MOMOTOMBO GEOTHERMAL RESERVOIR

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INTRODUCTION

Flow tests and pressure measurements were made on a group of five wells in the Momotombo geothermal reservoir, Nicaragua. The purpose of these tests was to evaluate the hot water reservoir, to determine well interference effects, to determine reservoir boundary conditions and to obtain mass flow rates and enthalpy.

Static bottom hole pressures were measured on three wells and bottom hole flowing pressures and shut-in buildup pressures were measured on one of the wells. A Hewlett-Packard quartz crystal pressure gauge was used in connection with a Sperry Sun expandable chamber hung on steel capillary tubing to measure downhole pressure.

Flow tests were made on all five wells. Four wells were flowed through a horizontal discharge pipe. One well was flowed through a vertical discharge pipe.

GEOLOGY

The dominant feature in the area is the dormant volcano, Momotombo. It is the heat source for the geothermal system. The aquifer for the system is unknown but is probably deep seated and large.

The deepest penetration in the field has been to 7,384 feet. At total depth, the formations continued to be older pyroclastics. Andesitic-basaltic pyroclastic deposits and lavas predominate throughout the column. The area of geothermal development is part of a much older volcanic structure. A north-south cross section through the field shows correlative formations which are relatively flat with minor dipping that increases with depth to the north toward the center of the volcano.

The occurrence of geothermal fluids is not associated with a structure of closure. See Figure 1. The conduits containing geothermal fluids are a series of northwest/southeast-trending faults which connect the developed area to the aquifer. These faults are believed to be numerous and to form a band, or faulted zone. The occurrence of a fault conduit is generally indicated during drilling by a partial or total loss of drilling fluid. Subsequent to completion of the well, these faulted sections can be recognized by anomalies of high-temperature.

Following the development of the field, interference tests were made which suggested some interference between certain wells, little interference between

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other wells, and no interference between other wells. This suggests a series of fault planes, or conduits, with pressure and fluid connection in some instances and no connection in others. It is believed that all fluids come from the same aquifer but travel by different paths. Because of this common origin, the reservoir appears to have a common vapor-fluid interface, or flash point, recognized in MT-3 and MT-12 as being in the interval between 748 feet and 796 feet subsea.

The effects of rainfall on bottom-hole pressures are also pertinent to the geology of this area. This phenomenon was apparent following rainfall from June 1 through June 3, 1977, and suggests an "open" reservoir without structural closure. The closure for the system becomes the cooled, hydrostatic-fluid column at distance from the heat mass.

STATIC PRESSURES

Static bottom-hole pressures for MT-2 and MT-3 are shown in Figures 2 and 3 respectively. As can be seen the pressures show considerable fluctuation within any 24 hour period as well as from day to day with MT-2 showing considerably greater fluctuation than MT-3.

The reason for the difference in behavior is that the wellbore of MT-2 is filled with liquid to the surface whereas the wellbore of MT-3 contains steam to a depth that is below the pressure sensing device. Thus MT-2 can be considered a "hard" well; that is, the fluid in the wellbore has a low compressibility so that pressure pulses can be transmitted into the wellbore with a negligible quantity of fluid moving into the wellbore. On the other hand, MT-3 can be considered a "soft" well; that is, the fluid in the wellbore has a high compressibility so that a considerable amount of fluid would have to move into the wellbore in order to increase the pressure. In effect, the steam in the wellbore acts to dampen rapid pressure changes.

In order to get a better picture of pressure versus time, a daily average pressure and its standard deviation were calculated for 48 values at one-half hour intervals. A plot of the daily average pressure for MT-2, MT-3, and MT-9 prior to the time they were put on production is shown in Figure 4. The standard deviation range is plotted as a vertical line. Here the variation in standard deviation can be readily seen.

The dates that MT-9, MT-12, and MT-17 were opened is also shown. The pressure trend on MT-3 does not indicate an interference effect. The fluctuations in pressure on MT-2 are such that an interference effect cannot be determined. The distance between MT-2 and its nearest producer, MT-12, is 610 feet. The distance between MT-3 and its nearest producer, MT-9, is 1040 feet.

WELL FLOW CHARACTERISTICS

For the four wells that were flowed through horizontal discharge pipes, wellhead pressures, upstream and downstream orifice pressures, and lip pressures were measured. For the well that flowed through a vertical discharge pipe only, wellhead and lip pressures were measured. The method of James (1962, 1965) was used to calculate flow rates.

Flow characteristics of MT-2 are shown in Figure 5. The well required a little less than two weeks to stabilize after which wellhead pressure, mass flow rate, and enthalpy remained essentially constant within the accuracy of the data. The wellhead pressure stabilized at 142 psi and the mass flow rate at 520 kph. The enthalpy stabilized at an average of 545 Btu/lb. This enthalpy is greater than that of water at a maximum temperature in this well and indicates flow of steam from the steam cap into the wellbore.

The flow tests on the five wells indicate that from one to four weeks are required for the wells to stabilize. The stabilized rate averaged about one-half of the maximum flow rate exhibited in the first few hours of production. For MT-2, for example, the stabilized rate was almost exactly one-half the rate calculated from the data obtained shortly after the well was opened.

The time that MT-9 was shut in is also shown in Figure 5. Here, no effect can be seen on the wellhead pressure, for example, again indicating no interference between MT-2 and MT-9.

DRAWDOWN AND BUILDUP ON MT-9

The drawdown behavior of MT-9 is shown in Figure 6. For the first 3 days, or until MT-12 was placed on production, the pressure, except for the variations within a 24-hour period, decreased linearly with the logarithm of time. After MT-17 was placed on production, the pressure decreased linearly with time at a rate of one psi per day for the next 23 days, at which time the well was shut-in. This constant rate of pressure decrease seems to suggest that pseudo steady state behavior had been reached by this well and it is producing from a limited source. As will be shown later this conclusion is at variance with the conclusion based on other data that the Momotombo reservoir is a large resource.

The pressure buildup on MT-9 is shown in Figure 7. The initial rise in pressure was very rapid, increasing from 423 psi to 480 psi in 30 minutes. Thereafter, the pressure rose much more slowly, showing an average daily increase of about one psi per day for five days. After MT-2, MT-12 and MT-17 were shut-in, the pressure increased about two psi per day to an average of 498 psi on 28 July, the last full day of pressure measurements. Pressures measured the last day of the test program fell in the pressure range that existed prior to the start of production as shown in Figure 7. It appears highly likely that the average daily pressure would reach the 510 to 511 psi that existed prior to the start of the flow test on MT-9. This would then indicate essentially complete recharge.

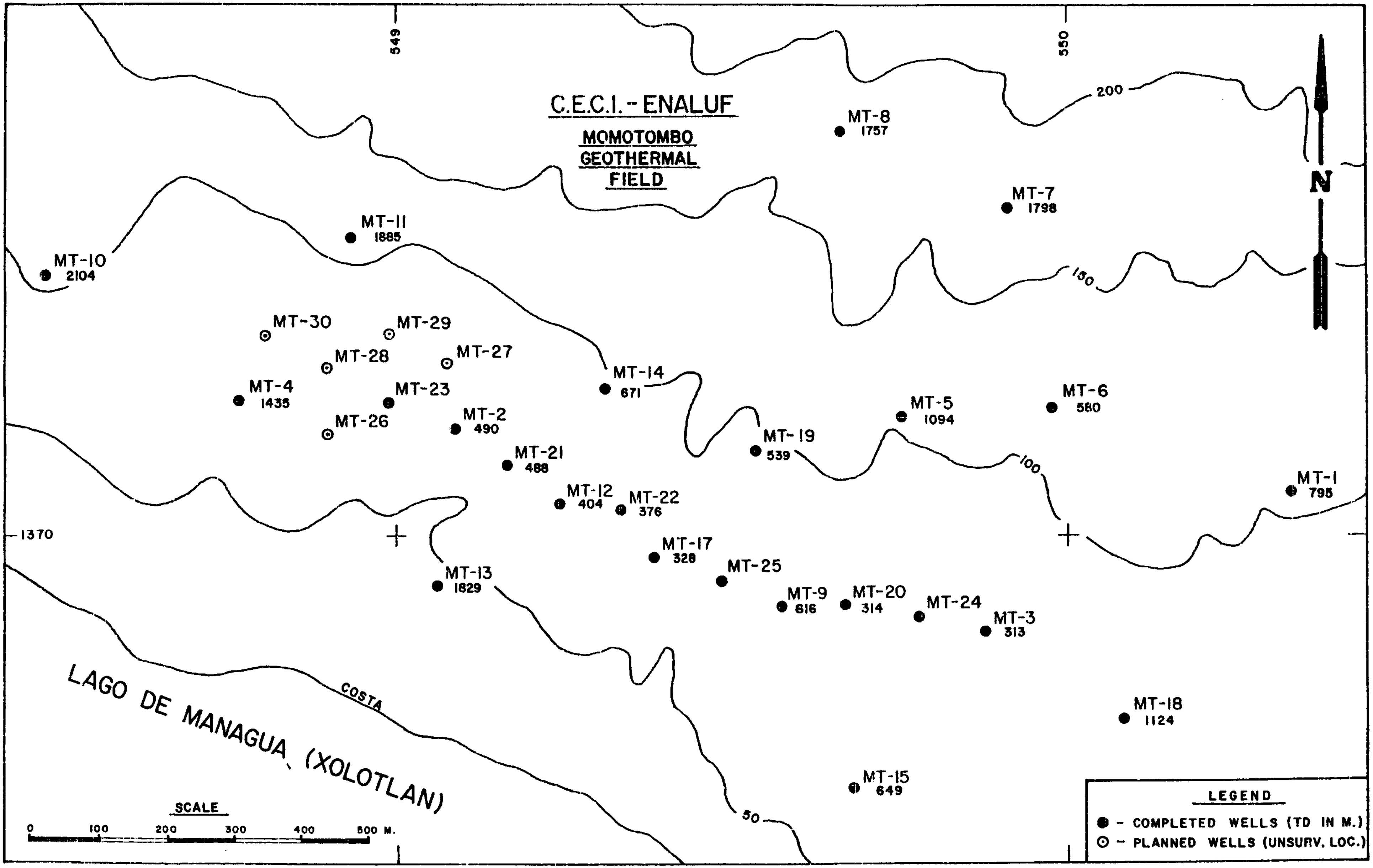
Wellhead pressures were also measured on MT-3 during 16 days of production and during the subsequent shut-in. At the end of the test period, the wellhead pressure had built up to essentially the same value that existed prior to the start of production, again indicating essentially complete recharge.

In the discussion of the drawdown of MT-9, it was mentioned that the linear decline in pressure seemed to indicate pseudo steady state. A more likely explanation in the light of data showing almost complete recharge is that the production rate of MT-9 exceeded the ability of the system to supply fluid to MT-9. If so, then a lower rate or a longer time should result in the flowing pressure of MT-9 leveling off at a pressure consistent with the ability of the system to supply fluid.

REFERENCES

1. James, Russell; "Steam-Water Critical Flow Through Pipes"; Proc. Inst. Mech. Engrs. (1962) 76 No. 26, 741

2. James, Russell; "Metering of Steam-Water Two Phase Flow by Shrp Edged Orifices"; Proc. Inst. of Mech. Engrs. (1965-66) 180 Part 2, 549



C.E.C.I. - ENALUF
MOMOTOMBO GEOTHERMAL FIELD
549
550
1370
200
150
100
50
N
MT-8 1757
MT-7 1798
MT-11 1885
MT-10 2104
MT-30
MT-29
MT-28
MT-27
MT-14 671
MT-4 1435
MT-23
MT-2 490
MT-26
MT-21 488
MT-19 539
MT-5 1094
MT-6 580
MT-12 404
MT-22 376
MT-1 795
MT-17 328
MT-25
MT-13 1629
MT-9 616
MT-20 314
MT-24
MT-3 313
MT-18 1124
MT-15 649
LAGO DE MANAGUA (XOLOTLAN)
COSTA
SCALE
0 100 200 300 400 500 M.
LEGEND
● - COMPLETED WELLS (TD IN M.)
⊙ - PLANNED WELLS (UNSURV. LOC.)

FIGURE I

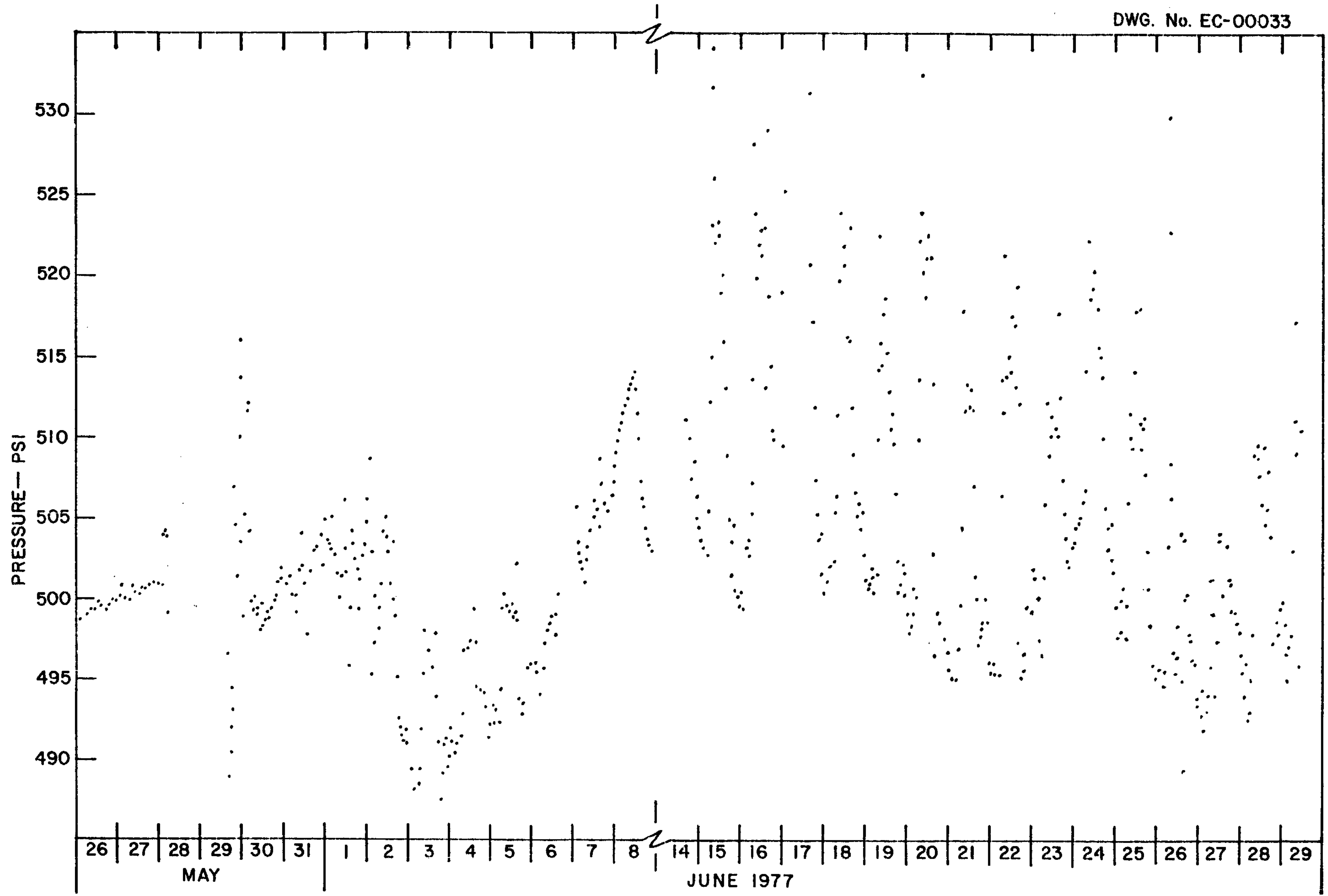


FIGURE 2. STATIC BOTTOM HOLE PRESSURES – WELL MT-2.

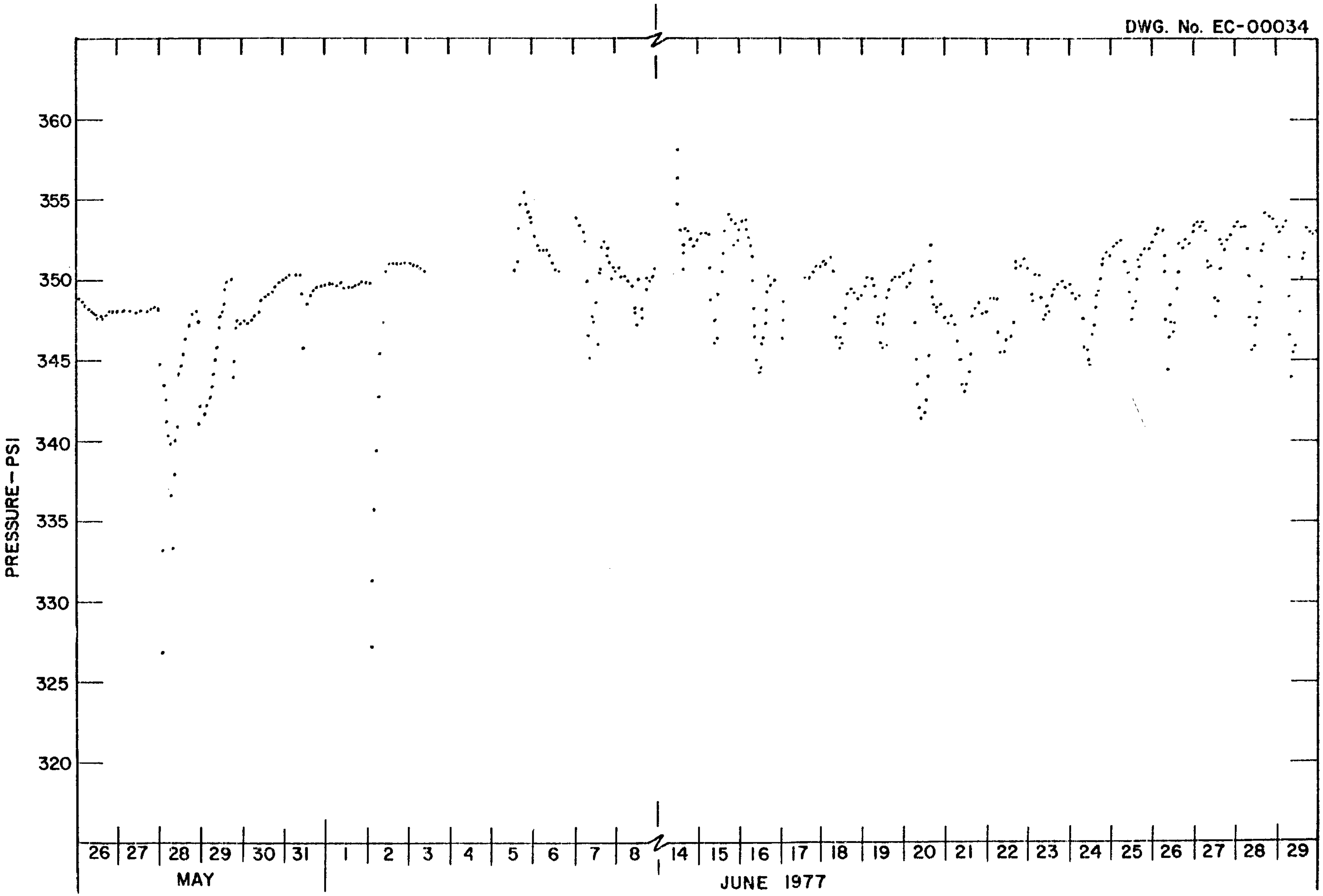


FIGURE 3. STATIC BOTTOM HOLE PRESSURES – WELL MT-3.

DWG. No. EC-00035

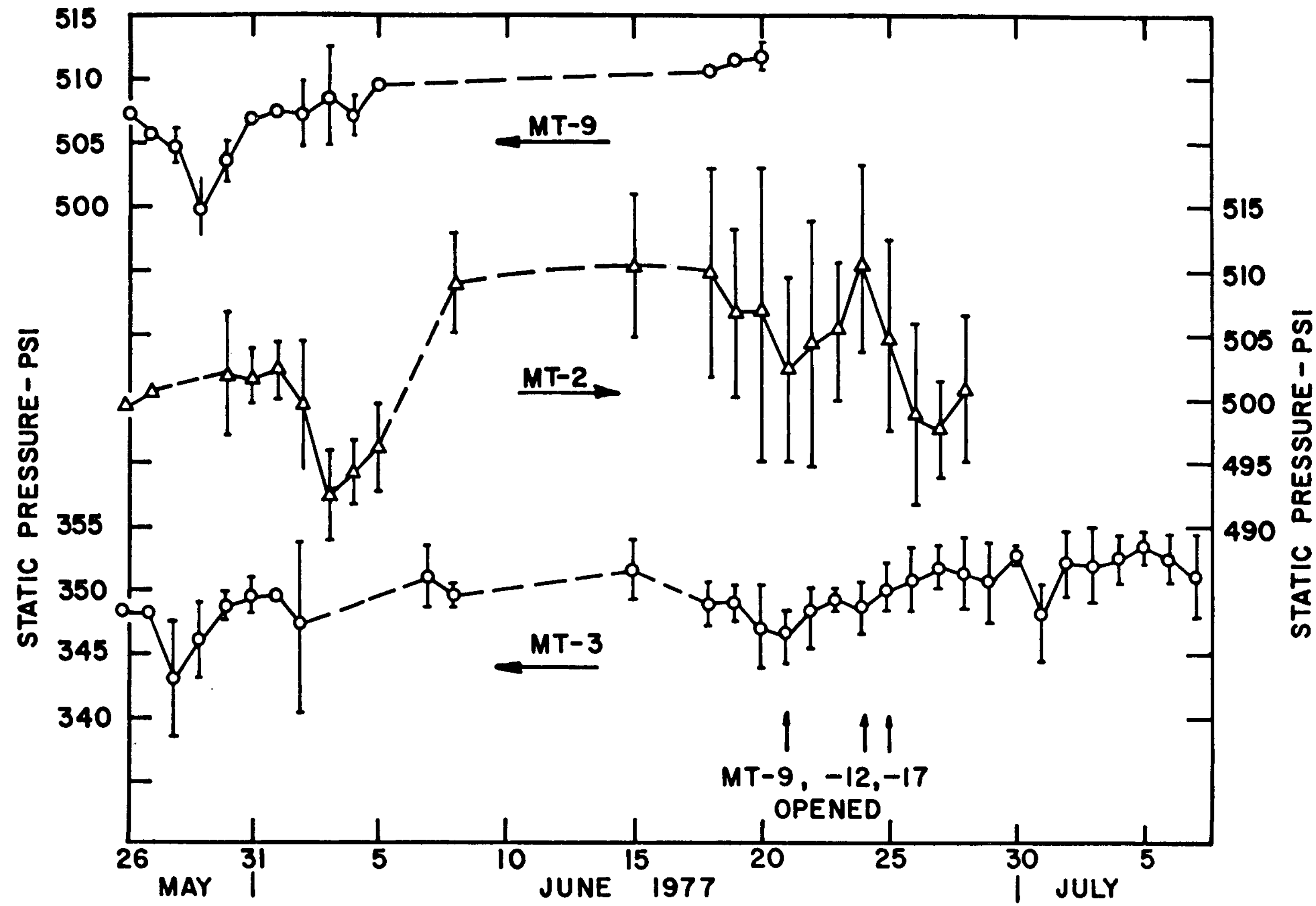


FIGURE 4. AVERAGE DAILY STATIC BOTTOM HOLE PRESSURES

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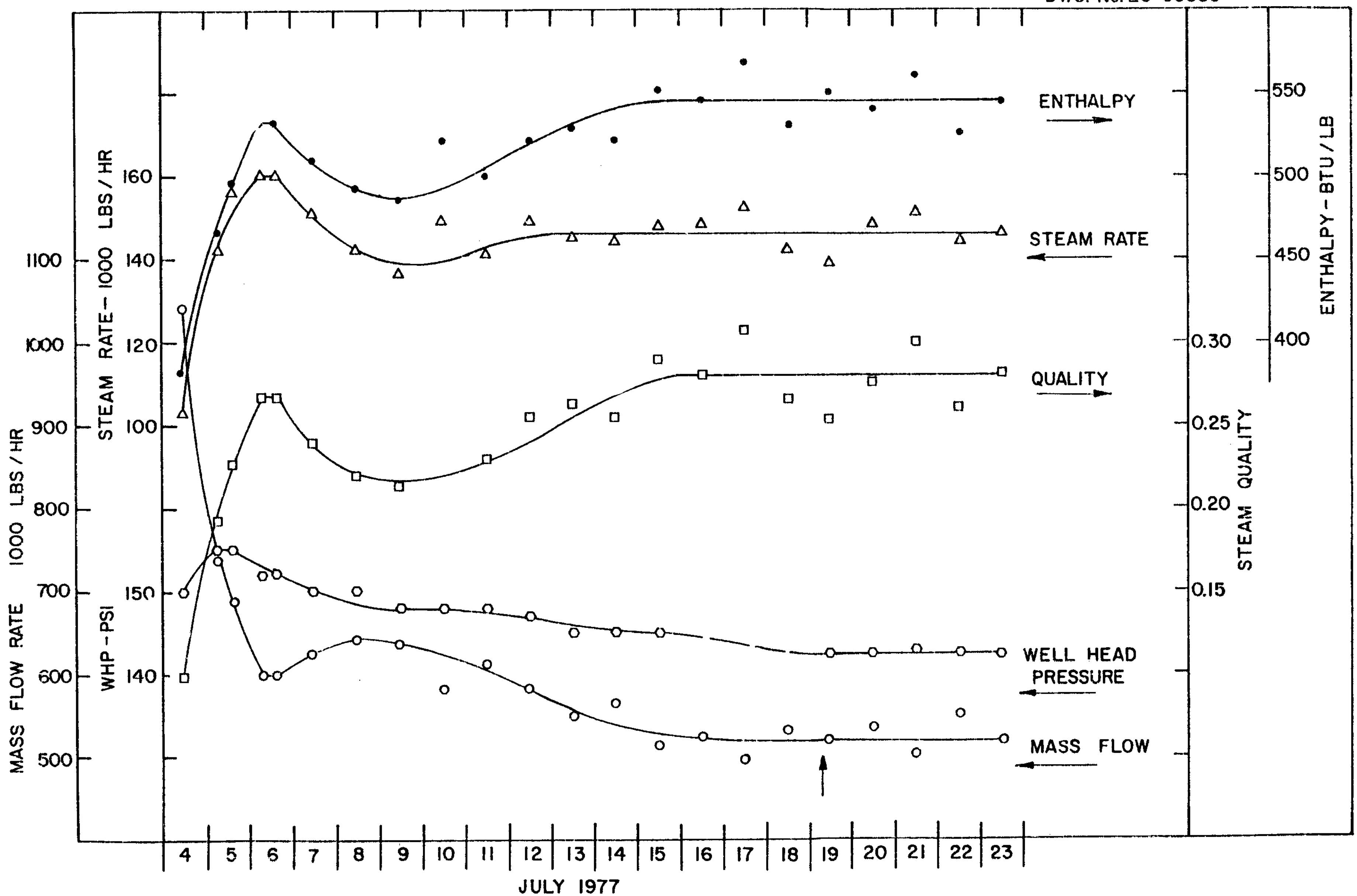

FIGURE 5. FLOW CHARACTERISTICS - WELL MT-2

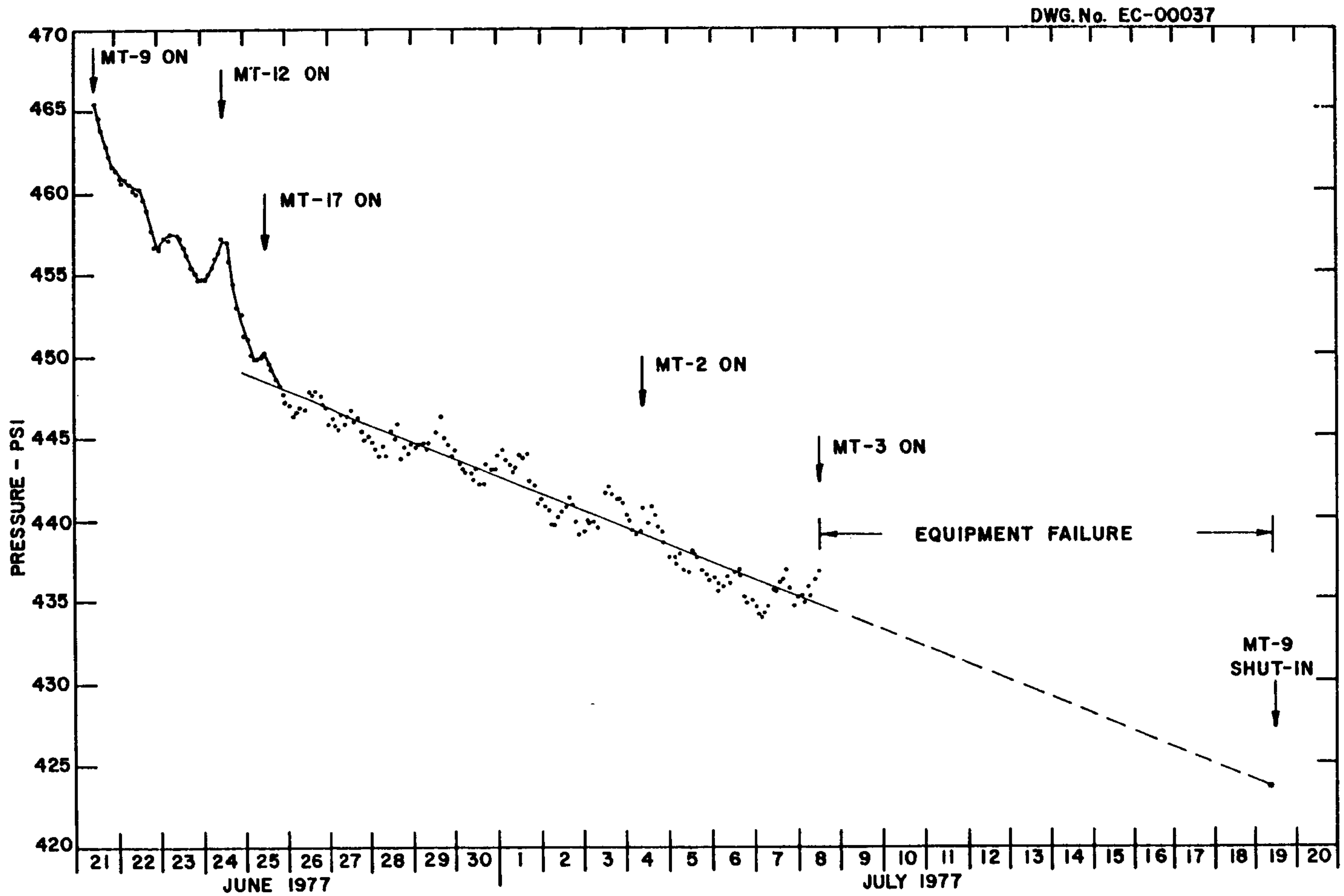

FIGURE 6. BOTTOM HOLE FLOWING PRESSURE WELL MT-9

DWG. No. EC-00038

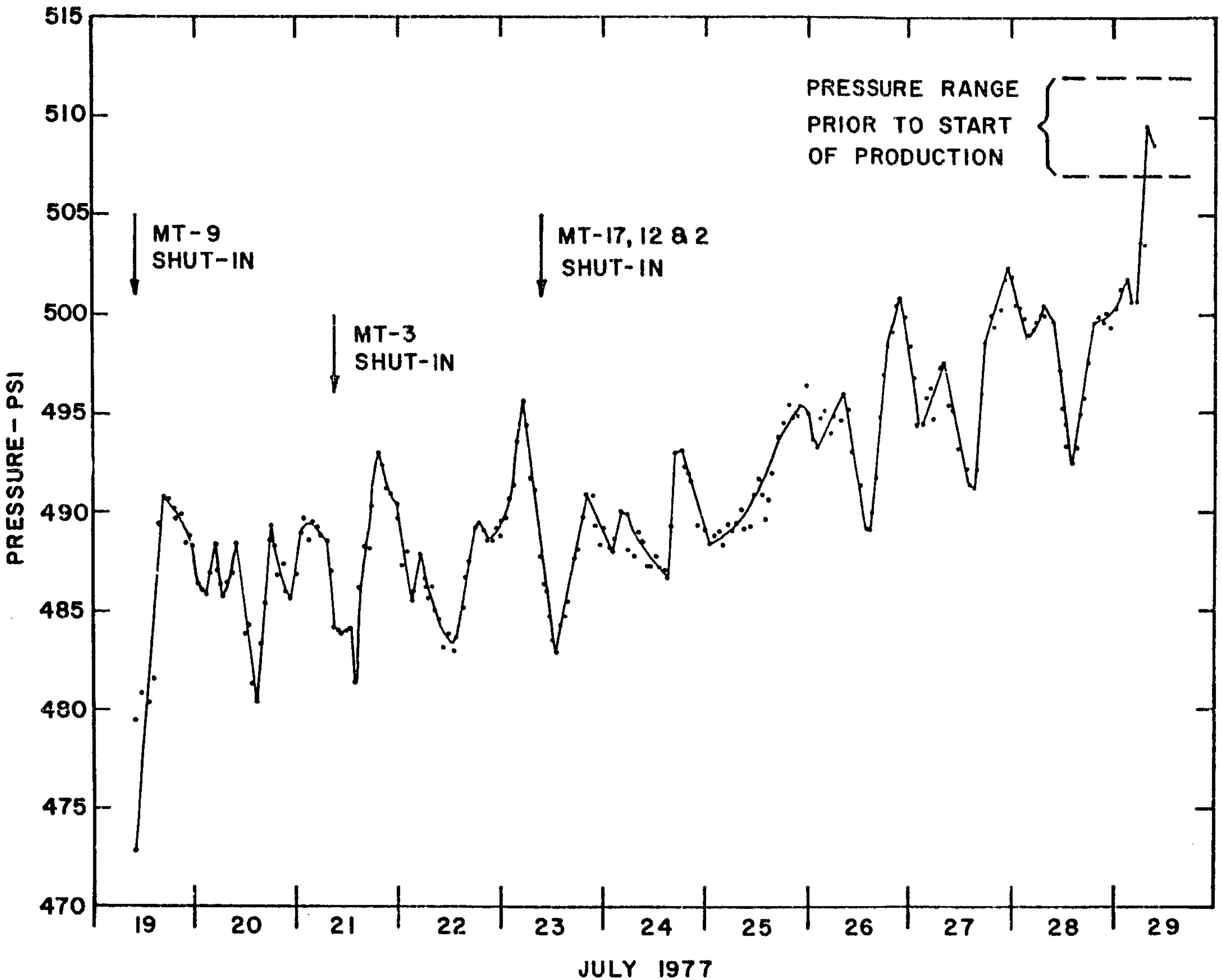

FIGURE 7. BOTTOM HOLE SHUT-IN PRESSURES WELL MT-9