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HYDRAULIC-FRACTURING MEASURMEMENTS IN TWO BOREHOLES NEAR THE SPENT FUEL TEST-CLIMAX, CLIMAX STOCK, NEVADA TEST SITE

By

William L. Ellis

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ABSTRACT

Hydraulic-fracturing measurements are used to infer the magnitude of the least principal stress in the vicinity of the Spent Fuel Test-Climax, located in the Climax stock at the Nevada Test Site. The measurements, made at various depths in two exploratory boreholes, suggest that the local stress field is not uniform. Estimates of the least principal stress magnitude vary over distances of a few tens of meters, with the smaller values averaging 2.9 MPa and the larger values averaging 5.5 MPa. The smaller values are in agreement with the minimum-stress magnitude of 2.8 MPa determined in a nearby drift in 1979, using an overcoring technique. Jointing in the granitic rock mass and (or) the influence of nearby faults may account for the apparent variation in minimum-stress magnitude indicated by the hydrofracture data.

INTRODUCTION

In June 1982, the U.S. Geological Survey (USGS) conducted hydraulic-fracturing measurements in the two NX-diameter drill holes at the site of the Lawrence Livermore National Laboratories (LLNL) Spent Fuel Test-Climax (SFT-C) in the Climax stock, Nevada Test Site (fig. 1). The purpose of the measurements was to demonstrate the feasibility of hydraulic fracturing in the Climax granite and obtain estimates of the least principal stress magnitude in the vicinity of the SFT-C. In this report, the results of the measurements are presented and discussed, and the procedures and equipment used in obtaining the field data are briefly described.

The work was performed for the U.S. Department of Energy under purchase order no. DE-AP-03-82-SF-13999.

The SFT-C is located at a depth of 418 m in the Climax stock, a composite stock composed of quartz monzonite and granodiorite of Cretaceous age that intrudes sedimentary rocks of Paleozoic and Precambrian age. The stock and sedimentary rocks are overlain by Tertiary rocks consisting of tuff, welded tuff, and breccia. The geology of the Climax stock area is shown in figure 2. Figure 3 shows the location of the SFT-C, along with two other tunnel complexes, Hard Hat and Pile Driver, which were previously mined for underground nuclear tests.

The hydraulic-fracturing measurements were conducted in the UG-2 and UG-3 exploratory boreholes (fig. 4), which were collared in the old Pile Driver workings and cored prior to construction of the SFT-C in 1978. The UG-2 hole was originally cored to a depth of 125 m, but was subsequently deepened to 183 m. A total of 19 hydraulic-fracturing measurements were conducted in the two drill holes; 15 in UG-3 and 4 in UG-2. Approximately 20 measurements were originally planned for the UG-2 hole, but a hoist-cable failure caused a straddle packer assembly to fall and wedge into the hole at a depth of approximately 103 m. Attempts to clear the hole of the straddle packer and high-pressure tubing were unsuccessful, preventing further testing in UG-2.

Funding for this investigation was provided by LLNL. Operational support was arranged by Dr. Wesley C. Patrick and Mr. Richard K. Thorpe of LLNL. Mr. Thorpe provided geologic data from the core logs of the two holes, and also assisted with some of the field measurements. J. D. Kibler and J. E. Magner of the USGS provided technical field support.

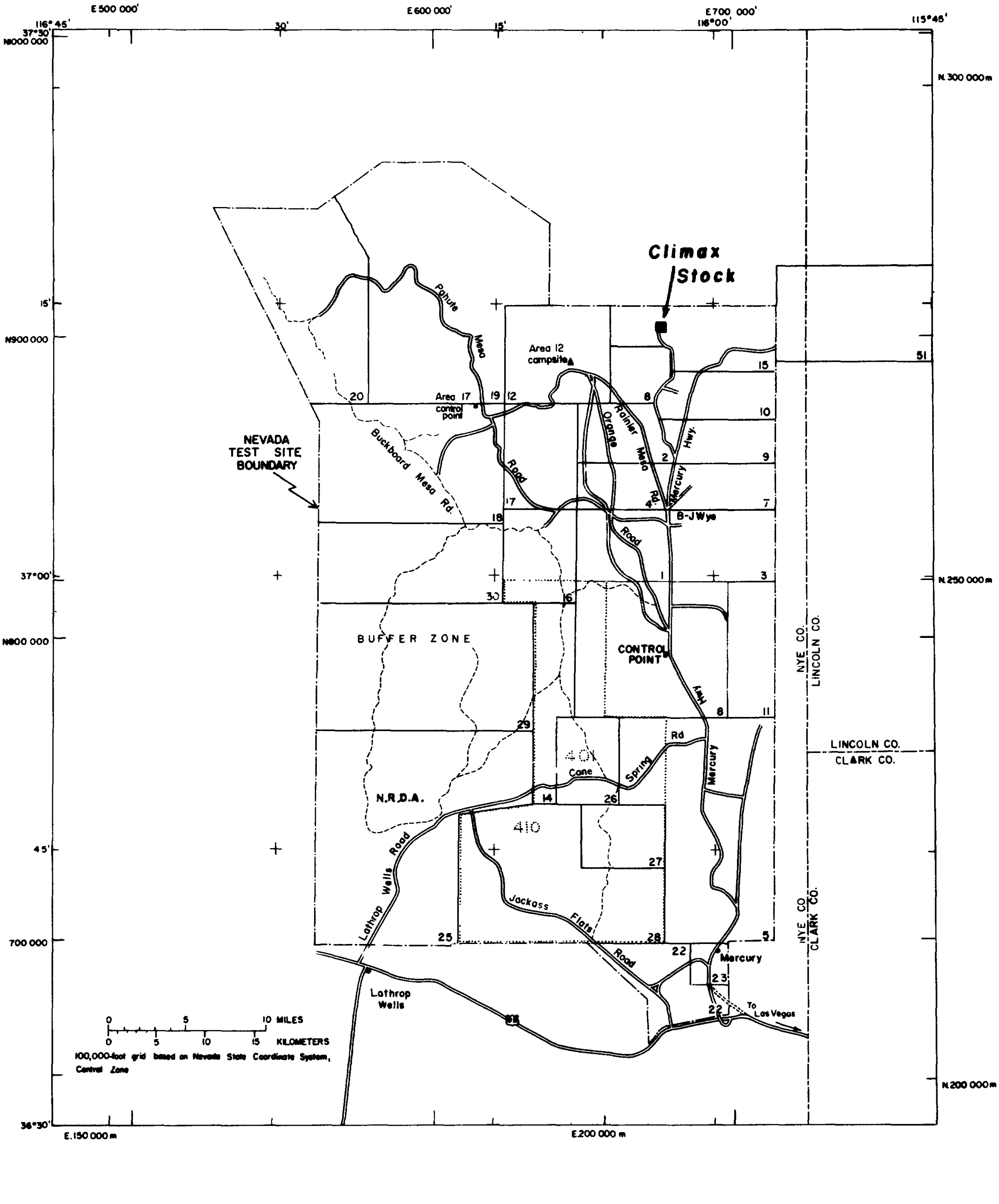

Figure 1.--Index map of Nevada Test Site showing location of Climax stock.

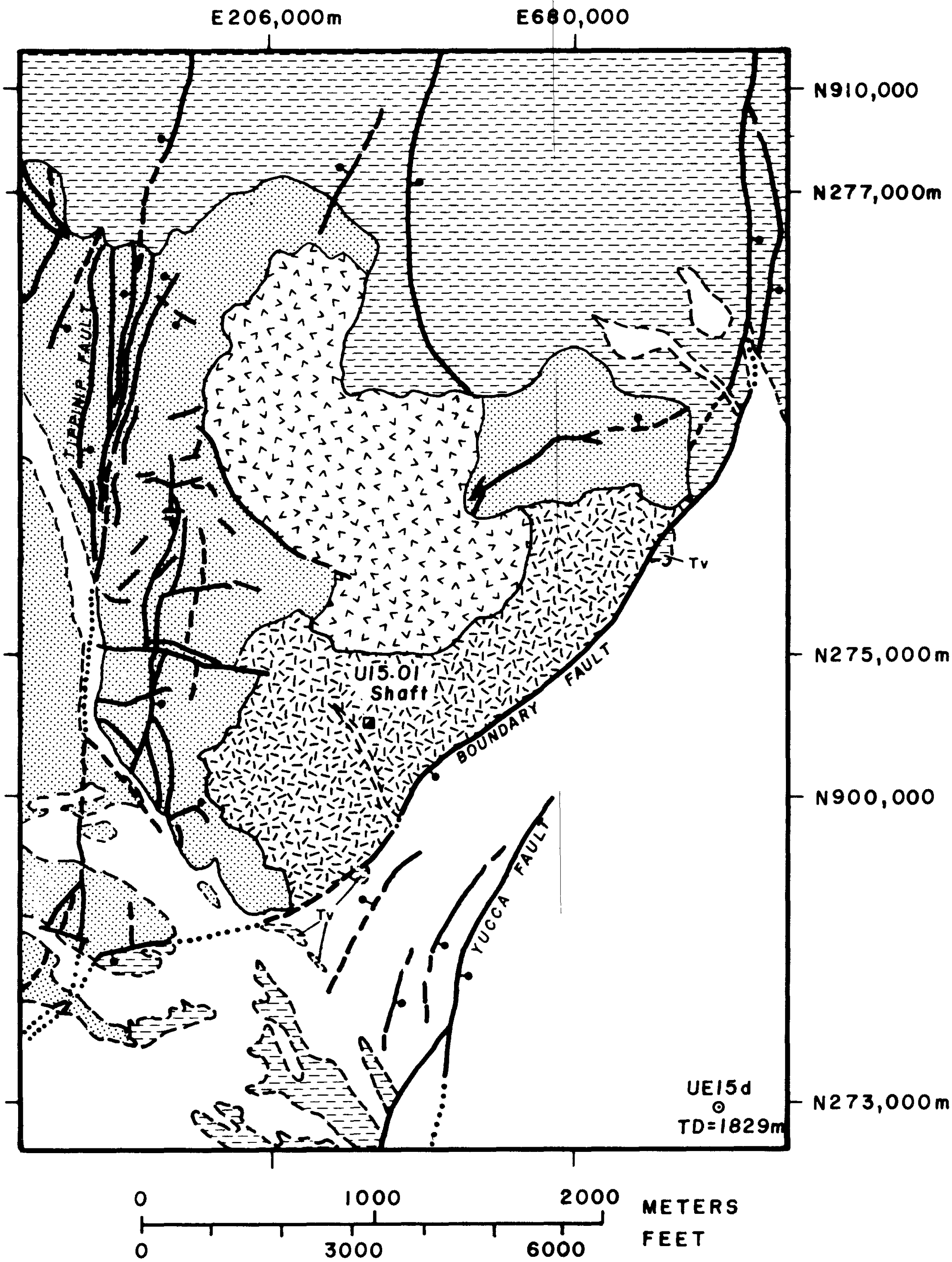

Figure 2.--Geologic map of Climax stock. (Modified from Barnes and others, 1963.)

EXPLANATION

Qal	*ALLUVIUM (QUATERNARY)*
Tv	*VOLCANIC TUFF, UNDIFFERENTIATED (TERTIARY)*
Kqm	*QUARTZ MONZONITE, CLIMAX STOCK (CRETACEOUS)*
Kgd	*GRANODIORITE, CLIMAX STOCK (CRETACEOUS)*
Pz	*LIMESTONE, DOLOMITE, SHALE, AND QUARTZITE, UNDIVIDED (PALEOZOIC)*
	CONTACT -- Dashed where approximately located
	FAULT -- Dashed where approximately located. Dotted where concealed. Bar and ball on downthrown side
U15.01	*SHAFT*
UE15d TD=1829m	*DRILL HOLE -- Showing total depth in meters*

Figure 2.--Continued

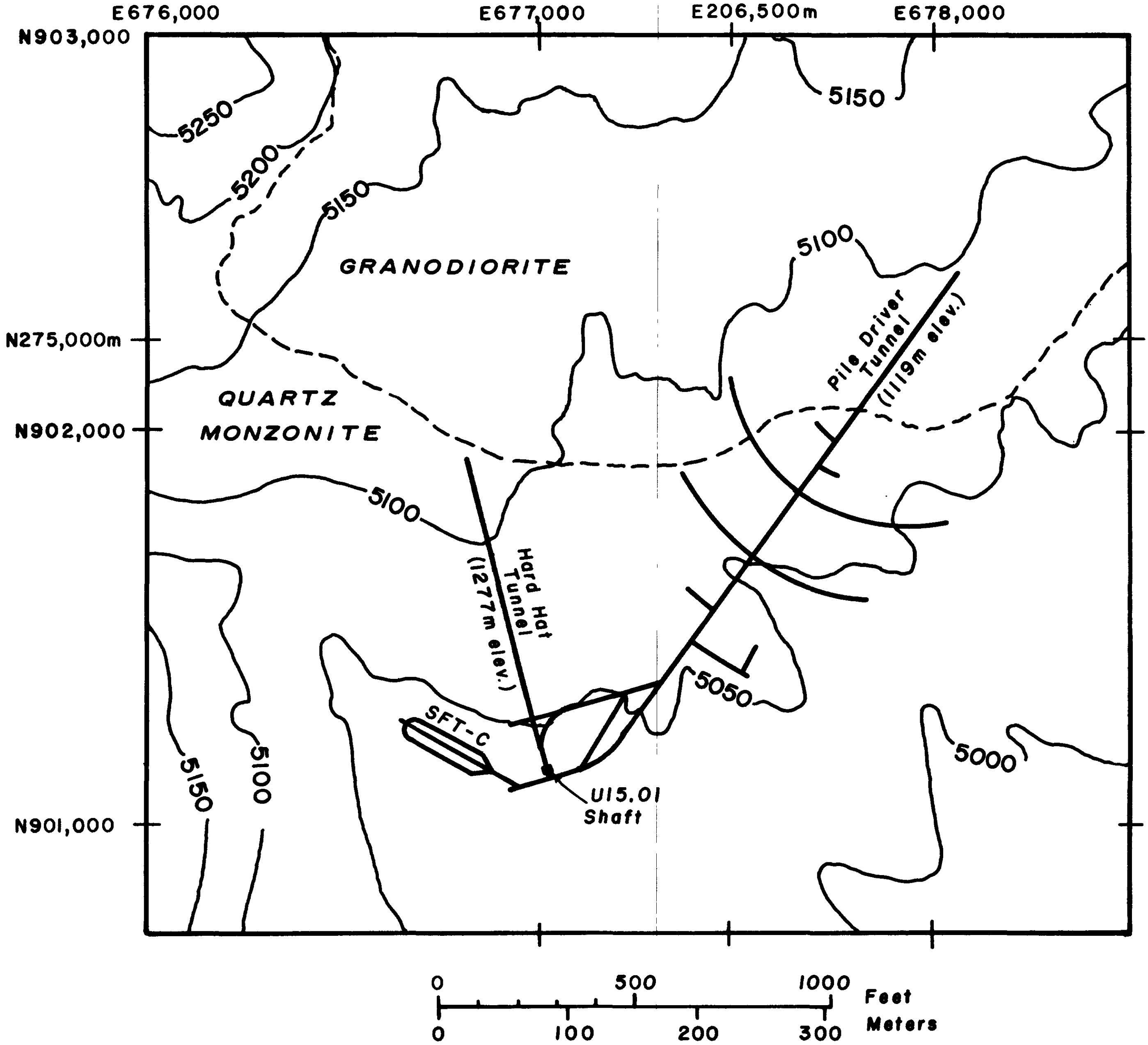

Figure 3.--Map of Climax stock area showing SFT-C, Pile Driver, and Hard Hat tunnels (topographic contours in feet, dashed line is contact between quartz monzonite and granodiorite at ground surface).

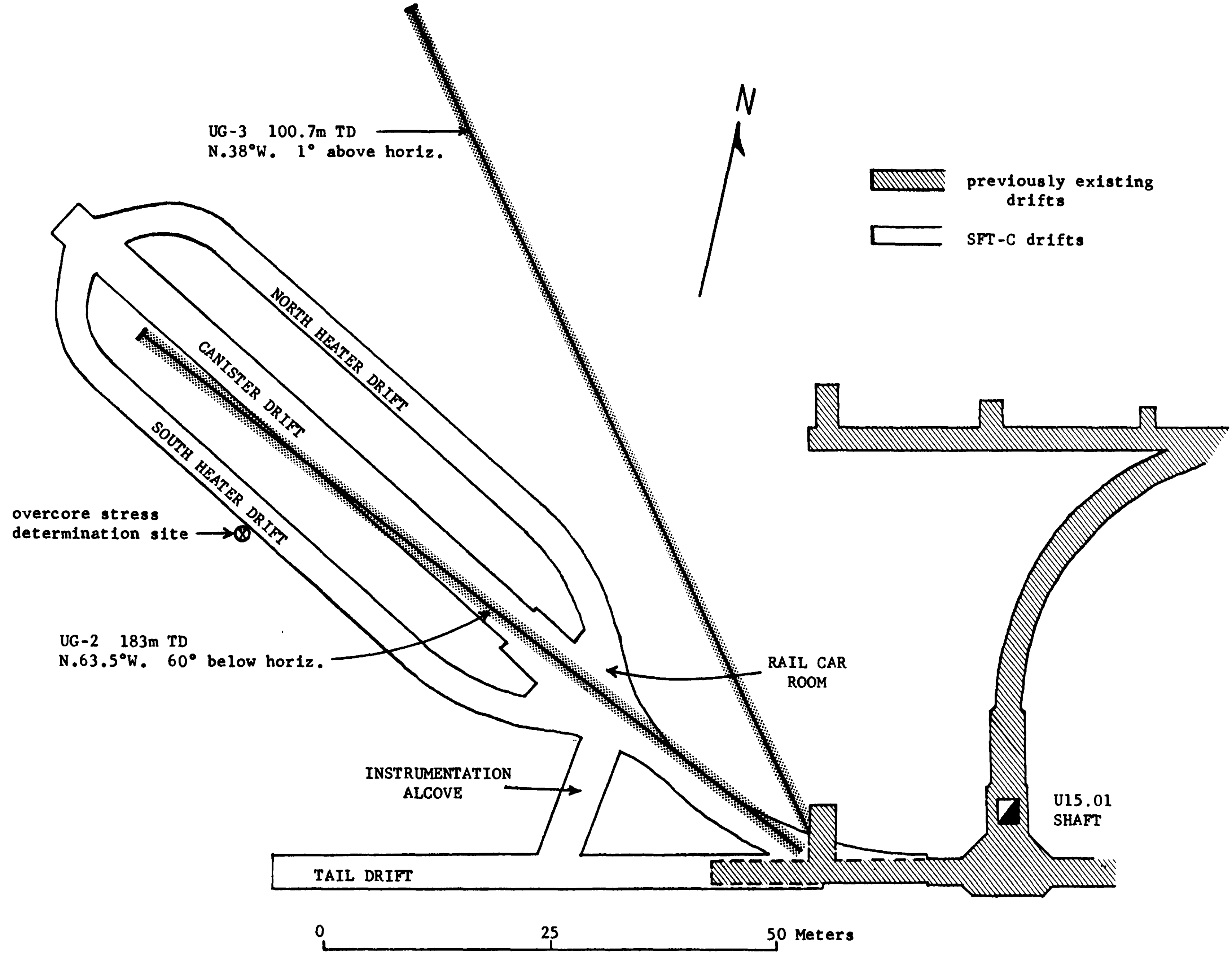

Figure 4.--Map of SFT-C showing location and configuration of UG-2 and UG-3 drill holes. Location of overcoring stress determination conducted in 1979 is also shown.

TEST EQUIPMENT

The hydraulic-fracturing measurements were obtained using a portable hydrofracture system developed by the USGS for use in shallow (<300-m) NX-diameter boreholes drilled from the surface or underground workings. The principal components of the system are

1. an electrically powered hydraulic pump capable of providing up to 34 MPa of pressure at flow rates of 1.0 to 2.0 l/min,
2. a straddle packer assembly fitted with modified end components,
3. flexible high-pressure tubing, and
4. pressure and flow recording instruments.

Downhole pressures in the test zone are monitored during the hydrofracture tests by a pressure transducer mounted in the straddle packer assembly; packer pressures are measured by a dial gauge mounted on the hydraulic pump. Records of test-zone pressures and flow as a function of time are obtained using a chart recorder.

TEST PROCEDURE

The procedure used in conducting the hydraulic-fracturing tests is as follows. First, a preselected 1.4-m-long section of the drill hole is isolated using the straddle packer assembly. Packer pressures are set at approximately 6.9 MPa to assure adequate sealing of the test zone. The test zone is then pressurized using clean water until fracturing of the rock (breakdown pressure) occurs, as indicated by a rapid pressure drop in the test zone. Pumping is then stopped and the test zone is shut in while the pressure decay is monitored. After a short time, the pressure in the test zone is released. Subsequent cycles of pressurization and shut-in are then conducted to obtain fracture-reopening pressures and to extend the fracture until shut-in pressures stabilize and become repeatable. The tests are sometimes repeated at higher packer pressures to insure that the test zone is adequately sealed and to verify that packer pressure effects are not influencing the tests results. A continuous record of pressure and flow as a function of time during each test is obtained using a strip-chart recorder.

In preselecting zones for hydrofracture testing, it is desirable to avoid preexisting fractures. Fracture logs of the two holes were made available by LLNL and used to select the most favorable zones for testing. In the UG-2 hole, zones free of "open" fractures were selected. For the UG-3 hole, the fracture log provided did not contain specific information regarding the depths of individual joints or fractures. The log was based on open fractures in the core and indicated only the relative intensity of fracturing. Test zones were therefore selected in sections of the hole classified as having the least amount of open fracturing.

DATA INTERPRETATION

The basic equation that relates hydraulic fracturing pressures to the in situ stresses is:

$$P_c = 3\ S_h - S_H + T - P_o,$$

where

P_c = breakdown pressure,

S_h = minimum principal stress, or shut-in pressure,

S_H = maximum principal stress normal to borehole,

T = tensile strength of the rock, and

P_o = pore pressure.

For this equation to be valid, it is necessary that the drill hole be parallel to one of the principal stress components. To determine only the least principal stress magnitude from hydrofracture data, however, alinement of the drill hole with one of the principal stresses is not required. The induced fracture, regardless of its initial direction, will aline itself normal to the least principal stress component as it propagates away from the borehole. Shut-in pressure is therefore interpreted as representative of the least principal stress magnitude, regardless of the orientation of the drill hole relative to the principal stresses.

To obtain estimates of the maximum or intermediate stress magnitudes from hydrofracture data, however, requires the assumption that the drill hole is alined with one of the principal stresses. In deep vertical drill holes in structurally simple geologic terranes, this assumption is reasonably valid. In this investigation, however, neither the UG-2 or UG-3 drill holes were alined with a principal stress component, as indicated by the results of an overcoring stress determination in the south heater drift (fig. 4) (Ellis and Magner, 1982; Heuze and others, 1982). For this reason, the hydrofracture test results can only be considered reliable for estimating the minimum principal stress magnitude, and no effort is made to infer a second stress (S_H) component from the test data.

For similar reasons, the direction of the least principal stress has not been determined from the hydrofracture tests. Because the holes are not alined perpendicular to the least principal stress, impressions of the induced fracture at the borehole wall would not provide a reliable indication of stress direction. The initial orientation of the induced fracture is controlled by the stress concentrations around the borehole and the stresses induced by the fracturing process. As the fracture propagates away from the borehole, however, it will change direction to aline itself normal to the least principal stress. In this situation, stress directions inferred from impression packer tests would be erroneous. No effort was therefore made to infer stress directions from the UG-2 and UG-3 hydrofracture data. Results of the overcoring measurements (Ellis and Magner, 1982; Heuze and others, 1982) in the south heater drift provide the most reliable data available at this time on the orientation of the principal in situ stresses in the SFT-C area.

Only those tests that produced good breakdown pressures and distinct shut-in pressures are considered reliable for inferring the minimum stress magnitude. Figure 5 shows the time/pressure record of a typical successful test (UG-3, test #13). Figure 6 shows a time/pressure record (UG-3, test #14) in which, apparently, a preexisting fracture was opened, as suggested by the absence of a breakdown pressure and the presence of a high fracture extension, or pumping pressure. Such a test is not considered reliable because the preexisting fracture is likely not oriented normal to the least principal stress.

RESULTS

Table 1 lists the data obtained in all of the tests conducted in the UG-2 and UG-3 drill holes. Test results from the UG-3 hole are also plotted graphically as a function of drill-hole depth in figure 7, along with the joint and fracture intensity log of the hole. A similar plot for the results from UG-2 is not presented because only four tests were completed at shallow depths in the hole. For illustrative purposes, all of the data from the UG-3 hole have been plotted in figure 7, although only those tests that produced a breakdown pressure and a clearly distinct shut-in pressure are appropriate for estimating the least principal stress magnitude.

The test results within the first 35 m of UG-3 are apparently complicated by the proximity of the drill hole to the SFT-C excavation, as suggested by the variability in test results. Beyond 35-m depth, where the drill hole diverges from the SFT-C and previously existing drifts (fig. 4), the test results become much more uniform, with all but one of the tests producing a breakdown pressure. Shut-in pressures from these tests are interpreted as being representative of the minimum in-situ stress magnitude.

Between depths of about 35 and 67 m in UG-3, the shut-in pressures are quite uniform and indicate an average minimum stress magnitude of 2.9 MPa. This value is in close agreement with the minimum principal stress magnitude of 2.8 MPa determined from the overcoring measurements conducted in the south heater drift in 1979. The three hydrofracture measurements between 72- and 91-m depth in the hole indicate minimum stress magnitudes between 5.0 and 6.0 MPa. A transition from a relatively low to a relatively high minimum stress magnitude apparently occurs at a hole depth of around 70 m. The reason for this variation in minimum stress magnitude is uncertain. Most likely, it represents natural stress variations that are commonly observed in jointed rock masses (Obert and Duvall, 1967, p. 477), but could also possibly be related to two northeast-striking faults identified in the SFT-C drifts (Wilder and Patrick, 1981). Two of the intensely jointed intervals in the UG-3 hole occur at depths near where these faults would project into the hole, and are therefore indicated as "probable faults" in figure 7. The larger minimum-stress values occur between the two faults, suggesting that the observed stress distribution may be fault controlled.

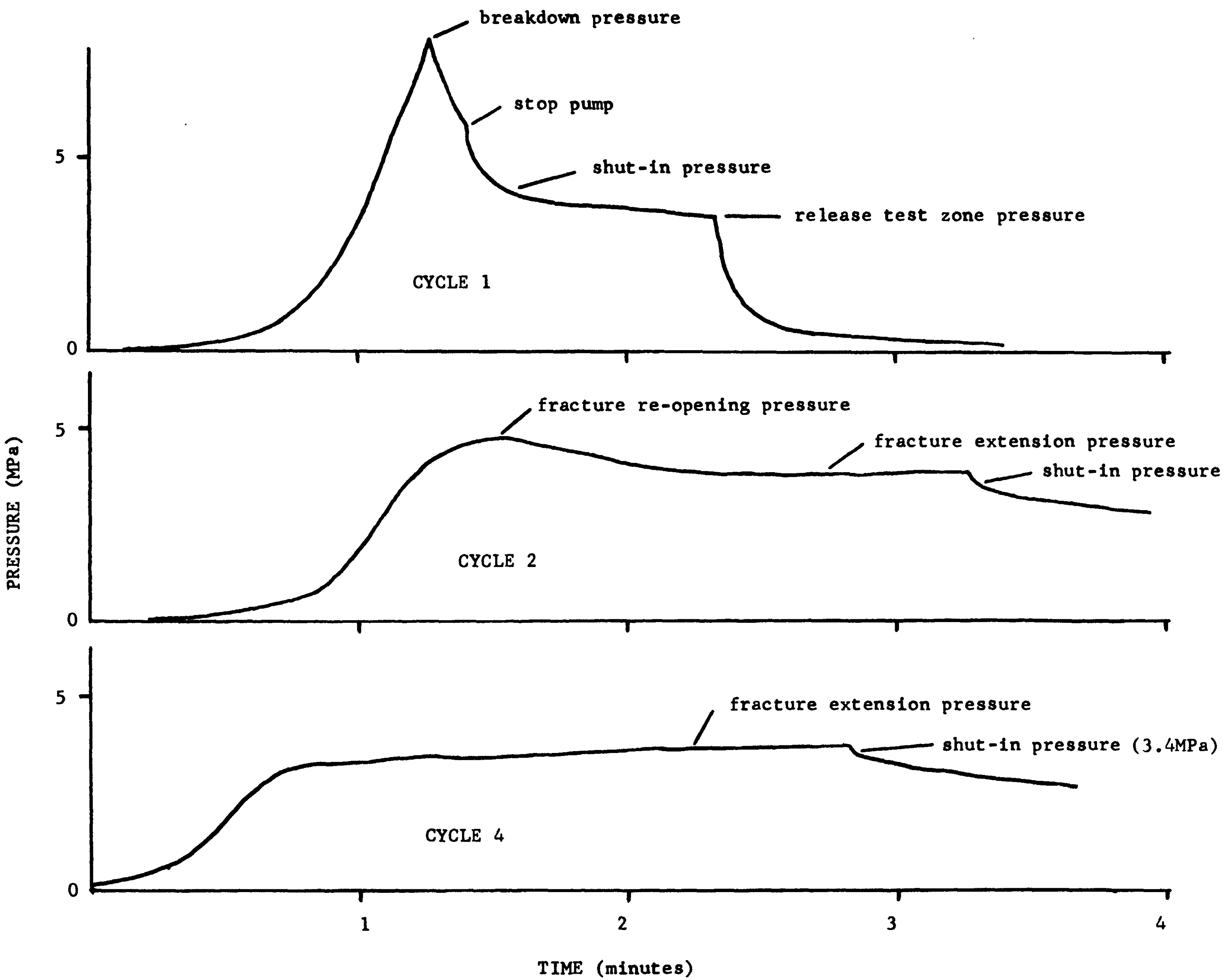

Figure 5.-- Time-pressure record for test #13, UG-3 hole. Test is considered reliable for estimating minimum stress magnitude from shut-in pressure.

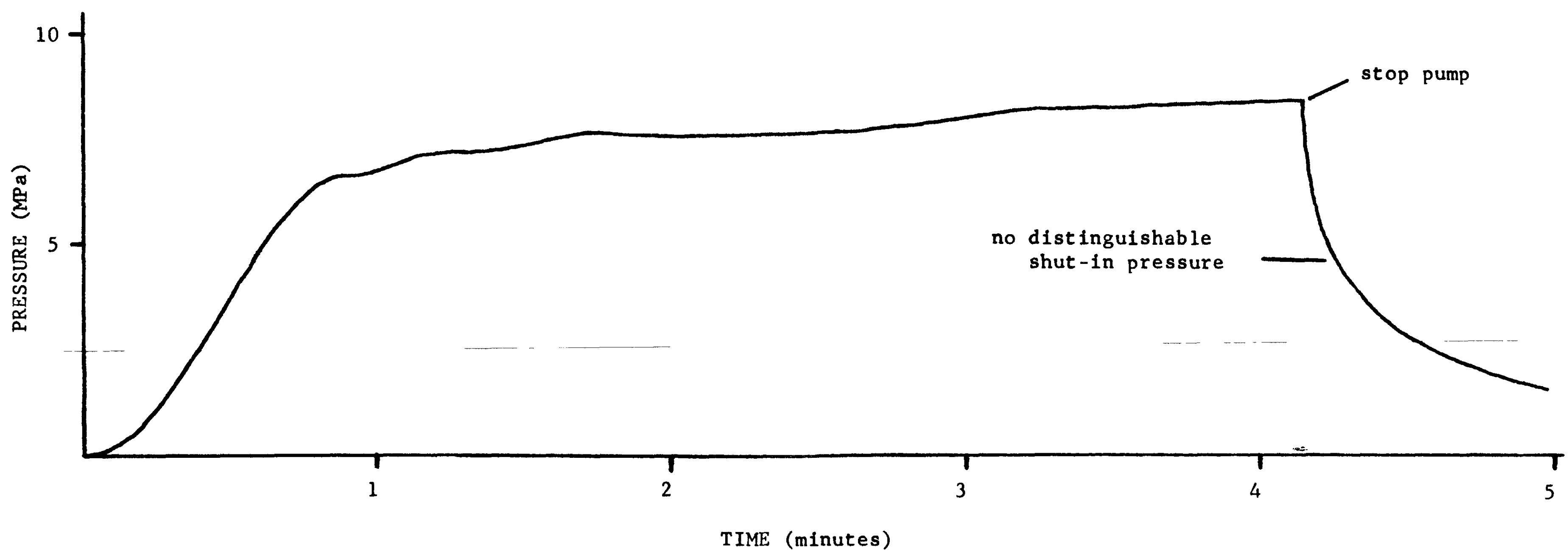

Figure 6.-- Time-pressure record for test #14, UG-3 hole. Absence of breakdown pressure and unusually high pumping pressure indicate pressurization of preexisting fracture. Note that a distinct shut-in pressure is not apparent.

Table 1.--Tabulation of hydrofracture data obtained in UG-2 and UG-3 drill holes, SFT-C

[Leaders (----) indicate pressure signature did not occur or was not distinguishable on time-pressure record; MPa, megapascals]

Test No.	Test interval depth (meters)	Breakdown pressure (MPa)	Fracture reopen pressure (MPa)	Fracture extension pressure (MPa)	Shut-in pressure (MPa)
		UG-3 drill hole			
1	9.1-10.5	11.4	4.7	3.4	3.1
2	15.2-16.6	12.1	9.0	7.9	4.5
[1]3	25.9-27.2	----	---	1.0	---
[1]3A	27.4-28.7	----	---	4.1	---
4	34.4-35.8	5.0	2.9	2.6	2.2
5	38.4-39.7	9.2	5.0	3.4	3.3
6	52.4-53.7	7.0	---	3.0	2.4
7	59.4-60.8	8.5	3.9	2.9	2.6
8	65.5-66.8	7.7	---	3.8	3.4
9	76.2-77.5	10.1	6.5	5.6	5.2
[2]10	84.7-86.1	----	---	9.0(?)	---
11	90.2-91.5	9.3	---	6.6	5.9
12	71.9-73.2	11.3	6.5	5.7	5.3
13	45.1-46.4	7.9	4.6	3.6	3.4
[2]14	18.9-20.2	----	---	8.1(?)	---
		UG-2 drill hole			
1	9.1-10.5	6.8	2.0	1.1	1.0
2	18.9-20.2	7.4	2.8	2.1	2.0
3	25.6-26.9	8.6	3.8	3.3	3.1
4	32.9-34.2	15.3	7.7	6.3	5.2

[1]May be open fracture in test zone.
[2]May be pressurization of preexisting fracture.

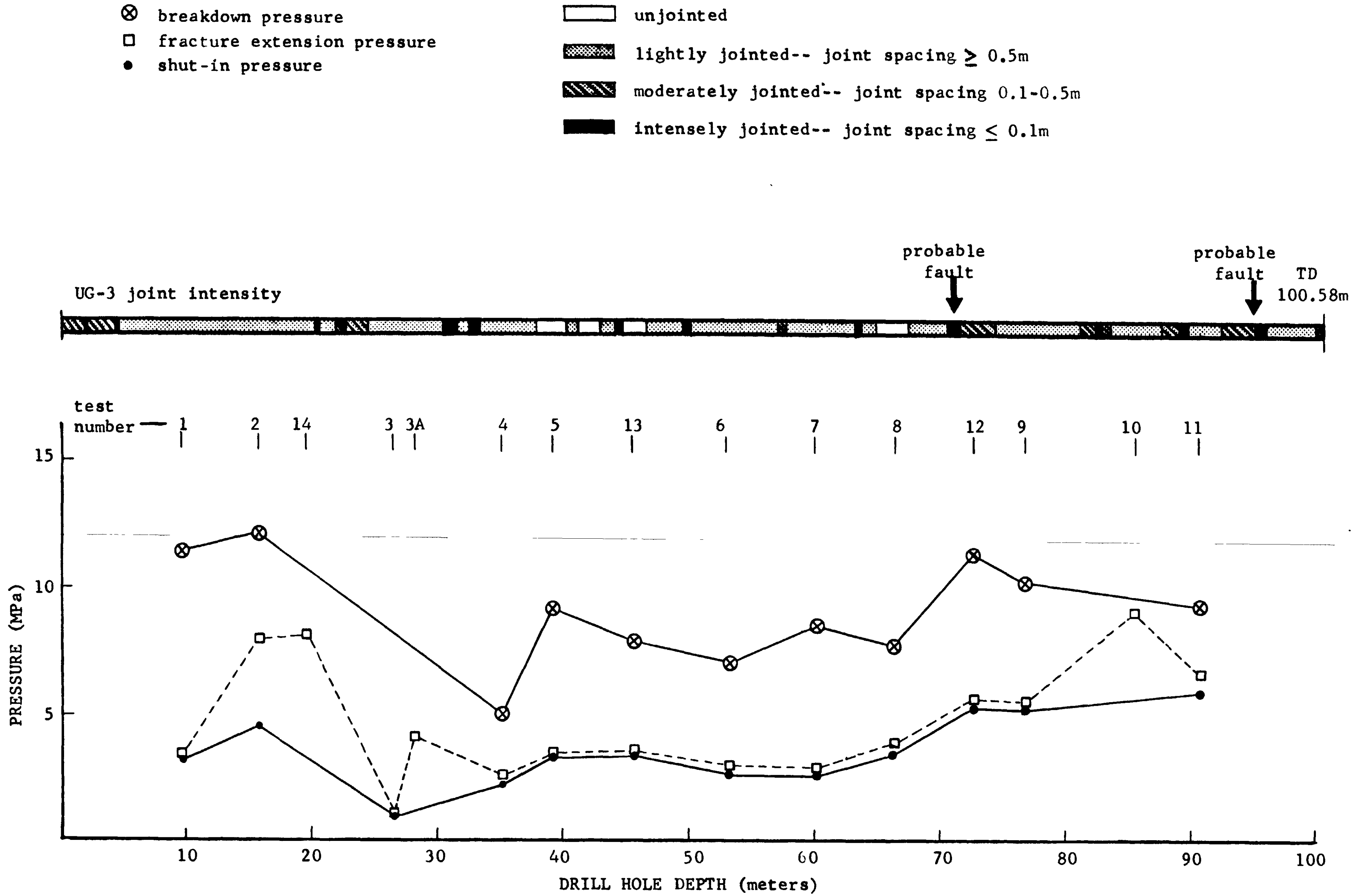

Figure 7.-- Hydrofracture test results versus drill hole depth, UG-3 drill hole.

Results from the four tests in the UG-2 hole (table 1) indicate an increase in minimum stress magnitude with increasing hole depth, from 1.0 MPa at about 9 m to 5.2 MPa at about 33 m. This trend in the test results implies an extensive zone of stress relief beneath the drift floor. Although this zone of apparent stress relief appears unexpectedly large, it may be reasonable considering the combined influence of the nearby rail-car room, instrumentation alcove, and tail drift extension. In effect, the proximity of these excavations to the test hole may produce a stress redistribution more characteristic of a larger excavation, and thus extend for a greater distance away from the openings.

SUMMARY

Hydraulic-fracturing measurements were conducted in the UG-2 and UG-3 drill holes in the vicinity of the SFT-C. Shut-in pressures from these tests have provided estimates of the minimum stress magnitude at various depths in the holes. In the UG-3 drill hole, the results indicate that between hole depths of 35 and 70 m, the minimum stress magnitude is quite uniform and averages 2.9 MPa. This value is in agreement with the minimum stress magnitude of 2.8 MPa determined from overcoring measurements in the south heater drift in 1979. Between 70 and 91 m in the hole, the minimum stress also appears quite uniform, but averages 5.5 MPa in magnitude. It is suggested that this variation in miminum stress magnitude may be structurally controlled, either by jointing in the rock mass or by nearby faults. In the UG-2 hole, only four tests were completed to a depth of 34 m. Results indicate an increase in minimum stress magnitude with hole depth indicative of a zone of stress relief beneath the tunnel floor. Because the UG-2 measurements were apparently within a zone of influence of the exacavation, they do not provide a reliable indication of the in-situ stress conditions.

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