = 16 W/m-°C
Friction Factor, ε = 1.6 mm

The characteristic data (Figure 5.52) and downhole pressure profile (Figure 5.54) are in good agreement with computed curves. The measured temperatures at shallow depths (depths < 800 m) generally lie above the calculated values (Figure 5.53). It is significant that the measured temperatures and pressures in the two-phase region (*i.e.*, above ~400 m) do not lie on the phase line for pure water. This implies that computed values cannot match both the measured pressures and temperatures. The effective thermal conductivity used (~16 W/m-°C) is rather high (Normal values of K usually lie in the range 4–10 W/m-°C.). The high value for K is symptomatic of enhanced heat loss at early production times.

With two exceptions (T_f and K), the characteristic data obtained during the long-term production test were simulated using the model parameters for the May–June 1984 test. Following values of T_f and K were employed for the long-term test data:

Effective Thermal Conductivity, K = 9 W/m-°C
Flowing Feedzone Temperature, T_f = 205°C

For the long-term test, the effective thermal conductivity is about one-half of that for the short-term discharge test. The characteristic data from the long-term test are compared with calculated characteristic curve in Figure 5.55. The calculated characteristic curve is in reasonably good agreement with the measurements.

Model parameters for the long-term test of TT-2 were used to calculate the discharge characteristics for the following hypothetical "Oguni/Sumikawa type" well:

Measured Depth (meters)	Vertical Depth (meters)	Angle with Vertical (degrees)	Internal Diameter (cm)
0.0–795.3	0.0–795.0	1.57	22.44
795.3–1604.4	795.0–1553.3	20.41	22.44
1604.4–1635.0	1553.3–1580.0	29.24	21.59

Other than the diameter for the uppermost section, the hypothetical well is assumed to have the same geometry as TT-2. The computed discharge characteristics for the hypothetical well are compared with those for well TT-2 in Figure 5.55. The maximum discharge rate for the hypothetical well (~135 tons/hour) is about one-half of that for well TT-2. Two-phase flow in TT-2 is restricted to the uppermost section (see Figures 5.53 and 5.54). A reduction in the diameter of the uppermost section causes two-phase flow to choke at much smaller discharge rates.

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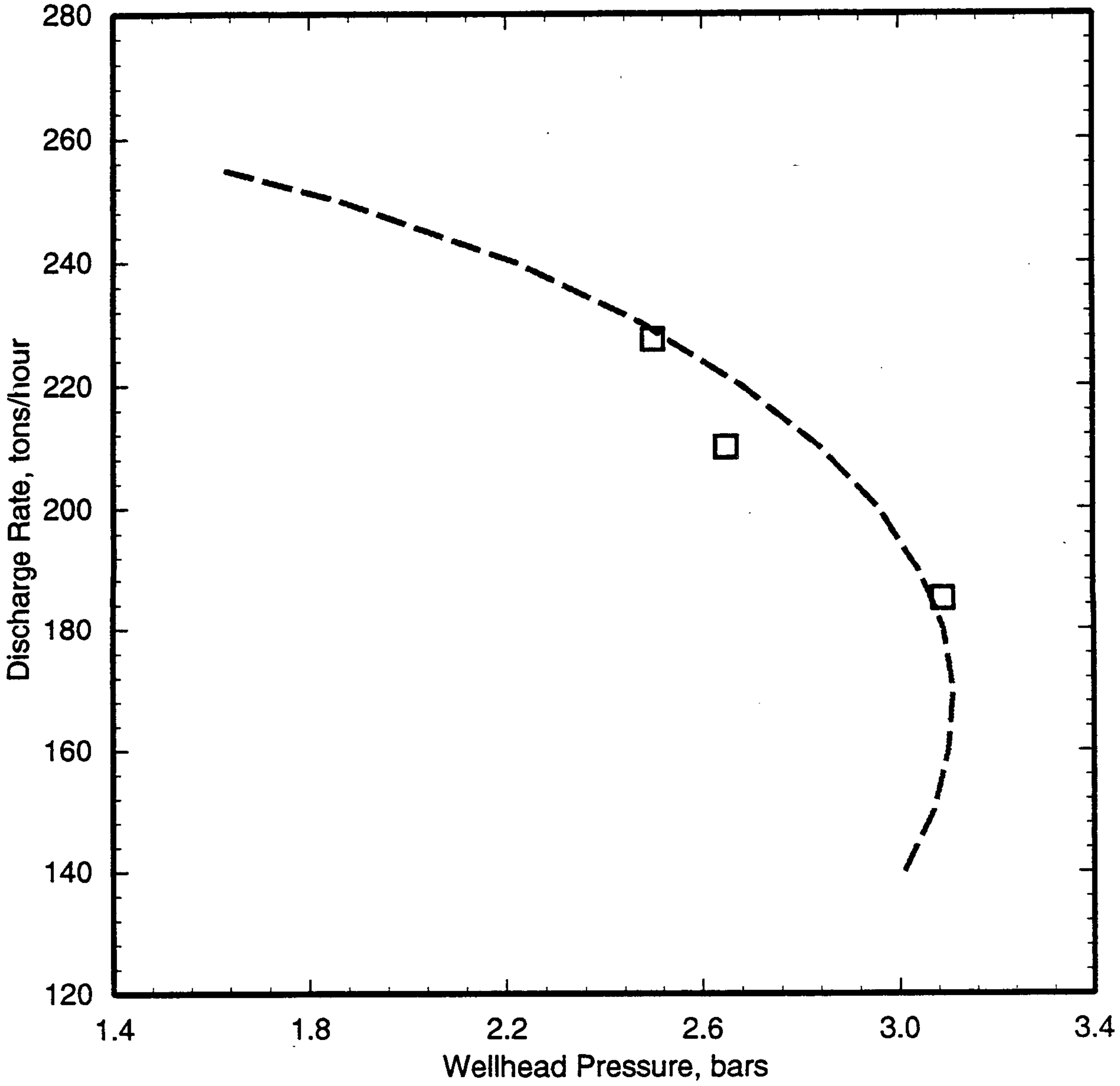

Figure 5.52. Discharge rate versus wellhead pressure for large-diameter production well TT-2 (May 30–June 1, 1984). The dashed line is the computed characteristic curve.

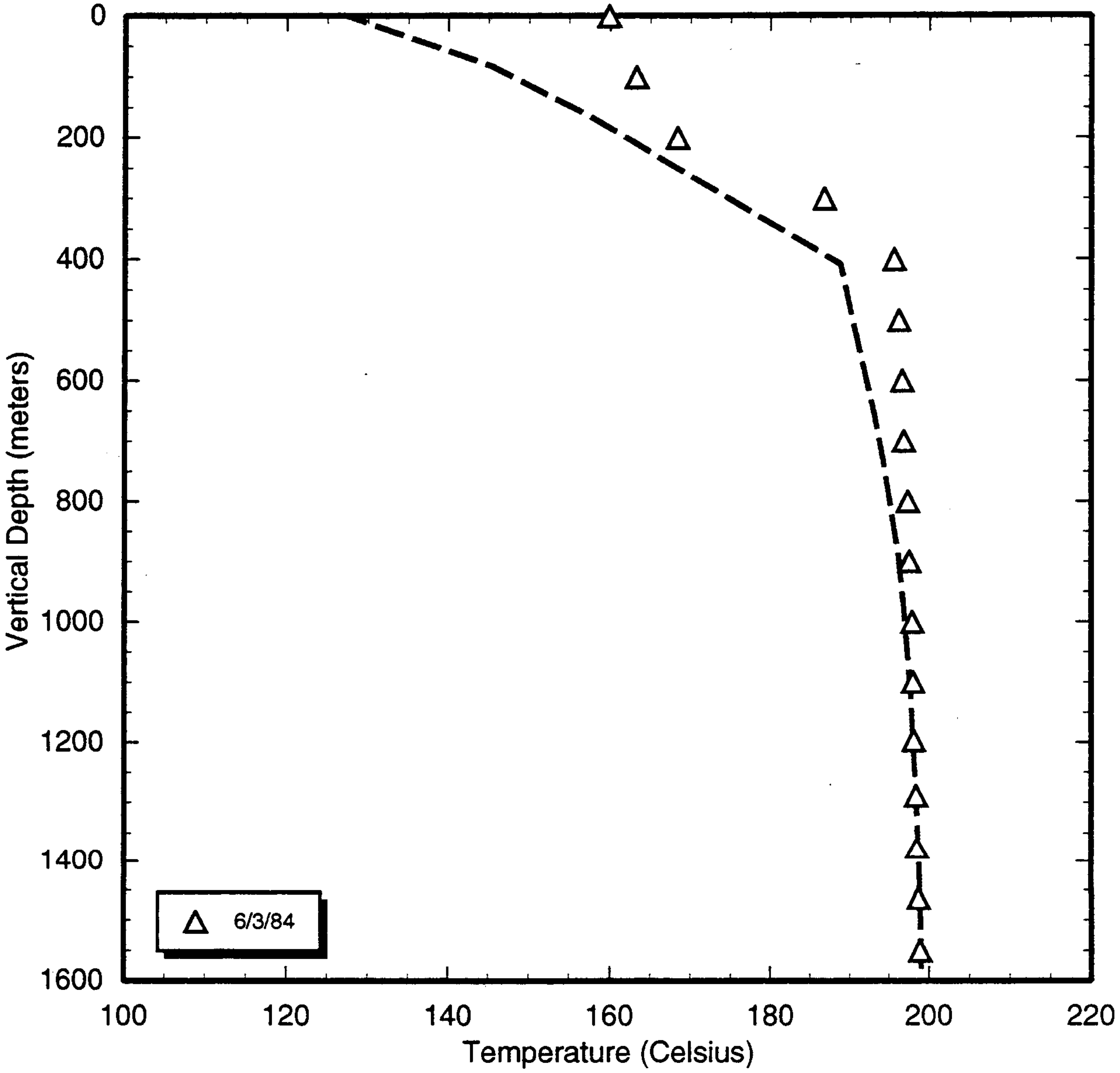

Figure 5.53. Temperature profile recorded in discharging TT-2 on June 3, 1984. The dashed line is the computed temperature profile.

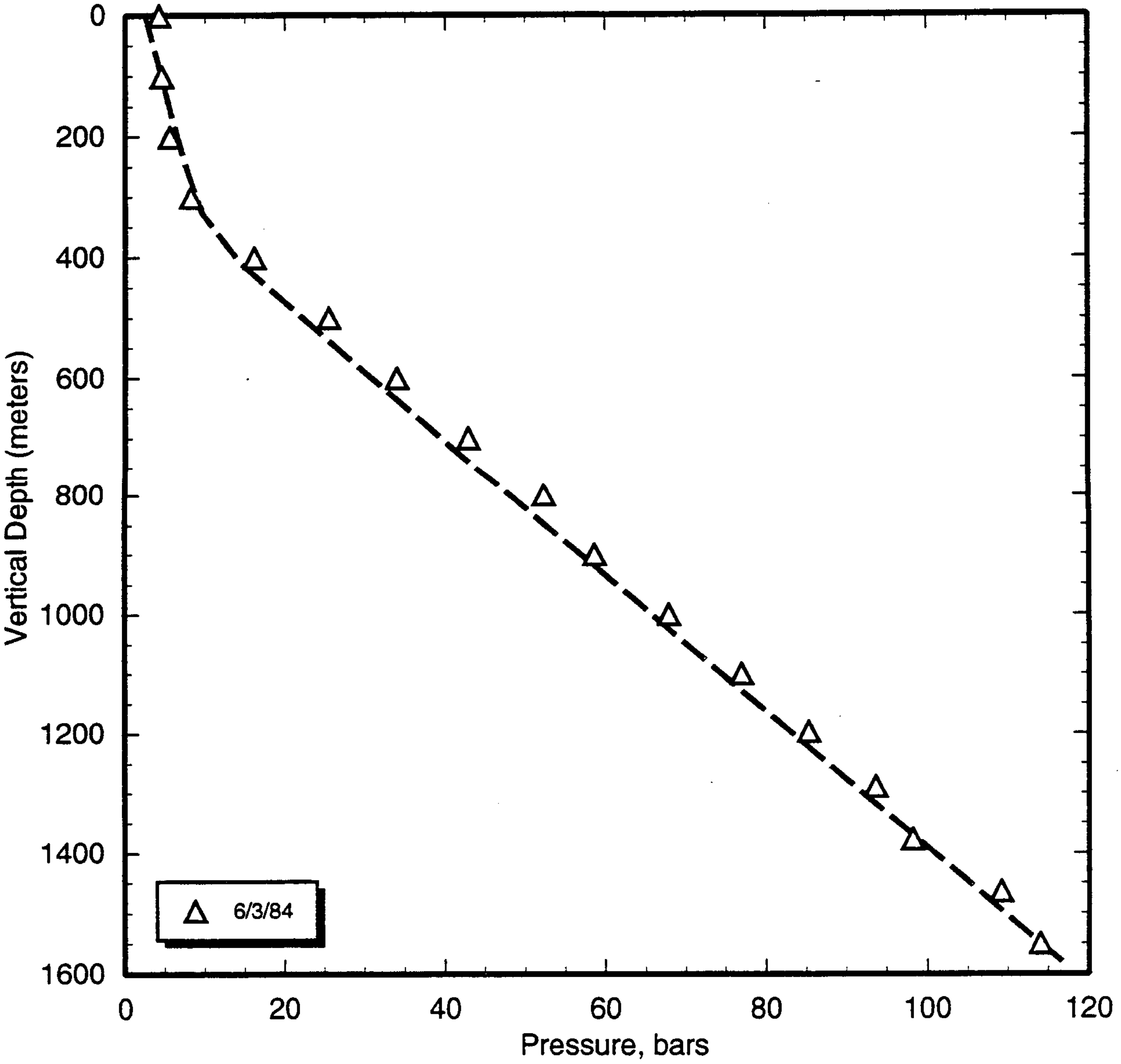

Figure 5.54. Pressure profile recorded in discharging TT-2 on June 3, 1984. The dashed line is the computed pressure profile.

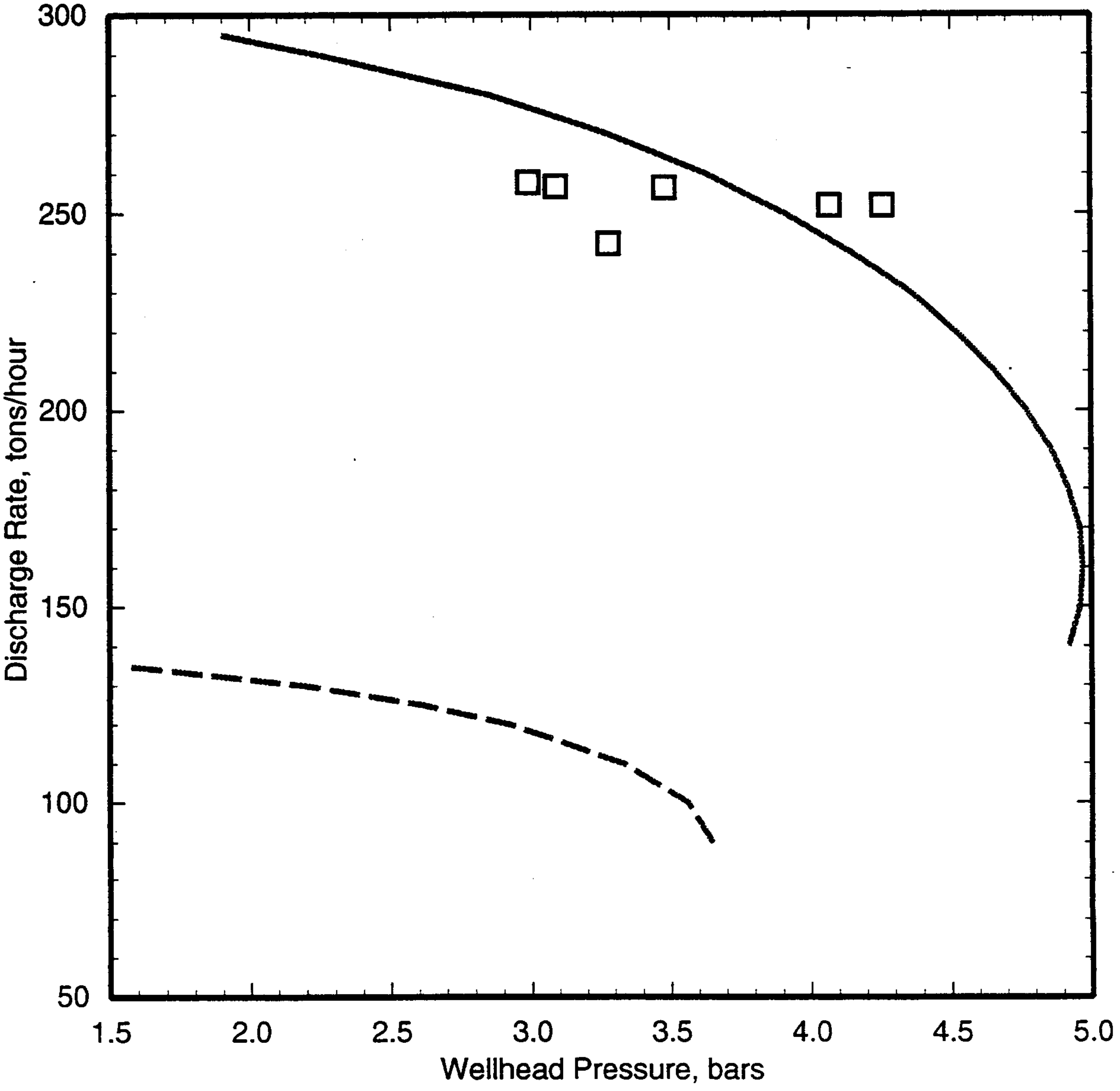

Figure 5.55. Discharge rate versus wellhead pressure for large-diameter production well TT-2 recorded during the long-term production test (November 1991–February 1992). The solid line represents the computed characteristic curve for TT-2. The dashed line is the computed characteristic curve for the hypothetical "Oguni/Sumikawa type" well (see text).

Production Well TT-7

The principal feedzone for production well TT-7 is located at 1070 m TVD. The stable feedzone pressure is ~64.5 bars. During the preliminary discharge test of TT-7 (August 29, 1986), a pressure/temperature survey was run to a depth of ~699 m TVD. Extrapolating the measured pressure profile, the flowing feedzone pressure is ~59.6 bars; with a discharge rate of 129 kg/s, the productivity index is computed as 26 kg/s-bar (see Section 4). Detailed numerical simulations with WELBOR (presented below) imply that the productivity index for TT-7 is ~30 kg/s-bar. Besides the preliminary discharge test of August 29, 1986, characteristic test data are also available from the 1991–1992 long-term discharge test. The feedzone temperature during the preliminary discharge test is estimated to be ~208°C; for the long-term test, the flowing feedzone temperature may be a little higher (~208.8°C).

The well geometry for TT-7 is as follows:

Measured Depth (meters)	Vertical Depth (meters)	Angle with Vertical (degrees)	Internal Diameter (cm)
0.0–752.4	0.0–751.0	3.49	38.13
752.4–942.5	751.0–949.4	7.47	22.44
952.5–1075.4	949.4–1070.0	11.10	21.59

The upper section of TT-7 has the largest diameter (ID = 38.13 cm) of all the Takigami production wells. The large-diameter of the upper section is directly responsible for TT-7 being the most prolific producer at Takigami.

The stable formation temperature (for the preliminary discharge test) was approximated by the following temperature distribution using linear interpolations between tabulated data:

Vertical Depth (meters)	Temperature (Celsius)
0	15
500	50
900	185
1070	208

For the long-term discharge test simulation, the temperature at 1070 m TVD was changed to 208.8°C.

The characteristic test data and downhole temperature/pressure surveys taken during the preliminary discharge test on August 29, 1986 were simulated using the following model parameters:

Productivity Index, $PI = 30$ kg/s-bar
Flowing Feedzone Temperature, $T_f = 208$°C
Effective Thermal Conductivity, $K = 25$ W/m-°C
Friction Factor, $\varepsilon = 0.29$ mm

The large value for K (25 W/m-°C) needed for matching characteristic data implies that heat losses were high during the preliminary flow test. Characteristic test data and downhole temperature/pressure surveys are compared with computed results in Figures 5.56 to 5.58; and the agreement is quite good.

The characteristic test data from the long-term discharge test of TT-7 were simulated using the following values for T_f and K:

Flowing Feedzone Temperature, $T_f = 208.8$°C
Effective Thermal Conductivity, $K = 4$ W/m-°C

All other parameters were assumed to be identical with those employed for the preliminary discharge test simulation. For the long-term test, the effective thermal conductivity (and hence the heat loss) is a small fraction of that for the preliminary discharge test. The conductive heat loss declines with

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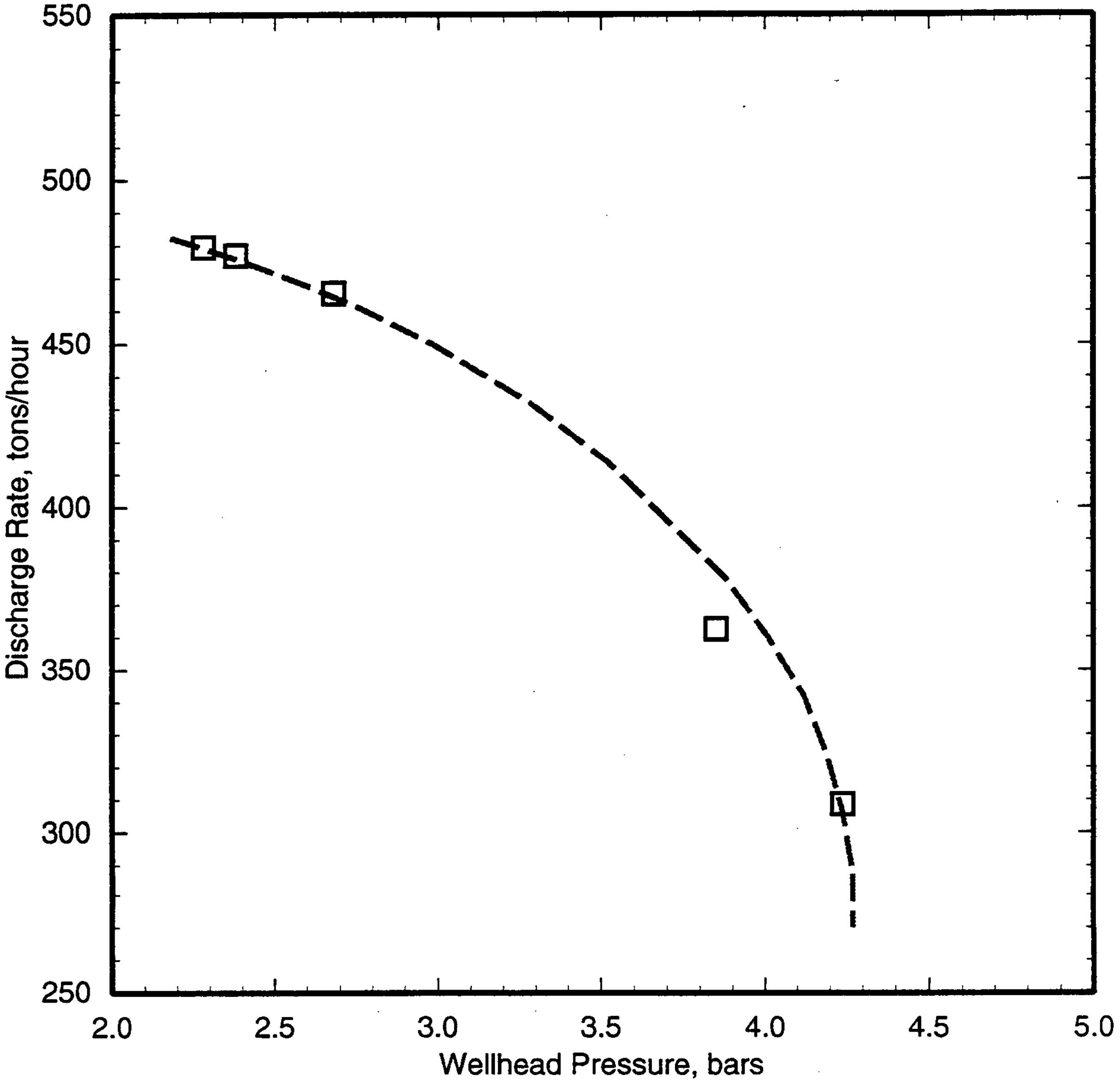

Figure 5.56. Discharge rate versus wellhead pressure for large-diameter production well TT-7 recorded during the preliminary flow test (August 29, 1986). The dashed line is the computed characteristic curve.

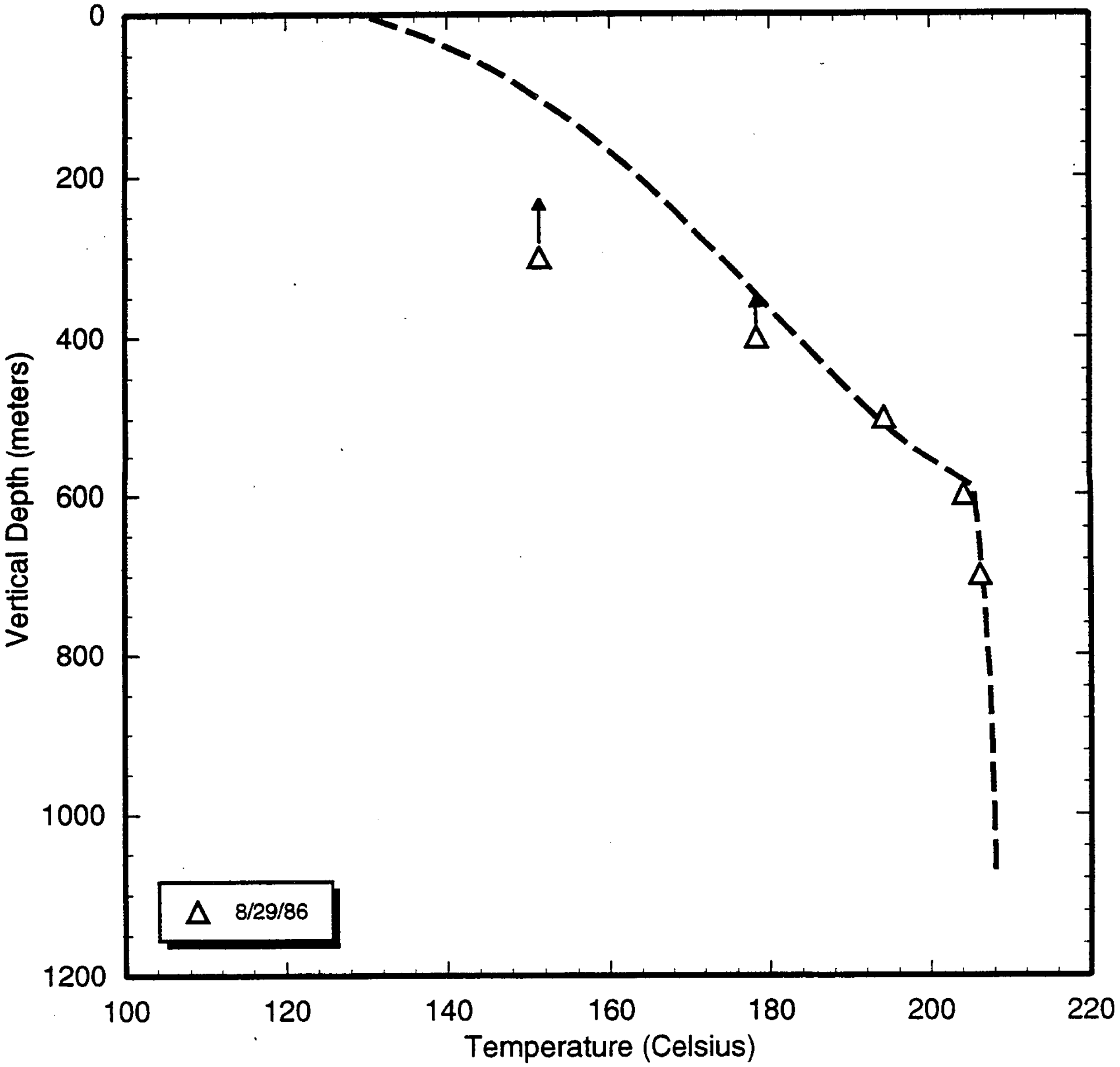

Figure 5.57. Temperature profile recorded in discharging TT-7 on August 29, 1986. ↑ indicates that the measured temperatures may be lower than the actual temperatures. The dashed line is the computed temperature profile.

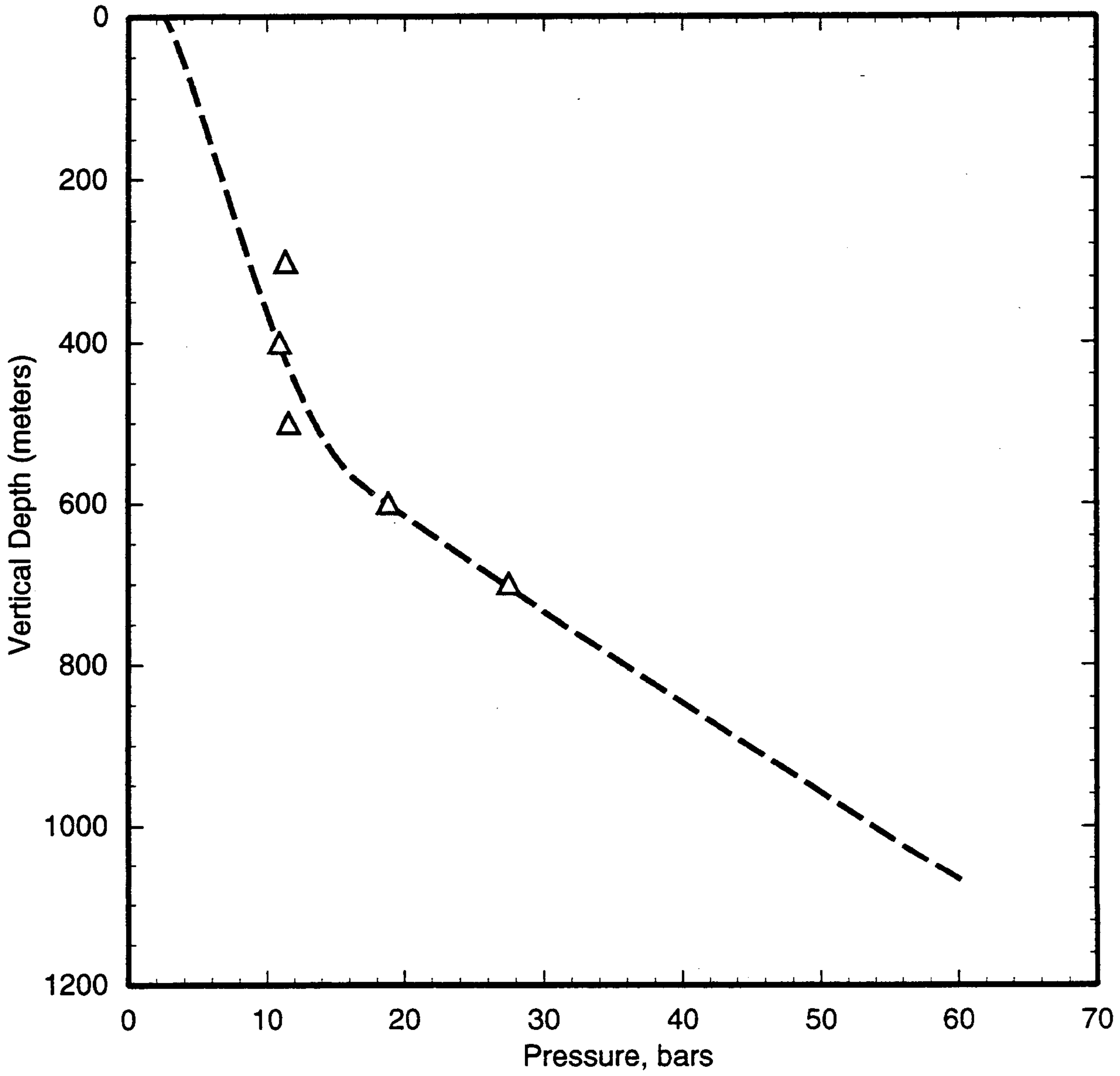

Figure 5.58. Pressure profile recorded in discharging TT-7 on August 29, 1986. The dashed line is the computed pressure profile.

increasing production time. The characteristic data from the long-term test are in good agreement with the simulated characteristic curve (Figure 5.59).

To assess the effect of the diameter of the upper section on the discharge behavior of TT-7, two calculations were run (using the same parameters as employed for the long-term test simulation) assuming that the inside diameter of the upper section equals (1) 31.79 cm and (2) 22.44 cm. Note that most of the Takigami production wells are completed with a 31.79 cm upper section. The upper section diameter of 22.44 cm defines the hypothetical "Oguni/Sumikawa type" well. The computed discharge characteristics for these two cases are shown in Figure 5.59. It is apparent from Figure 5.59 that the discharge rate is a strong function of the upper section diameter. For the 31.79 cm case, the maximum discharge rate is ~338 tons/hour. The maximum discharge rate for the hypothetical "Oguni/Sumikawa type" well is only ~144 tons/hour. By way of contrast, the measured maximum discharge rate for TT-7 is almost 500 tons/hour. Production data for TT-7 along with present simulations imply that increasing the pipe diameter in the two-phase flow regime (usually the upper part of the well) has a beneficial effect on the discharge capacity of a well.

Production Well TT-8S3

The principal feedzone for TT-8S3 is located at 1870 m TVD. The stable feedzone pressure is ~142.5 bars. Characteristic test data and/or downhole pressure/temperature data are available from three (3) discharge tests (short-term discharge tests of June 22–23, 1987 and April 5–?, 1988, and long-term discharge test of November 1991–February 1992). Downhole temperature/pressure surveys taken on June 23, 1987 indicated a feedzone temperature of ~191°C; discharge rate and downhole pressure data yield a productivity index of 3.1 kg/s-bar. Temperature survey of April 6, 1988 implies that the stable feedzone temperature (~214°C) is substantially higher than that recorded on June 23, 1987. Using the measured feedzone pressure on April 6, 1988, the productivity index is estimated to be 2.0 kg/s-bar. Apparently, the productivity index for TT-8S3 decreased substantially between the June 1987 and April 1988 discharge tests.

The well geometry for TT-8S3 is as follows:

Measured Depth (meters)	Vertical Depth (meters)	Angle with Vertical (degrees)	Internal Diameter (cm)
0.0–766.0	0.0–765.8	1.31	31.79
766.0–932.2	765.8–932.0	0.00	22.44
932.2–1565.2	932.0–1555.1	10.15	16.17
1565.2–1908.0	1555.1–1842.9	32.91	16.17
1908.0–1942.2	1842.9–1870.0	37.59	21.59

The stable formation temperature was approximated by the following temperature distribution using linear interpolations between tabulated data:

Vertical Depth (meters)	Temperature (Celsius)
0	20
500	40
800	180
1000	165
1200	170
1400	215
1600	225
1870	214

The characteristic test data and downhole temperature/pressure surveys taken during the short-term June 1987 discharge test were simulated using the following model parameters:

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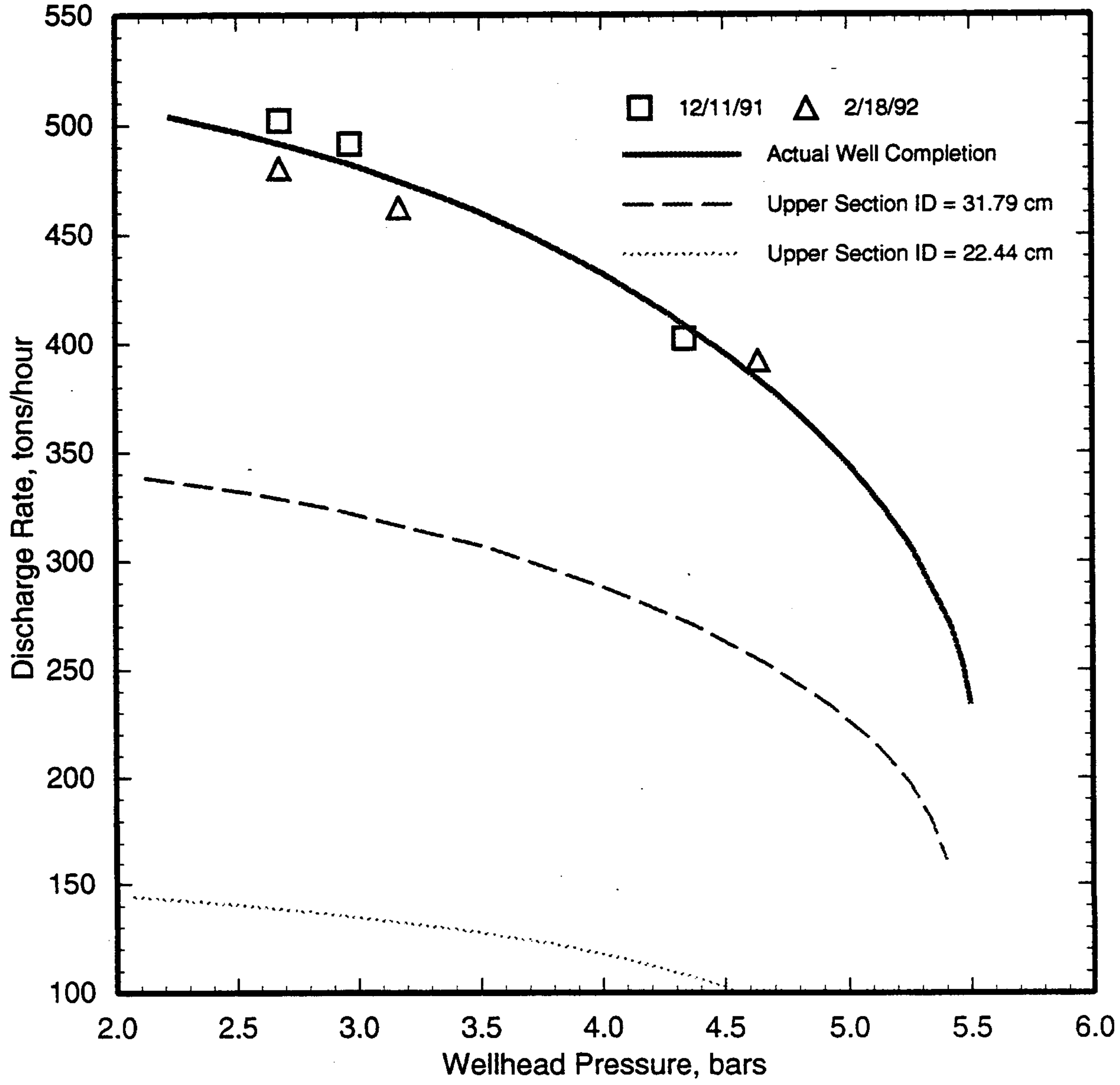

Figure 5.59. Discharge rate versus wellhead pressure for large-diameter production well TT-7 recorded during the long term production test (November 1991–February 1992). The solid line represents the computed characteristic curve for TT-7. The dashed and dotted lines denote the computed characteristic curves for two hypothetical well completions (see text).

Productivity Index, $PI = 3.1$ kg/s-bar
Flowing Feedzone Temperature, $T_f = 191.1$°C
Effective Thermal Conductivity, $K = 4$ W/m-°C
Friction Factor, $\varepsilon = 0.15$ mm

The computed results are compared with the measurements in Figures 5.60 to 5.62. Both the downhole pressure and temperature measurements (Figures 5.61 and 5.62) display excellent agreement with the computed profiles. With the exception of a single measurement at a relatively low discharge rate (~140 tons/hour), the computed characteristic curve provides a good approximation to the characteristic test data (Figure 5.60).

During the April 1988 discharge test, the well was discharged at a constant rate of ~52.1 kg/s and a wellhead pressure of ~3.6 bars. To simulate the downhole temperature/pressure profiles recorded on April 6, 1988, the following values for the productivity index and flowing feedzone temperature were used:

Productivity Index, $PI = 2.0$ kg/s-bar
Flowing Feedzone Temperature, $T_f = 214$°C

The other parameter values were left unchanged from those employed for the June 1987 test. It is apparent from Figures 5.63 and 5.64 that the measurements are closely approximated by the computed profiles.

During the 1991–1992 long-term discharge test, the well was apparently discharged at a fixed wellhead pressure (~3.1 bars). The discharge rate fluctuated between a low of 167 tons/hour and a high of 186 tons/hour (average ~175 tons/hour). With the single exception of the productivity index, the model parameters for the April 1988 test were used to compute the characteristic response curve for the long-term test. The productivity index for the long-term test was assumed to be 1.61 kg/s-bar. Considering data scatter, the computed results are in satisfactory agreement with the measurements (Figure 5.65).

Model parameters for the long-term test of TT-8S3 were employed to calculate the discharge characteristics for the following hypothetical "Oguni/Sumikawa type" well:

Measured Depth (meters)	Vertical Depth (meters)	Angle with Vertical (degrees)	Internal Diameter (cm)
0.0–766.0	0.0–765.8	1.31	22.44
766.0–932.2	765.8–932.0	0.00	22.44
932.2–1565.2	932.0–1555.1	10.15	21.59
1565.2–1908.0	1555.1–1842.9	32.91	21.59
1908.0–1942.2	1842.9–1870.0	37.59	21.59

The computed discharge characteristics for the hypothetical well are compared with those for well TT-8S3 in Figure 5.65. The maximum discharge rate for the hypothetical well (~130 tons/hour) is about 70 percent of that for well TT-8S3.

Production Well TT-13S

The principal feedzone for TT-13S is located at 2100 m TVD. The stable feedzone pressure is ~158 bars. Characteristic test data and/or downhole pressure/temperature data are available from three (3) discharge tests (short-term discharge tests of January 1988 and August 1988, and long-term discharge test of November 1991–February 1992). Downhole temperatures data indicate fluctuations in flowing feedzone temperature from survey-to-survey (230°C on January 20, 1988; 232°C on January 21, 1988; 237°C on August 4, 1988); these fluctuations may be due to feedzone heatup and/or instrument/measurement problems. Pressure surveys of January 20 and January 21, 1988 gave a productivity index of ~0.88 kg/s-bar; a slightly higher (~1.08 kg/s-bar) productivity index is implied by the pressure survey of August 4, 1988.

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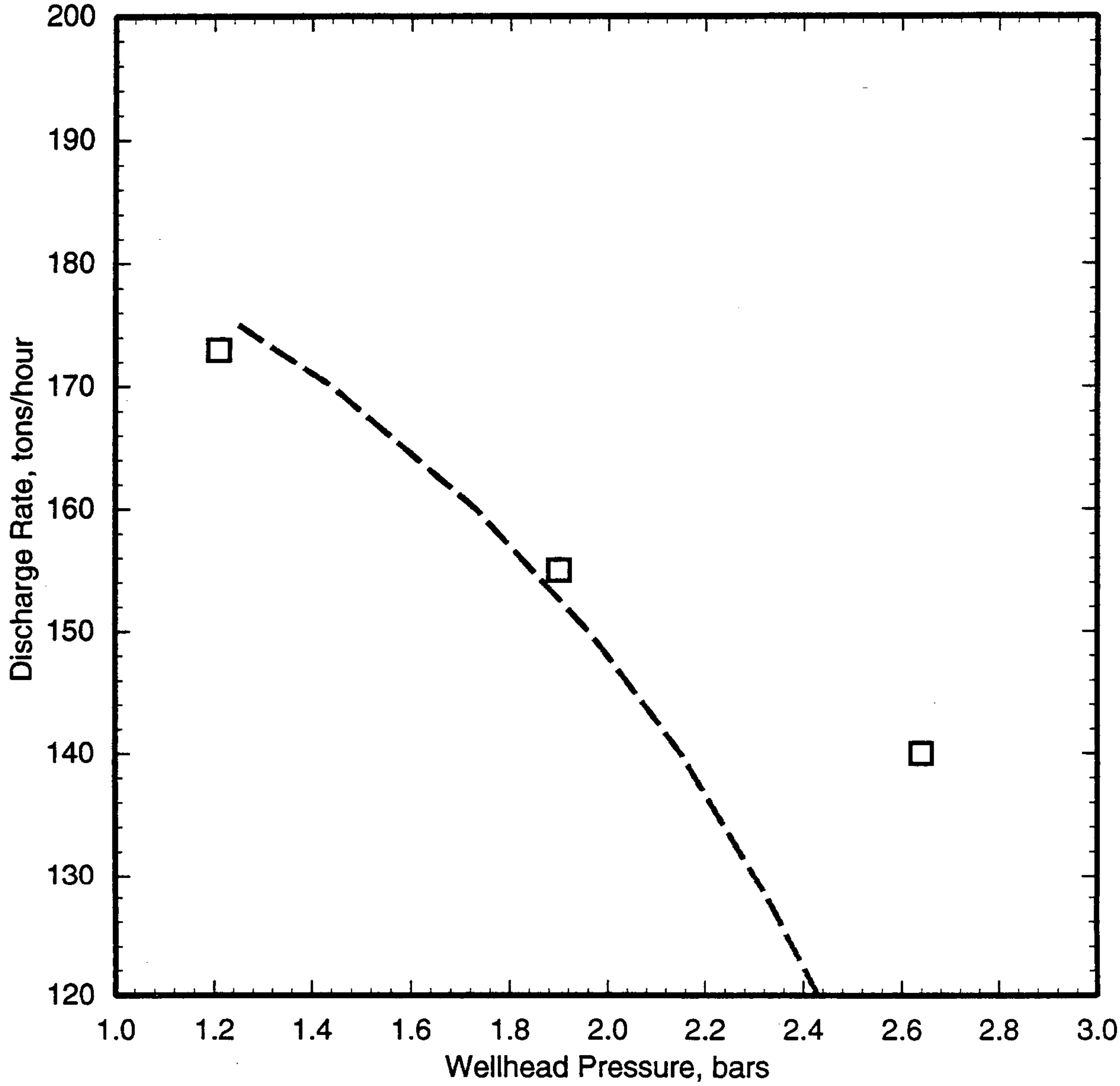

Figure 5.60. Discharge rate versus wellhead pressure for large-diameter production well TT-8S3 recorded during a short-term discharge test (June 22–23, 1987). The dashed line is the computed characteristic curve.

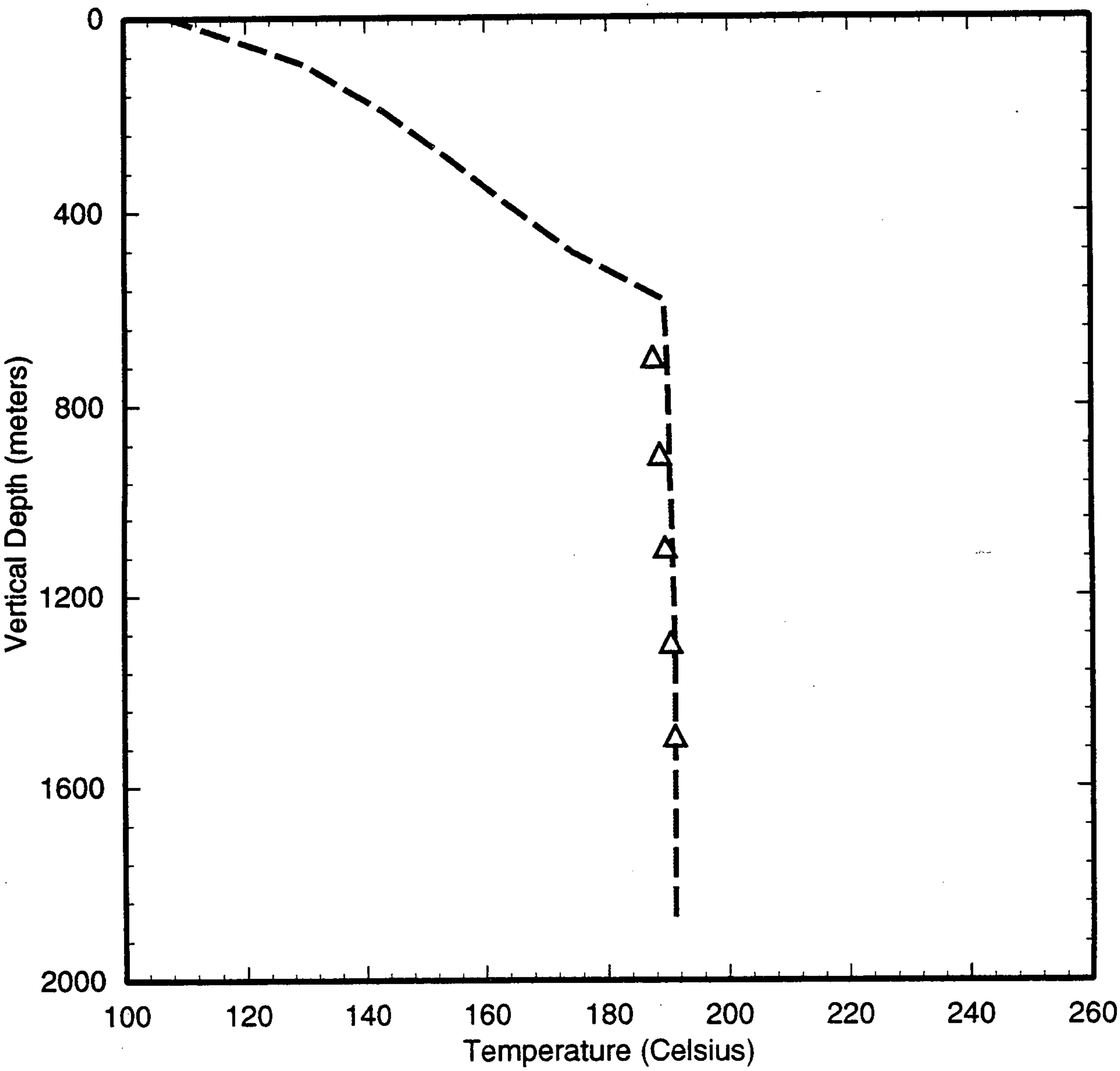

Figure 5.61. Temperature profile recorded in discharging TT-8S3 on June 23, 1987. The dashed line is the computed temperature profile.

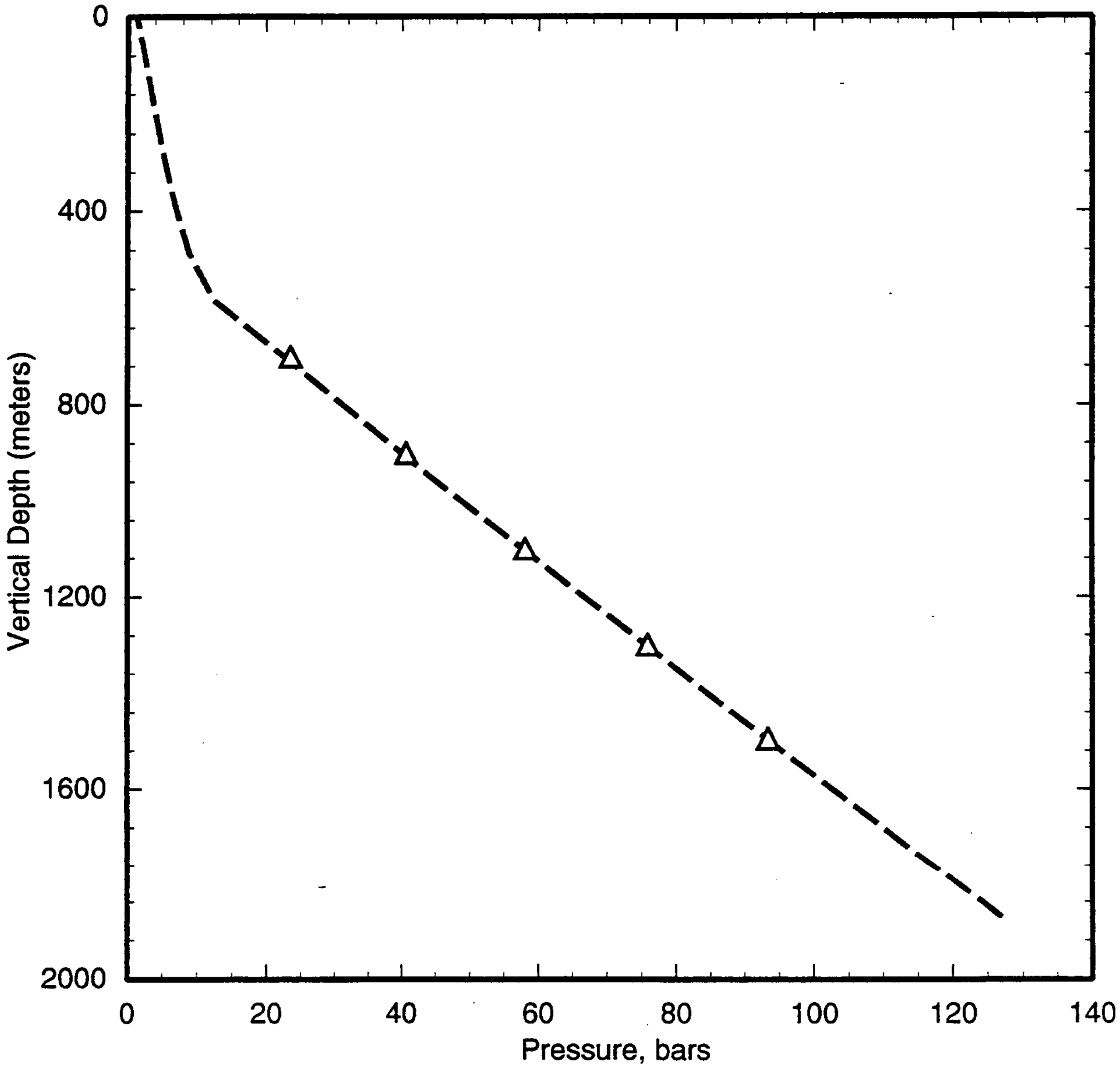

Figure 5.62. Pressure profile recorded in discharging TT-8S3 on June 23, 1987. The dashed line is the computed pressure profile.

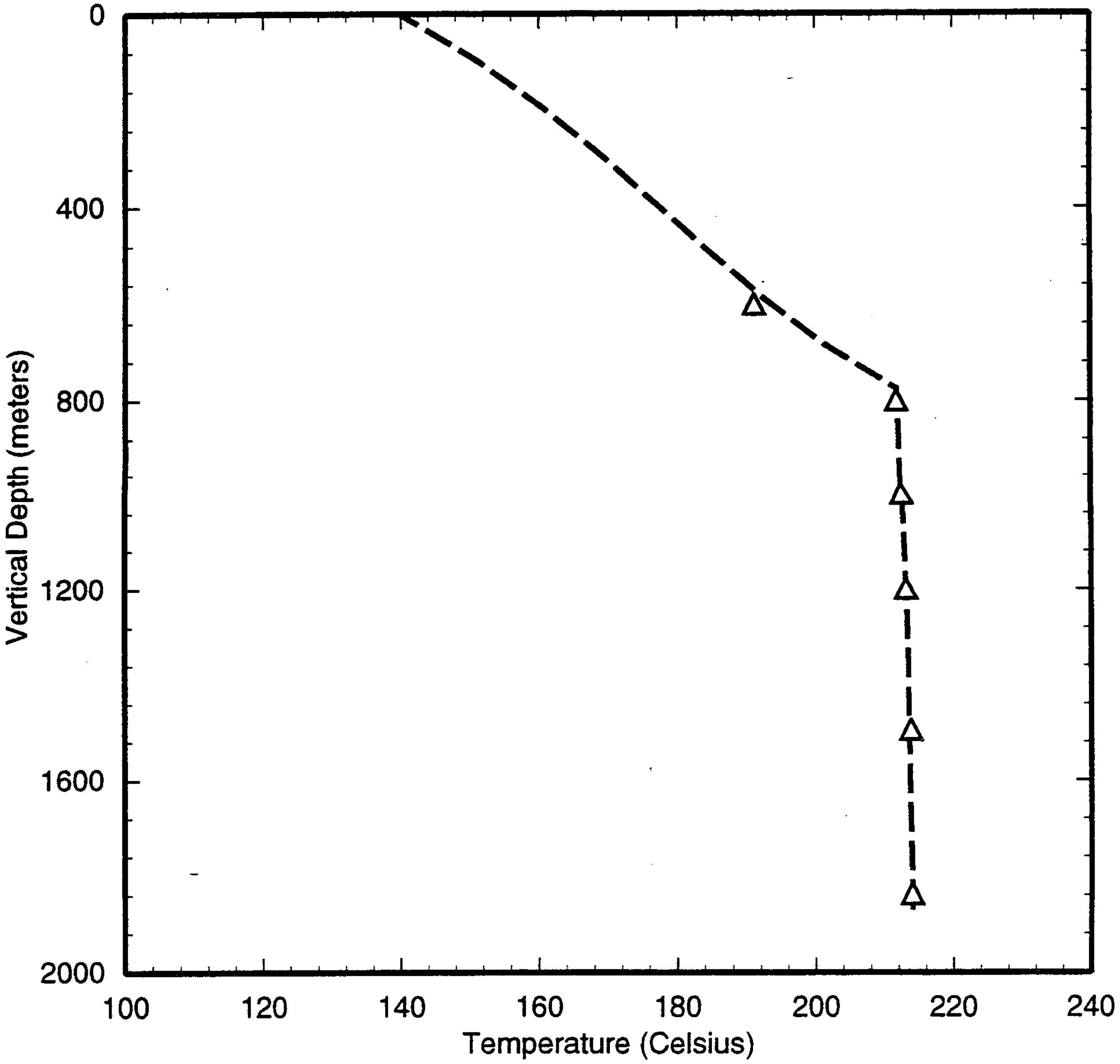

Figure 5.63. Temperature profile recorded in discharging TT-8S3 during a short-term discharge test on April 6, 1988. The dashed line is the computed temperature profile.

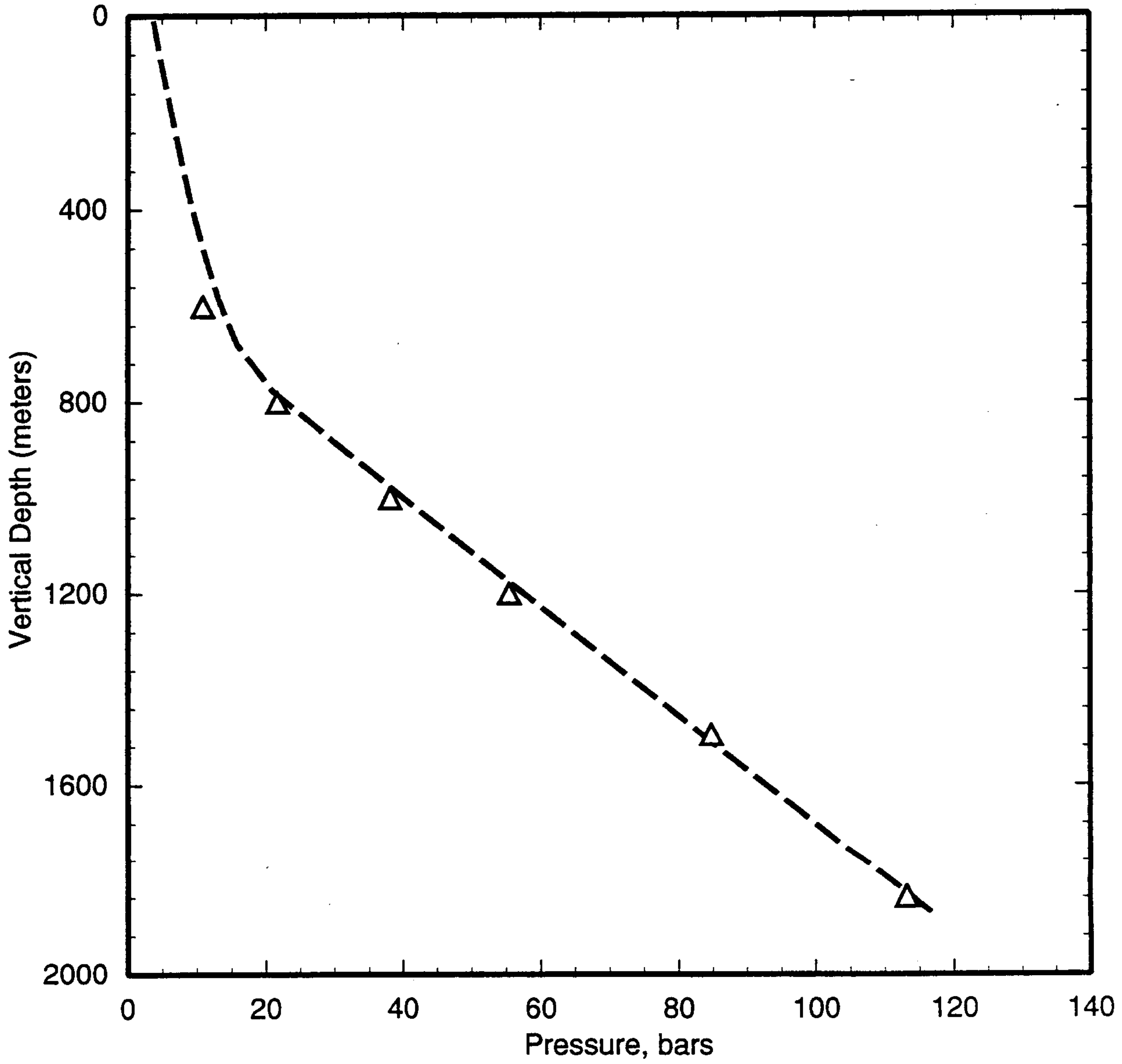

Figure 5.64. Pressure profile recorded in TT-8S3 during a short-term discharge test on April 6, 1988. The dashed line is the computed pressure profile.

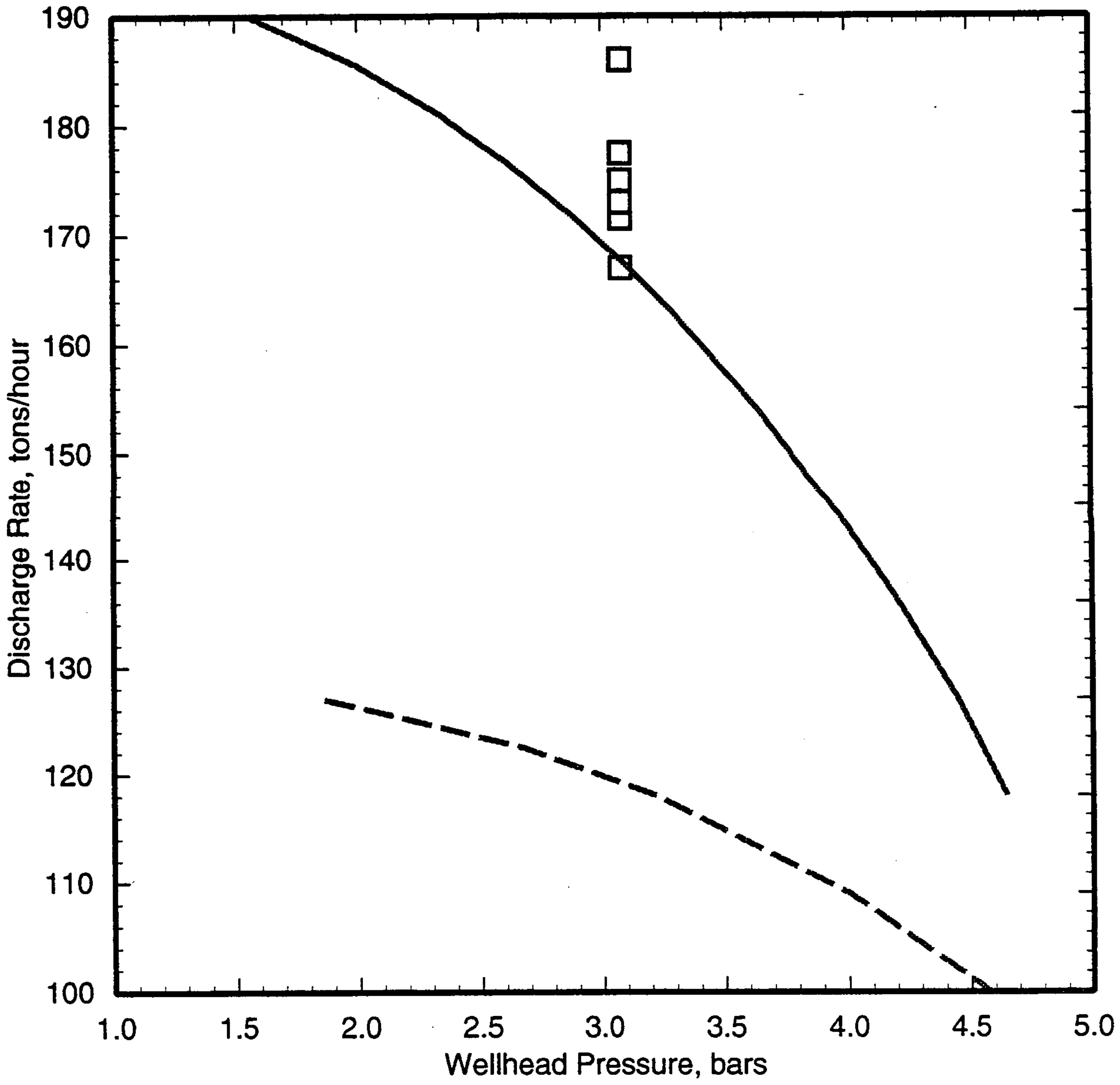

Figure 5.65. Discharge rate versus wellhead pressure for large-diameter production well TT-8S3 recorded during the long-term production test (November 1991–February 1992). The solid line represents the computed characteristic curve for TT-8S3. The dashed line is the computed characteristic curve for the hypothetical "Oguni/Sumikawa type" well (see text).

The well geometry for TT-13S is as follows:

Measured Depth (meters)	Vertical Depth (meters)	Angle with Vertical (degrees)	Internal Diameter (cm)
0.0–1060.5	0.0–1058.8	3.25	31.79
1060.5–1738.5	1058.8–1694.6	20.32	22.44
1738.5–2182.4	1694.6–2100.0	24.04	21.59

Well TT-13S is completed with a 7-inch uncemented slotted liner below ~1695 m TVD. Since the liner is uncemented, flow behind the liner is possible. It is, therefore, assumed that the presence of the slotted liner does not result in a reduction of the effective cross-section available for discharge. Any adverse effect of the liner on the discharge rate can be modeled through variations in the value of the friction factor (ε).

The stable formation temperature was approximated by the following temperature distribution using linear interpolations between tabulated data:

Vertical Depth (meters)	Temperature (Celsius)
0	20
800	45
1600	195
1800	235
2100	245

The characteristic test data and downhole temperature pressure/surveys taken during the short-term January 1988 discharge test were simulated using the following model parameters:

Flowing Feedzone Temperature, $T_f = 232°C$
Productivity Index, $PI = 0.88$ kg/s-bar
Effective Thermal Conductivity, $K = 8$ W/m-°C
Friction Factor, $\varepsilon = 0.02$ mm

(For the downhole pressure/temperature surveys taken on January 20, 1988 only, the flowing feedzone temperature was assumed to be 230°C). The computed results are compared with measurements in Figure 5.66–5.70; and the agreement is quite good.

The August 1988 characteristic data and downhole temperature/pressure profiles were fit using the following parameters:

Flowing Feedzone Temperature, $T_f = 237°C$
Productivity Index, $PI = 1.08$ kg/s-bar
Effective Thermal Conductivity, $K = 4$ W/m-°C
Friction Factor, $E = 0.23$ mm

The measurements are in excellent agreement with the model results (Figures 5.71 to 5.73). Model parameters for the August 1988 are rather different from those used to fit the January 1988 test data. It was remarked in Section 4 that the feedzone temperature had not fully recovered at the time of the January 1988 test. Therefore, it is likely that the August 1988 test data provide a more reliable description of the discharge behavior of TT-13S.

With the single exception of the flowing feedzone temperature, the model parameters from the August 1988 test were employed to model the characteristic data obtained during the 1991–92 long-term discharge test; for the latter test, a flowing feedzone temperature of 235°C was assumed (Figure 5.74). Apparently, the characteristic curve is quite sensitive to small changes in feedzone temperature. An increase in flowing feedzone temperature from 235°C to 237°C results in a three to five percent increase in the discharge rate (see Figure 5.74).

Model parameters for the 1991–92 long-term discharge test of TT-13S were employed to calculate the discharge characteristics for the following "Oguni/Sumikawa type" well:

Measured Depth (meters)	Vertical Depth (meters)	Angle with Vertical (degrees)	Internal Diameter (cm)
0.0–1060.5	0.0–1058.8	3.25	22.44
1060.5–1738.5	1058.8–1694.6	20.32	22.44
1738.5–2182.4	1694.6–2100.0	24.04	21.59

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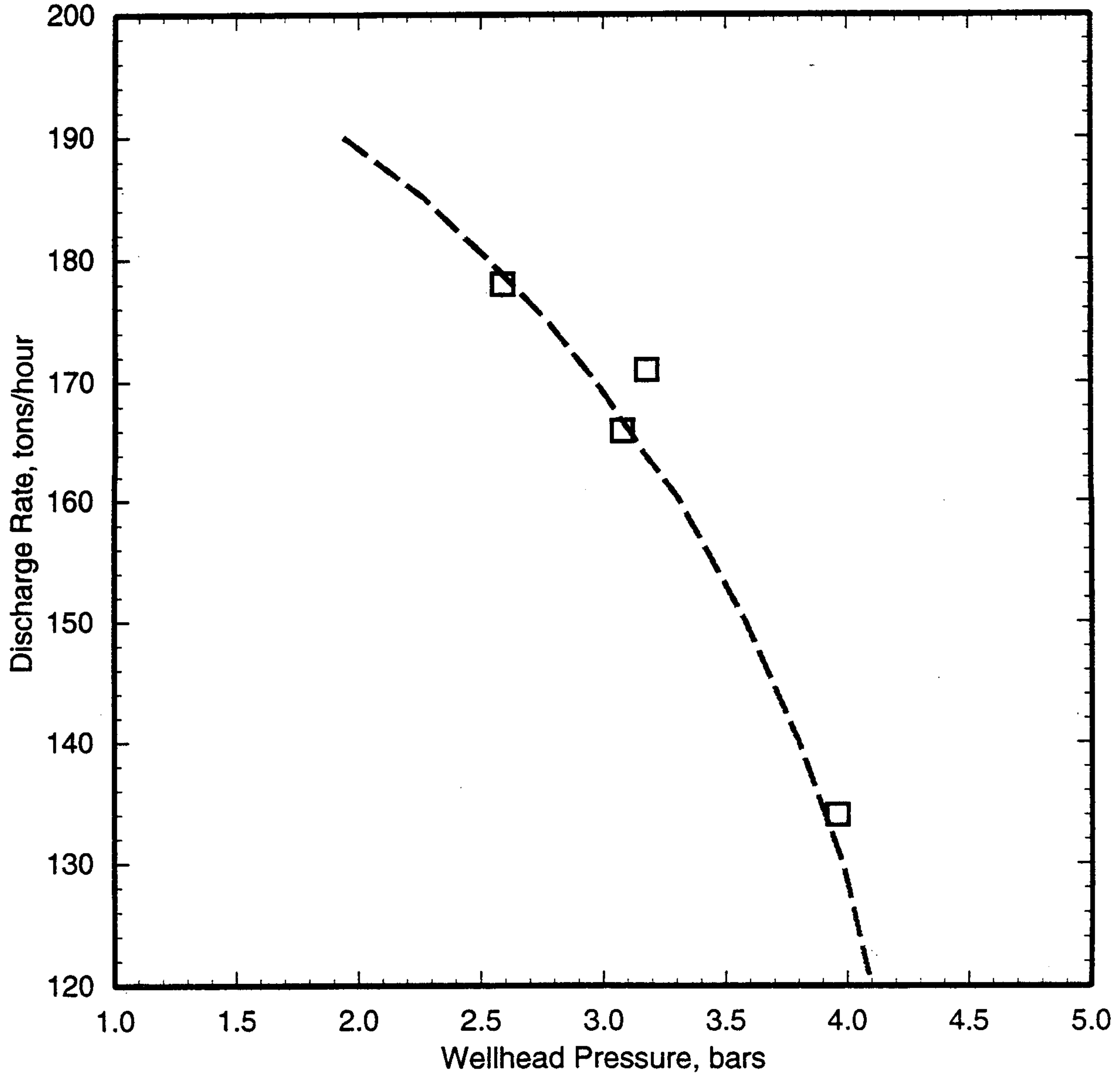

Figure 5.66. Discharge rate versus wellhead pressure for large-diameter production well TT-13S recorded during a short-term discharge test (January 12–22, 1988). The dashed line is the computed characteristic curve.

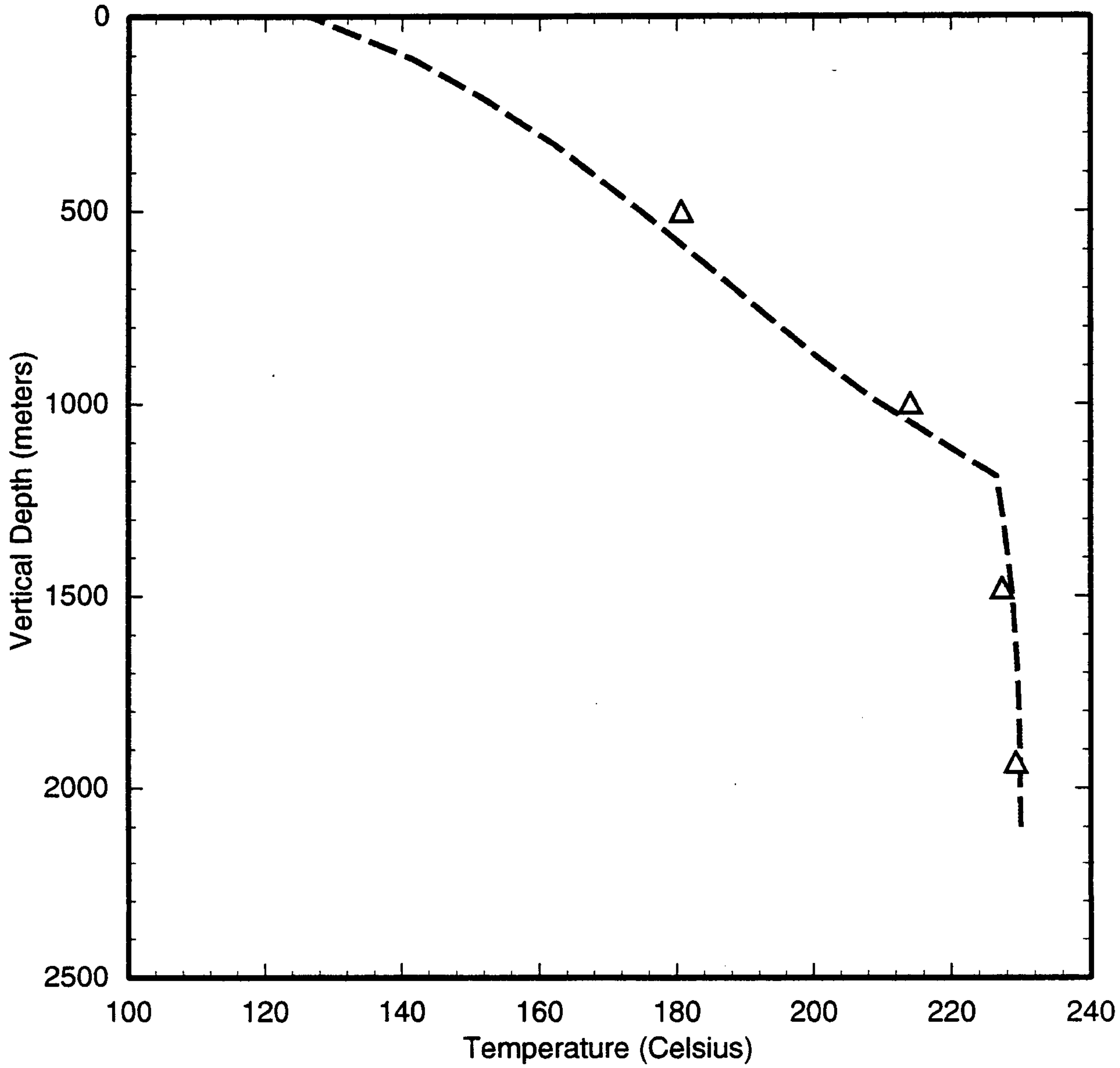

Figure 5.67. Temperature profile recorded in discharging TT-13S on January 20, 1988. The dashed line is the computed temperature profile.

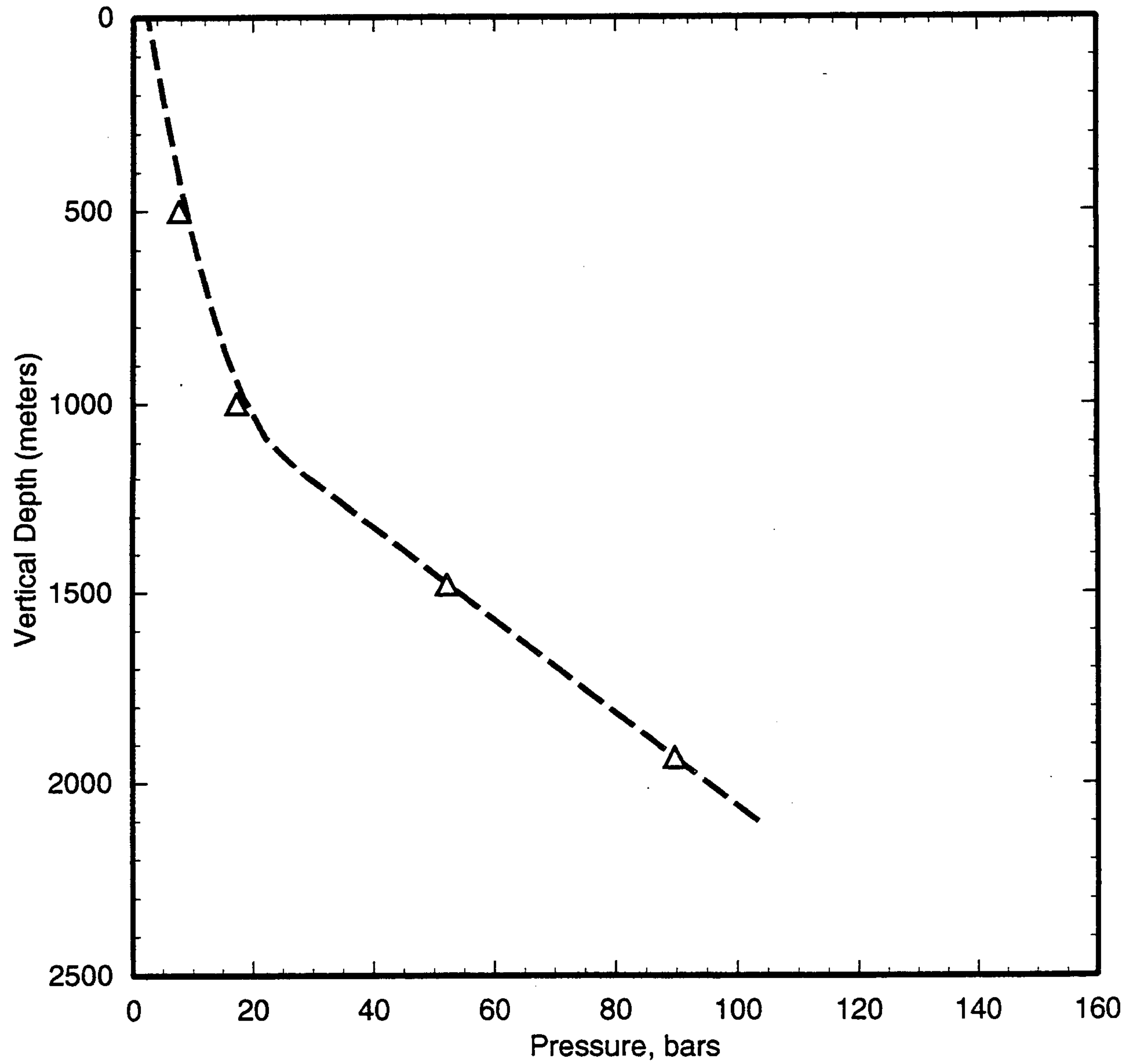

Figure 5.68. Pressure profile recorded in discharging TT-13S on January 20, 1988. The dashed line is the computed pressure profile.

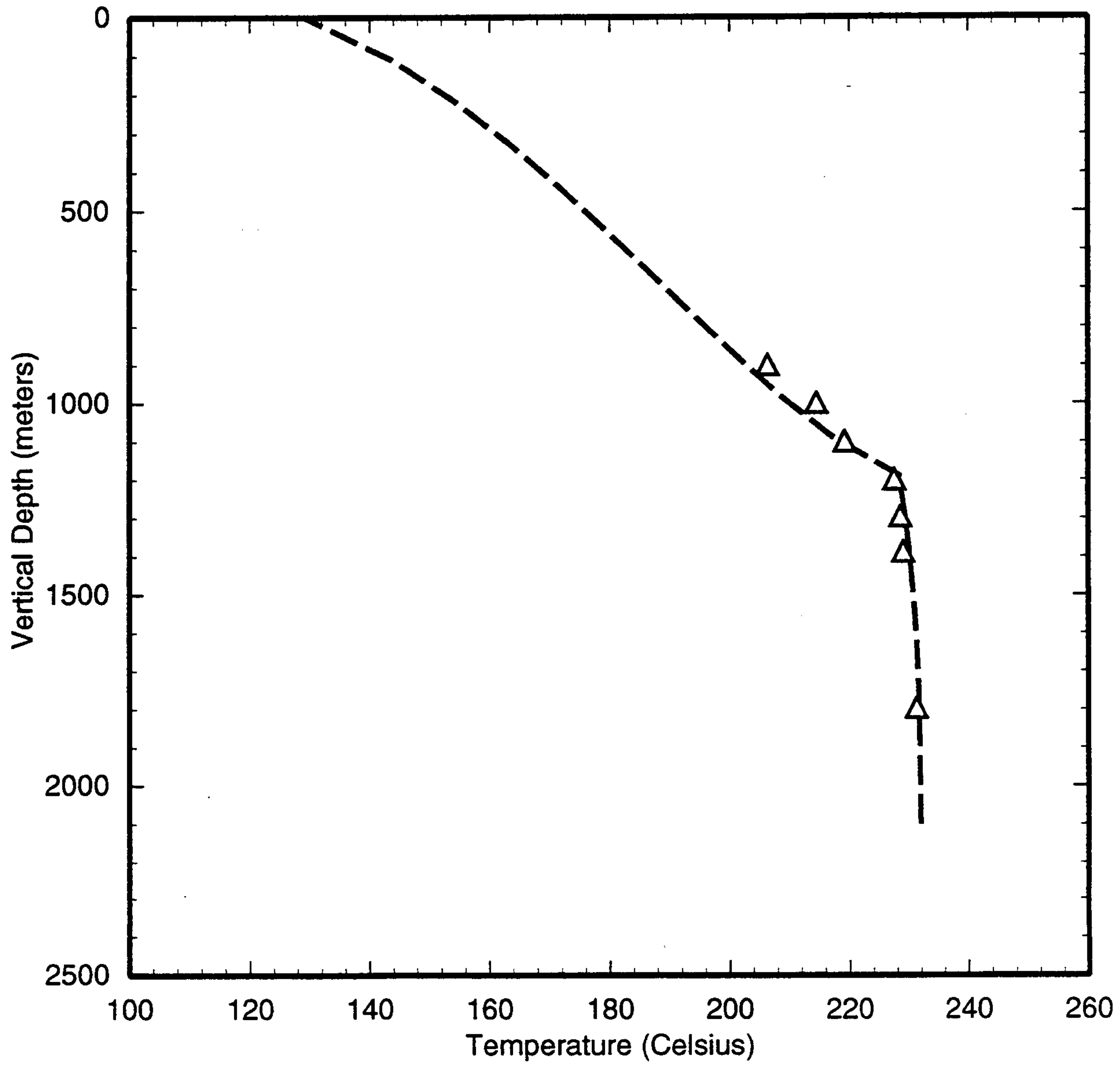

Figure 5.69. Temperature profile recorded in discharging TT-13S on January 21, 1988. The dashed line is the computed temperature profile.

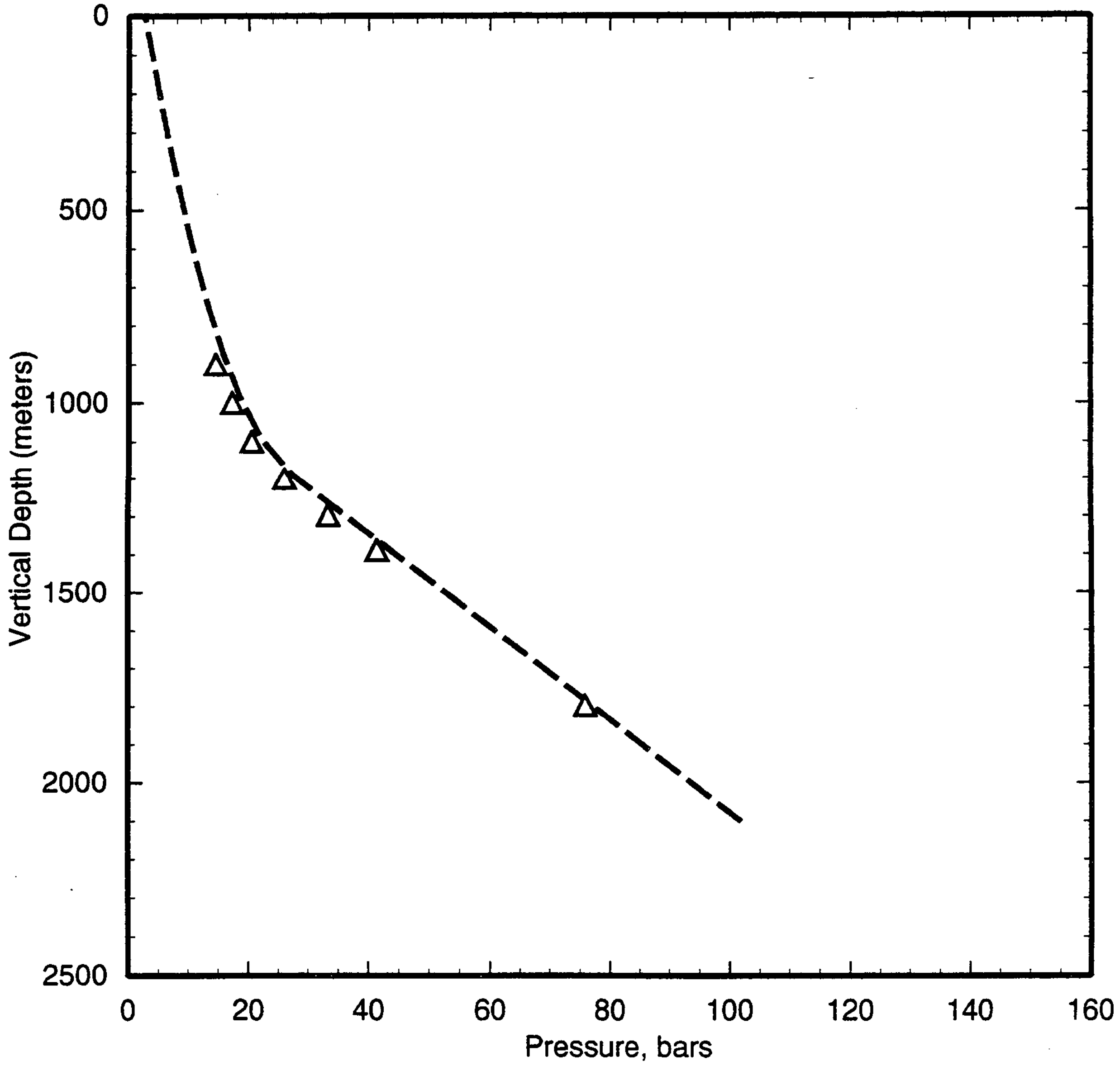

Figure 5.70. Pressure profile recorded in discharging TT-13S on January 21, 1988. The dashed line is the computed pressure profile.

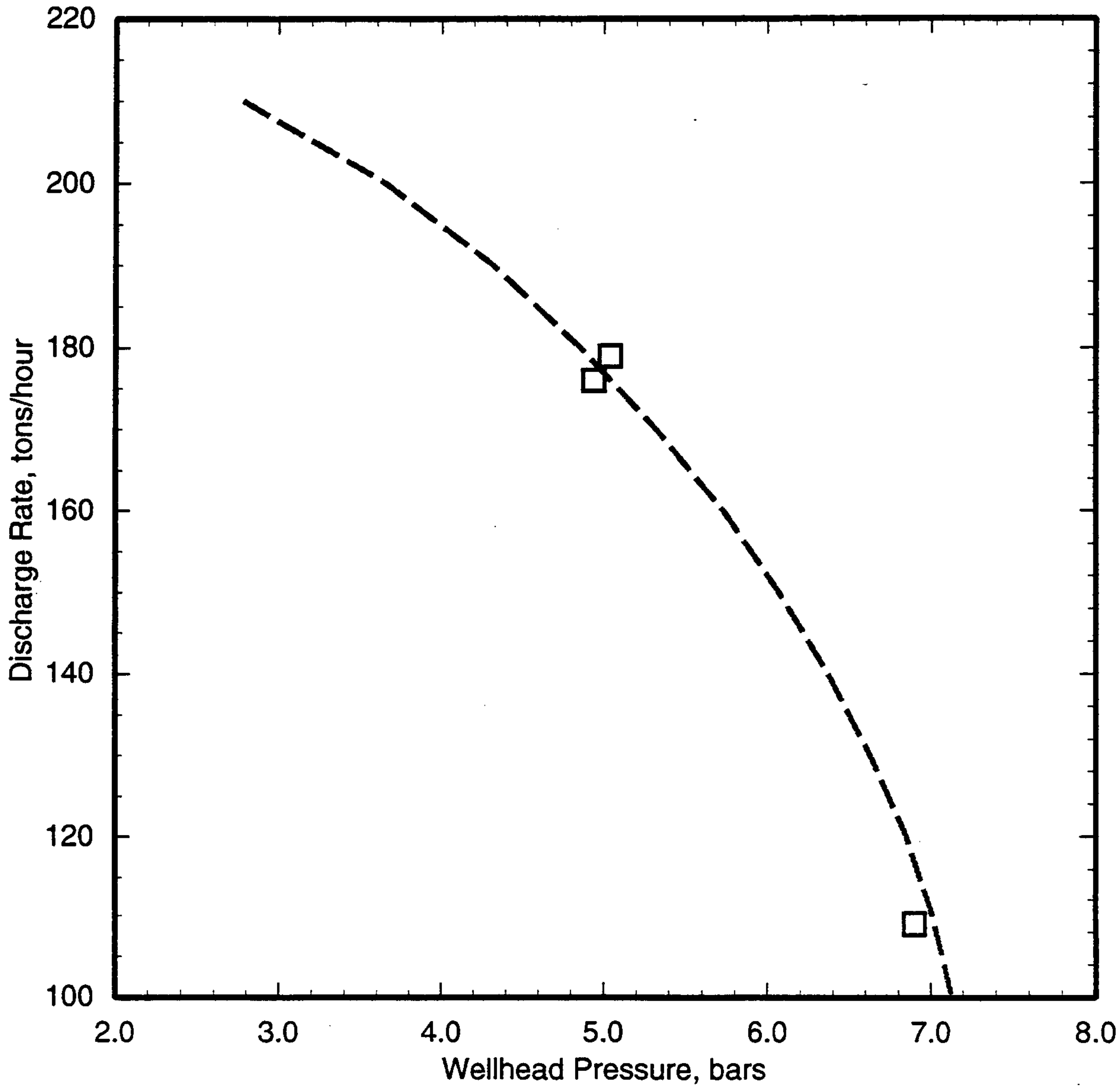

Figure 5.71. Discharge rate versus wellhead pressure for large-diameter production well TT-13S recorded during a short-term discharge test (August 2–9, 1988). The dashed line is the computed characteristic curve.

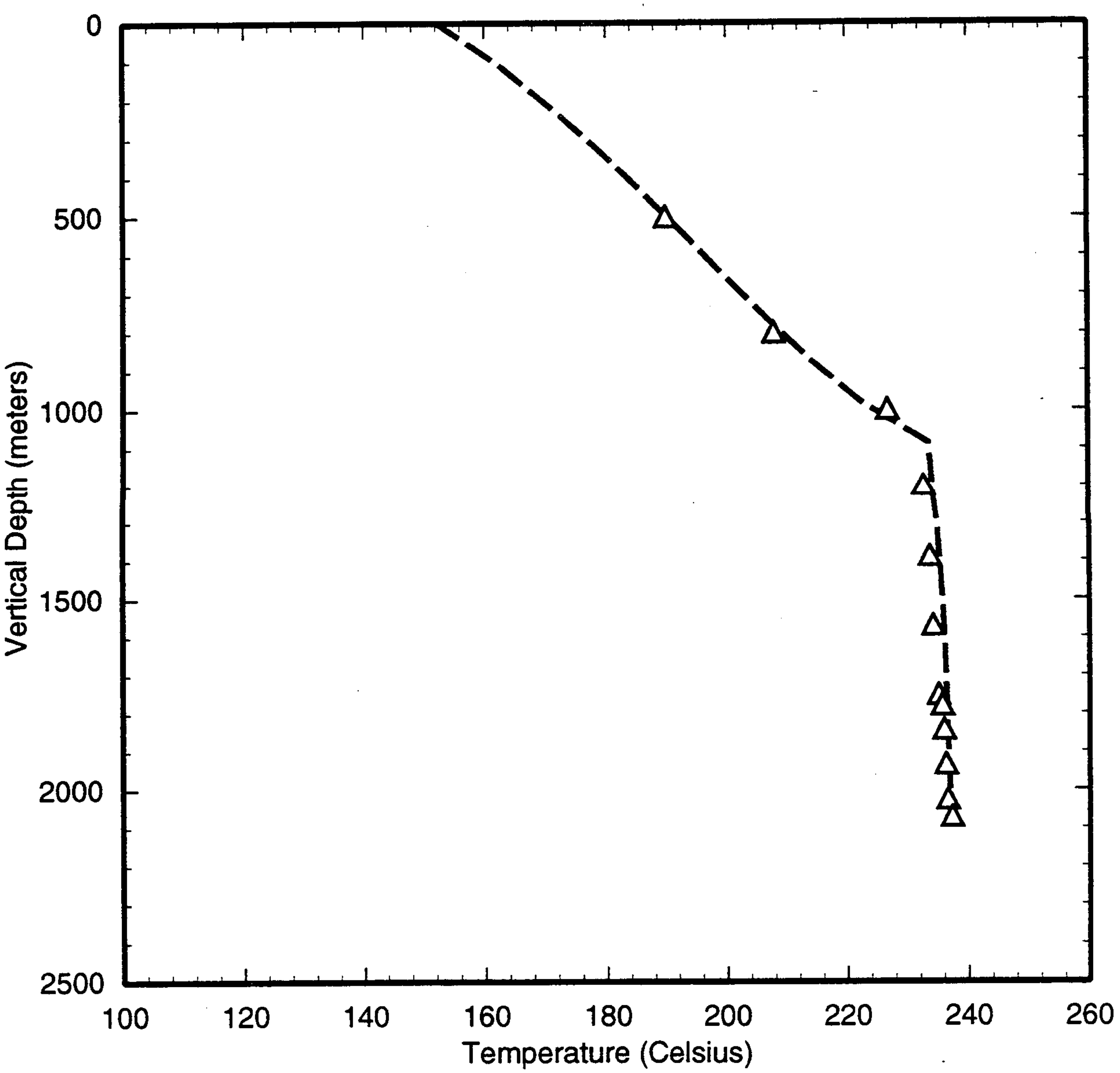

Figure 5.72. Temperature profile recorded in discharging TT-13S on August 4, 1988. The dashed line is the computed temperature profile.

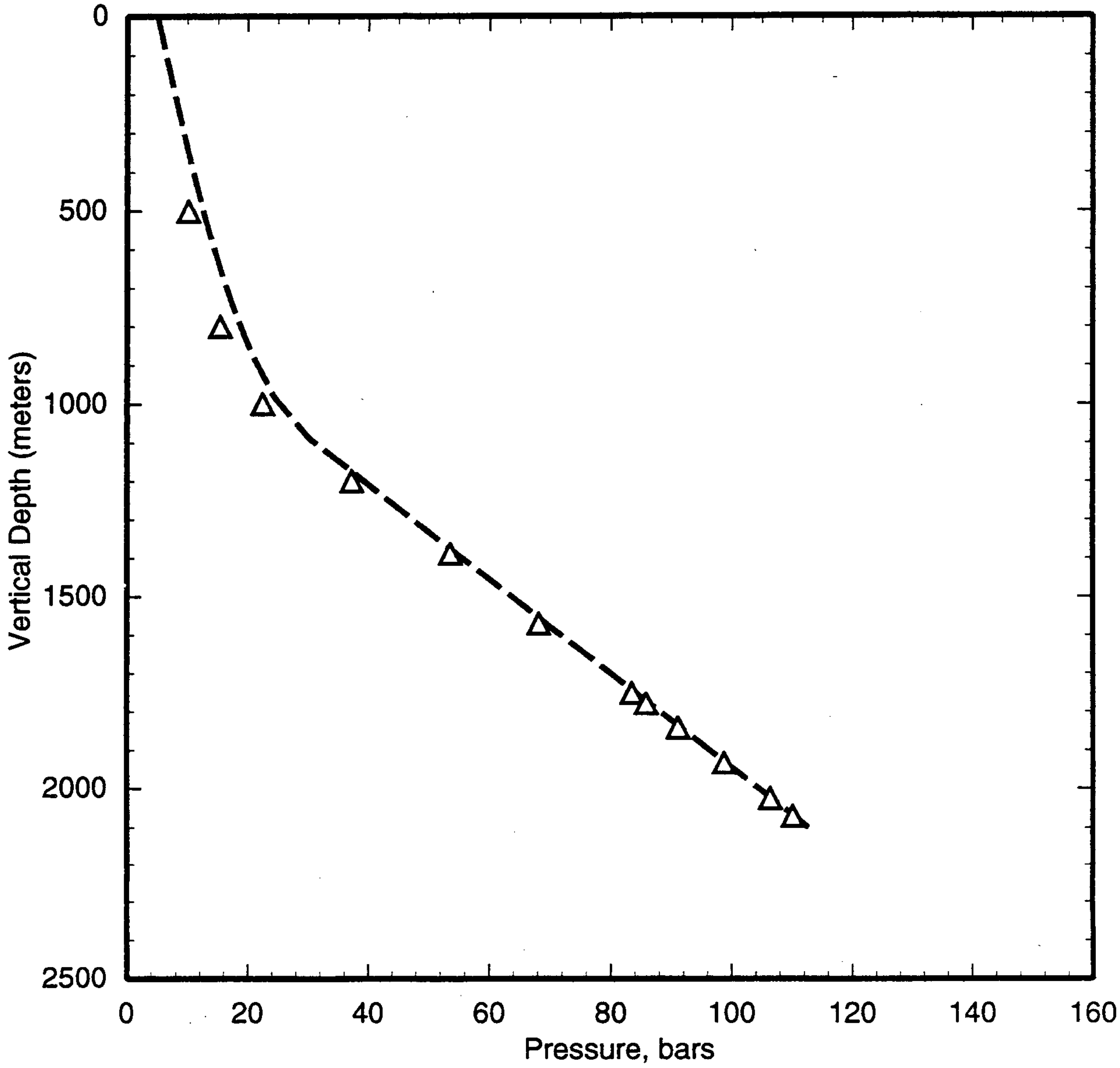

Figure 5.73. Pressure profile recorded in discharging TT-13S on August 4, 1988. The dashed line is the computed pressure profile.

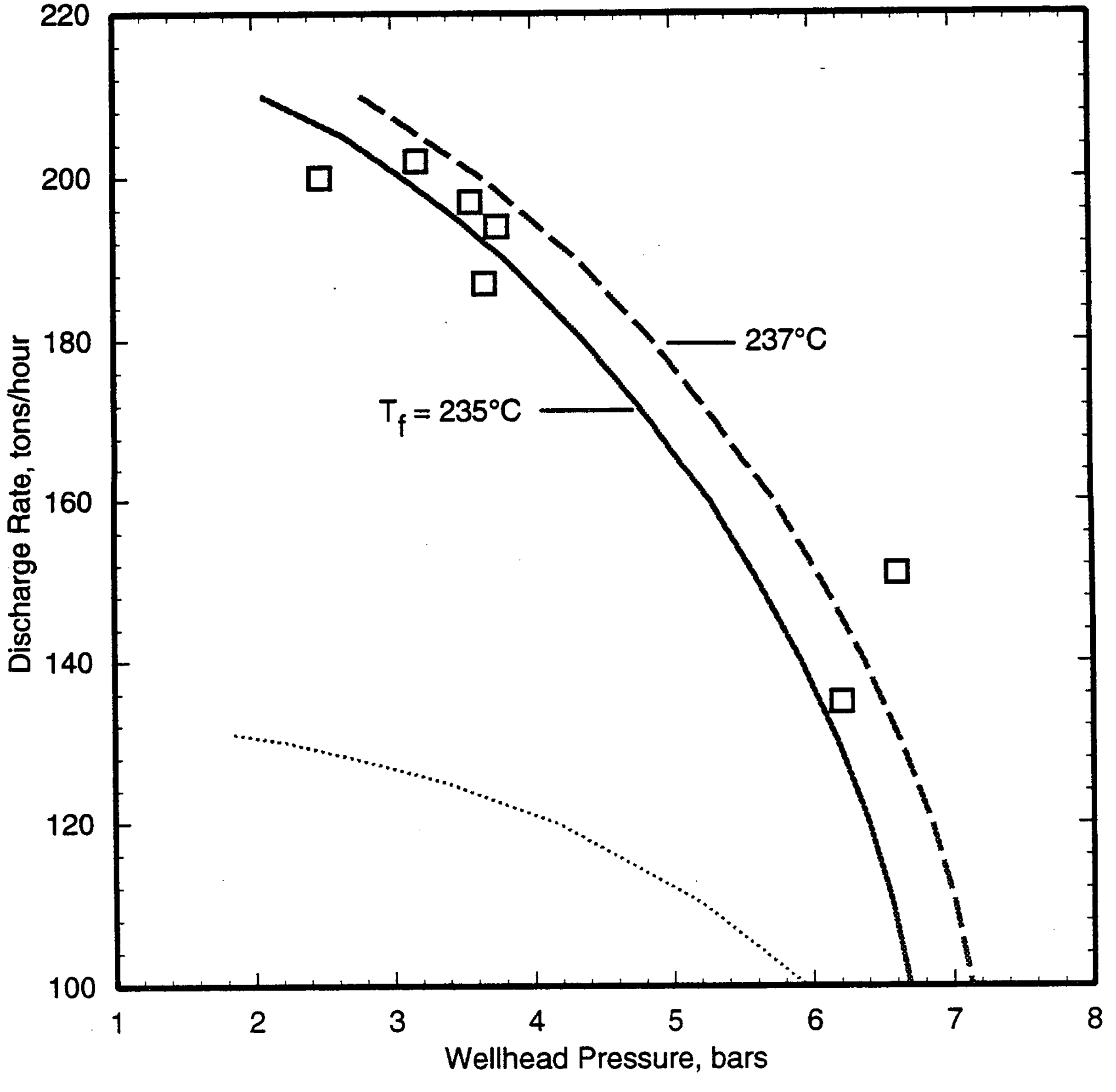

Figure 5.74. Discharge rate versus wellhead pressure for large-diameter production well TT-13S recorded during the long-term production test (November 1991–February 1992). The solid line (flowing temperature, T_f = 235°C) represents the computed characteristic curve (long-term test) for TT-13S. The dashed line shows a computed characteristic curve for TT-13S with T_f = 237°C. The dotted line is the computed characteristic curve for the hypothetical "Oguni/Sumikawa type" well (see text).

The computed discharge characteristics for the hypothetical well are compared with those for well TT-13S in Figure 5.74. The maximum discharge rate for the hypothetical well (~131 tons/hour) is about 65 percent of that for well TT-13S.

Production Well TT-14R

The principal feedzone for TT-14R is located at 1730 m TVD. The stable feedzone pressure is ~131.5 bars. Based on a pressure survey in the discharging well during the preliminary flow test (November 6–9, 1986), the productivity index is 1.46 kg/s-bar. The flowing feedzone temperature (estimated from the temperature survey of November 7, 1986) is ~236°C. Subsequent to the completion of the preliminary flow test, a 7-inch uncemented slotted liner was installed below ~1663 m TVD. Since fluid can flow in the annulus behind the uncemented liner, it is assumed that the liner has negligible influence on the discharge characteristics of TT-14R.

The well geometry for TT-14R is as follows:

Measured Depth (meters)	Vertical Depth (meters)	Angle with Vertical (degrees)	Internal Diameter (cm)
0.0–881.5	0.0–880.6	2.59	31.79
881.5–1763.6	880.6–1663.3	27.46	22.44
1763.6–1849.0	1663.3–1730.0	38.65	21.59

The stable formation temperature was approximated by the following temperature distribution using linear interpolations between tabulated data:

Vertical Depth (meters)	Temperature (Celsius)
0	20
800	45
1450	200
1730	236

The characteristic test data and downhole temperature/pressure surveys taken during the preliminary November 1986 discharge test were simulated using the following model parameters:

Flowing Feedzone Temperature, $T_f = 236°C$
Productivity Index, $PI = 1.46$ kg/s-bar
Effective Thermal Conductivity, $K = 11.5$ W/m-°C
Friction Factor, $\varepsilon = 0.032$ mm

The computed results, Figures 5.75–5.77, display satisfactory agreement with the measurements.

Discharge characteristics of TT-14R were also recorded during the November 1991–February 1992 long-term discharge test. Apart from the effective thermal conductivity, parameters for the 1986 test were also used for simulating the 1991–1992 characteristic data. For the latter calculations, the effective thermal conductivity was assumed to be 6.9 W/m-°C. The computed characteristic curve for TT-14R is in excellent agreement with the measurements (Figure 5.78).

Model parameters for the 1991–92 long-term discharge test of TT-14R were employed to calculate the discharge characteristics for the following "Oguni/Sumikawa type" well:

Measured Depth (meters)	Vertical Depth (meters)	Angle with Vertical (degrees)	Internal Diameter (cm)
0.0–881.5	0.0–880.6	2.59	22.44
881.5–1763.6	880.6–1663.3	27.46	22.44
1763.6–1849.0	1663.3–1730.0	38.65	21.59

The computed discharge characteristics for the hypothetical well are compared with those for well TT-14R in Figure 5.78. The maximum discharge rate for the hypothetical well (~178 tons/hour) is about 65 percent of the measured maximum discharge rate for well TT-14R.

Continued on page 5-98

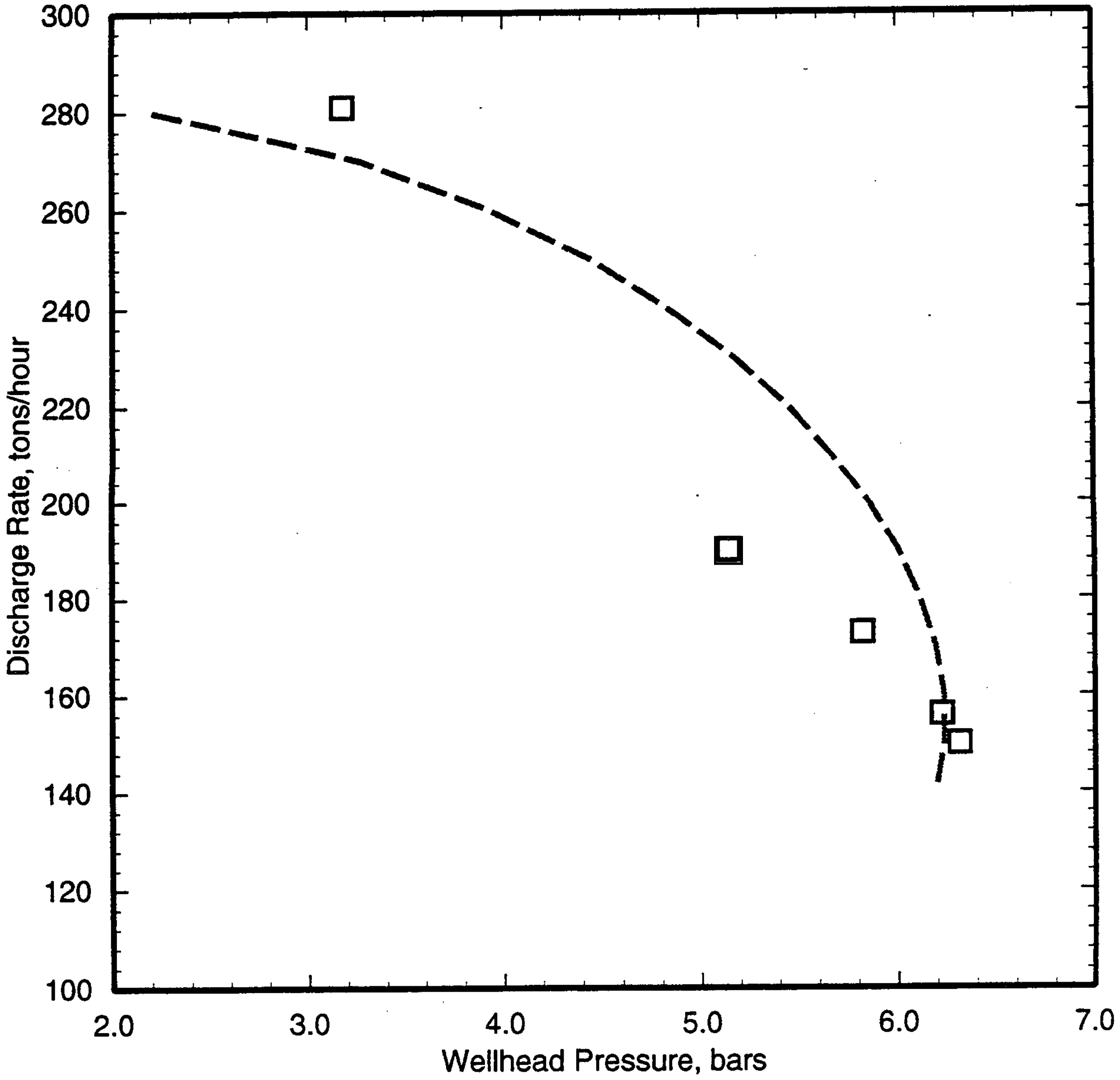

Figure 5.75. Discharge rate versus wellhead pressure for large-diameter production well TT-14R recorded during the preliminary flow test (November 6–9, 1986). The dashed line is the computed characteristic curve.

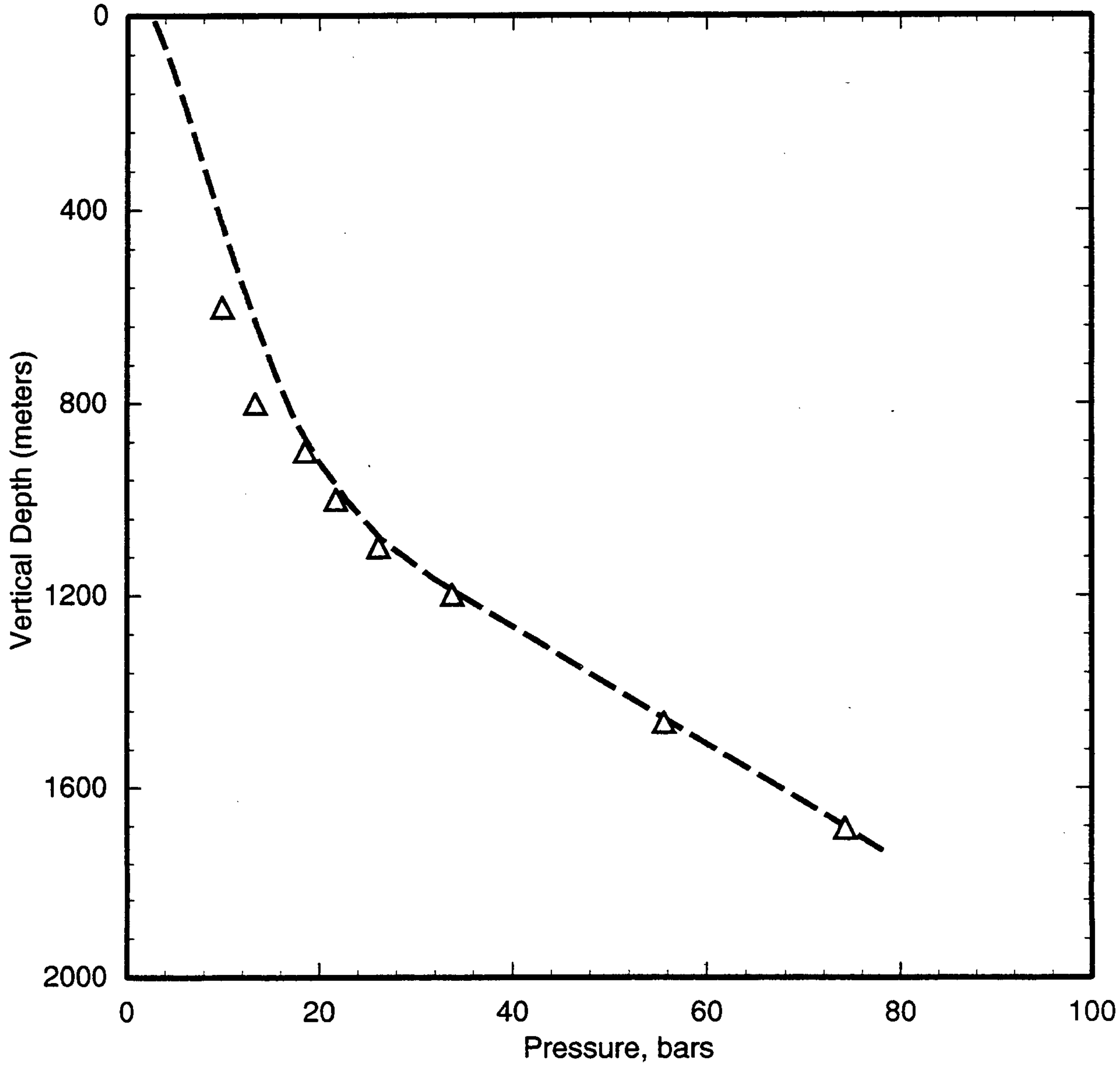

Figure 5.76. Temperature profile recorded in discharging TT-14R on November 7, 1986. The dashed line is the computed temperature profile.

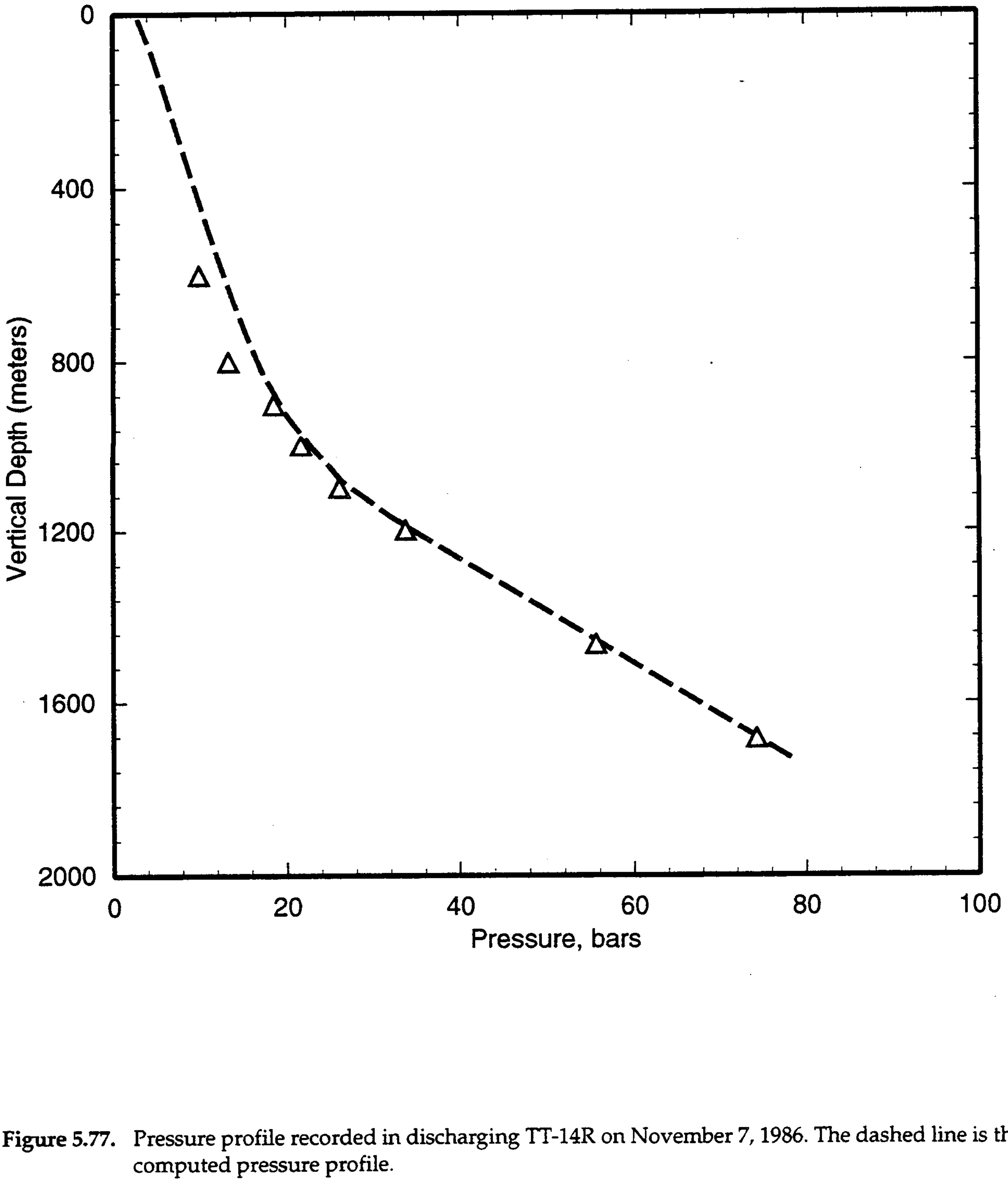

Figure 5.77. Pressure profile recorded in discharging TT-14R on November 7, 1986. The dashed line is the computed pressure profile.

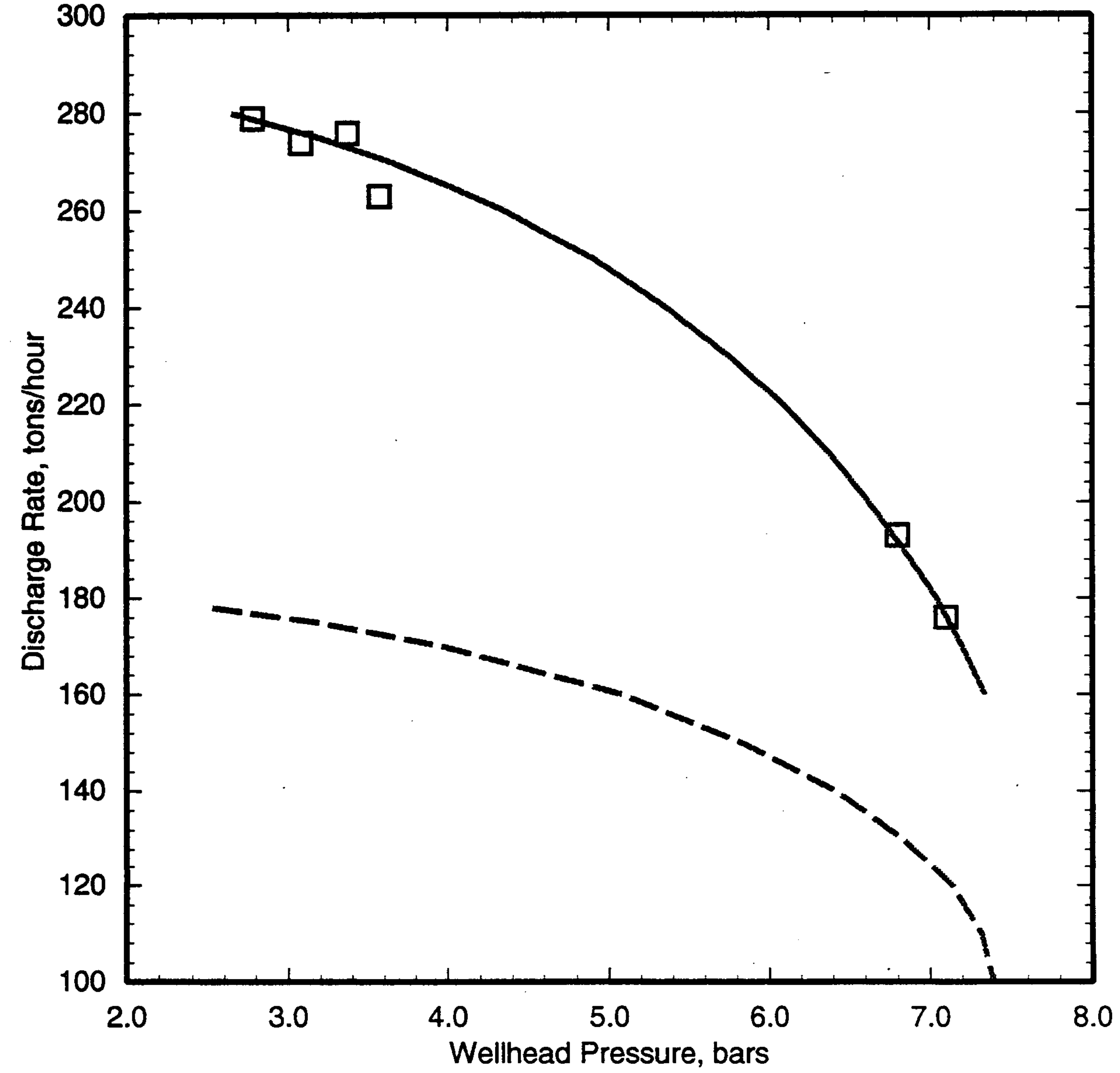

Figure 5.78. Discharge rate versus wellhead pressure for large-diameter production well TT-14R recorded during the long-term discharge test (November 1991–February 1992). The solid line represents the computed characteristic curve for TT-14R. The dashed line is the computed characteristic curve for the hypothetical "Oguni/Sumikawa type" well (see text).

Production Well TT-16S

The principal feedzone for TT-16S is located at 1740 m TVD. The stable feedzone pressure is 131 bars. During a low rate (55 tons/hour = 15.3 kg/s) discharge test of TT-16S on February 16, 1989, a temperature/pressure survey was run in the well (Figures 5.79 and 5.80). Based on the latter pressure survey, the productivity index for TT-16S is ~0.82 kg/s-bar. The feedzone temperature on February 16, 1989 was ~212°C. It is likely that the feedzone temperature had not fully recovered at the time of the February 1989 test; later shutin temperature surveys indicate that the stable feedzone temperature is ~230°C.

The well geometry for TT-16S is as follows:

Measured Depth (meters)	Vertical Depth (meters)	Angle with Vertical (degrees)	Internal Diameter (cm)
0.0–1413.6	0.0–1286.9	24.44	22.44
1413.6–2022.3	1286.9–1740.0	41.90	21.59

TT-16S is the only Takigami production well with an "Oguni/Sumikawa type" casing program ($9\text{-}^{5}/_{8}$ inch cemented casing and $8\text{-}^{1}/_{2}$ inch open hole). Not surprisingly, TT-16S has the lowest discharge capacity of all the Takigami production wells. Like wells TT-13S and TT-14R, well TT-16S is completed with a 7-inch uncemented liner in the open hole part of the well (*i.e.*, below ~1287 m TVD). In the following, it is assumed that the liner has only a negligible influence on the discharge characteristics of TT-16S.

The stable formation temperature distribution was approximated using linear interpolations between tabulated data:

Vertical Depth (meters)	Temperature (Celsius)
0	20
800	60
1000	110
1300	205
1740	230

The February 16, 1989 test data (wellhead pressure, and downhole surveys) were simulated using the following model parameters:

Flowing Feedzone Temperature, $T_f = 212°C$
Productivity Index, $PI = 0.82$ kg/s-bar
Effective Thermal Conductivity, $K = 9$ W/m-°C
Friction Factor, $\varepsilon = 0.11$ mm

The computed wellhead pressure (1.49 bars) compares favorably with the measured value (1.47 bars). Downhole temperature and pressure measurements (Figures 5.79 and 5.80) are also in good agreement with computed values.

A four-week discharge test of TT-16S was carried out from November 22, 1991 to December 18, 1991. The well was discharged at a more or less constant rate (87 ± 5 tons/hour) during the latter test. Somewhat surprisingly, the wellhead pressure increased by about one (1) bar (from ~2 bars to over 3 bars) around December 8, 1991.; the reasons for this change in wellhead pressure are not known to the authors. Because of the more or less discontinuous change in wellhead pressure on December 8, 1991, it was decided to simulate only the characteristic data obtained after the latter date. The December 1991 characteristic data were simulated using a feedzone temperature of 230°C and an effective thermal conductivity of 11 W/m-°C; all other model parameters were assumed to be identical with those for the February 1989 test. The computed characteristic curve is compared with measurements in Figure 5.81. Considering the scatter in data, the agreement between the computed values and measurements is satisfactory. Based on the computed characteristic curve, the maximum discharge rate for TT-16S is ~111 tons/hour.

5.3 Comparison of Discharge Rate Predictions for "Oguni-Sumikawa Type" Wells

Several interesting conclusions can be drawn from the mathematical models of Takigami boreholes presented in Subsection 5.2. Many of the Takigami slim holes (NE-5(i1), NE-5(i2), NE-6(i1), NE-6(i2), and NE-11) have part of their discharge directed through the annulus between the

Continued on page 5-102

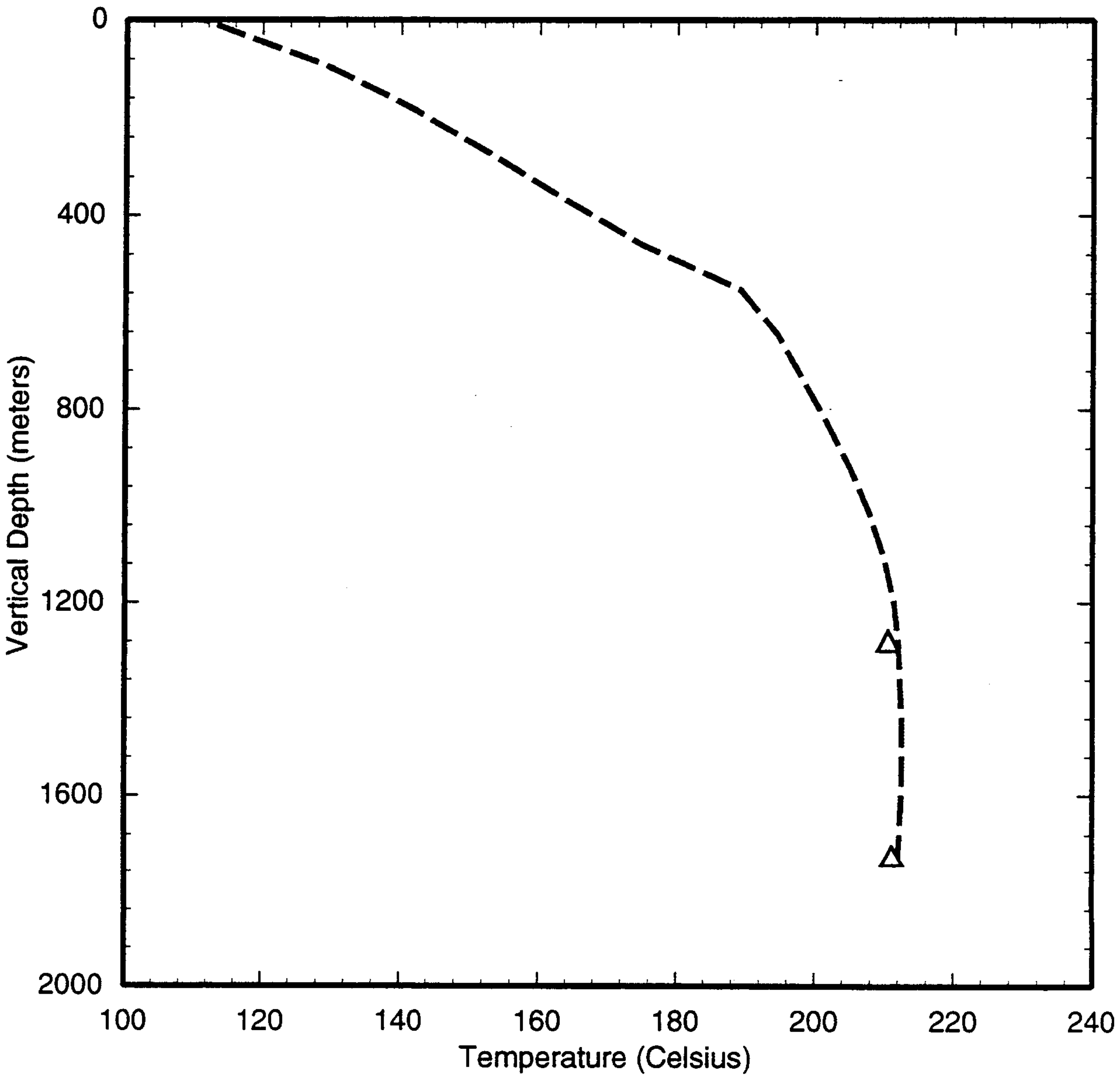

Figure 5.79. Temperature profile recorded in discharging TT-16S on February 16, 1989. The well discharged 55 tons/hour (15.3 kg/s) at a wellhead pressure of 1.47 bars. The dashed line is the computed temperature profile.

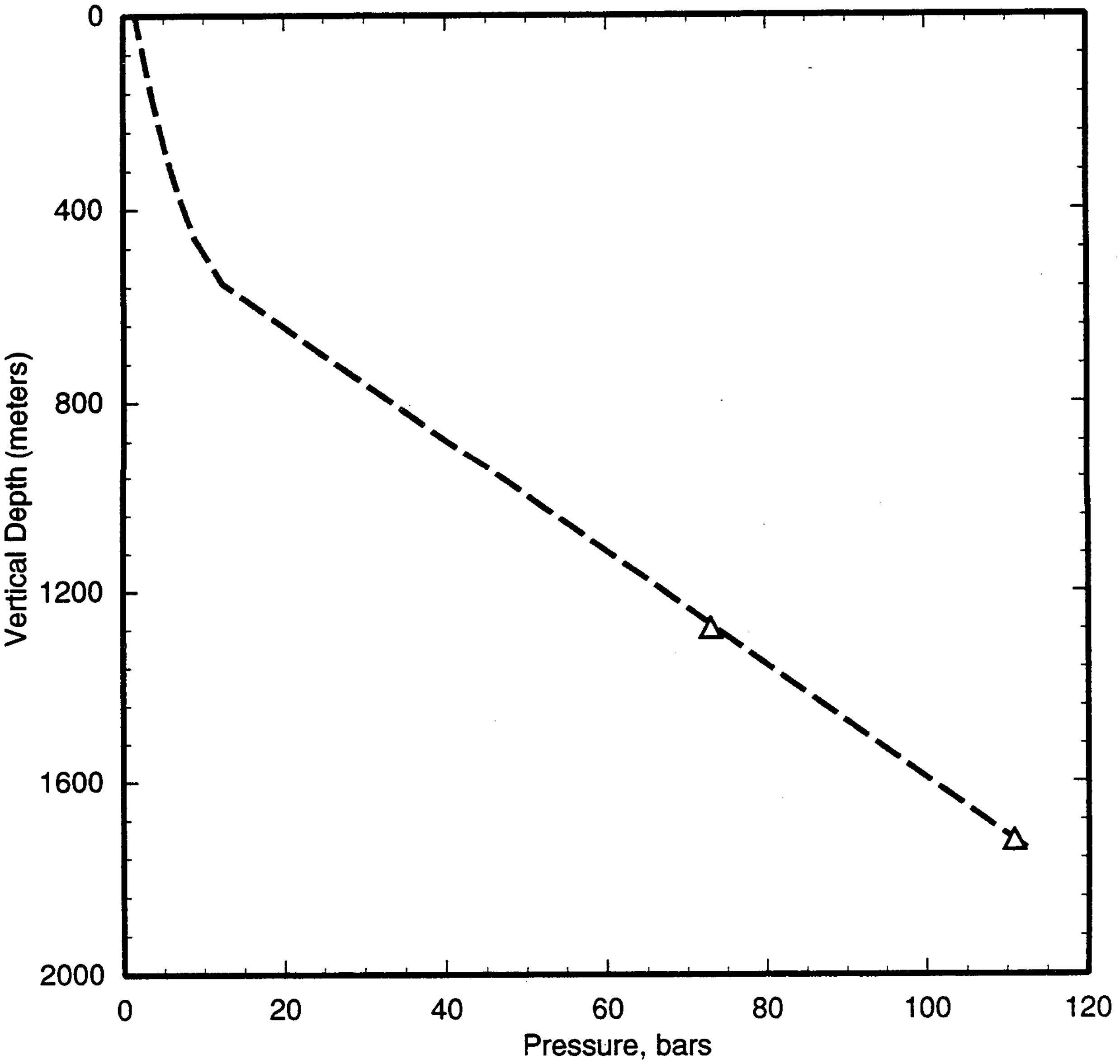

Figure 5.80. Pressure profile recorded in discharging TT-16S on February 16, 1989. The well discharged 55 tons/hour (15.3 kg/s) at a wellhead pressure of 1.47 bars. The dashed line is the computed pressure profile.

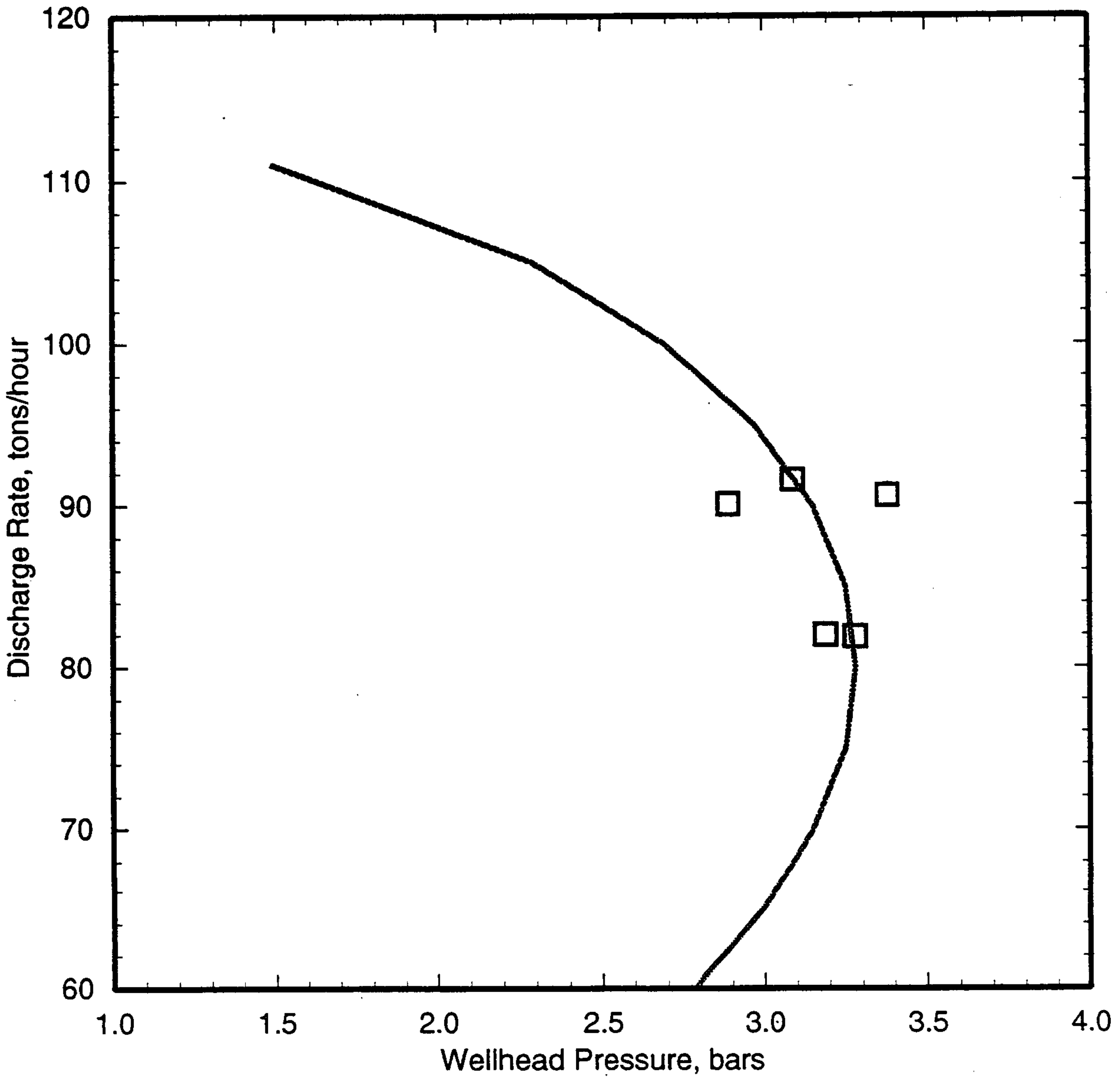

Figure 5.80. Discharge rate versus wellhead pressure for large-diameter production well TT-16S recorded during the later part (December 10, 1991–December 18, 1991) of the November–December 1991 discharge test. The solid line denotes the computed characteristic curve for TT-16S.

"cemented" casing and the formation. A simple algebraic scaling rule (*e.g.*, Pritchett's scaling rule) cannot be used to predict the discharge rate of large-diameter wells based on discharge data from these slim holes. For boreholes with poor injectivity/ productivity (*e.g.*, slim hole NE-4), the pressure loss in the formation cannot be neglected, and detailed models of fluid flow in the borehole are needed to make useful predictions. As an example, the predicted discharge rate (18 tons/hour) for an "Oguni-Sumikawa type" well using the detailed mathematical model for slim hole NE-4 is only a small fraction of the scaled maximum discharge rate (144 tons/hour) given in Table 5.2. As remarked elsewhere in this report, Pritchett (1993) invoked three key assumptions (*i.e.*, (1) liquid feedzone, (2) uniform wellbore diameter, and (3) large productivity index) in deriving his scaling rule. Clearly, the scaling rule should not be expected to apply in situations where one or more of the key assumptions do not hold.

With the single exception of well TT-16S, all of the large-diameter Takigami production wells have a non-uniform internal diameter (318 mm ID casing in the upper part, 224 mm ID casing in the middle part, and 216 mm ID open hole). For production well TT-7, internal diameter of the cemented casing in the upper part of the borehole is 381 mm. By way of contrast, most geothermal production wells at the Oguni and Sumikawa Geothermal Fields are completed with a 224 mm ID cased interval and a 216 mm ID open hole. Mathematical modeling of large-diameter production wells (Subsection 5.2) implies that the diameter of the upper section has a large influence on the discharge capacity of a borehole. As an example, a reduction in the diameter of the upper section from 381 mm to 224 mm for well TT-7 results in an almost 70 percent decrease in the discharge capacity (*i.e.*, from 490 tons/hour to 144 tons/hour). For the existing large-diameter Takigami wells, the two-phase part of the flow column is contained entirely within the upper cased interval. Since the pressure drop in the two-phase flow regime is a strong function of well diameter, the large diameter for the upper section is largely responsible for the large discharge capacity (relative to "Oguni-Sumikawa type" wells) of Takigami wells.

Predicted maximum discharge rates for "Oguni-Sumikawa type" wells based on modeling of Takigami boreholes (Subsection 5.2) are tabulated in Table 5.3. The predicted average discharge rate obtained using Takigami slim hole data, is 123 tons/ hour. Slim hole NE-4 was drilled in an unproductive part of the Takigami Geothermal Field. Excluding the discharge rate prediction corresponding to NE-4 in Table 5.3, the predicted average discharge rate (using slim hole data) is 138 tons/hour. The latter value is in exact agreement with the predicted average discharge rate obtained from the modeling of large-diameter Takigami wells. Although the exact agreement between the two predicted average discharge rates is fortuitous, it can be safely concluded that the Takigami discharge data are consistent with the premise that it is possible to predict the discharge characteristics of large-diameter geothermal wells (with liquid feedzones) based on discharge data for slim holes.

Table 5.3. Predicted maximum discharge rates for "Oguni-Sumikawa type" wells based on measured discharge charcteristics for Takigami boreholes.

Borehole Name	Open Hole Diameter (mm)	Measured Discharge Rate* (tons/hour)	Predicted Maximum Discharge Rate** (tons/hour)
NE-3	101	23	168
NE-4	79	11	18
NE-5(i1)	98	36	210
NE-5(i2)	98	31	188
NE-6(i1)	100	26	118
NE-6(i2)	100	25	116
NE-11	100	20	60
NE-11R	100	12	103
Average (NE-3 to NE-11R)			123
TT-2	216	260	135
TT-7	216	490	144
TT-8S3	216;	180	130
TT-13S	216	200	131
TT-14R	216	280	178
TT-16S	216	90	111
Average			138

* In most cases, measured discharge rate is the maximum discharge rate reported for a borehole.

** Predicted discharge rate is for an "Oguni-Sumikawa type" well (22.44 cm ID cased interval, and a 21.59 cm ID open interval).

Conclusions and Recommendations

Discharge and injection data from slim holes and large-diameter wells at the Takigami Geothermal Field were analyzed to establish relationships (1) between injectivity and productivity indices of slim holes and large-diameter wells, (2) between productivity/injectivity indices and borehole diameter, and (3) between discharge capacity of slim holes and large-diameter wells. Reservoir pressures and temperatures at Takigami are such that the reservoir fluid is single-phase liquid. Furthermore, discharge from Takigami boreholes does not induce *in situ* boiling.

The productivity and injectivity indices for Takigami boreholes are more or less equal. The latter conclusion is in accord with similar data for Oguni and Sumikawa boreholes with liquid feedzones. Based on the rather large volume of data from these three geothermal fields, it can be concluded that in the absence of discharge testing, the injectivity index may be used to characterize the flow resistance of naturally fractured geothermal reservoir rocks to liquid production.

The productivity and injectivity indices for Takigami boreholes display no correlation with borehole diameter. Garg *et al.* (1995b) noted that while the injectivity indices for the Sumikawa boreholes show no systematic variation with borehole diameter, both the productivity and injectivity indices for the Oguni boreholes display a strong dependence on borehole diameter. It was suggested by Garg *et al.* (1995a) that enhanced formation plugging in slim holes (caused by blind drilling *i.e.*, drilling with total mud loss) is responsible for the variation of productivity/injectivity indices with diameter at Oguni. In so far as blind drilling was not required at Sumikawa, Garg and Combs (1995) indicated that enhanced formation plugging is not a factor at Sumikawa. Since many of the Takigami slim holes were drilled with a total loss of circulation, the absence of a correlation between productivity/injectivity indices and borehole diameter at Takigami tends to cast doubt on the explanation advanced by Garg *et al.* (1995a). Data from additional geothermal fields would be helpful in determining if enhanced formation plugging in boreholes drilled with coring rigs is an isolated or a pervasive phenomenon. In any event, the productivity/injectivity indices for slim holes provide a lower bound on the corresponding indices for large-diameter wells. Thus, the productivity index (or more importantly, injectivity index in the absence of discharge data) from a slim hole with a liquid feed can be used to provide a first estimate of the probable discharge capacity of a large-diameter geothermal production well.

Unlike a typical "Oguni/Sumikawa" geothermal production well, most of the Takigami production wells are completed with a 13-$^3/_8$ inch cemented casing (31.8 cm ID) in the upper part, 9-$^5/_8$ inch casing (22.4 cm ID) in the middle section, and a 8-$^1/_2$ inch (21.6 cm) open hole in the lower part of the borehole. Because of non-uniform internal diameter, a simple algebraic scaling rule (*e.g.*, Pritchett's scaled maximum discharge rate) cannot be used to relate the discharge rates for slim holes and production wells at Takigami. A wellbore simulator (WELBOR) was, therefore, employed to model the discharge characteristics of both the slim holes and large-diameter wells at Takigami; the model parameters were used to calculate the probable discharge characteristics of "Oguni/Sumikawa" type wells. The predicted average maximum rate discharge (for "Oguni/Sumikawa" type wells) using Takigami slim hole data is identical with that obtained from large-diameter production wells at Takigami. Thus, the Takigami data imply that the discharge characteristics of large-diameter wells may be predicted based on test data for slim holes.

Modeling of large-diameter wells also suggests that using large-diameter casing in the two-phase section of the well has a large beneficial effect on discharge capacity of geothermal wells with liquid feeds and moderate to good productivity. By way of contrast, increasing well diameter in the liquid portion of the well has little influence on the discharge capacity. Also for wells with low productivity, the discharge rate is largely independent of well diameter. These results suggest the importance of well design. For optimum performance, the well design should include consideration of fluid state (pressure, temperature, gas content, *etc.*) and formation characteristics (*e.g.*, productivity index).

The analyses of discharge and injection data from Takigami boreholes, together with earlier analyses for Oguni, Sumikawa, and Steamboat Hills Geothermal Fields, provide a validation of the premise that it should be possible to forecast the performance of large-diameter wells (with liquid feeds) using discharge and/or injection data from slim holes (with liquid feeds). Currently available data and analyses are, however, insufficient to predict the discharge characteristics of large-diameter wells with two-phase feeds based on slim hole data. Because of relative permeability effects in two-phase flow, the productivity index (with *in situ* boiling) is likely to be much smaller than the injectivity index. Additional studies are required to understand relationships (1) between injectivity index and two-phase productivity index, (2) between borehole diameter and two-phase productivity index, and (3) between well completion (*i.e.*, diameter) and the discharge capacity of boreholes with two-phase feeds. Data from a set of high-temperature geothermal fields spanning a wide range of transmissivities are needed for these latter studies.

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Appendix A

Drilling and Completion Data for Takigami Boreholes

```
NE-2R -- Borehole Summary

Surface Elevation: 746.0 mASL
Coordinates:       East=  1181.9
                   North= 2838.7
Vertical Borehole? T
Vertical depth:    2010.0 meters
Total depth:       2010.0 meters

History:
Start Time      End Time        Status
------------------------------------------
21jul82 00:00   30sep82 00:00   Drilling
14dec82 16:30                   ShutIn
21feb84 00:00                   ShutIn

=============================================================================
NE-2R -- Lost circulation

starting    ending    starting    ending
   depth*    depth*       rate#     rate#
   -------------------------------------------------------
    59.0     130.0          10         0  750 l/m
   477.6     479.3         750       750  total loss
   479.4     502.3          40        30  750 l/m
   557.0     566.0          45        45  750 l/m
   566.1     651.0          34         0  750 l/m
   662.0     706.4          20        22  650 l/m
   711.3     712.0         450       450  total loss
   954.5     976.0          37        37  450 l/m
   976.1     983.0          50        70  450 l/m
   983.1    1013.7          60        30  450 l/m
  1104.4    1104.4           8         8  275 l/m
  1139.2    1139.7         275       275  total loss
  1159.6    1524.3         140        60  275 l/m
  1524.4    1604.4          46        60  140 l/m
  1604.5    1618.2         130       130  total loss
  1618.3    1634.4         120       140  140 l/m
  1634.5    1700.0         140       140  total loss
  1700.1    2010.0         130       130  total loss

* Measured Depth (m)
# l/min
=============================================================================
NE-2R -- Hole/Casing data

starting     ending
   depth*     depth*      hole_size     casing_size
----------------------------------------------------------------
     0.0       31.4         17 1/2"          14"SGP  cemented
     0.0      203.3         12 1/4"      9 5/8" H40  cemented
     0.0      649.7          8 5/8"          7" H40  cemented
     0.0     1093.2          6 1/4"      4 1/2" J55  cemented
   800.0     1685.6       101 mm HQ      79 mm NQNU  cemented
  1665.0     2010.0        79 mm NQ      76 mm BW ?  uncemented

slotted regions:
   1685.6     2010.0

* Measured Depth (m)
=============================================================================
NE-2R -- Stratigraphy data

starting   ending
   depth*   depth*  maj.code  maj.name     min.code   min.name
------------------------------------------------------------------------

     0.0  1806.5      ND     Undefined        -      -
  1806.5  2010.0      TL     Lower Takigami  -      -

* Measured Depth (m)
=============================================================================
NE-2R -- Deviation data (m)

Meas.depth  Vert.depth     E_dev.     N_dev.
-------------------------------------------
      0.0         0.0       0.00       0.00
   2010.0      2010.0       0.00       0.00
```

```
NE-3 -- Borehole Summary

Surface Elevation: 693.8 mASL
Coordinates:       East=  1093.9
                   North= 3522.8
Vertical Borehole? T
Vertical depth:    2303.1 meters
Total depth:       2303.1 meters

History:
Start Time      End Time        Status
----------------------------------------
18may82 00:00   27feb83 00:00   Drilling
26jul82 00:00                   ShutIn
09sep82 12:00                   ShutIn
17oct82 00:00                   ShutIn
18dec82 00:00                   ShutIn
01jun84 00:00                   ShutIn

=============================================================================
NE-3 -- Lost circulation

starting    ending    starting    ending
   depth*    depth*       rate#     rate#
   ---------------------------------------------------
  1067.2    1067.2          90         90  520 l/m
  1620.0    1620.0         465        465  480 l/m
  1677.1    1677.1         480        480  total loss
  1681.8    1681.8         480        480  total loss
  1684.8    1684.8         194        194  480 l/m
  1688.8    2303.2         160        160  total loss

* Measured Depth (m)
# l/min
=============================================================================
NE-3 -- Hole/Casing data

starting      ending
   depth*      depth*      hole_size     casing_size
-----------------------------------------------------------------
     0.0        33.0        17 1/2"          14" SGP   cemented
     0.0       221.9        12 1/4"       9 5/8"H40   cemented
     0.0       894.2         8 5/8"           7" H40   cemented
     0.0      1675.0         6 1/4"       4 1/2" H40   cemented
  1675.0      2300.0        101mm HQ       open hole
  2300.0      2303.1        80 mm NQ       open hole

* Measured Depth (m)
=============================================================================
NE-3 -- Stratigraphy data

starting   ending
   depth*   depth*  maj.code  maj.name       min.code   min.name
--------------------------------------------------------------------------
     0.0    489.0      NV     Noinedake Volcanics -        -
   489.0    515.0      KU     Kusu Formation  -        -
   515.0    812.0      AJ     Ajibaru Formation -        -
   812.0   1200.0      TU     Upper Takigami  -        -
  1200.0   1500.0      TM     Middle Takigami -        -
  1500.0   2303.1      TL     Lower Takigami  -        -

* Measured Depth (m)
=============================================================================
NE-3 -- Deviation data (m)

Meas.depth  Vert.depth     E_dev.      N_dev.

---------------------------------------------
     0.0         0.0        0.00        0.00
  2303.1      2303.1        0.00        0.00
```

```
NE-4 -- Borehole Summary

Surface Elevation: 707.0 mASL
Coordinates:       East=  1001.1
                   North= 3178.6
Vertical Borehole? F
Vertical depth:    2243.3 meters
Total depth:       2406.0 meters

History:
Start Time      End Time        Status
-----------------------------------------
22may85 00:00   24dec85 00:00   Drilling
29oct85 00:00                   ShutIn
27nov85 16:00                   ShutIn
27dec85 00:15                   ShutIn
16jan86 09:17                   Discharging
25jan86 00:30                   Discharging
05feb86 00:00                   ShutIn

=============================================================================
NE-4 -- Lost circulation

starting    ending    starting    ending
   depth*    depth*       rate#      rate#
   -------------------------------------------------------
   651.8     672.3          80         80  1050 l/m
  1062.5    1062.5         150        150  total loss
  1074.5    1074.5         150        150  total loss
  1079.4    1079.4          60         60  150 l/m
  1082.0    1082.0          80         80  300 l/m
  1092.5    1092.5          25         25  150 l/m
  1209.4    1209.4          80         40  150 l/m
  1312.5    1312.5          50         50  150 l/m
  1331.0    1331.0          50         50  150 l/m
  1390.0    1390.0          50         50  150 l/m
  1418.0    1418.0          50         50  150 l/m
  1438.5    1438.5          41         41  105 l/m
  1456.5    1456.5          40         40  105 l/m
  1478.0    1478.0          35         35  105 l/m
  1502.0    1502.0          50         50  105 l/m
  2014.5    2014.5          20         35  100 l/m
  2051.1    2051.1           9          9  95 l/m
  2389.7    2389.7          40         40  95 l/m
  2390.6    2390.6          95         95  total loss

* Measured Depth (m)
# l/min
=============================================================================
NE-4 -- Hole/Casing data

starting     ending
   depth*     depth*      hole_size      casing_size
-------------------------------------------------------------------
     0.0        30.0        14 3/4"              12"   cemented
     0.0       300.0        10 5/8"     8.625"H40/28   cemented
     0.0       989.4         7 5/8"      4.5"H40/9.5   cemented
     0.0      1490.8      101mm HQ        79mm NQNU    cemented
  1456.8      2399.0      79 mm NQ         76mm CHD    uncemented
  2399.0      2406.0      79 mm NQ        open hole

slotted regions:
   2002.8      2032.8
   2350.9      2398.9

* Measured Depth (m)
```

```
============================================================================
NE-4 -- Stratigraphy data

starting   ending
   depth*   depth*  maj.code  maj.name      min.code   min.name
-------------------------------------------------------------------------
     0.0    459.0      NV     Noinedake Volcanics -       -
   459.0    525.0      KU     Kusu Formation  -     -
   525.0   1032.0      AJ     Ajibaru Formation -     -
  1032.0   1324.0      TU     Upper Takigami  -     -
  1324.0   1743.0      TM     Middle Takigami -     -
  1743.0   2283.0      TL     Lower Takigami  -     -
  2283.0   2406.0      UF     Usa Group       -     -

* Measured Depth (m)
============================================================================
NE-4 -- Deviation data (m)

Meas.depth  Vert.depth     E_dev.     N_dev.
--------------------------------------------
     0.0          0.0       0.00       0.00
   100.0         99.6      -4.86       7.92
   200.0        199.3      -8.81      15.19
   300.0        299.1     -10.94      21.15
   400.0        398.6     -18.59      23.30
   500.0        497.7     -30.09      16.76
   600.0        595.4     -47.09       4.45
   700.0        690.7     -70.16     -14.97
   800.0        783.0    -102.01     -36.05
   900.0        868.7    -143.37     -66.54
  1000.0        950.3    -189.47    -101.25
  1100.0       1034.5    -235.94    -128.15
  1200.0       1120.1    -286.85    -135.26
  1300.0       1207.8    -334.71    -139.20
  1400.0       1297.1    -379.33    -145.87
  1500.0       1388.2    -420.03    -151.94
  1600.0       1478.1    -463.24    -158.67
  1700.0       1569.8    -501.71    -169.23
  1800.0       1664.5    -531.53    -180.66
  1900.0       1759.5    -560.78    -190.85
  2000.0       1853.9    -592.45    -197.23
  2100.0       1944.2    -630.58    -217.14
  2200.0       2039.9    -656.14    -230.89
  2300.0       2138.4    -672.08    -236.18
  2406.0       2243.3    -687.80    -236.23
```

```
NE-5 -- Borehole Summary

Surface Elevation: 874.1 mASL
Coordinates:       East=  1856.2
                   North= 2368.9
Vertical Borehole? F
Vertical depth:    1999.4 meters
Total depth:       2003.1 meters

History:
Start Time      End Time        Status
------------------------------------------
27oct84 00:00   22may85 00:00   Drilling
15feb85 16:40   16feb85 21:25   Discharging
15mar85 14:30   17mar85 22:00   Discharging
18mar85 11:00                   ShutIn
18may85 08:17                   ShutIn
19may85 09:00                   ShutIn
18mar85 08:05   18mar85 11:00   Injection

============================================================================
NE-5 -- Lost circulation

starting    ending    starting    ending
   depth*    depth*       rate#     rate#
   ---------------------------------------------------------
    75.5      75.5         160       160  1000 l/m
   112.1     127.4         180       180  1000 l/m
   127.5     127.5        1045      1045  total loss
   130.0     130.0         360       400  1000 l/m
   713.0     718.0         100       100  total loss
   718.0     748.0          45        45  100
   748.0     758.0         100       100  total loss
   758.0     810.0          45        45  ?
   810.0     853.0          35        35  ?
   853.0     898.0          45        45  ?
   898.0     938.0          72        72  ?
   938.0     969.0          36        36  ?
   969.0     995.0          45        45  ?
   995.0    1000.5          40        40  ?
  1077.1    1077.1         120       120  total loss
  1109.6    1228.6         120       120  total loss
  1228.6    1289.1         200       200  total loss
  1427.6    1427.6         200       200  total loss
  1440.2    1442.0         140         5  ?
  1447.0    1517.0         140       140  total loss
  1550.7    1550.7         100       100  total loss
  1637.3    1649.8         100       100  total loss
  1752.5    1799.9         100       100  total loss
  1800.0    2003.1         150       150  total loss

* Measured Depth (m)
# l/min
============================================================================
NE-5 -- Hole/Casing data

starting     ending
  depth*      depth*      hole_size     casing_size
-------------------------------------------------------------------
     0.0       32.2       14 3/4"          12" SGP   cemented
     0.0      301.0       10 5/8"     8.625"H40/28   cemented
     0.0      997.0        6 1/4"      4.5"J55/9.5   cemented
   992.0     1428.3       98mm HQ       79mm NQNU    cemented
  1356.1     1950.2      79 mm NQ         2.5"STPG   uncemented
  1950.2     2003.1      79 mm NQ        open hole

slotted regions:
   1848.9      1950.2

* Measured Depth (m)
```

```
============================================================================
NE-5 -- Stratigraphy data

starting   ending
  depth*    depth*  maj.code  maj.name     min.code   min.name
------------------------------------------------------------------------
    0.0     559.0     NV      Noinedake Volcanics -       -
  559.0     571.0     KU      Kusu Formation  -       -
  571.0     900.0     AJ      Ajibaru Formation -       -
  900.0    1056.0     TU      Upper Takigami  -       -
 1056.0    2003.1     UF      Usa Group       -       -

* Measured Depth (m)
============================================================================
NE-5 -- Deviation data (m)

Meas.depth  Vert.depth     E_dev.     N_dev.
-------------------------------------------
     0.0          0.0       0.00       0.00
   100.0        100.0       0.00      -0.19
   200.0        200.0       0.77      -0.24
   300.0        300.0       2.36      -0.92
   400.0        400.0       3.14      -1.07
   500.0        500.0       4.37      -0.95
   600.0        600.0       4.82      -1.06
   700.0        700.0       4.99      -1.18
   800.0        800.0       5.34      -1.31
   900.0        900.0       6.84      -1.41
  1000.0        999.9       8.37      -1.03
  1100.0       1099.9      11.05       0.19
  1200.0       1199.7      17.63      -1.72
  1300.0       1299.3      20.67       5.93
  1400.0       1398.9      29.18       8.25
  1500.0       1498.5      38.51       9.20
  1600.0       1598.1      46.61       8.69
  1700.0       1697.8      55.17       7.18
  1800.0       1797.4      63.74       5.84
  1900.0       1896.8      74.00       4.07
  2003.1       1999.4      84.63       2.24
```

```
NE-6 -- Borehole Summary

Surface Elevation: 896.8 mASL
Coordinates:       East=  2713.2
                   North= 3410.7
Vertical Borehole? T
Vertical depth:    1881.7 meters
Total depth:       1881.7 meters

History:
Start Time      End Time        Status
-------------------------------------------
28oct84 00:00   10may85 00:00   Drilling
17mar85 10:00                   ShutIn
24apr85 11:43                   ShutIn
24apr85 22:55                   ShutIn

==========================================================================
NE-6 -- Lost circulation

starting    ending    starting    ending
   depth*    depth*       rate#     rate#
   --------------------------------------------------------
    50.6      50.6         600       600  total loss
    64.6      64.6         134       600  600 l/m
    85.2      85.2          40       250  450 to 600 l/m
   126.2     126.2         348       348  600 l/m
   194.0     194.0         292        97  450 to 750 l/m
   199.3     199.3         435       600  total loss
   238.0     238.0         380        40  741 l/m
   289.2     289.2         381       612  total loss
   301.4     301.4         381       936  total loss
   596.0     596.0          40        70  total loss
   608.1     608.1          70       133  total loss
   629.3     629.3          70        70  total loss
   704.1     704.1          70       133  total loss
   763.5     860.0         300       300  total loss
   860.0    1403.0         120       120  total loss
  1410.9    1410.9          26        26  46 l/m
  1434.1    1881.7          46        46  total loss

* Measured Depth (m)
# l/min
==========================================================================
NE-6 -- Hole/Casing data

starting    ending
   depth*    depth*      hole_size     casing_size
-------------------------------------------------------------
     0.0      36.1         14 3/4"         12" SGP   cemented
     0.0     300.0          9 5/8"          7" H40   cemented
     0.0     684.0          6 1/4"        4.5" J55   cemented
   668.7    1400.0       100 mm HQ     82mm NQNU?   cemented
  1392.4    1881.7      80.9 mm NQ     2 1/2"STPG   uncemented

slotted regions:
   1779.5     1881.7

* Measured Depth (m)
==========================================================================
NE-6 -- Stratigraphy data

starting   ending
   depth*   depth*  maj.code  maj.name     min.code   min.name
-------------------------------------------------------------------------
     0.0   451.7       NV     Noinedake Volcanics -       -

   451.7  1881.7       UF     Usa Group        -       -

* Measured Depth (m)
==========================================================================
NE-6 -- Deviation data (m)

Meas.depth  Vert.depth      E_dev.      N_dev.
---------------------------------------------
      0.0          0.0       0.00        0.00
   1881.7       1881.7       0.00        0.00
```

```
NE-9 -- Borehole Summary

Surface Elevation: 914.0 mASL
Coordinates:       East=  1931.3
                   North= 4033.9
Vertical Borehole? F
Vertical depth:    1147.8 meters
Total depth:       1151.6 meters

History:
Start Time       End Time        Status
-----------------------------------------
03jul85 00:00   12mar86 00:00   Drilling
24nov85 00:00                   ShutIn
24nov85 17:00                   ShutIn
04dec85 21:40                   ShutIn
06dec85 08:00                   ShutIn
12feb86 11:30                   ShutIn
22feb86 09:00                   ShutIn
12mar86 00:00                   ShutIn

============================================================================
NE-9 -- Lost circulation

starting    ending    starting    ending
   depth*    depth*       rate#     rate#
   ---------------------------------------------------
    10.1      12.8         850       850  total loss
    87.9      87.9         850       850  total loss
    99.5     173.5         170       170  total loss
   181.5     217.3         130       130  total loss
   218.2     227.0         130       130  total loss
   228.9     245.5         130       130  total loss
   255.0     310.5          80        80  total loss
   313.4     344.4         105       105  total loss
   344.5     370.5          90        90  total loss
   370.9     534.0          80        80  total loss
   534.0     748.0         100       100  total loss
   748.0     755.6          80        80  total loss
   770.0     788.2          80        80  total loss
   788.4     800.5          90        90  total loss
   855.0    1099.7          90        90  total loss
  1100.3    1110.5          20        30  60 l/m
  1110.5    1151.6          60        60  total loss

* Measured Depth (m)
# l/min
============================================================================
NE-9 -- Hole/Casing data

starting     ending
   depth*     depth*      hole_size     casing_size
--------------------------------------------------------------
    0.0        33.5          9 5/8"          7"  H40    cemented
    0.0       172.1          6 1/4"        4.5" J55     cemented
    0.0       747.2       100 mm HQ      82mm NQNU?     cemented
    0.0      1080.0        80 mm NQ      2 1/2"STPG     cemented
 1067.1      1151.6      59.94mm BQ      58.4mm BQ?     uncemented

slotted regions:
   1080.0     1151.6

* Measured Depth (m)
============================================================================
NE-9 -- Stratigraphy data

starting   ending
   depth*   depth*  maj.code  maj.name       min.code   min.name
--------------------------------------------------------------------------
    0.0    387.2      NV     Noinedake Volcanics -        -
  387.2    806.7      AJ     Ajibaru Formation -        -
  806.7    886.6      TM     Middle Takigami -        -
  886.6   1151.6      TL     Lower Takigami  -        -

* Measured Depth (m)
```

```
=============================================================================
NE-9 -- Deviation data (m)

Meas.depth  Vert.depth     E_dev.     N_dev.
--------------------------------------------
       0.0         0.0       0.00       0.00
     100.0        99.9       0.00       0.00
     200.0       199.8      -1.64       4.04
     300.0       299.6      -4.31       9.52
     400.0       399.4      -7.90      14.45
     500.0       499.2     -11.49      20.43
     600.0       598.9     -15.34      26.59
     700.0       698.5     -19.29      34.69
     800.0       798.0     -24.20      43.92
     900.0       897.5     -26.92      53.41
    1000.0       997.0     -29.62      63.50
    1100.0      1096.5     -32.50      73.55
    1151.6      1147.8     -33.99      78.74
```

```
NE-10 -- Borehole Summary

Surface Elevation: 831.8 mASL
Coordinates:       East=  1065.7
                   North= 2002.5
Vertical Borehole? F
Vertical depth:    2164.0 meters
Total depth:       2174.0 meters

History:
Start Time      End Time        Status
-----------------------------------------
17jul85 00:00   04dec85 00:00   Drilling
27sep85 00:00                   ShutIn
14oct85 11:45                   ShutIn
15oct85 22:00                   ShutIn
31oct85 10:00                   ShutIn
07nov85 00:00                   ShutIn
15nov85 20:00                   ShutIn
24nov85 20:00                   ShutIn
05dec85 14:00                   ShutIn
14dec85 12:00                   ShutIn
14dec85 23:10                   ShutIn

=============================================================================
NE-10 -- Lost circulation

starting   ending   starting   ending
   depth*   depth*     rate#     rate#
   ----------------------------------------------------
    68.7     68.7        70        70  700 l/m
   128.2    128.2       700       700  total loss
   277.5    277.5        55        55  700 l/m
   375.0    375.0        90        15  700 l/m
   535.1    535.1       700       700  total loss
   546.6    557.2       270       270  total loss
   557.2    609.8       150       150  total loss
   609.8    666.4       200       140  total loss
   694.0    729.7        95        40  120 to 80 l/m
   769.2    769.2        80        80  total loss
   769.3    782.1        80        75  80 l/m
   782.1   1205.0        52        79  total loss
  1497.0   1497.0        10        10  60 l/m
  1650.8   2174.0        60        60  total loss

* Measured Depth (m)
# l/min
=============================================================================
NE-10 -- Hole/Casing data

starting    ending
   depth*    depth*     hole_size     casing_size
-------------------------------------------------------------------
     0.0      30.8        12 1/4"              10"   cemented
     0.0     205.0         9 5/8"       7"H-40/20    cemented
     0.0     724.0         6 1/4"     4.5"J55/9.5    cemented
     0.0    1204.0       101mm HQ      79 mm NQNU    cemented
  1179.1    2174.0       79 mm NQ      2 1/2"STPG    uncemented

slotted regions:
   1496.8     1704.3
   2064.7     2174.0

* Measured Depth (m)
=============================================================================
NE-10 -- Stratigraphy data

starting  ending
   depth*  depth* maj.code  maj.name      min.code   min.name
-------------------------------------------------------------------------
     0.0    650.0     NV    Noinedake Volcanics -      -
   650.0    999.0     AJ    Ajibaru Formation -      -
   999.0   1247.0     TU    Upper Takigami  -      -
  1247.0   1602.0     TM    Middle Takigami -      -
  1602.0   2145.0     TL    Lower Takigami  -      -
  2145.0   2174.0     UF    Usa Group       -      -

* Measured Depth (m)
```

```
==================================================================================
NE-10 -- Deviation data (m)

Meas.depth  Vert.depth      E_dev.      N_dev.
-----------------------------------------------
       0.0         0.0        0.00        0.00
     100.0       100.0       -1.08       -0.13
     200.0       200.0       -2.80       -0.40
     300.0       299.9       -5.79       -0.20
     400.0       399.7      -12.05        0.61
     500.0       499.0      -23.42        3.13
     600.0       597.9      -37.96        7.36
     700.0       696.2      -55.68       11.31
     800.0       794.9      -71.19       15.52
     900.0       893.9      -82.66       23.36
    1000.0       993.2      -92.85       30.02
    1100.0      1092.7     -101.51       34.06
    1200.0      1192.2     -111.68       34.29
    1300.0      1291.7     -121.24       36.88
    1400.0      1391.3     -129.55       38.34
    1500.0      1491.0     -137.07       40.44
    1600.0      1590.8     -143.74       42.59
    1700.0      1690.6     -149.87       45.30
    1800.0      1790.4     -155.36       48.00
    1900.0      1890.3     -159.88       49.97
    2000.0      1990.1     -164.81       53.09
    2100.0      2090.0     -169.42       52.41
    2174.0      2164.0     -169.82       52.92
```

```
NE-11 -- Borehole Summary

Surface Elevation: 825.7 mASL
Coordinates:       East=  1298.3
                   North= 1439.3
Vertical Borehole? F
Vertical depth:    1381.6 meters
Total depth:       1447.7 meters

History:
Start Time      End Time        Status
------------------------------------------
18apr86 00:00   07sep86 00:00   Drilling
07sep86 00:00                   ShutIn

===========================================================================
NE-11 -- Lost circulation

starting    ending    starting    ending
   depth*    depth*       rate#     rate#
   --------------------------------------------------------
    31.2      31.2        1000      1000  total loss
    58.1      64.1        1000      1000  total loss
    66.2      66.2          60        60  1000 l/m
    70.0      84.3        1000      1000  total loss
   132.2     133.0        1000      1000  total loss
   235.0     235.0        1000      1000  total loss
   400.6     429.5          50         0  800 l/m
   430.5     430.5         150       150  total loss
   503.5     518.0         300        20  800 l/m
   556.0     564.0         600         7  600 l/m
   567.4     586.7         600        30  600 l/m
   666.3     666.3         600       600  total loss
   694.0     716.0          35        16  600 l/m
   716.3     717.3         600         0  600 l/m
   717.3     790.9          40        20  600 l/m
   910.2     911.5          45        30  600 to 500 l/m
  1104.7    1104.7         130       130  total loss
  1104.7    1236.6          30        10  130 l/m
  1236.7    1238.3          47        60  140 l/m
  1239.5    1241.8         140       120  total loss
  1265.0    1447.7         100       100  total loss

* Measured Depth (m)
# l/min
===========================================================================
NE-11 -- Hole/Casing data

starting     ending
   depth*     depth*      hole_size     casing_size
-------------------------------------------------------------
     0.0       30.0        17 1/2"          14"SGP   cemented
     0.0      208.5        12 1/4"       9 5/8"H40   cemented
     0.0      901.8         8 1/2"          7" H40   cemented
     0.0      825.7         8 1/2"          4 1/2"   cemented
   901.8     1447.7        100mm HQ     open hole ?  uncemented

* Measured Depth (m)
===========================================================================
NE-11 -- Stratigraphy data

starting   ending
   depth*   depth*  maj.code  maj.name       min.code   min.name
----------------------------------------------------------------------
     0.0    700.0      NV     Noinedake Volcanics -        -
   700.0   1107.0      TU     Upper Takigami  -        -
  1107.0   1447.7      TM     Middle Takigami -        -


* Measured Depth (m)
```

```
===============================================================================
NE-11 -- Deviation data (m)

Meas.depth  Vert.depth      E_dev.      N_dev.
---------------------------------------------
       0.0         0.0        0.00        0.00
     100.0        99.9       -2.62        0.91
     200.0       199.9       -4.14        0.02
     300.0       299.9       -4.56        1.16
     400.0       399.1        6.73        2.49
     500.0       496.6       28.60        4.53
     600.0       591.0       61.13        8.90
     700.0       683.5       98.88       12.33
     800.0       775.2      138.65       16.42
     900.0       866.6      178.91       21.05
    1000.0       957.9      219.39       24.93
    1100.0      1050.2      256.72       34.19
    1200.0      1144.5      289.03       42.74
    1300.0      1239.7      318.22       51.83
    1400.0      1335.7      344.81       60.39
    1447.7      1381.6      357.37       64.00
```

```
NE-11R -- Borehole Summary

Surface Elevation: 825.7 mASL
Coordinates:       East=  1298.3
                   North= 1439.3
Vertical Borehole? F
Vertical depth:    1889.3 meters
Total depth:       2000.4 meters

History:
Start Time       End Time        Status
-------------------------------------------
22sep86 00:00   21feb87 00:00   Drilling
25dec86 00:00                   ShutIn
28dec86 00:00                   ShutIn
18feb87 18:30                   ShutIn

==============================================================================
NE-11R -- Lost circulation

starting    ending    starting    ending
   depth*    depth*       rate#     rate#
   -----------------------------------------------------
    31.2      31.2        1000      1000  total loss
    58.1      64.1        1000      1000  total loss
    66.2      66.2          60        60  1000 l/m
    70.0      84.3        1000      1000  total loss
   132.2     133.0        1000      1000  total loss
   235.0     235.0        1000      1000  total loss
   400.6     429.5          50         0  800 l/m
   430.5     430.5         150       150  total loss
   503.5     518.0         300        20  800 l/m
   556.0     564.0         600         7  600 l/m
   567.4     586.7         600        30  600 l/m
   666.3     666.3         600       600  total loss
   694.0     716.0          35        16  600 l/m
   716.3     717.3         600         0  600 l/m
   717.3     790.9          40        20  600 l/m
  1115.5    1115.5         600       750  total loss
  1119.4    1119.4         115       115  600 l/m
  1123.2    1160.2          90        30  600 l/m
  1253.3    1352.7          20        70  550 to 570 l/m
  1352.8    1377.6         100       140  570 l/m
  1377.7    1387.4         200       120  550 l/m
  1387.5    1413.0         200       300  550 l/m
  1413.1    1444.9          80       180  550 l/m
  1445.0    1474.6         190       140  550 l/m
  1474.7    1500.0         150       160  total loss
  1540.0    1540.0         160       160  total loss
  1655.4    1700.0         160       160  total loss
  1730.0    1730.0         180       180  total loss
  1822.9    1822.9         560       560  total loss
  1837.7    2000.4         180       180  total loss

* Measured Depth (m)
# l/min
==============================================================================
NE-11R -- Hole/Casing data

starting     ending
   depth*     depth*      hole_size     casing_size
-------------------------------------------------------------------
     0.0       30.0        17 1/2"           14"SGP   cemented
     0.0      208.5        12 1/4"       9 5/8"H40    cemented
     0.0      901.2         8 1/2"           7" H40   cemented
     0.0     1452.0         6 1/4"       4 1/2"H40    cemented
  1430.2     2000.4        100mm HQ      79mm NQNU    uncemented

slotted regions:
   1472.3     1478.3
   1480.3     1486.3
   1670.3     1676.3
   1772.3     1778.3
   1868.3     1874.3
   1952.3     1970.3

* Measured Depth (m)
```

```
===========================================================================
NE-11R -- Stratigraphy data

starting   ending
   depth*   depth*  maj.code  maj.name     min.code   min.name
-----------------------------------------------------------------------
     0.0    700.0     NV      Noinedake Volcanics -       -
   700.0   1107.0     TU      Upper Takigami  -      -
  1107.0   1590.0     TM      Middle Takigami -      -
  1590.0   2000.4     UF      Usa Group       -      -

* Measured Depth (m)
===========================================================================
NE-11R -- Deviation data (m)

Meas.depth  Vert.depth      E_dev.     N_dev.
--------------------------------------------
      0.0         0.0       0.00       0.00
    100.0        99.9      -2.62       0.91
    200.0       199.9      -4.14       0.02
    300.0       299.9      -4.56       1.16
    400.0       399.1       6.73       2.49
    500.0       496.6      28.60       4.53
    600.0       591.0      61.13       8.90
    700.0       683.5      98.88      12.33
    800.0       775.2     138.65      16.42
    900.0       866.6     178.92      21.05
   1000.0       957.4     220.32      27.46
   1100.0      1050.8     255.42      34.09
   1200.0      1144.2     290.49      40.93
   1300.0      1237.3     326.22      48.92
   1400.0      1329.5     363.71      58.44
   1500.0      1421.4     401.02      70.82
   1600.0      1515.0     433.54      86.30
   1700.0      1608.9     466.27      94.79
   1800.0      1702.3     502.21      92.50
   1900.0      1795.6     537.92      94.38
   2000.4      1889.3     571.38     107.83
```

```
TP-1 -- Borehole Summary

Surface Elevation: 824.6 mASL
Coordinates:       East=  980.0
                   North= 1970.0
Vertical Borehole? F
Vertical depth:    2030.7 meters
Total depth:       2151.0 meters

History:
Start Time       End Time         Status
------------------------------------------
19sep93 00:00   22nov93 00:00    Drilling
19nov93 16:00                    ShutIn
28jan94 17:30                    ShutIn

============================================================================
TP-1 -- Lost circulation

starting    ending    starting    ending
   depth*    depth*       rate#     rate#
   -----------------------------------------------------
    31.5       31.5        2125       2125  total loss
    41.5       41.5        1500       1500  total loss
    67.0       67.0        3100       3100  total loss
    70.0       78.0         270        330  1250 l/m
    82.8       82.8        1560       1560  total loss
    97.7       97.7         300        300  1560 l/m
   665.0      665.0        1200       1200  3070 l/m
  1340.0     1340.0         440        440  2000 l/m
  1445.0     1445.0        2100       2100  total loss
  1770.0     1770.0         230        230  2200 l/m
  1868.0     1868.0        1500       1500  total loss
  1868.1     2151.0           0          0  aerated drilling

* Measured Depth (m)
# l/min
============================================================================
TP-1 -- Hole/Casing data

starting     ending
   depth*     depth*      hole_size     casing_size
-------------------------------------------------------------------
     0.0      100.0            26"       20"STPG38   cemented
     0.0     1005.5        17 1/2"     13 3/8"K55   cemented
   958.4     1756.0        12 1/4"      9 5/8"K55   cemented
  1723.0     2150.2         8 1/2"          7"K55   uncemented
  2150.2     2151.0         8 1/2"      open hole

slotted regions:
   1750.0     1800.0
   1810.0     1820.0
   1830.0     1840.0
   1850.0     1900.0
   1950.0     1960.0
   1970.0     1980.0
   1990.0     2000.0
   2010.0     2060.0

* Measured Depth (m)
============================================================================
TP-1 -- Stratigraphy data

starting   ending
   depth*   depth*  maj.code  maj.name      min.code    min.name
------------------------------------------------------------------------

     0.0   1053.0     ND     Undefined        -           -
  1053.0   1338.0     TU     Upper Takigami   -           -
  1338.0   1545.0     TM     Middle Takigami  -           -
  1545.0   2151.0     TL     Lower Takigami   -           -

* Measured Depth (m)
```

```
=============================================================================
TP-1 -- Deviation data (m)

Meas.depth  Vert.depth     E_dev.     N_dev.
--------------------------------------------
      0.0         0.0       0.00       0.00
    140.0       140.0       0.49      -0.46
    243.0       243.0       0.53      -0.12
    350.0       350.0       0.01       0.22
    495.0       495.0      -1.67       1.80
    599.0       598.9      -4.41       4.40
    793.0       792.5     -14.26      10.56
    899.0       898.3     -20.00      14.12
   1033.0      1032.1     -26.85      17.19
   1144.0      1142.8     -21.95      14.08
   1257.0      1254.4      -9.47       1.82
   1379.0      1375.3      -5.72     -14.49
   1484.0      1477.9      -2.17     -35.90
   1597.0      1584.3       0.68     -73.50
   1713.0      1686.1      -0.54    -129.10
   1834.0      1784.3       0.90    -199.71
   2014.0      1922.7       1.89    -314.80
   2151.0      2030.7       2.49    -399.07
```

```
TT-1 -- Borehole Summary

Surface Elevation: 708.5 mASL
Coordinates:       East=  1220.5
                   North= 3331.7
Vertical Borehole? F
Vertical depth:    3001.4 meters
Total depth:       3003.1 meters

History:
Start Time      End Time        Status
-------------------------------------------
09jul83 00:00   13dec83 00:00   Drilling
11oct83 12:00                   ShutIn
13oct83 20:35                   ShutIn
14oct83 12:00                   ShutIn
02nov83 08:55                   ShutIn
09nov83 00:30                   ShutIn
11nov83 20:00                   ShutIn
13nov83 04:00                   ShutIn
15nov83 09:15                   ShutIn
17feb84 00:00                   ShutIn
26jun84 00:00                   ShutIn
01jan90 00:00                   ShutIn

==============================================================================

==============================================================================
TT-1 -- Hole/Casing data

starting    ending
   depth*    depth*      hole_size     casing_size
------------------------------------------------------------------
     0.0       71.7           26"?       20"STPY41   cemented
     0.0      902.3        17 1/2"     13.375"J55   cemented
     0.0      750.0        12 1/4"      9.625"K55   cemented
   750.0     1624.5        12 1/4"      9.625"N80   cemented
  1624.5     3003.1         8 1/2"      open hole

* Measured Depth (m)
==============================================================================
TT-1 -- Stratigraphy data

starting   ending
   depth*   depth*  maj.code  maj.name     min.code   min.name
-----------------------------------------------------------------------
     0.0    610.0      NV     Noinedake Volcanics -       -
   610.0    634.0      KU     Kusu Formation  -      -
   634.0    790.0      AJ     Ajibaru Formation -      -
   790.0   2402.0      TU     Upper Takigami  -      -
  2402.0   3003.1      UF     Usa Group       -      -

* Measured Depth (m)
```

```
=============================================
TT-1 -- Deviation data (m)

Meas.depth  Vert.depth     E_dev.     N_dev.
---------------------------------------------
      0.0         0.0       0.00       0.00
    100.0       100.0      -0.75      -0.75
    200.0       200.0      -2.99      -0.28
    300.0       299.9      -4.58       0.90
    400.0       399.9      -7.61       2.86
    500.0       499.8     -10.47       4.01
    600.0       599.8     -11.74       5.41
    700.0       699.8     -11.78       6.75
    800.0       799.8     -11.07       7.87
    900.0       899.8     -10.50       8.74
   1000.0       999.8     -10.08       9.65
   1100.0      1099.8      -9.53      10.40
   1200.0      1199.8      -9.11      10.94
   1300.0      1299.8      -9.35      11.96
   1400.0      1399.8      -9.17      13.29
   1500.0      1499.8      -9.01      14.25
   1600.0      1599.7      -8.85      14.95
   1700.0      1699.7      -8.90      15.02
   1800.0      1799.7      -7.75      14.94
   1900.0      1899.7      -6.12      16.75
   2000.0      1999.7      -3.61      18.17
   2100.0      2099.6      -1.34      20.57
   2200.0      2199.6       0.00      23.17
   2300.0      2299.5      -0.35      26.92
   2400.0      2399.4      -0.25      31.89
   2500.0      2499.2       0.68      37.35
   2600.0      2599.1       2.81      41.96
   2700.0      2698.9       6.42      46.70
   2800.0      2798.7      10.37      50.19
   2900.0      2898.6      14.19      54.33
   3003.1      3001.4      19.56      59.63
```

```
TT-2 -- Borehole Summary

Surface Elevation: 708.5 mASL
Coordinates:       East=  1227.8
                   North= 3326.3
Vertical Borehole? F
Vertical depth:    1608.6 meters
Total depth:       1667.8 meters

History:
Start Time      End Time        Status
-------------------------------------------
16dec83 00:00   05jun84 00:00   Drilling
23jan84 17:12                   ShutIn
28jan84 16:35                   ShutIn
19sep87 00:00                   ShutIn
20feb92 00:00                   ShutIn

==============================================================================
TT-2 -- Lost circulation

starting    ending    starting   ending
   depth*    depth*      rate#     rate#
   ------------------------------------------------------
   546.0     546.0        200       200  2800 l/m
  1139.0    1143.0        200       200  1830 l/m
  1201.0    1205.0        220       220  2220 l/m
  1219.0    1226.0        177       244  2220 l/m
  1318.0    1319.0        340       340  2070 l/m
  1401.0    1404.0        117       117  2340 l/m
  1444.0    1446.0        215       215  2390 l/m
  1586.0    1591.0        248       248  2070 l/m
  1597.0    1604.0        106       106  1770 l/m
  1621.0    1624.0        230       230  1770 l/m
  1666.0    1666.0       1770      1770  total loss

* Measured Depth (m)
# l/min
==============================================================================
TT-2 -- Hole/Casing data

starting     ending
   depth*     depth*      hole_size     casing_size
-----------------------------------------------------------------
     0.0       72.0            26"       20"STPY41    cemented
     0.0      902.0        17 1/2"     13.375"J55     cemented
   795.3     1604.4        12 1/4"      9.625"N80     cemented
  1604.4     1667.8         8 1/2"       open hole

* Measured Depth (m)
==============================================================================
TT-2 -- Stratigraphy data

starting   ending
   depth*   depth*  maj.code  maj.name     min.code   min.name
-----------------------------------------------------------------------
     0.0    620.0      NV     Noinedake Volcanics -       -
   620.0    634.0      KU     Kusu Formation  -      -
   634.0    810.0      AJ     Ajibaru Formation -      -
   810.0   1190.0      TU     Upper Takigami  -      -
  1190.0   1465.0      TM     Middle Takigami -      -
  1465.0   1566.0      TL     Lower Takigami  -      -
  1566.0   1667.8      UF     Usa Group       -      -

* Measured Depth (m)
==============================================================================
```

TT-2 -- Deviation data (m)

Meas.depth	Vert.depth	E_dev.	N_dev.
0.0	0.0	0.00	0.00
100.0	100.0	0.68	-0.51
200.0	200.0	1.95	-1.49
300.0	300.0	3.23	-1.28
400.0	399.9	2.63	0.77
500.0	499.9	1.62	3.51
600.0	599.8	1.34	7.04
700.0	699.8	2.64	10.46
800.0	799.7	3.18	13.31
900.0	899.7	3.18	15.70
1000.0	999.7	3.48	18.23
1100.0	1099.1	12.68	15.51
1200.0	1196.1	34.07	5.06
1300.0	1288.3	68.63	-11.80
1400.0	1376.2	111.38	-32.71
1500.0	1462.7	155.27	-57.08
1600.0	1549.5	195.52	-85.96
1667.8	1608.6	214.93	-112.96

```
TT-3 -- Borehole Summary

Surface Elevation: 708.5 mASL
Coordinates:       East=  1235.2
                   North= 3321.1
Vertical Borehole? F
Vertical depth:    2736.0 meters
Total depth:       2811.2 meters

History:
Start Time      End Time        Status
-------------------------------------------
03jul83 00:00   21apr84 00:00   Drilling
11apr84 10:30                   ShutIn
12apr84 14:26                   ShutIn
19apr84 13:10                   ShutIn

==============================================================================
TT-3 -- Lost circulation

starting    ending    starting    ending
   depth*    depth*       rate#     rate#
   ------------------------------------------------------------
   645.0     655.0          30        60  3070 l/m
   684.0     686.0          30        30  3070 l/m
   828.0     840.0          30        30  2990 l/m
   900.0     908.0          30        30  2990 l/m
  1172.0    1260.0          70       140  2320 l/m
  1272.0    1280.0          23        23  2320 l/m
  1303.0    1310.0          23        23  2320 l/m
  1604.0    1606.0          98        98  1950 l/m
  1678.0    1684.0          29        29  1950 l/m
  1894.0    1896.6        1020      1020  1700 l/m

* Measured Depth (m)
# l/min
==============================================================================
TT-3 -- Hole/Casing data

starting     ending
   depth*     depth*      hole_size     casing_size
-----------------------------------------------------------------
     0.0       67.8             26"       20"STPY41    cemented
     0.0      901.9         17 1/2"     13.375"J55     cemented
   784.8     1688.8         12 1/4"      9.625"N80     cemented
  1688.8     2811.2          8 1/2"      open hole

* Measured Depth (m)
==============================================================================
TT-3 -- Stratigraphy data

starting   ending
   depth*   depth* maj.code  maj.name      min.code   min.name
---------------------------------------------------------------------
     0.0    620.0     NV     Noinedake Volcanics -       -
   620.0    634.0     KU     Kusu Formation  -       -
   634.0    810.0     AJ     Ajibaru Formation -       -
   810.0   2811.2     ND     Undefined       -       -

* Measured Depth (m)
```

```
============================================================================
TT-3 -- Deviation data (m)

Meas.depth  Vert.depth     E_dev.     N_dev.
--------------------------------------------
      0.0         0.0       0.00       0.00
    100.0       100.0       0.26      -0.21
    200.0       200.0      -1.15       0.27
    300.0       299.9      -3.77       3.12
    400.0       399.9      -4.32       5.33
    500.0       499.9      -4.30       6.98
    600.0       599.8      -3.33       9.24
    700.0       699.8      -1.03      10.40
    800.0       799.8       1.16      11.50
    900.0       899.7       3.16      12.73
   1000.0       999.7       5.54      13.78
   1100.0      1099.4       3.63      19.79
   1200.0      1198.2      -2.72      33.84
   1300.0      1295.5     -11.13      55.32
   1400.0      1392.1     -20.13      79.56
   1500.0      1488.6     -29.13     104.19
   1600.0      1585.0     -36.78     129.49
   1700.0      1681.9     -36.79     154.01
   1800.0      1778.1     -36.40     181.40
   1900.0      1874.1     -33.97     209.13
   2000.0      1969.3     -30.65     239.60
   2100.0      2063.9     -26.62     271.78
   2200.0      2158.2     -22.15     304.89
   2300.0      2252.6     -18.24     337.39
   2400.0      2346.8     -11.81     370.47
   2500.0      2441.0      -4.33     403.09
   2600.0      2535.7       4.61     433.93
   2700.0      2630.8      12.64     463.70
   2811.2      2736.0      22.12     498.57
```

```
TT-7 -- Borehole Summary

Surface Elevation: 872.5 mASL
Coordinates:       East=  1800.2
                   North= 2394.1
Vertical Borehole? F
Vertical depth:    1108.9 meters
Total depth:       1115.0 meters

History:
Start Time      End Time        Status
-----------------------------------------
28jun86 00:00   02sep86 00:00   Drilling
22aug86 00:00                   ShutIn
29aug86 00:00                   ShutIn
10jan87 00:00                   ShutIn
26dec87 00:00                   ShutIn
14mar91 00:40                   ShutIn
15mar91 00:40                   ShutIn
19feb92 00:00                   ShutIn

============================================================================
TT-7 -- Lost circulation

starting    ending    starting    ending
   depth*    depth*       rate#      rate#
   ----------------------------------------------------
    70.9       70.9         230        230  3400 l/m
   114.0      126.0         100        100  3400 l/m
   143.0      145.0         150        150  2700 l/m
   145.0      146.0         100        100  2700 l/m
   166.0      171.0         130        130  2700 l/m
   178.0      181.0         165        165  2700 l/m
   191.0      199.0         130        130  2700 l/m
   560.0      574.0         105        105  2000 l/m
   717.0      717.0         150        150  2000 l/m
  1054.0     1059.0          40         40  1600 l/m
  1074.8     1080.0        1400       1400  1600 l/m
  1080.0     1115.0        1640       1640  total loss

* Measured Depth (m)
# l/min
============================================================================
TT-7 -- Hole/Casing data

starting     ending
   depth*     depth*      hole_size     casing_size
-------------------------------------------------------------------
     0.0       70.6          26" ?        22"STPY41   cemented
     0.0      782.9            20"        16"K55/84   cemented
   752.4      952.5        12 1/4"     9.625"K55/40   cemented
   952.5     1115.0         8 1/2"        Open hole   uncemented

* Measured Depth (m)
============================================================================
TT-7 -- Stratigraphy data

starting   ending
   depth*   depth* maj.code  maj.name      min.code   min.name
------------------------------------------------------------------------
     0.0    557.0     NV     Noinedake Volcanics -       -
   557.0    580.0     KU     Kusu Formation  -       -
   580.0    955.0     AJ     Ajibaru Formation -       -
   955.0   1057.0     TM     Middle Takigami -       -
  1057.0   1115.0     UF     Usa Group       -       -


* Measured Depth (m)
```

```
==============================================================================
TT-7 -- Deviation data (m)

Meas.depth  Vert.depth      E_dev.      N_dev.
---------------------------------------------
      0.0         0.0        0.00        0.00
    100.0        99.9        1.14       -2.43
    200.0       199.8        3.64       -6.65
    300.0       299.6        8.50      -11.07
    400.0       399.3       14.80      -16.53
    500.0       498.9       21.00      -22.39
    600.0       598.7       24.80      -26.47
    700.0       698.7       26.92      -29.77
    800.0       798.6       28.36      -32.66
    900.0       898.1       37.20      -30.52
   1000.0       995.9       57.15      -25.00
   1060.0      1054.9       67.79      -21.87
   1115.0      1108.9       77.54      -19.00
```

```
TT-8 -- Borehole Summary

Surface Elevation: 764.0 mASL
Coordinates:       East=  1609.9
                   North= 2800.7
Vertical Borehole? F
Vertical depth:    1104.8 meters
Total depth:       1105.0 meters

History:
Start Time      End Time        Status
------------------------------------------
10jul86 00:00   18sep86 00:00   Drilling
28aug86 18:00                   ShutIn

==============================================================================
TT-8 -- Lost circulation

starting    ending    starting    ending
   depth*    depth*       rate#     rate#
   -------------------------------------------------------
   290.5     453.0         300       300  2950 l/m
   513.3     616.0         200       200  3000 l/m
   840.1     840.1        3000      3000  total loss
   843.1     854.7        2700      1500  3000 l/m
   859.6     859.6        2300      2300  3000 l/m
   869.7     902.4        2650      2870  3000 l/m
   902.4     911.0        2870      1700  3000 to 1900 l/m
   911.0     913.3        1700      2700  1900 to 3000 l/m
  1096.9    1096.9        2000      2000  2100 l/m
  1105.0    1105.0        2100      2100  total loss

* Measured Depth (m)
# l/min
==============================================================================
TT-8 -- Hole/Casing data

starting     ending
   depth*      depth*       hole_size     casing_size
-------------------------------------------------------------------
     0.0        70.1           26"?          20"SS41?   cemented
     0.0       822.5        17 1/2"       13 3/8"K55   cemented
   822.5      1105.0        12 1/4"        Open hole   uncemented

* Measured Depth (m)
==============================================================================
TT-8 -- Stratigraphy data

starting    ending
   depth*    depth*  maj.code  maj.name       min.code   min.name
------------------------------------------------------------------------------
     0.0    618.0      NV      Noinedake Volcanics -        -
   618.0    639.0      KU      Kusu Formation  -        -
   639.0    928.0      TU      Upper Takigami  -        -
   928.0   1105.0      UF      Usa Group       -        -

* Measured Depth (m)
```

```
==============================================================================
TT-8 -- Deviation data (m)

Meas.depth  Vert.depth      E_dev.      N_dev.
-------------------------------------------
     0.0          0.0        0.00        0.00
   100.0        100.0        0.67       -1.78
   200.0        199.9       -0.03       -3.92
   300.0        299.9       -1.44       -5.65
   400.0        399.9       -3.33       -5.22
   500.0        499.9       -4.33       -3.61
   600.0        599.9       -4.68       -1.97
   700.0        699.9       -4.54       -0.48
   800.0        799.8       -4.12        0.17
   900.0        899.8       -3.10        1.19
  1000.0        999.8       -2.17        2.26
  1105.0       1104.8       -0.72        2.86
```

```
TT-8S1 -- Borehole Summary

Surface Elevation: 764.0 mASL
Coordinates:       East=  1609.9
                   North= 2800.7
Vertical Borehole? F
Vertical depth:    1963.2 meters
Total depth:       2202.8 meters

History:
Start Time      End Time        Status
-----------------------------------------
26sep86 00:00   05dec86 00:00   Drilling
09oct86 17:00                   ShutIn
01dec86 04:00                   ShutIn

============================================================================
TT-8S1 -- Lost circulation

starting   ending    starting   ending
   depth*   depth*      rate#     rate#
   ----------------------------------------------------
   290.5    453.0        300       300  2950 l/m
   513.3    616.0        200       200  3000 l/m
   840.1    840.1       3000      3000  total loss
   843.1    854.7       2700      1500  3000 l/m
   859.6    859.6       2300      2300  3000 l/m
   869.7    902.4       2650      2870  3000 l/m
   902.4    911.0       2870      1700  3000 to 1900 l/m
   911.0    913.3       1700      2700  1900 to 3000 l/m
  1184.8   1184.8         50        50  1600 l/m
  1210.5   1210.5       2000      2000  2200 l/m
  1216.3   1216.3       2200      2200  total loss
  1224.0   1224.0       2200      2200  total loss
  1233.6   1233.6       2500      2500  total loss
  1240.7   1240.7        800       800  2000 l/m
  1252.5   1252.5        244       244  2000 l/m
  1281.0   1281.0        512         0  2300 l/m
  1309.7   1309.7       1950      1950  2000 l/m
  1357.5   1357.5        300       300  2300 l/m
  1410.0   1410.0       2300      2300  total loss
  1434.0   1434.0       2300      2300  total loss
  1509.8   1509.8       2200      2200  total loss
  1533.0   1533.0        625       625  2200 l/m

* Measured Depth (m)
# l/min
============================================================================
TT-8S1 -- Hole/Casing data

starting     ending
   depth*     depth*      hole_size      casing_size
---------------------------------------------------------------
     0.0        70.1          26"?         20"SS41?   cemented
     0.0       822.5       17 1/2"       13 3/8"K55   cemented
   766.0      1455.8       12 1/4"        9 5/8"K55   cemented
  1455.8      2200.8        8 1/2"        Open hole   uncemented
  2200.8      2202.8      8 15/32"        open hole

* Measured Depth (m)
```

```
=============================================================================
TT-8S1 -- Stratigraphy data

starting   ending
   depth*   depth*  maj.code  maj.name      min.code   min.name
-------------------------------------------------------------------------

     0.0    618.0      NV     Noinedake Volcanics -       -
   618.0    639.0      KU     Kusu Formation  -       -
   639.0    928.0      TU     Upper Takigami  -       -
   928.0   1333.0      UF     Usa Group       -       -
  1333.0   2202.8      TL     Lower Takigami  -       -

* Measured Depth (m)
=============================================================================
TT-8S1 -- Deviation data (m)

Meas.depth  Vert.depth      E_dev.      N_dev.
--------------------------------------------
      0.0          0.0        0.00        0.00
    100.0        100.0        0.67       -1.78
    200.0        199.9       -0.03       -3.92
    300.0        299.9       -1.44       -5.65
    400.0        399.9       -3.33       -5.22
    500.0        499.9       -4.33       -3.61
    600.0        599.9       -4.68       -1.97
    700.0        699.9       -4.54       -0.48
    800.0        799.8       -4.12        0.17
    900.0        899.8       -3.10        1.19
   1000.0        999.8       -4.03        3.28
   1100.0       1097.4      -21.12       14.86
   1200.0       1191.1      -49.50       35.04
   1300.0       1280.8      -80.25       66.41
   1400.0       1364.2     -119.14      105.49
   1500.0       1444.7     -160.74      147.48
   1600.0       1518.5     -211.68      191.93
   1700.0       1590.9     -264.38      236.39
   1800.0       1663.5     -316.04      281.83
   1900.0       1736.4     -368.18      326.21
   2000.0       1810.2     -419.84      369.59
   2100.0       1885.0     -470.99      411.97
   2202.8       1963.2     -524.27      452.72
```

```
TT-8S3 -- Borehole Summary

Surface Elevation: 764.0 mASL
Coordinates:       East=  1609.9
                   North= 2800.7
Vertical Borehole? F
Vertical depth:    1875.9 meters
Total depth:       1949.7 meters

History:
Start Time      End Time        Status
------------------------------------------
24dec86 00:00   28apr87 00:00   Drilling
03may87 13:46                   ShutIn
23jun87 19:00                   ShutIn
08jan90 00:00                   ShutIn
20feb92 00:00                   ShutIn

==============================================================================
TT-8S3 -- Lost circulation

starting   ending    starting    ending
   depth*   depth*      rate#     rate#
   ---------------------------------------------------------
   290.5     453.0        300       300  2950 l/m
   513.3     616.0        200       200  3000 l/m
   840.1     840.1       3000      3000  total loss
   843.1     854.7       2700      1500  3000 l/m
   859.6     859.6       2300      2300  3000 l/m
   869.7     902.4       2650      2870  3000 l/m
   902.4     911.0       2870      1700  3000 to 1900 l/m
   911.0     913.3       1700      2700  1900 to 3000 l/m
  1163.6    1163.6        292       292  1700 l/m
  1170.7    1170.7       1700      1700  total loss
  1187.6    1197.2        268       622  1700 l/m
  1216.3    1225.8        561       561  1700 l/m
  1502.4    1502.4        122       122  1300 l/m
  1551.2    1760.9        305       305  1700 l/m
  1783.1    1783.1        158       158  1300 l/m
  1852.6    1934.3        488       488  1300 l/m
  1949.7    1949.7       1342      1342  total loss

* Measured Depth (m)
# l/min
==============================================================================
TT-8S3 -- Hole/Casing data

starting    ending
  depth*     depth*      hole_size     casing_size
-------------------------------------------------------------
    0.0       70.1           26"?       20"SS41?   cemented
    0.0      822.5       17 1/2"     13 3/8"K55    cemented
  766.0      950.5       12 1/4"      9 5/8"K55    cemented
  932.2     1135.0        8 1/2"         7 "K55    uncemented
 1135.0     1565.2        8 1/2"         7 "K55    cemented
 1565.2     1908.0        8 1/2"         7 "K55    uncemented
 1908.0     1949.7        8 1/2"      Open hole    uncemented

* Measured Depth (m)
==============================================================================
```

```
============================================================================
TT-8S3 -- Deviation data (m)

Meas.depth  Vert.depth     E_dev.     N_dev.
--------------------------------------------

     0.0         0.0       0.00       0.00
   100.0       100.0       0.67      -1.78
   200.0       199.9      -0.03      -3.92
   300.0       299.9      -1.44      -5.65
   400.0       399.9      -3.33      -5.22
   500.0       499.9      -4.33      -3.61
   600.0       599.9      -4.68      -1.97
   700.0       699.9      -4.54      -0.48
   800.0       799.8      -4.12       0.17
   900.0       899.8      -3.10       1.19
  1000.0       999.8      -4.51       0.67
  1100.0      1099.2     -15.36       0.24
  1200.0      1198.7     -25.78      -0.24
  1300.0      1298.3     -33.02       0.78
  1400.0      1397.1     -44.01      11.98
  1500.0      1493.9     -65.30      24.42
  1600.0      1587.8     -90.50      47.76
  1700.0      1676.0    -126.27      78.10
  1800.0      1757.4    -173.55     111.47
  1900.0      1836.6    -222.62     147.96
  1949.7      1875.9    -246.89     166.26
```

```
TT-10 -- Borehole Summary

Surface Elevation: 699.8 mASL
Coordinates:       East=  1231.8
                   North= 4265.5
Vertical Borehole? T
Vertical depth:    1284.5 meters
Total depth:       1284.5 meters

History:
Start Time      End Time        Status
-------------------------------------------
29apr86 00:00   06aug86 00:00   Drilling
12jun86 12:00                   ShutIn
09jul86 00:00                   ShutIn
20jul86 14:00                   ShutIn
22jul86 00:00                   ShutIn
26jul86 18:17                   ShutIn
16aug86 00:00                   ShutIn
30oct86 15:00                   ShutIn
23dec86 12:00                   ShutIn

==========================================================================
TT-10 -- Lost circulation

starting    ending    starting    ending
   depth*    depth*       rate#     rate#
   -----------------------------------------------------
   364.5     369.5           4        23  850 l/m
   393.8     483.8           8        38  850 l/m
   483.9     516.5           7        14  850 l/m
   516.6     618.3           5        20  850 l/m
   618.4     760.6          16         0  850 l/m
   823.6     864.8          80         7  750 l/m
   864.9     882.2          14         8  750 l/m
   882.3     897.8          11        11  850 l/m
   906.9     919.6         300        70  800 l/m
   919.7     938.6          72        50  750 l/m
   938.7    1067.5          60        30  750 l/m
  1067.6    1195.0          35        18  750 l/m
  1195.1    1199.1          25        25  750 l/m
  1275.2    1275.6          50        50  750 l/m
  1275.6    1284.5         550       500  total loss

* Measured Depth (m)
# l/min
==========================================================================
TT-10 -- Hole/Casing data

starting     ending
  depth*      depth*      hole_size     casing_size
--------------------------------------------------------------
     0.0        30.6        17 1/2"          14"SGP   cemented
     0.0       200.9        12 1/4"      9 5/8"J55   cemented
     0.0      1196.8         8 1/2"           7"H40   cemented
  1196.8      1284.5         6 1/4"       Open hole   uncemented

* Measured Depth (m)
```

```
==============================================================================
TT-10 -- Stratigraphy data

starting   ending
  depth*   depth*  maj.code  maj.name      min.code   min.name
--------------------------------------------------------------------------
    0.0    305.0      NV     Noinedake Volcanics -       -
  305.0    325.0      KU     Kusu Formation  -      -
  325.0    645.0      AJ     Ajibaru Formation -      -
  645.0   1125.0      TU     Upper Takigami  -      -
 1125.0   1180.0      TM     Middle Takigami -      -
 1180.0   1284.5      TL     Lower Takigami  -      -

* Measured Depth (m)
==============================================================================
TT-10 -- Deviation data (m)

Meas.depth  Vert.depth     E_dev.     N_dev.
---------------------------------------------
     0.0          0.0       0.00       0.00
  1284.5       1284.5       0.00       0.00
```

```
TT-13S -- Borehole Summary

Surface Elevation: 824.6 mASL
Coordinates:       East=  971.3
                   North= 1984.9
Vertical Borehole? F
Vertical depth:    2582.3 meters
Total depth:       2707.1 meters

History:
Start Time      End Time        Status
------------------------------------------
05aug87 00:00   22sep87 00:00   Drilling
12sep87 02:15                   ShutIn
12sep87 12:00                   ShutIn
22sep87 12:00                   ShutIn
14oct87 15:16   18oct87 12:00   Discharging
12nov87 12:00                   ShutIn
19nov87 14:00                   ShutIn
22dec87 17:00                   ShutIn
12jan88 12:00   22jan88 12:00   Discharging
08feb88 00:00                   ShutIn
02aug88 15:45   09aug88 14:07   Discharging
09aug88 14:07                   ShutIn
21feb92 12:00                   ShutIn
20may94 00:00                   ShutIn

=============================================================================
TT-13S -- Lost circulation

starting    ending    starting    ending
   depth*    depth*       rate#     rate#
   --------------------------------------------------------
    32.2      33.2        1000      1000 2200 l/m
    42.6      49.0          50      2400 2400 l/m
    52.3      52.3          80        80 2200 l/m
    81.6      82.0         200      1400 2700 l/m
    90.6      97.1         270        80 2800 to 2900 l/m
   623.7     633.4        1600      2000 2900 l/m
  1324.4    1327.8         200      1500 1600 l/m
  1327.8    1348.0          50       700 1800 to 1900 l/m
  1494.8    1497.0         550       270 1900 l/m
  1606.8    1606.8        1900      1900 total loss
  1725.9    1728.6         120       487 1900 l/m
  1775.3    1780.3         430       430 1930 l/m
  1780.4    1789.5        1860      1830 total loss
  1789.6    2707.1           ?         ? Air Drilling

* Measured Depth (m)
# l/min
? missing data
=============================================================================
TT-13S -- Hole/Casing data

starting     ending
   depth*     depth*      hole_size     casing_size
----------------------------------------------------------------
     0.0       73.0             26"        20"SS-41   cemented
     0.0     1094.3         17 1/2"   13.375"K55/61   cemented
  1060.5     1771.7         12 1/4"    9.625"K55/40   cemented
  1738.5     2703.2          8 1/2"        7"K55/23   uncemented
  2703.2     2707.1          8 1/2"       open hole

slotted regions:
   1799.7     1944.6
   2069.0     2298.7


* Measured Depth (m)
```

```
===========================================================================
TT-13S -- Stratigraphy data

starting   ending
   depth*   depth*  maj.code  maj.name      min.code   min.name
-----------------------------------------------------------------------
     0.0    550.0      NV     Noinedake Volcanics -       -
   550.0    980.0      AJ     Ajibaru Formation -       -
   980.0   1250.0      TU     Upper Takigami  -       -
  1250.0   1640.0      TM     Middle Takigami -       -
  1640.0   2270.0      TL     Lower Takigami  -       -
  2270.0   2707.1      UF     Usa Group       -       -

* Measured Depth (m)
===========================================================================
TT-13S -- Deviation data (m)

Meas.depth  Vert.depth     E_dev.     N_dev.
---------------------------------------------
     0.0         0.0        0.00        0.00
   100.0       100.0       -0.74       -1.10
   200.0       200.0       -1.26       -1.48
   300.0       299.8       -1.37        3.60
   400.0       399.7       -3.44        8.79
   500.0       499.4       -8.14       15.04
   600.0       599.1      -11.23       21.58
   700.0       698.7      -16.55       28.79
   800.0       798.5      -18.41       35.29
   900.0       898.3      -17.77       40.05
  1000.0       998.3      -16.61       43.19
  1100.0      1098.3      -15.13       44.70
  1200.0      1198.1      -13.10       41.61
  1300.0      1295.2      -24.34       21.63
  1400.0      1387.3      -48.89       -8.54
  1500.0      1478.6      -74.73      -40.04
  1600.0      1569.3     -101.77      -72.25
  1700.0      1659.7     -129.27     -105.02
  1800.0      1750.3     -156.55     -137.49
  1900.0      1841.2     -183.71     -169.15
  2000.0      1932.7     -210.50     -199.29
  2100.0      2024.5     -237.44     -228.34
  2200.0      2116.1     -265.45     -256.97
  2300.0      2207.6     -294.53     -284.89
  2400.0      2299.4     -324.06     -311.36
  2500.0      2391.7     -353.59     -336.25
  2600.0      2483.9     -383.74     -360.65
  2707.1      2582.3     -416.76     -386.73
```

```
TT-14R -- Borehole Summary

Surface Elevation: 824.6 mASL
Coordinates:       East=  977.2
                   North= 1985.0
Vertical Borehole? F
Vertical depth:    1960.6 meters
Total depth:       2113.8 meters

History:
Start Time      End Time        Status
----------------------------------------
23oct86 00:00   24nov86 00:00   Drilling
06nov86 15:40   09nov86 17:07   Discharging
20nov86 02:00                   ShutIn
20feb92 12:00                   ShutIn

=============================================================================
TT-14R -- Lost circulation

starting    ending    starting    ending
   depth*    depth*       rate#      rate#
   --------------------------------------------------------
    11.5      11.5        1700       1700  total loss
    24.8      36.6        3000       3000  total loss
    36.7      38.0         600        600  2500 l/m
    39.2      39.2        3000        250  3000 l/m
    75.0      80.9         220       2200  2200 l/m
   216.0     222.4         900       1350  3000 l/m
   262.0     264.1        1740       2465  2900 l/m
   264.1     362.4        2465          0  2900 l/m
   365.0     367.0          84         84  2800 l/m
   388.0     390.0         150        150  3000 l/m
   400.0     402.0           0        280  2800 to 2900 l/m
   429.0     465.0          50          0  2800 l/m
  1348.0    1349.0         221        221  1700 l/m
  1465.0    1471.3         380        380  1900 l/m
  1498.0    1514.0         190        210  1900 to 2100 l/m
  1614.0    1619.8         360        360  1800 l/m
  1946.0    1948.0         280        288  1400 l/m
  1948.0    2001.5         288         40  1400 l/m
  2071.0    2071.0         423        423  1500 l/m
  2071.9    2071.9        1460       1460  total loss
  2074.2    2074.2         230        230  1500 l/m
  2110.0    2110.0         300        300  1500 l/m
  2113.8    2113.8        1500       1500  total loss

* Measured Depth (m)
# l/min
=============================================================================
TT-14R -- Hole/Casing data

starting     ending
  depth*      depth*       hole_size     casing_size
--------------------------------------------------------------------
     0.0        72.3             26"          20"H40/94    cemented
     0.0       903.6         17 1/2"    13.375"K55/61    cemented
   881.5      1799.8         12 1/4"     9.625"K55/40    cemented
  1763.3      2100.6          8 1/2"          7"K55/23    uncemented
  2100.6      2113.8          8 1/2"        open hole

slotted regions:
  2039.7      2100.6

* Measured Depth (m)
=============================================================================
```

TT-14R -- Stratigraphy data

starting depth*	ending depth*	maj.code	maj.name	min.code	min.name
0.0	650.0	NV	Noinedake Volcanics	-	-
650.0	979.0	AJ	Ajibaru Formation	-	-
979.0	1234.0	TU	Upper Takigami	-	-
1234.0	1680.0	TM	Middle Takigami	-	-
1680.0	2113.8	TL	Lower Takigami	-	-

* Measured Depth (m)

TT-14R -- Deviation data (m)

Meas.depth	Vert.depth	E_dev.	N_dev.
0.0	0.0	0.00	0.00
100.0	100.0	-1.75	-1.88
200.0	199.9	-4.24	-2.99
300.0	299.9	-6.75	-3.56
400.0	399.8	-10.03	-3.85
500.0	499.8	-13.31	-3.69
600.0	599.7	-18.00	-2.37
700.0	699.4	-23.97	0.42
800.0	799.2	-29.53	3.02
900.0	899.1	-33.47	5.65
1000.0	999.1	-35.78	8.11
1100.0	1098.7	-41.71	2.71
1200.0	1197.2	-53.31	-8.95
1300.0	1292.2	-74.84	-31.27
1400.0	1382.6	-109.68	-55.41
1500.0	1463.4	-156.03	-91.31
1600.0	1540.2	-209.51	-126.11
1700.0	1615.4	-267.78	-157.09
1800.0	1690.7	-326.11	-187.64
1900.0	1770.9	-381.08	-210.13
2000.0	1858.0	-428.06	-224.46
2113.8	1960.6	-475.79	-235.96

```
TT-16 -- Borehole Summary

Surface Elevation: 756.4 mASL
Coordinates:       East=  708.2
                   North= 2712.0
Vertical Borehole? F
Vertical depth:    2460.7 meters
Total depth:       2537.0 meters

History:
Start Time      End Time        Status
------------------------------------------
07oct87 00:00   13jan88 00:00   Drilling
25dec87 11:00                   ShutIn
06jan88 11:00                   ShutIn
15mar88 00:00                   ShutIn
16mar88 00:35                   ShutIn
24may88 00:00                   ShutIn
06jun88 18:03                   ShutIn
07jul88 17:30                   ShutIn
12jul88 00:00                   ShutIn

==============================================================================
TT-16 -- Lost circulation

starting    ending     starting    ending
   depth*    depth*        rate#      rate#
   -----------------------------------------------------
   347.5     347.5          213         213  3100 l/m
   432.0     432.0          184         184  3100 l/m
   447.0     447.0           45          45  3100 l/m
   477.0     477.0           23          23  3100 l/m
   503.0     503.0           25          25  3100 l/m
   519.6     519.6         2800        2800  3100 l/m
   549.6     549.6         3100        3100  total loss
   568.6     568.6          398         398  3100 l/m
   578.3     578.3          804         804  3100 l/m
   633.0     635.4         1640        1640  3100 l/m
   647.5     647.5          880         880  3100 l/m
   831.0     855.0          530         530  3100 l/m
  1322.0    1326.0          330         500  2100 l/m
  1704.0    1735.5           70         200  2100 l/m
  1911.0    1911.0           60          60  2100 l/m
  2231.7    2231.7          450         450  2100 l/m
  2352.0    2352.0          470         470  2100 l/m

* Measured Depth (m)
# l/min
==============================================================================
TT-16 -- Hole/Casing data

starting     ending
   depth*     depth*       hole_size     casing_size
-------------------------------------------------------------------
     0.0       73.7             26"          20"SS-41    cemented
     0.0     1286.9         17 1/2"   13.375"K55/61    cemented
  1221.5     2126.9         12 1/4"    9.625"K55/40    cemented
  2040.1     2395.0         12 1/4"         7"K55/23    uncemented
  2395.0     2537.0         12 1/4"        open hole

* Measured Depth (m)
```

```
============================================================================
TT-16 -- Stratigraphy data

starting   ending
  depth*   depth*  maj.code  maj.name      min.code   min.name
--------------------------------------------------------------------
    0.0    384.0     NV      Noinedake Volcanics -       -
  384.0    504.0     KU      Kusu Formation  -       -
  504.0    850.0     AJ      Ajibaru Formation -       -
  850.0   1250.0     TU      Upper Takigami  -       -
 1250.0   1656.0     TM      Middle Takigami -       -
 1656.0   2200.0     TL      Lower Takigami  -       -
 2200.0   2537.0     UF      Usa Group       -       -

* Measured Depth (m)
============================================================================
TT-16 -- Deviation data (m)

Meas.depth  Vert.depth      E_dev.      N_dev.
-----------------------------------------------
     0.0          0.0        0.00        0.00
   100.0        100.0        0.41        1.65
   200.0        199.9        0.94        5.08
   300.0        299.9        0.97        8.92
   400.0        399.8        0.04       13.17
   500.0        499.7       -1.19       17.36
   600.0        599.6       -2.66       21.46
   700.0        699.5       -3.68       25.70
   800.0        799.4       -4.31       30.02
   900.0        899.3       -4.96       34.33
  1000.0        999.2       -5.74       38.62
  1100.0       1099.1       -6.73       42.87
  1200.0       1199.0       -7.71       47.12
  1300.0       1298.9       -8.63       51.34
  1400.0       1398.8       -8.25       54.42
  1500.0       1498.7       -4.62       51.20
  1600.0       1597.4       -4.70       36.14
  1700.0       1694.7      -15.95       16.37
  1800.0       1789.0      -34.91      -10.79
  1900.0       1879.4      -59.09      -46.21
  2000.0       1970.1      -84.04      -80.13
  2100.0       2061.5     -107.20     -113.33
  2200.0       2153.0     -128.97     -147.29
  2300.0       2245.3     -149.70     -179.84
  2400.0       2336.9     -171.98     -213.18
  2500.0       2427.5     -197.78     -246.57
  2537.0       2460.7     -208.25     -259.06
```

```
TT-16S -- Borehole Summary

Surface Elevation: 756.4 mASL
Coordinates:       East=  708.2
                   North= 2712.0
Vertical Borehole? F
Vertical depth:    1849.5 meters
Total depth:       2156.5 meters

History:
Start Time      End Time        Status
-----------------------------------------
07dec88 00:00   01mar89 00:00   Drilling
05feb89 17:15                   ShutIn
16feb89 20:17                   ShutIn
03jun89 12:00                   ShutIn

=============================================================================
TT-16S -- Lost circulation

starting    ending    starting    ending
   depth*    depth*       rate#     rate#
   -------------------------------------------------------
   347.5     347.5         213       213  3100 l/m
   432.0     432.0         184       184  3100 l/m
   447.0     447.0          45        45  3100 l/m
   477.0     477.0          23        23  3100 l/m
   503.0     503.0          25        25  3100 l/m
   519.6     519.6        2800      2800  3100 l/m
   549.6     549.6        3100      3100  total loss
   568.6     568.6         398       398  3100 l/m
   641.0     651.9         420       213  1500 l/m
   657.0     903.0          83        17  1500 l/m
   969.0    1050.0          67        33  2200 l/m
  1062.0    1074.0          25         8  2200 l/m
  1094.0    1145.0          17        17  2200 l/m
  1158.0    1197.0          17         0  2200 l/m
  1245.0    1260.0           8         8  2200 l/m
  1350.0    1457.0           8        30  2200 l/m
  1470.0    1518.0          17        17  2200 l/m
  1518.0    2156.5           ?         ?  Aerated Mud Drilling
  1767.0    1769.0         120       120  1500 l/m
  1769.0    1779.0          30        30  1500 l/m
  1895.0    1896.0          83        83
  1927.0    1927.0           ?         ?  ?
  1992.7    2013.2        1000      1800  total loss ?
  2072.9    2072.9          33        42  ?
  2095.1    2095.1           ?         ?  ?
  2152.3    2152.3           ?         ?  injection test
  2152.3    2156.5           ?         ?  ?

* Measured Depth (m)
# l/min
? missing data
=============================================================================
TT-16S -- Hole/Casing data

starting     ending
  depth*      depth*      hole_size     casing_size
---------------------------------------------------------------
     0.0       73.7           26"           20"SS-41    cemented
     0.0      574.6       17 1/2"     13.375"K55/61    cemented
     0.0     1453.6       12 1/4"      9.625"K55/40    cemented
  1413.6     2155.1        8 1/2"          7"K55/23    uncemented
  2155.1     2156.5      8 15/32"         Open hole    uncemented

slotted regions:
   1599.0     1669.3
   1720.4     2052.8

* Measured Depth (m)
```

```
============================================================================
TT-16S -- Stratigraphy data

starting   ending
   depth*   depth*  maj.code  maj.name     min.code   min.name
--------------------------------------------------------------------------
     0.0    384.0      NV     Noinedake Volcanics -       -
   384.0    438.0      KU     Kusu Formation  -       -
   438.0    903.0      AJ     Ajibaru Formation -       -
   903.0   1500.0      TU     Upper Takigami  -       -
  1500.0   1800.0      TM     Middle Takigami -       -
  1800.0   2156.5      TL     Lower Takigami  -       -

* Measured Depth (m)
============================================================================
TT-16S -- Deviation data (m)

Meas.depth  Vert.depth      E_dev.     N_dev.
-------------------------------------------
      0.0         0.0        0.00       0.00
    100.0       100.0        0.41       1.65
    200.0       199.9        0.94       5.08
    300.0       299.9        0.97       8.92
    400.0       399.8        0.04      13.17
    500.0       499.7       -1.18      17.36
    600.0       599.6       -1.79      20.99
    700.0       699.4        2.48      18.65
    800.0       798.1       14.29       8.32
    900.0       894.2       34.80     -10.12
   1000.0       984.2       66.98     -39.12
   1100.0      1065.2      110.94     -77.61
   1200.0      1134.9      165.93    -123.59
   1300.0      1204.6      220.82    -169.70
   1400.0      1276.8      273.90    -214.10
   1500.0      1351.0      325.48    -256.87
   1600.0      1425.7      376.07    -300.08
   1700.0      1500.0      427.26    -343.14
   1800.0      1574.2      479.18    -385.66
   1900.0      1647.8      531.77    -428.22
   2000.0      1722.4      583.49    -470.11
   2100.0      1801.3      631.77    -508.11
   2156.5      1849.5      655.20    -525.84
```

```
TT-18 -- Borehole Summary

Surface Elevation: 664.2 mASL
Coordinates:       East=  680.6
                   North= 4368.5
Vertical Borehole? F
Vertical depth:    1372.0 meters
Total depth:       1500.0 meters

History:
Start Time       End Time         Status
-----------------------------------------
24sep87 00:00    20feb88 00:00    Drilling
27nov87 00:00                     ShutIn
28nov87 00:00                     ShutIn
13dec87 00:00                     ShutIn
15dec87 00:00                     ShutIn
15dec87 16:00                     ShutIn
01jan93 00:00                     ShutIn

============================================================================
TT-18 -- Lost circulation

starting    ending    starting    ending
   depth*    depth*       rate#      rate#
   ---------------------------------------------------------
    13.4      15.6         720        720  total loss
    78.9      78.9         720        720  total loss
    81.3     106.7          13         30  720 l/m
   139.3     139.3         720        720  total loss
   142.0     144.8          60         16  720 l/m
   151.4     151.4         720        720  total loss
   196.1     196.1          17         17  720 l/m
   478.1     488.7          15          0  720 l/m
   504.2     504.2           5          5  720 l/m
   792.1     800.3         210         27  720 l/m
   827.1     837.6           9          0  720 l/m
   856.3     862.5          36         31  720 l/m
   874.9     889.2          18         45  720 l/m
   906.1     906.1          18         18  720 l/m
   931.1     937.3          10          5  720 l/m
   981.0     981.0           5          5  720 l/m
   991.0     991.0         270          0  720 l/m
  1048.1    1048.1          23         23  500 l/m
  1072.3    1073.0         100         50  600 l/m
  1076.2    1076.2         600        100  600 l/m
  1078.5    1079.3         500        500  total loss
  1087.2    1120.9         400        515  total loss
  1127.6    1140.7         290        195  400 l/m
  1142.6    1149.6         250        240  400 l/m
  1151.0    1262.2         270        190  540 l/m
  1262.3    1309.3         217        160  515 l/m
  1309.4    1371.7         242        225  525 l/m
  1371.9    1374.9         400        400  total loss
  1375.0    1387.5         380        298  550 to 450 l/m
  1387.6    1500.0         450        450  total loss

* Measured Depth (m)
# l/min
============================================================================
TT-18 -- Hole/Casing data

starting     ending
   depth*     depth*      hole_size     casing_size
------------------------------------------------------------------
     0.0       33.0        17 1/2"          14"SGP   cemented
     0.0      304.0        12 1/4"      9 5/8"K55    cemented
     0.0      989.0         8 1/2"           7"H40   cemented
   960.2     1496.7         6 1/4"      4 1/2"H40    uncemented
  1496.7     1500.0         6 1/4"      open hole

slotted regions:
   1274.7     1496.7

* Measured Depth (m)
```

```
==============================================================================
TT-18 -- Stratigraphy data

starting    ending
   depth*    depth*  maj.code  maj.name     min.code   min.name
-------------------------------------------------------------------------
     0.0     518.0      NV     Noinedake Volcanics -       -
   518.0     580.0      KU     Kusu Formation  -      -
   580.0     728.0      AJ     Ajibaru Formation -      -
   728.0    1200.0      TU     Upper Takigami  -      -
  1200.0    1460.0      ND     Undefined       -      -
  1460.0    1500.0      TL     Lower Takigami  -      -

* Measured Depth (m)
==============================================================================
TT-18 -- Deviation data (m)

Meas.depth  Vert.depth     E_dev.     N_dev.
--------------------------------------------
      0.0         0.0       0.00       0.00
    100.0       100.0      -0.84      -0.24
    200.0       200.0      -2.51      -0.73
    300.0       300.0      -4.24      -0.47
    400.0       399.8      -4.26       3.24
    500.0       498.4       5.59      16.68
    600.0       594.9      22.74      36.40
    700.0       689.5      45.99      59.12
    800.0       782.7      71.01      85.32
    900.0       874.0      98.49     115.41
   1000.0       962.7     128.70     150.25
   1100.0      1048.4     165.14     186.63
   1200.0      1131.8     205.08     224.52
   1300.0      1211.1     249.43     266.31
   1400.0      1289.1     294.46     309.83
   1500.0      1372.0     333.54     349.74
```

```
TT-19 -- Borehole Summary

Surface Elevation: 667.4 mASL
Coordinates:       East=  729.7
                   North= 4252.7
Vertical Borehole? F
Vertical depth:    1376.8 meters
Total depth:       1428.7 meters

History:
Start Time      End Time        Status
-------------------------------------------
21jan88 00:00   14mar88 00:00   Drilling
02mar88 00:00                   ShutIn
10aug88 00:00                   ShutIn
01jan93 00:00                   ShutIn

=============================================================================
TT-19 -- Lost circulation

starting    ending   starting    ending
   depth*   depth*       rate#     rate#
   ----------------------------------------------------
    20.9      20.9        1100      1100  total loss
    40.7      40.7        1200      1200  total loss
   224.2     224.2         700       700  2060 l/m
   477.3     477.3         280       280  2060 l/m
   665.2     665.2         250       250  1700 l/m
   930.2     930.2         200       200  2000 l/m
  1139.7    1139.7         200       200  2000 l/m
  1378.7    1378.7         300       300  2000 l/m
  1395.2    1428.7        2000      2000  total loss

* Measured Depth (m)
# l/min
=============================================================================
TT-19 -- Hole/Casing data

starting     ending
   depth*     depth*       hole_size     casing_size
-----------------------------------------------------------------
     0.0        33.2             26"        20"STPY41   cemented
     0.0       601.4         17 1/2"          13 3/8"   cemented
   564.1      1411.0         12 1/4"        9 5/8"K55   uncemented
  1411.0      1428.7         12 1/4"        open hole

slotted regions:
   1356.6     1411.0

* Measured Depth (m)
```

```
==============================================================================
TT-19 -- Stratigraphy data

starting   ending
   depth*   depth*  maj.code  maj.name     min.code   min.name
--------------------------------------------------------------------------
     0.0    532.0      NV     Noinedake Volcanics -       -
   532.0    590.0      KU     Kusu Formation  -       -
   590.0    756.0      AJ     Ajibaru Formation -       -
   756.0    990.0      TU     Upper Takigami  -       -
   990.0   1428.7      TM     Middle Takigami -       -

* Measured Depth (m)
==============================================================================
TT-19 -- Deviation data (m)

Meas.depth  Vert.depth      E_dev.      N_dev.
---------------------------------------------
      0.0         0.0        0.00        0.00
    100.0       100.0        0.23        0.41
    200.0       200.0        0.22        2.10
    300.0       300.0       -0.88        4.29
    400.0       399.9       -1.57        6.74
    500.0       499.9       -1.94        9.05
    600.0       599.9       -2.43       11.12
    700.0       699.8       -2.94       15.52
    800.0       799.2        6.40       16.32
    900.0       896.4       27.95        7.45
   1000.0       989.4       61.02       -7.76
   1100.0      1078.6      101.58      -27.70
   1200.0      1169.4      139.76      -44.42
   1300.0      1263.3      173.72      -48.84
   1400.0      1352.0      219.90      -50.46
   1428.7      1376.8      234.22      -50.67
```

```
TT-23 -- Borehole Summary

Surface Elevation: 667.4 mASL
Coordinates:       East=  733.9
                   North= 4245.9
Vertical Borehole? F
Vertical depth:    1632.3 meters
Total depth:       1739.5 meters

History:
Start Time       End Time         Status
-------------------------------------------
24jul88 00:00    21sep88 00:00    Drilling
15sep88 03:30                     ShutIn
19sep88 07:23                     ShutIn
20sep88 10:14                     ShutIn
01jan93 00:00                     ShutIn

==============================================================================
TT-23 -- Lost circulation

starting    ending    starting    ending
   depth*    depth*       rate#     rate#
   ---------------------------------------------------------
    12.7      14.2        1500       280  1700 to 1000 l/m
    44.6      47.6        2000      2000  total loss
   112.8     136.2          41        41  3000 l/m
   220.0     225.0          81        81  3000 l/m
   999.6    1042.9         168        49  2200 l/m
  1406.3    1406.3         448      1232  2200 l/m
  1407.3    1425.4         126        52  1700 l/m
  1430.3    1438.4         110        42  1700 l/m
  1442.7    1447.9         112       336  1700 l/m
  1448.5    1448.7        1100       225  1700 l/m
  1452.5    1465.5         470       112  1700 l/m
  1478.5    1479.7         540       700  1700 to 1145 l/m
  1482.6    1482.6        1700      2400  total loss
  1485.3    1489.6         700       916  2426 l/m
  1495.5    1496.1         500       833  2426 l/m
  1513.2    1517.4        1260      1120  2426 l/m
  1530.9    1530.9         840       980  2426 l/m
  1543.7    1559.3        1416      1266  2426 l/m
  1568.4    1603.6        1540      1200  2426 l/m
  1622.7    1640.8        1333      1133  2426 l/m
  1658.8    1663.9        1266       750  2426 l/m
  1695.0    1695.0        1133      1083  2426 l/m
  1723.3    1723.3        1200      1216  2426 l/m
  1739.5    1739.5        1116      2426  2426 l/m

• Measured Depth (m)
# l/min
==============================================================================
```

```
TT-23 -- Hole/Casing data

starting     ending
   depth*     depth*       hole_size      casing_size
---------------------------------------------------------------
     0.0       40.0              26*      20*STPY41   cemented
     0.0      692.6          17 1/2*    13 3/8*K55   cemented
   645.0     1393.1          12 1/4*     9 5/8*K55   cemented
  1393.1     1739.5           8 1/2*     open hole

* Measured Depth (m)
==============================================================================
TT-23 -- Stratigraphy data

starting   ending
  depth*    depth*  maj.code  maj.name     min.code   min.name
-----------------------------------------------------------------------
     0.0    156.0      NV     Noinedake Volcanics -       -
   156.0    647.0      AJ     Ajibaru Formation -       -
   647.0   1015.0      TU     Upper Takigami  -       -
  1015.0   1160.0      TM     Middle Takigami -       -
  1160.0   1739.5      TL     Lower Takigami  -       -

* Measured Depth (m)
==============================================================================
TT-23 -- Deviation data (m)

Meas.depth  Vert.depth     E_dev.     N_dev.
---------------------------------------------
      0.0         0.0       0.00       0.00
    100.0       100.0       1.50       0.62
    200.0       199.9       4.43       2.36
    300.0       299.9       7.26       4.54
    400.0       399.8       8.00       6.25
    500.0       499.8       6.93       9.38
    600.0       599.7       5.51      12.84
    700.0       699.6       3.38      16.23
    800.0       798.9       4.05      26.89
    900.0       893.8      16.41      55.37
   1000.0       983.4      36.80      94.72
   1100.0      1067.7      62.09     142.07
   1200.0      1152.7      85.70     189.22
   1300.0      1238.0     102.09     238.78
   1400.0      1324.7     115.90     286.61
   1500.0      1411.7     132.76     332.76
   1600.0      1500.5     150.45     374.90
   1700.0      1594.4     165.64     405.92
   1739.5      1632.3     170.99     415.69
```

Appendix B

Characteristic Mass Output Data for Takigami Boreholes

Slim Hole NE-2R

Test Interval: November & December 1982

Date & Time	WHP (bars)	Hot-Wat (T/HR)	Steam (T/HR)	Total (T/HR)
	1.19	13.89	0.68	14.57
	1.24	9.44	1.98	11.42
	1.26	11.87	2.00	13.87
	1.29	15.05	2.09	17.14
	1.31	15.07	2.15	17.22
	1.33	13.97	2.18	16.15
	1.33	14.34	2.18	16.52

Slim Hole NE-3(i)

Test Interval: October 1982

Date & Time	WHP (bars)	Hot-Wat (T/HR)	Steam (T/HR)	Total (T/HR)
10-15-82	1.91	27.56	4.60	32.16
	2.25	26.76	4.37	31.13
	2.55	28.66	4.01	32.67
	2.94	25.62	3.19	28.81
	3.23	22.20	2.49	24.69
	3.77	16.16	1.38	17.54
10-16-82	1.91	27.56	4.91	32.47
	2.45	28.01	4.41	32.42
	2.75	27.68	4.29	31.97
	3.14	26.82	3.49	30.31
	3.68	20.01	2.11	22.12
	3.78	11.72	1.05	12.77

Slim Hole NE-3

Test Interval: January 25 to February 21, 1983

Date & Time	WHP (bars)	Hot-Wat (T/HR)	Steam (T/HR)	Total (T/HR)
01-27-83	1.94	15.39	2.61	18.00
01-30-83	2.07	21.02	2.41	23.43
02-06-83	2.13	24.49	2.61	27.10
02-09-83	2.08	19.67	3.01	22.68
02-12-83	2.18	19.72	3.04	22.76
02-15-83	2.08	19.67	3.37	23.04
02-18-83	2.07	19.68	3.39	23.07
02-21-83	2.08	19.67	3.43	23.10

Slim Hole NE-4

Test Interval: January 20 and January 27, 1986

Date & Time	WHP (bars)	Hot-Wat (T/HR)	Steam (T/HR)	Total (T/HR)
01-20-86	1.32	8.10	2.30	10.40
	1.57	7.50	2.30	9.80
	1.91	6.80	2.05	8.85
	2.11	7.20	1.82	9.02
01-27-86	1.37	8.6	2.30	10.90
	1.71	8.6	2.25	10.85
	2.11	9.2	2.20	11.40
	2.30	8.9	1.80	10.70
	1.42	9.2	2.35	11.55

Slim Hole NE-5(i1)

Test Interval: February 15-16, 1985

Date & Time	WHP (bars)	Hot-Wat (T/HR)	Steam (T/HR)	Total (T/HR)
02-16-85	2.97	30.	6.3	36.3
	3.36	29.	6.1	35.1
	3.66	29.	6.1	35.1
	4.34	18.	3.8	21.8

Slim Hole NE-5(i2)

Test Interval: March 15-17, 1985

Date & Time	WHP (bars)	Hot-Wat (T/HR)	Steam (T/HR)	Total (T/HR)
	2.68	25.	6.1	31.1

Slim Hole NE-6(i1)

Test Interval: February 14-15, 1985

Date & Time	WHP (bars)	Hot-Wat (T/HR)	Steam (T/HR)	Total (T/HR)
02-15-85	1.79			26.8
	2.09			25.7
	2.28			25.7
	2.58			25.7

Slim Hole NE-6(i2)

Test Interval: March 14-17, 1985

Date & Time	WHP (bars)	Hot-Wat (T/HR)	Steam (T/HR)	Total (T/HR)
	1.60	20.2	4.1	25.3

Slim Hole NE-11

Test Interval: September 12-19, 1986

Date & Time	WHP (bars)	Hot-Wat (T/HR)	Steam (T/HR)	Total (T/HR)
09-19-86	1.95	16.5	3.5	20.0
	2.10	15.4	3.3	18.7
	2.29	14.9	3.1	18.0
	2.44	11.7	2.6	14.3

Slim Hole NE-11R

Test Interval: January 30 - February 18, 1987

Date & Time	WHP (bars)	Hot-Wat (T/HR)	Steam (T/HR)	Total (T/HR)
02-16-87	1.26	11.00	1.45	12.45

Well Hole TT-1

Test Interval: November 11-15, 1983

Date & Time	WHP (bars)	Hot-Wat (T/HR)	Steam (T/HR)	Total (T/HR)
	0.93	63.	12.	75. *
	1.42	0.	0.	0.

*4-$^1/_2$ inch drill pipe in hole at 400 m → 1071 m (variable depth)

Well TT-2

Test Interval: January 1984, May & June 1984, November 1991-February 1992

Date & Time	WHP (bars)	Hot-Wat (T/HR)	Steam (T/HR)	Total (T/HR)
01-27-84*	2.11	240.	36.	276.
	3.09	230.	30.	260.
	3.68	220.	22.	242.
	4.17	200.	16.	216.
01-28-84*	3.19	280.	43.5	323.5
	3.77	280.	35.	315.
	4.75	260.	26.	286.
	4.95	200.	16.5	216.5
	5.05	160.	13.	173.
05-30-84	3.09	165.	20.	185.
05-31-84	2.65	182.	28.	210.
06-01-84	2.50	192.	35.5	227.5
11-28-91	3.48	224.5	32.	256.5
12-02-91	4.26	220.5	31.5	252.
12-05-91	4.07	219.5	32.5	252.
12-11-91	3.28	210.7	31.7	242.4
02-10-92	3.09	220.2	36.6	256.8
02-18-92	2.99	220.8	37.1	257.9

*Drill pipe 4-$^1/_2$ inch at 400 m

Well TT-7

Test Interval: August 29, 1986, December 11, 1991, February 18, 1992

Date & Time	WHP (bars)	Hot-Wat (T/HR)	Steam (T/HR)	Total (T/HR)
08-29-86*	2.28			479.5
	2.38			477.0
	2.68			465.4
	3.85			362.5
	4.24			308.7
12-11-91	2.68	418.6	83.7	502.3
	2.97	409.7	81.9	491.6
	4.34	343.4	59.0	402.4
02-18-92	2.68	401.4	79.2	480.6
	3.17	389.7	72.9	462.6
	4.64	338.0	54.2	392.2

*5-inch drill pipe in hole at 705 m?

Well TT-8(i)

Test Interval: August 27 - September 2, 1986

Date & Time	WHP (bars)	Hot-Wat (T/HR)	Steam (T/HR)	Total (T/HR)
08-28-86*	1.41			222.
	1.90			187.
	3.18			0.

*4-$^1/_2$ inch drill pipe in hole at 650 m

Well TT-8S1(i)

Test Interval: October 5-9, 1986

Date & Time	WHP (bars)	Hot-Wat (T/HR)	Steam (T/HR)	Total (T/HR)
	0.92	91.	12.	103.*

*4-$^1/_2$ inch drill pipe in hole at 657.6 m MD

Well TT-8S3

Test Interval: June 23, 1987, April 6, 1988, November & December 1991

Date & Time	WHP (bars)	Hot-Wat (T/HR)	Steam (T/HR)	Total (T/HR)
06-23-87	1.21	144.	29.	173.
	1.90	130.	25.	155.
	2.64	115.	25.	140.
04-06-88	3.61	145.5	42.	187.5
11-16-91	3.08	155.5	30.5	186.
11-20-91	3.08	137.	30.	167.
11-24-91	3.08	145.5	32.	177.5
11-28-91	3.08	145.5	29.5	175.
12-01-91	3.08	140.	31.5	171.5
12-04-91	3.08	142.	31.	173.

Well TT-13S

Test Interval: 10/17/87, 01/21/88, August 1988, 12/16/91, 02/21/92

Date & Time	WHP (bars)	Hot-Wat (T/HR)	Steam (T/HR)	Total (T/HR)
10-17-87	2.39	114.	38.	152.
	4.06	79.	31.	110.
	3.18	100.	38.	138.
01-21-88	2.59	138.	40.	178.
	3.08	127.	39.	166.
	3.18	131.	40.	171.
	3.96	101.	33.	134.
08-03-88	6.90	80.	29.	109.
	5.04	138.	41.	179.
08-04-88	4.94	135.	41.	176.
12-16-91	2.49	152.	48.	200.
	3.67	144.	43.	187.
	6.21	108.	27.	135.
02-21-92	3.18	146.	56.	202.
	3.57	144.	53.	197.
	3.76	141.	53.	194.
	6.61	117.	34.	151.

Well TT-14R

Test Interval: 11/09/86, 12/13/91, 02/20/92

Date & Time	WHP (bars)	Hot-Wat (T/HR)	Steam (T/HR)	Total (T/HR)
11-09-86	3.18	220.	61.	281.
	5.14	146.	44.	190.
	5.82	132.	41.	173.
	6.22	118.	38.	156.
	6.31	114.	36.	150.
12-13-91	2.78	216.	63.	279.
	3.37	215.	61.	276.
	6.80	161.	32.	193.
02-20-92	3.08	213.	61.	274.
	3.57	206.	57.	263.
	7.10	147.	29.	176.

Well TT-16S

Test Interval: 01/29-30/89, 02/13-16/89, 11/22/91 - 12/18/91

Date & Time	WHP (bars)	Hot-Wat (T/HR)	Steam (T/HR)	Total (T/HR)
01-30-89	2.50	84.	25.	109.
02-16-89	1.47	43.	12.	55.
11-27-91	1.62	64.	20.5	84.5
12-01-91	1.71	66.	22.	88.
12-05-91	1.91	66.	21.5	87.5
12-07-91	2.11	66.4	21.3	87.7
12-10-91	3.19	64.5	17.5	82.
12-13-91	2.89	70.5	19.6	90.1
12-16-91	3.28	64.6	17.3	81.9
12-17-91	3.38	71.3	19.3	90.6
12-18-91	3.09	70.8	20.8	91.6

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