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LA FRACTURE ANOMALEUX - LES PRESSIONS EXTENSION EN ROCHES GRANITQUES
UNREGELNÄSSIGER DRUCK FÜR DIE AUSDEHNUNG VON BRÜCHEN IN GRANIT

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ANOMALOUS FRACTURE-EXTENSION PRESSURES IN GRANITIC
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ABSTRACT

Fracture-extension pressures appreciably higher than the least principal earth-stress have been observed in hydraulic fractures formed in a pair of 3 km (9600 ft) deep boreholes drilled near the Valles Caldera in northern New Mexico. Pressurization of open wellbores in rock containing preexisting fractures may open these fractures, instead of creating new fractures at right angles to the least principal stress. The pressure necessary to flow into these fractures may be appreciably higher than the least principal stress. Upon sand-propping one such preexisting fracture, a lower fracture extension pressure was observed. A second fracture in a parallel wellbore 92 m (300 ft) away, at the same depth of 2 km (6500 ft) exhibited the lower fracture extension pressure without propping, but with about 90° difference in fracture direction. Fractures created through perforations at a depth of 3 km (9600 ft) not only exhibited breakdown pressures upon initial pressurization, but sometimes even higher "breakdown" pressures upon repressurization. These phenomena may be of interest in the interpretation of earth stress measurements made by hydraulic fracturing.

INTRODUCTION

Two adjacent wells, identified as GT-2 and EE-1, were drilled on Fenton Hill, about three kilometers southwest of the Valles Caldera ring fault in northern New Mexico, in the course of the Los Alamos Scientific Laboratory Hot Dry Rock Geothermal Energy experiment. The wells entered Precambrian granitic rock at a depth of 730 m. Hydraulic fracture experiments were conducted in both wells at similar intermediate depths, about 1993 m in GT-2 and 1963 m in EE-1. The horizontal distance between the wells at these depths was only 90 m, so it was expected that the fracture direction

in the two wells would be the same and that the pressure required to extend the fractures would be similar. This was not the case, and the discrepancy was puzzling until recently, when the data were re-analyzed in the light of later hydraulic fracturing experiments near 3 km depth. These later experiments were interpreted as the opening of preexisting, perhaps weakly cemented, fractures, and it was concluded that we have probably never broken previously uncracked rock by hydraulic pressure in either GT-2 or EE-1. This conclusion derives partially from the fact that breakdown peaks are not observed in the pressure-volume curves, or, if such peaks are observed, they may reappear when a fracture is reinflated and therefore cannot represent the initial breakdown of the rock. The breakdown pressures of three cores of similar granite from the GT-1 wellbore, about 2.5 km north of GT-2, were measured by B. Haimson¹, and averaged 10 MPa.*

Cores taken from GT-2 and EE-1 show numerous sealed fractures, usually filled with calcite but sometimes with more complex mixtures. One GT-2 core at 1.672 km contained a vertical fracture oriented N60E, sealed with an assemblage of quartz, clay, muscovite, biotite, calcite, and tourmaline. The strength of the fracture filling material has not been measured, but must generally be less than that of competent rock.

These sealed fractures are oriented horizontally, vertically, or dipping roughly 60°, and are usually spaced one to eight cm apart. Thus, in any hydraulic fracturing experiment there must be preexisting fractures, perhaps not oriented normal to the least

* 1 MPa = 10 Bar.

principal stress, which can be opened at lower pressure than is required to form a new fracture.

GT-2 FRACTURE AT 1993 m

Wellbore Geometry. One such fracture was apparently formed in GT-2 at 1993 m depth. Figure 1 shows the geometry of the GT-2 well at the time. Open hole packers proved unreliable in GT-2, so a steel liner, 64 m long and 165 mm i.d., with a polished bore receptacle at the top, was cemented into the wellbore and the drill pipe joined to it. The bottom 61 m of the wellbore was uncased. The perforations shown in the figure were not present at the time the open hole section was fractured.

GT-2 Fracture Creation. The open hole section was pressurized to 17.2 MPa for one minute, during which time 250 l of water was injected into the fracture. No breakdown peak and no well defined instantaneous shut-in pressure was observed, as may be seen in Fig. 2. In later pressurizations, the peak pressure changed slightly as the flow rate was changed, but remained constant in time at a steady flow rate, as may be seen in Fig. 3. The initial rate of rise of pressure, 6.2 MPa per minute is close to that due to compressibility of water in the drill pipe -- the fracture apparently remains closed until a certain pressure is reached, acting somewhat like a flap valve.

GT-2 Fracture Geometry. Figure 4 depicts a spinner survey conducted in GT-2, and Fig. 5 shows the result of the survey, which showed that two entrance regions of equal length were present in the wellbore, with lengths consistent with two parallel vertical fractures. The flows into these fracture connections were equal. This unusual geometry suggested that these fractures were preexisting, and, from their equal flow acceptance, probably joined together near the wellbore.

GT-2 Fracture Orientation. The fracture depths obtained from the spinner survey were very useful in positioning impression packers. Packers were set over each fracture and inflated. Figure 6 is a photograph of these packers showing impressions of almost vertical complex intersections. These impressions were taken after an additional 600 m of drilling which may explain the erosion at the edges of the fractures. Borehole televiwer scans of this region show features that agree in depth with those obtained from the spinner survey and whose orientations are

similar to those obtained from the impression packers.

TABLE 1

Fracture Measurements in GT-2 at 6525-6570 ft.

Log	Upper Fracture		Lower Fracture	
	Orient- ation	Vertical Range (m)	Orient- ation	Vertical Range (m)
Spinner	--	1989-93	--	1989-2002
Televiwer	N3°E	1989-93	N12°E	1989-2002
Impression Packer	N25°E	--	N25°E	--

Summary of Preliminary GT-2 Fracture Information.

The GT-2 fracture(s) began to accept fluid freely at pressures near 17 MPa. It (they) intersected the wellbore in two distinct regions about 4.2 m long separated by 4 m. The strike of the fractures were N to NNE.

EE-1 FRACTURE AT 1963 m

The GT-2 fracture experiments were carried out in September 1974. Almost one year later, in August, 1975, the EE-1 well was drilled to 2099 m. A 10-3/4 in. casing was run from the surface to 1957 m. A first attempt to fracture the open hole section failed because a porous zone near the bottom made it impossible to pressurize the wellbore above 8.27 MPa at a pumping rate of 10.6 l/s. A packer was centered at 1975 m and the region above it pressurized at .574 l/s through the 10-3/4 in. casing to create a fracture. Figure 7 shows the pressure-time history with the packer at this location and at 2048 m, about 73 m lower. Both plots show a break near 9 MPa, but at the upper location the pressure continued to rise to about 13 MPa where a surface leak developed. At the lower position the pressure leveled off at 9 MPa, suggesting a leak through or around the packer to the porous region below. A cement plug was set from the bottom to 1975 m depth to seal off the porous region, and the remaining open wellbore was pressurized for various experiments. The geometry at this time is shown in Fig. 8.

EE-1 Experiments. The pressure time curve from a first attempt to use an impression packer to determine orientation is shown in Fig. 9. A sharp breakdown after an initial pressure rise appeared at 12.4 MPa. This breakdown was attributed to the impression packer covering the fracture, but the next inflation, for a self-potential measurement, showed a similar but more complicated breakdown at a slightly

higher pressure (Fig. 10). On the same day, the next inflation, an attempt to measure acoustic attenuation arising from fracture inflation, showed a slight break at ~ 11.7 MPa (Fig. 11), and another inflation showed the break back near 12.4 MPa (Fig. 12). The break appeared to be diminishing, but the next inflation, still on the same day, looked very much like Fig. 9, with a well-developed pressure breakdown as the fracture opened (Fig. 13). A slight indication of the break reappeared the next day (Fig. 14). A second, successful, attempt was made to get an impression of the fracture to determine orientation, as described below.

EE-1 Fracture Orientation. A series of SP logs (self-potential) run before, during and after the fracturing in EE-1 showed quite precisely the initiation of the fracture and its depth. The fracture again intersected the wellbore in two places, as in GT-2. Two impression packers were centered at 1962 m and 1965 m, the fracture inflated by pressurizing the casing (Fig. 15), and the packers then inflated through the drill pipe to squeeze them into the open fracture. Examination of the packer afterwards showed a very distinct ridge ~ 1 mm wide by 1 mm high (Fig. 16). The orientation (strike) of these fractures was N70W, $\sim 90^\circ$ to that of the GT-2 fracture. The impressions were almost parallel to the wellbore, indicating nearly vertical fractures.

Summary of EE-1 Fracture Information. The EE-1 fracture(s) began to accept fluid at pressures near 12.4 MPa. It (they) intersected the wellbore in two regions about 3 m apart. The strike of the fracture(s) was N70°W.

RECONCILIATION OF DIFFERENCES BETWEEN EE-1 AND GT-2 FRACTURES.

As the last experiment in the GT-2 fracture, it was propped with 4500 kg of sand. After the sand was emplaced, the fracture was again pressurized as shown in Fig. 17. Several changes were observed. It now took 20 minutes, at the same flow rate as in Fig. 3, to inflate the fracture to 12.4 MPa, while the inflation shown in Fig. 3 took two minutes. In addition, the pressure levelled off near this value, which was also the pressure at which EE-1 began to accept fluid freely. It seems likely that the GT-2 fracture was part of a preexisting set conjugate to the EE-1 set, and was oriented so as to see a higher normal stress.

It intersected a fracture with normal stress like that of the EE-1 fracture, close enough to the wellbore so the fracture connection could be propped by the treatment applied.

MISLEADING PRESSURE BREAKDOWNS

As shown above, repeated apparent pressure breakdowns have been observed in previously fractured sections of open wellbore. This phenomena may be due to a "caking" of suspended particles against the wellbore wall around the fracture entrance. Such a phenomenon appears in exaggerated form in perforation fractures. Figure 18 and Figure 19 show the initial breakdown and repump of two such fractures at depths of 2880 m and 2911 m in GT-2. After these fractures were created, an attempt was made to grow them together by straddling both sets of perforations with a straddle packer and inflating them simultaneously. The attempt was not successful, but an interesting feature of it was that 34.5 MPa had to be applied to the perforations before either fracture would accept fluid, a pair of remarkably high second breakdown values. Since such false breakdown values also appear in open holes, we have concluded that measurements of the two horizontal principal earth stresses in our Precambrian rock by the standard hydraulic fracturing techniques is difficult, if not impossible, and that measurements of the least principal compressive stress by fracture extension pressures at low flow rates may also give values which are too high, because preexisting fractures are unlikely to be aligned along or normal to the present-day principal stresses.

ACKNOWLEDGMENTS

We wish to thank Dr. Bezalel Haimson for measurements of hydraulic fracture tensile strength on GT-1 core samples. Many members of the Los Alamos Hot Dry Rock Geothermal Energy Project, under the direction of Morton C. Smith, participated in the design and conduct of experiments discussed here.

REFERENCES

1. B. C. Haimson, University of Wisconsin, Personal communication, November 1972.

ILLUSTRATIONS

Fig. 1. Geometry of the GT-2 wellbore.

Fig. 2. Surface pressure and flow during initial pressurization of GT-2 wellbore.

Illustrations (Continued)

Fig. 3. Surface pressure and flow during later pressurization of GT-2 wellbore.

Fig. 4. Geometry of spinner survey in GT-2.

Fig. 5. Results of spinner survey in GT-2.

Fig. 6. Impression packers retrieved from GT-2.

Fig. 7. Surface pressure vs time in EE-1, with packer in two locations.

Fig. 8. Geometry of EE-1 wellbore after cement plug emplaced.

Fig. 9. Surface pressure vs time in first attempt to use impression fracture for orientation.

Fig. 10. Surface pressure vs time when self-potential measurement carried out in EE-1.

Fig. 11. Surface pressure vs time during subsequent acoustic experiment in EE-1.

Fig. 12. Surface pressure vs time in second EE-1 acoustic experiment.

Fig. 13. Surface pressure vs time in first induced potential measurement in EE-1.

Fig. 14. Surface pressure vs time in second induced potential measurement in EE-1.

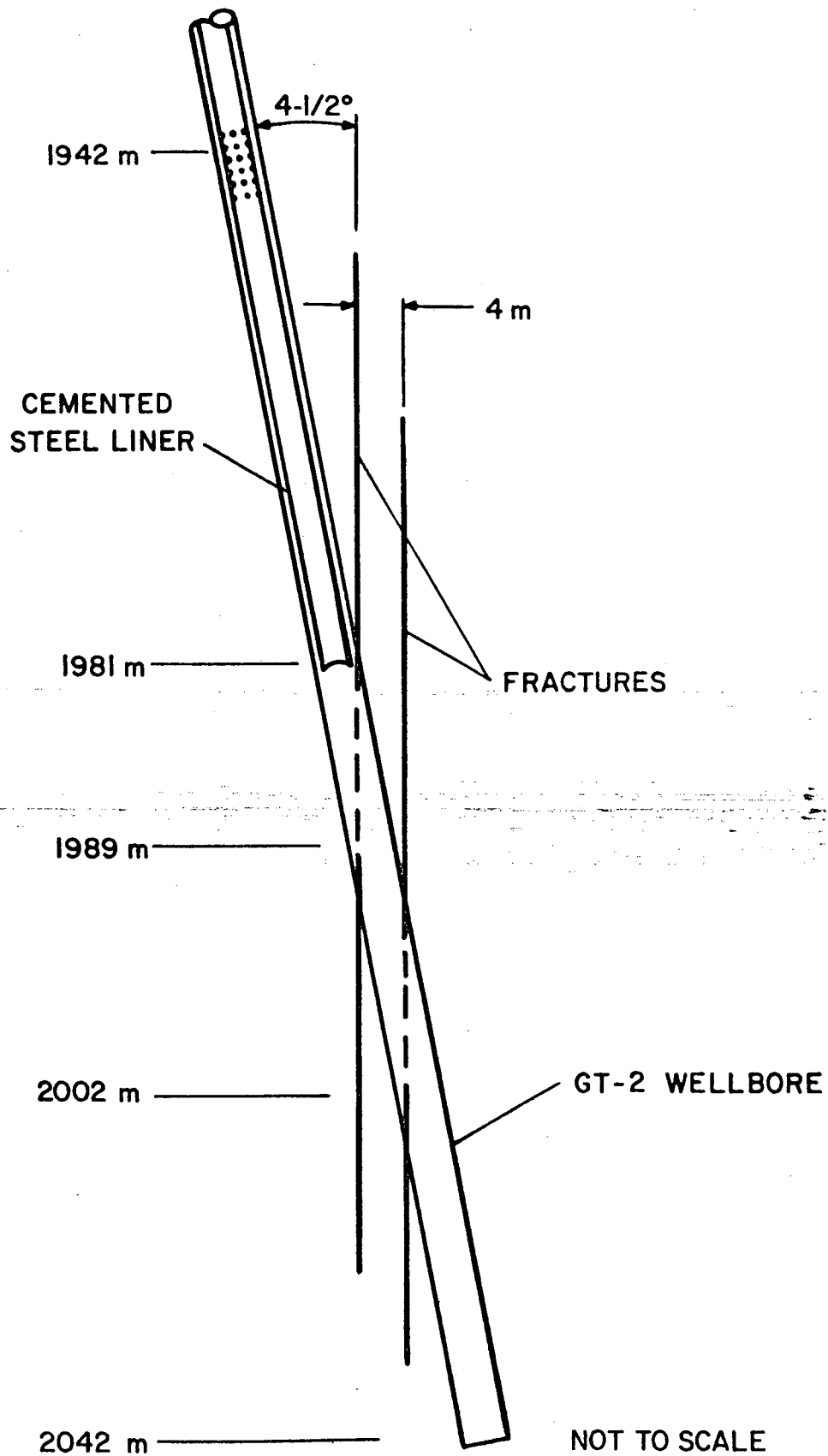
Fig. 15. Complex surface pressure vs time curve observed during second (successful) impression packer experiment.

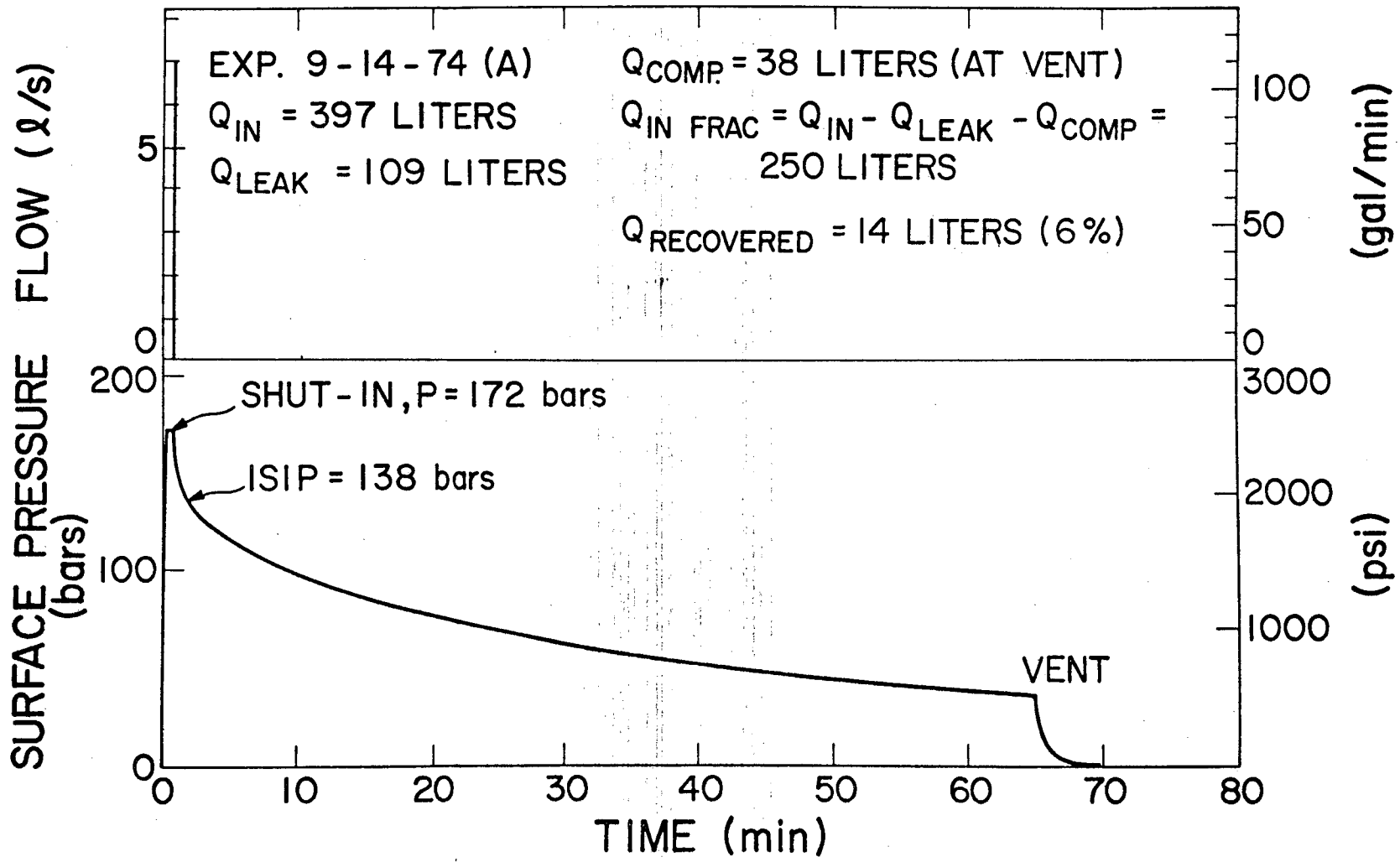
Fig. 16. Photograph of EE-1 impression packer.

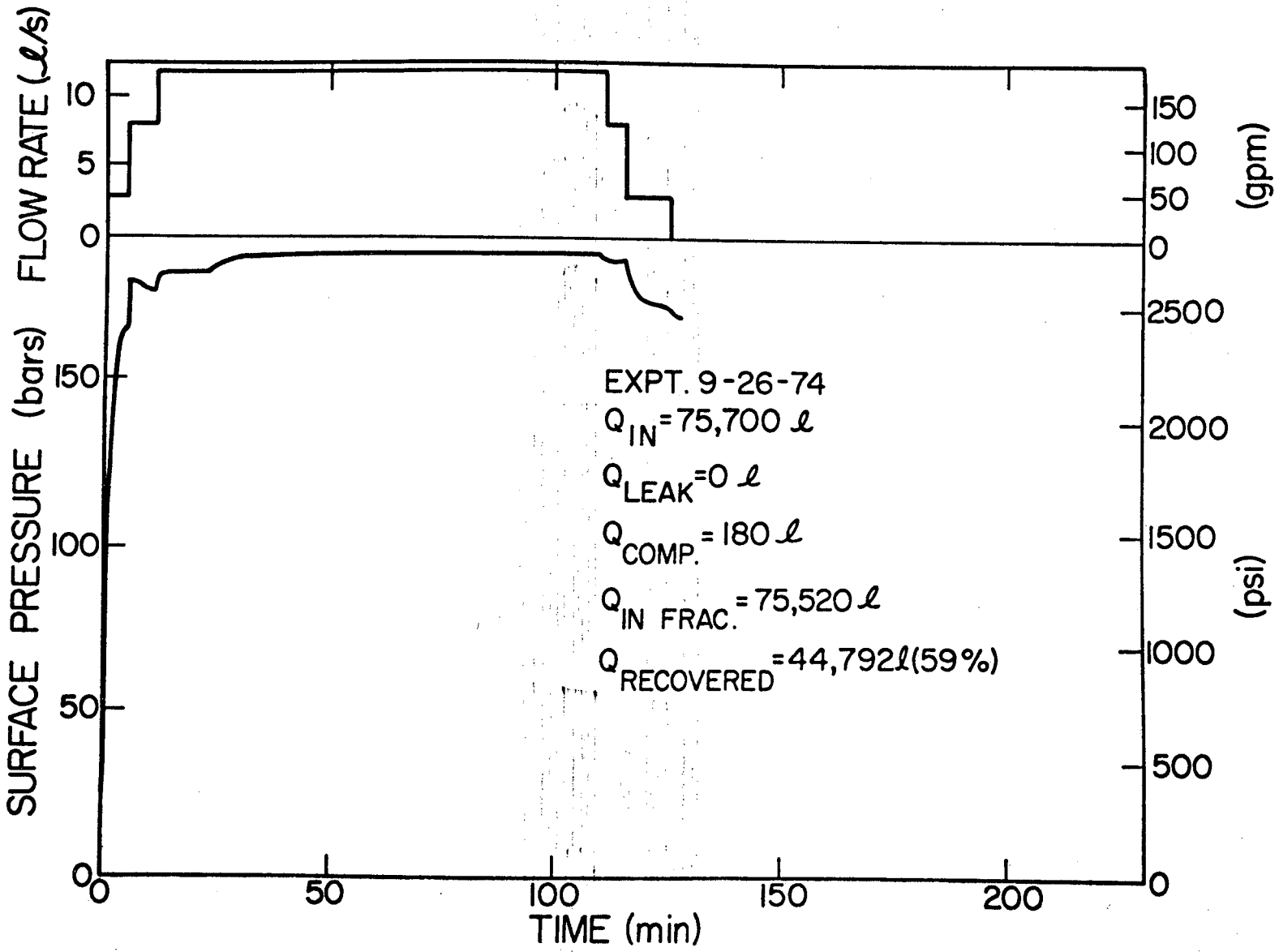
Fig. 17. Surface pressure vs time at same flow rate as in Fig. 3, after sand propping fracture.

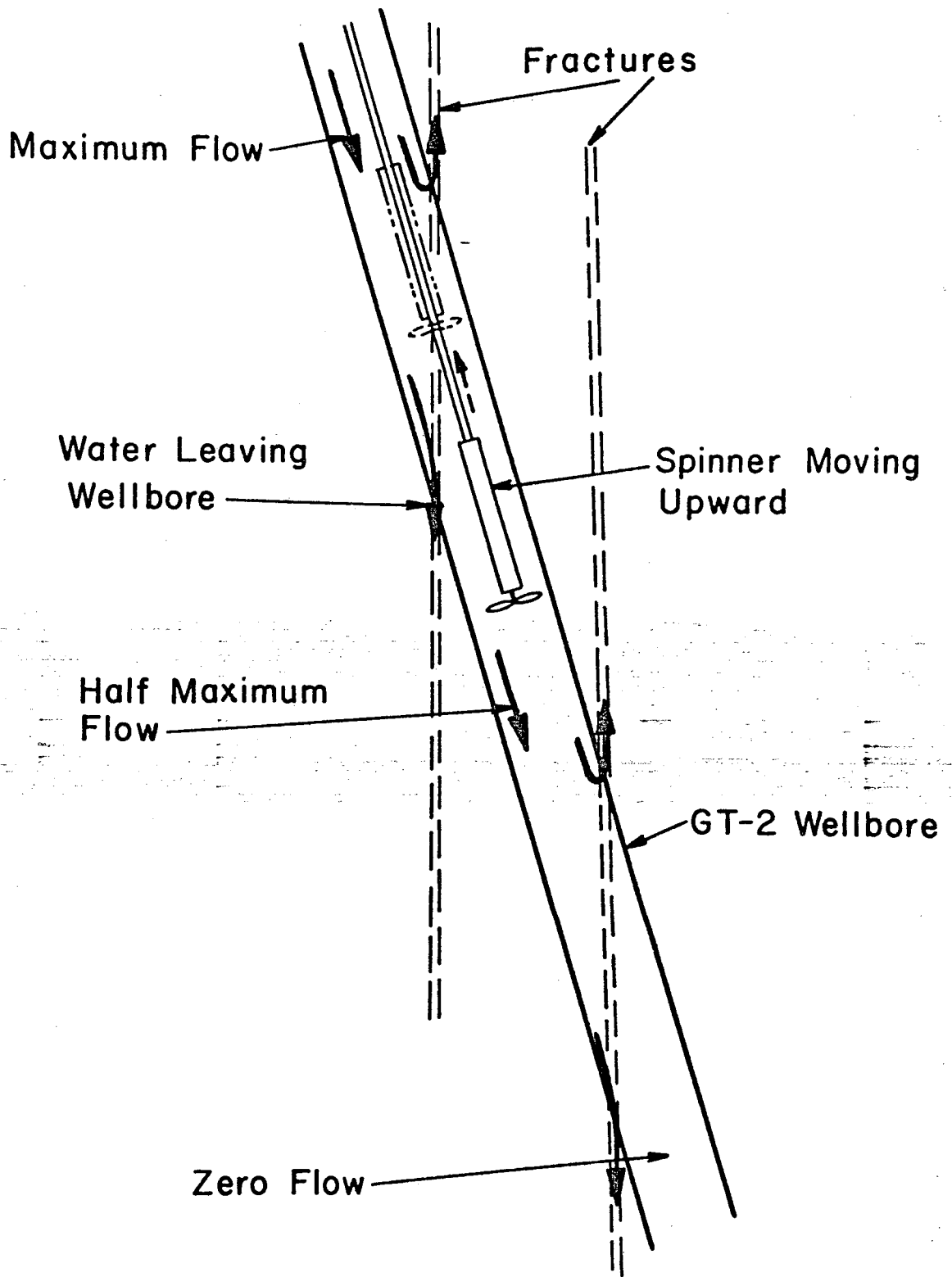
Fig. 18. Initial pressurization through casing perforations, and subsequent repump, near bottom of GT-2.

Fig. 19. Similar to Fig. 18, but 30 m lower in cased region of GT-2.

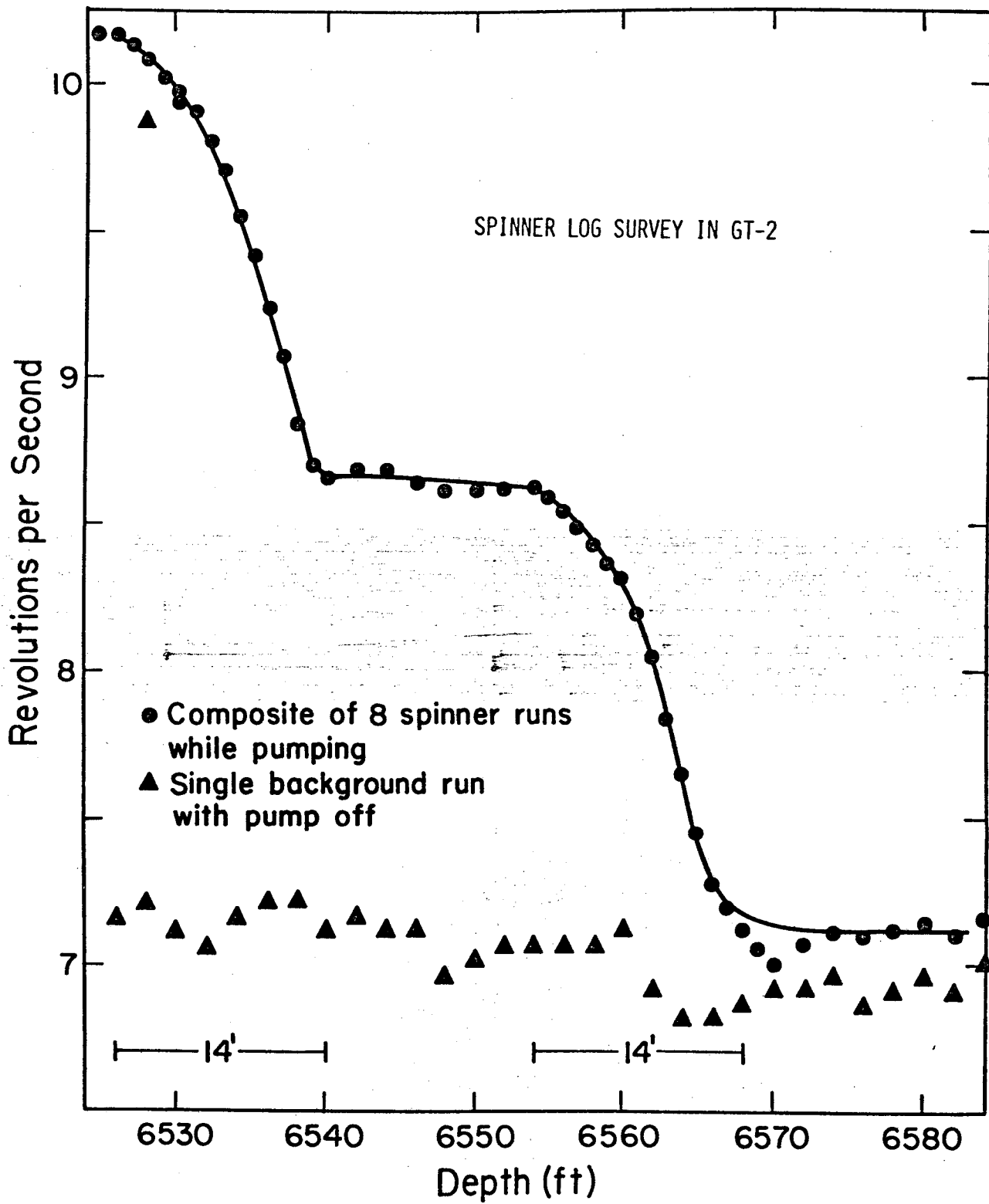


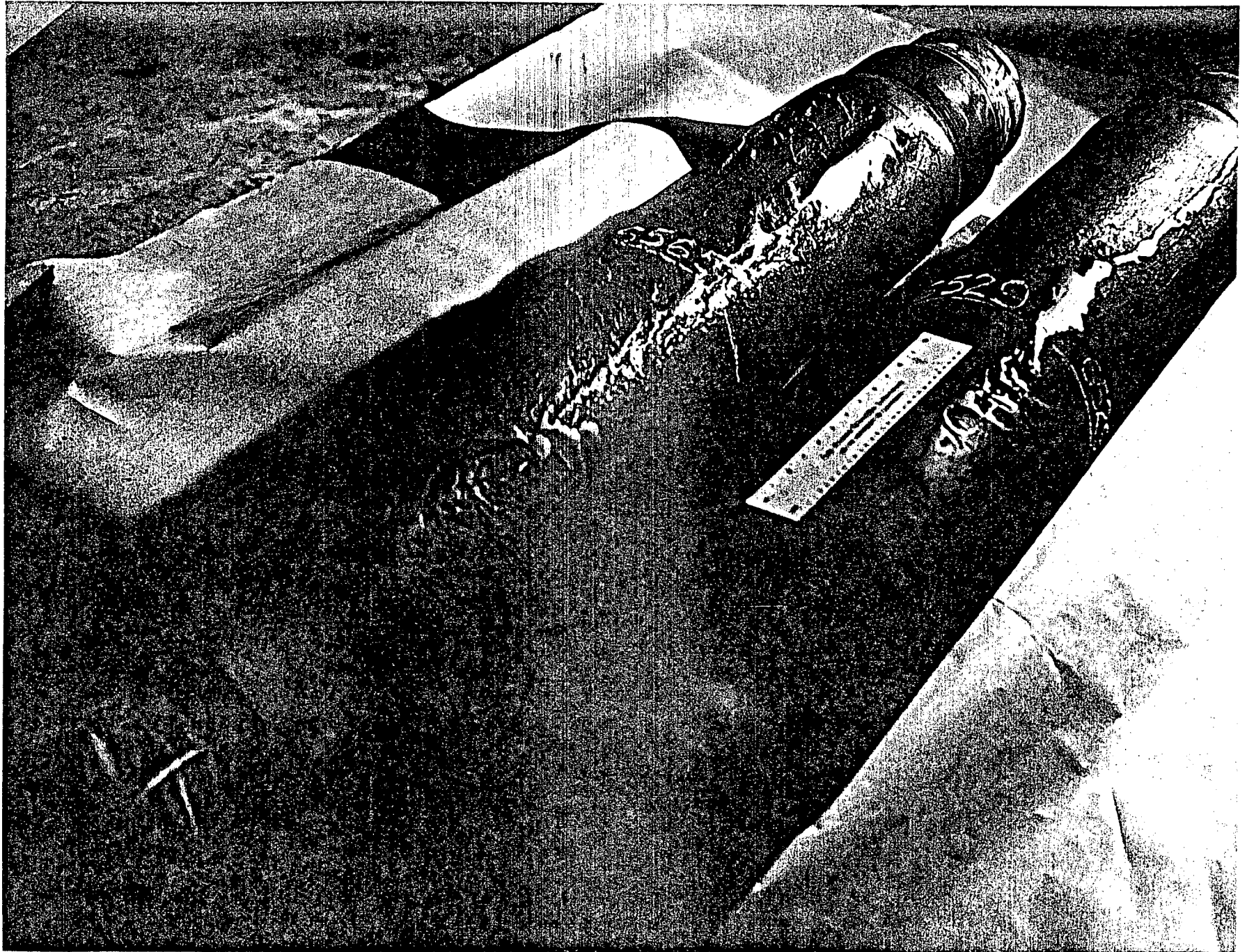


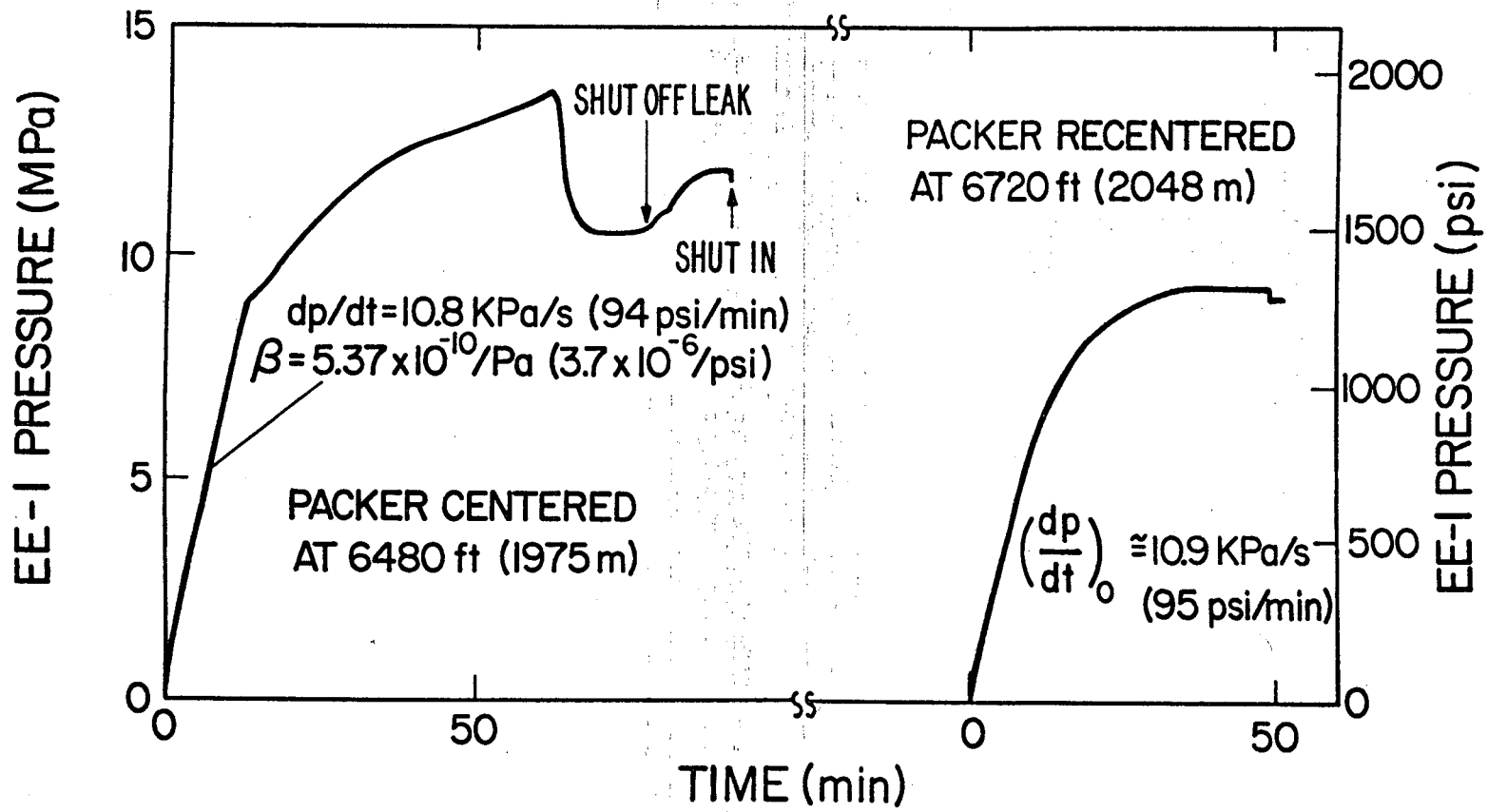


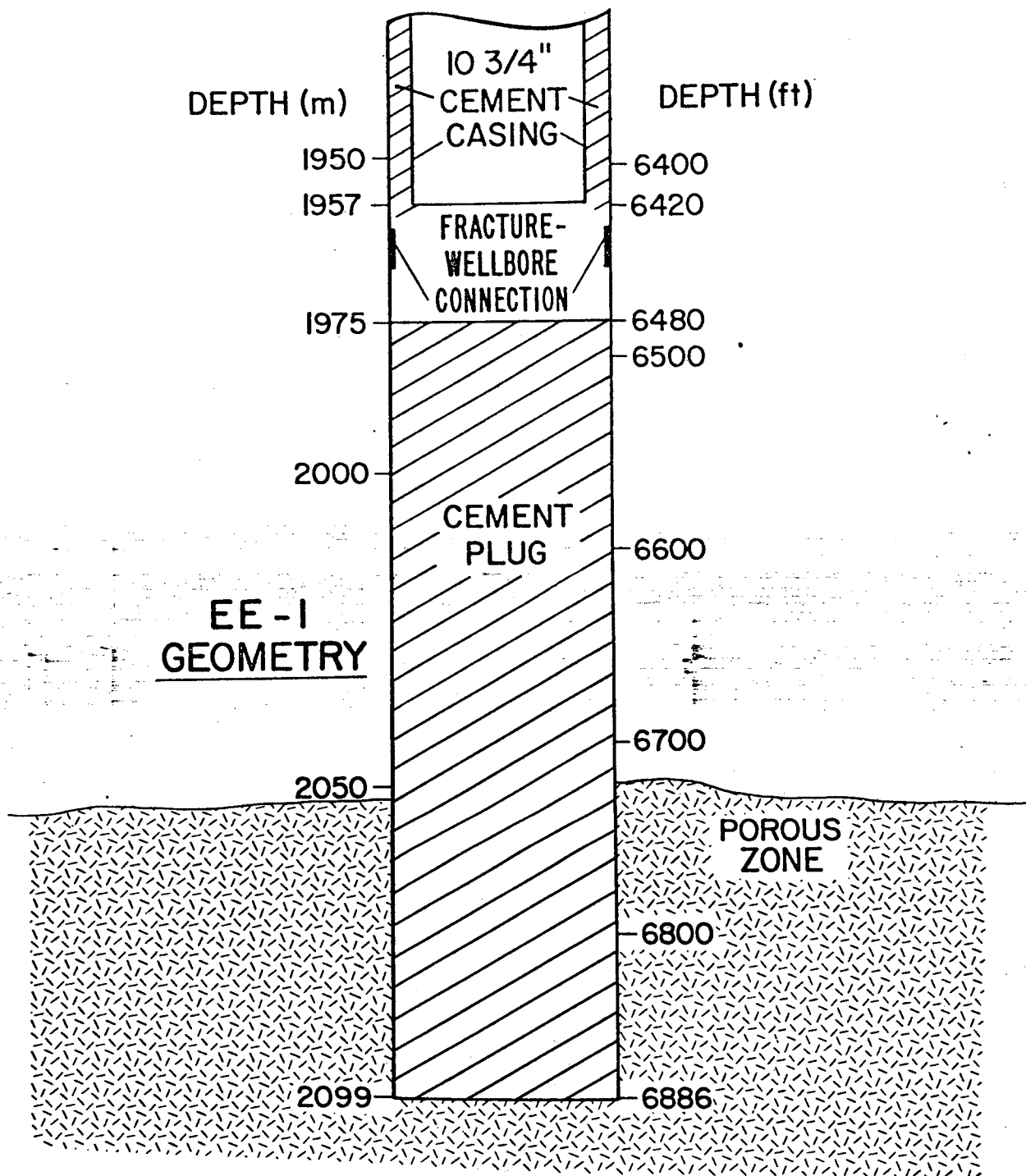


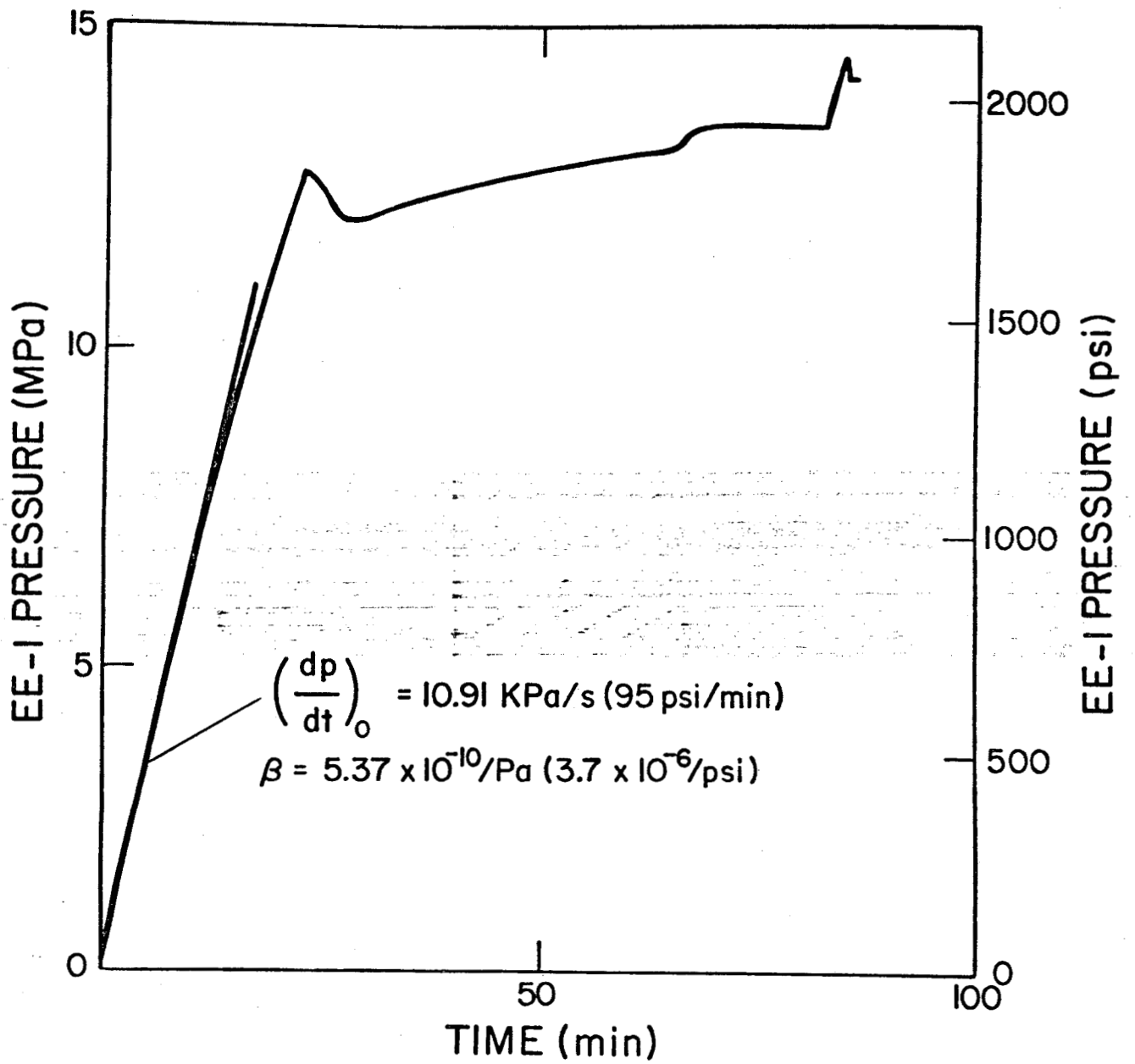
Geometry of Spinner Survey

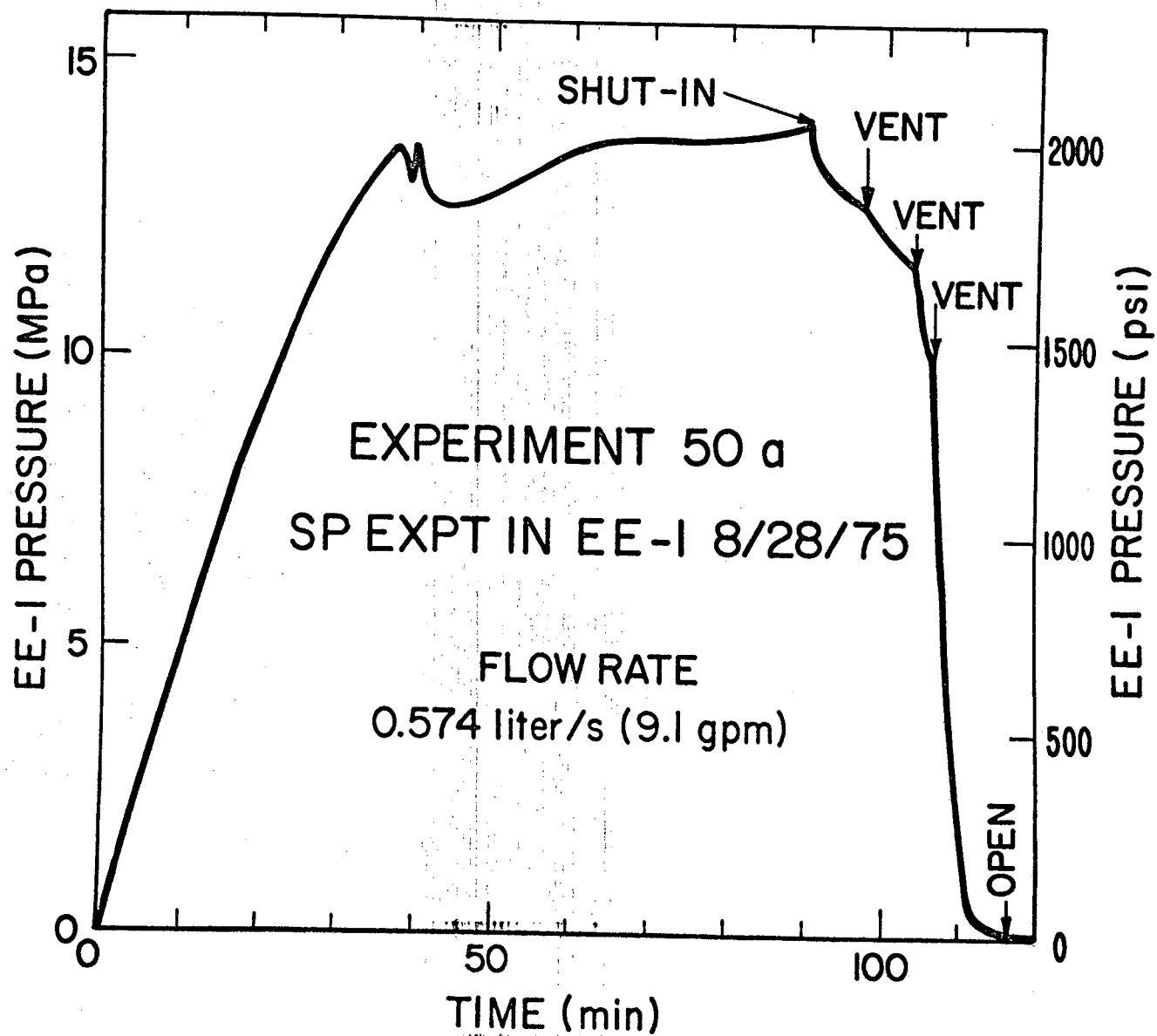




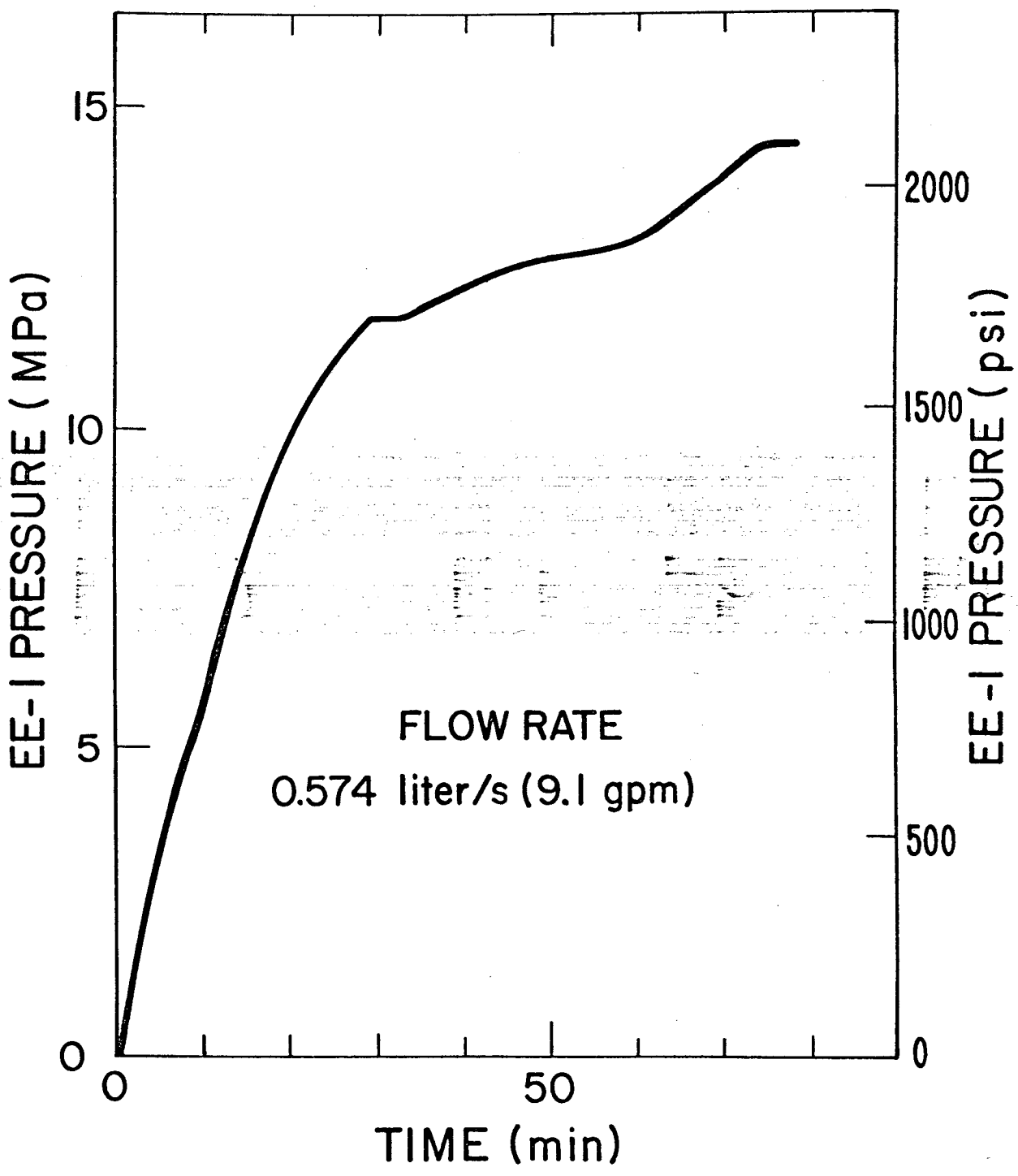


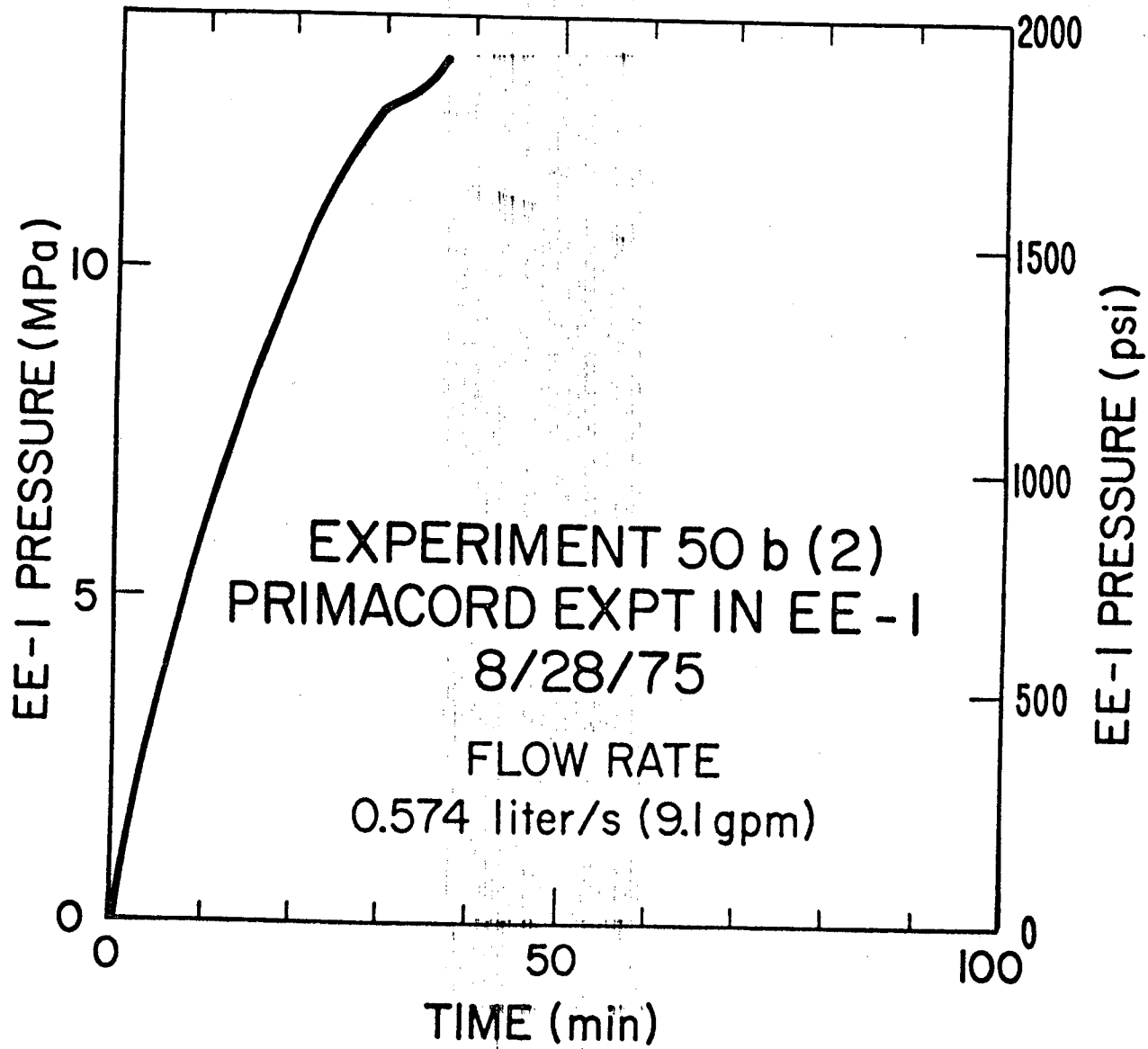




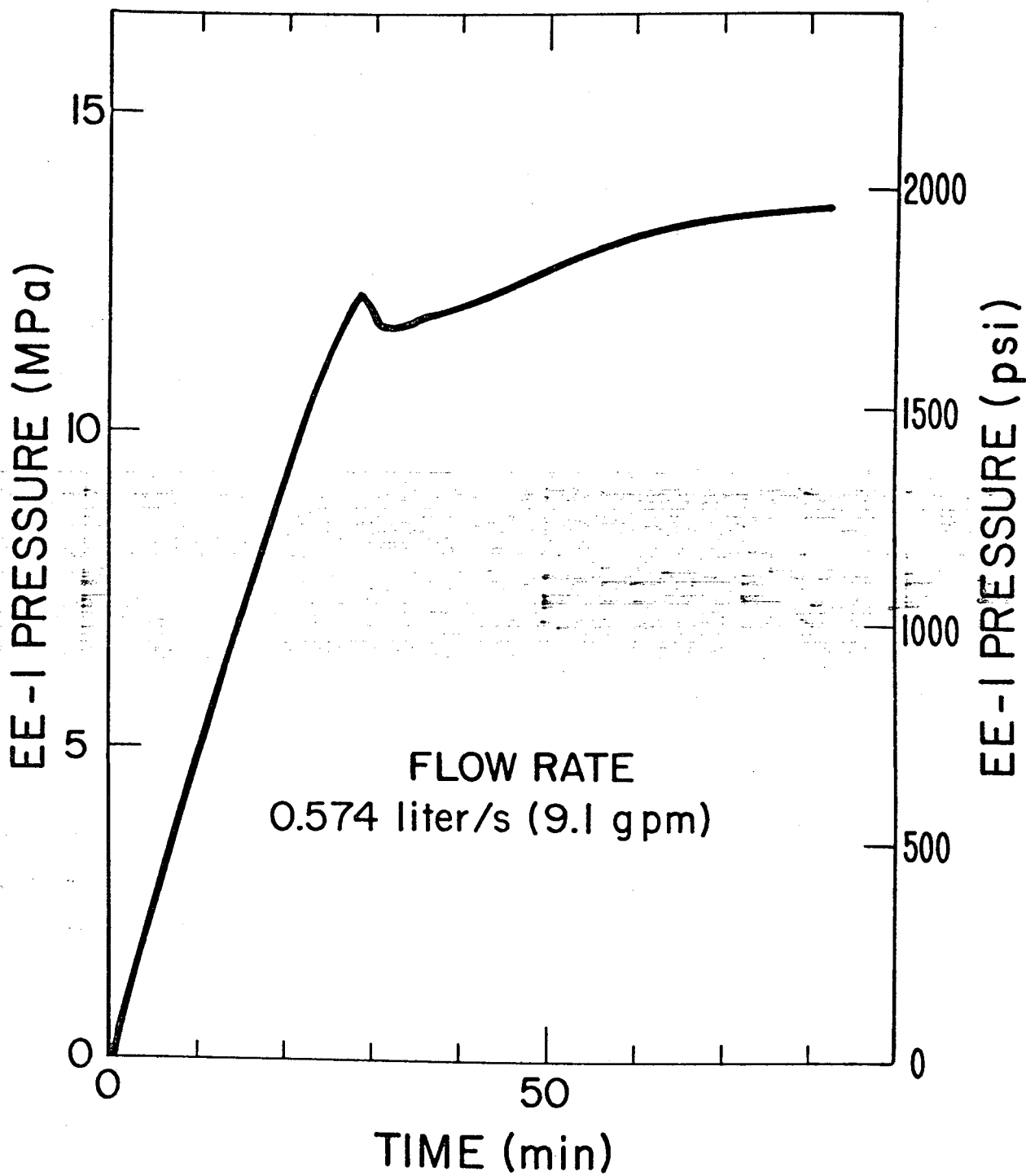


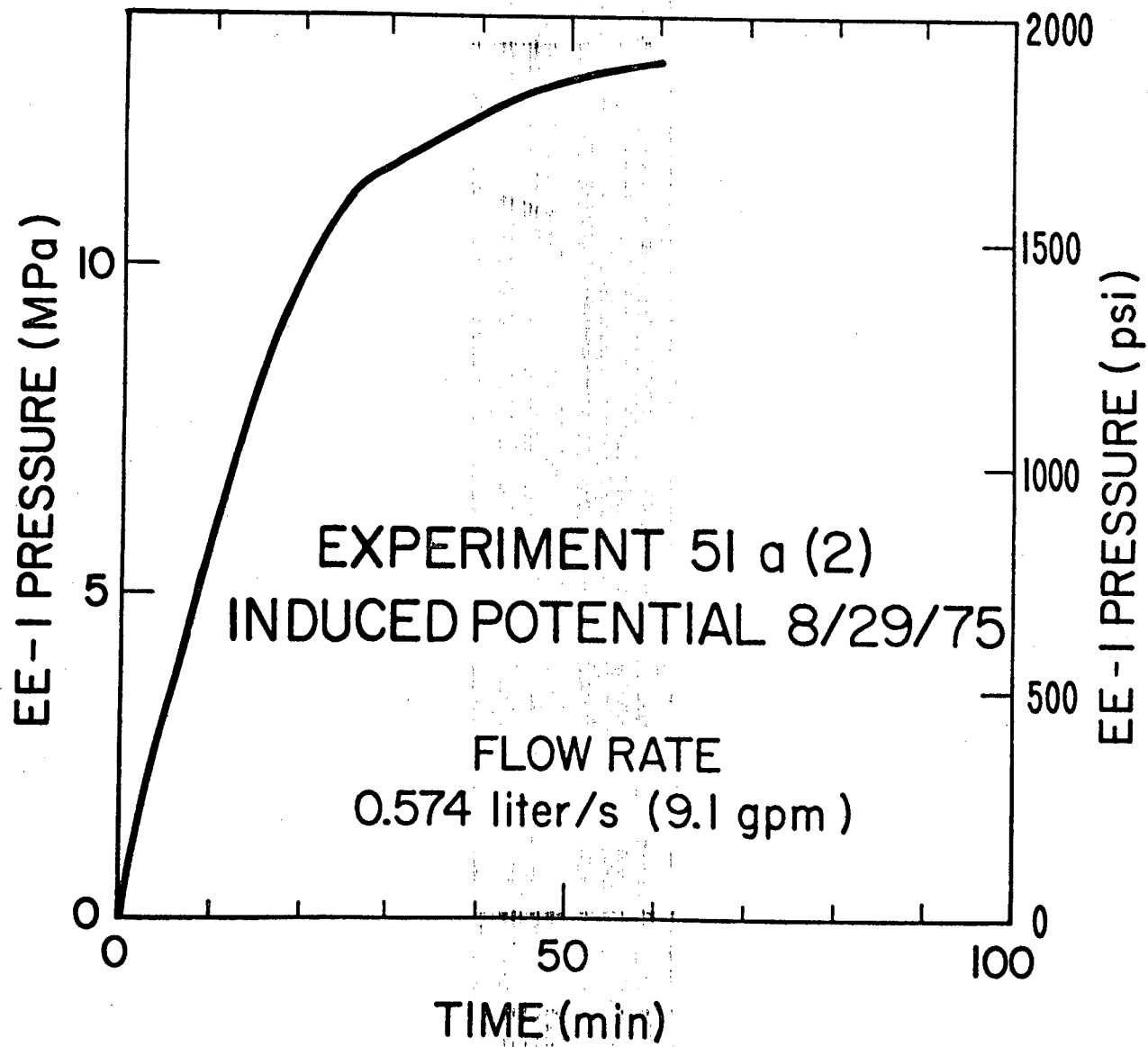
EXPERIMENT 50 b (I)
PRIMACORD EXPT IN EE-1 8/28/75

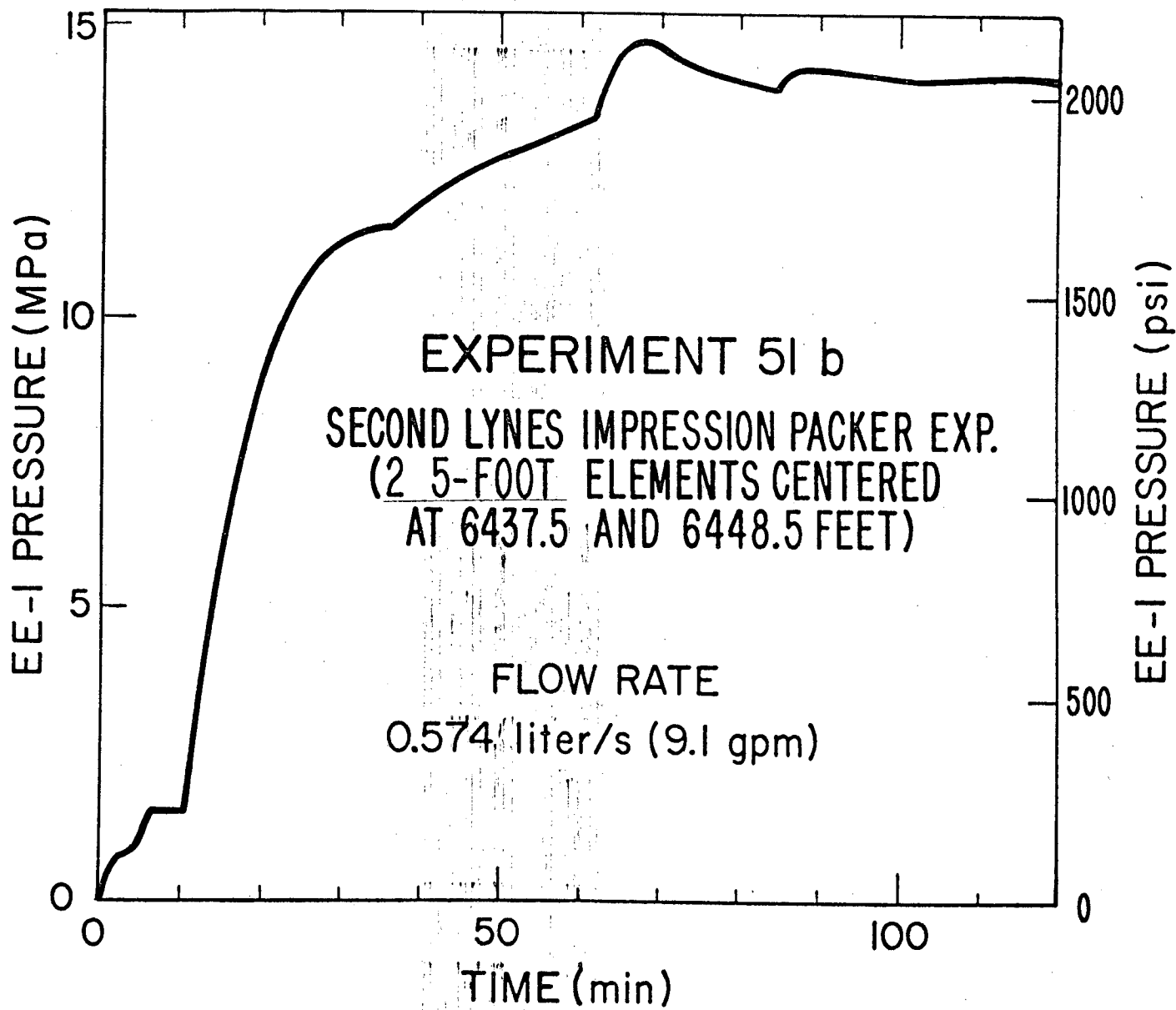


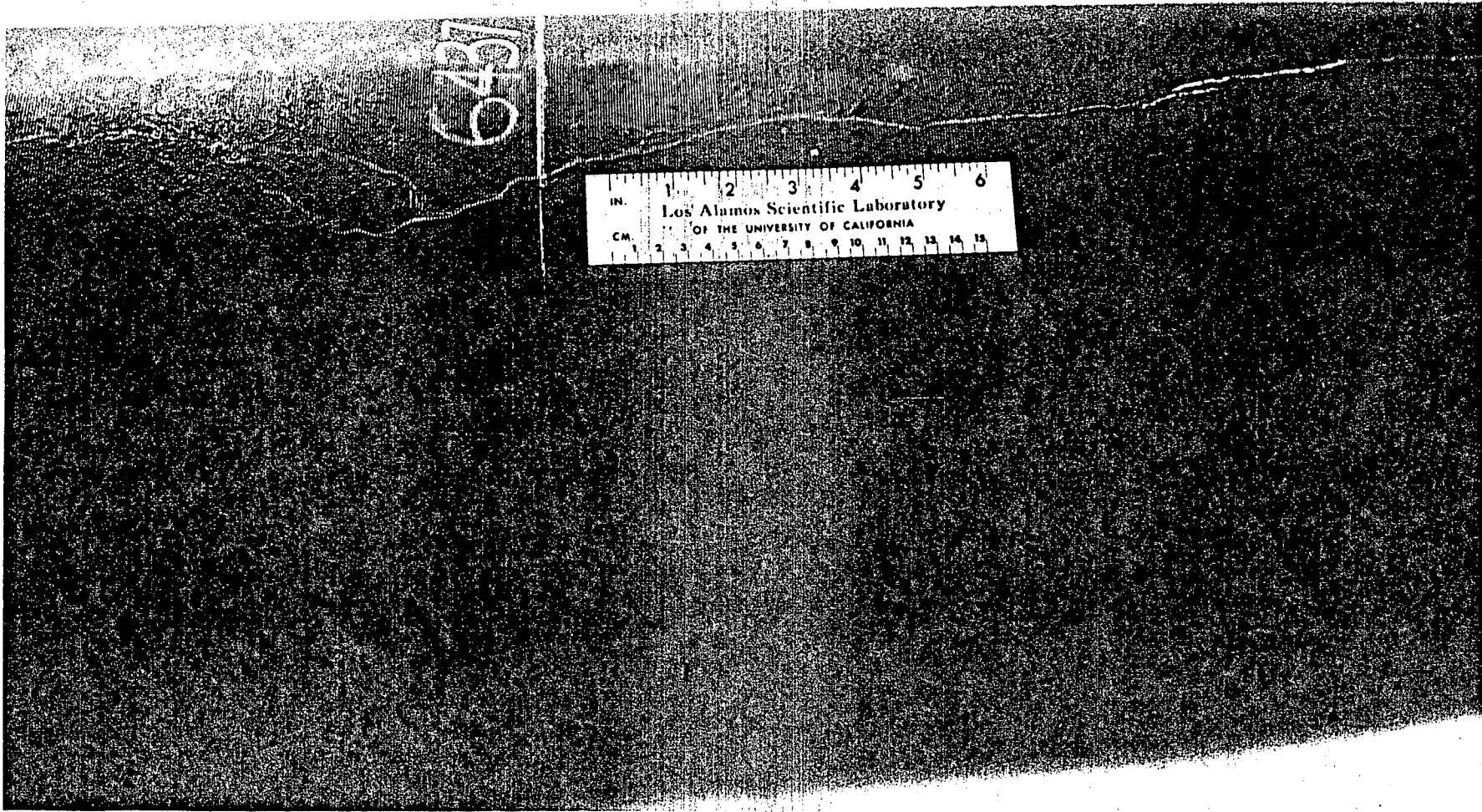


EXPERIMENT 5I a (I)
INDUCED POTENTIAL 8/28/75

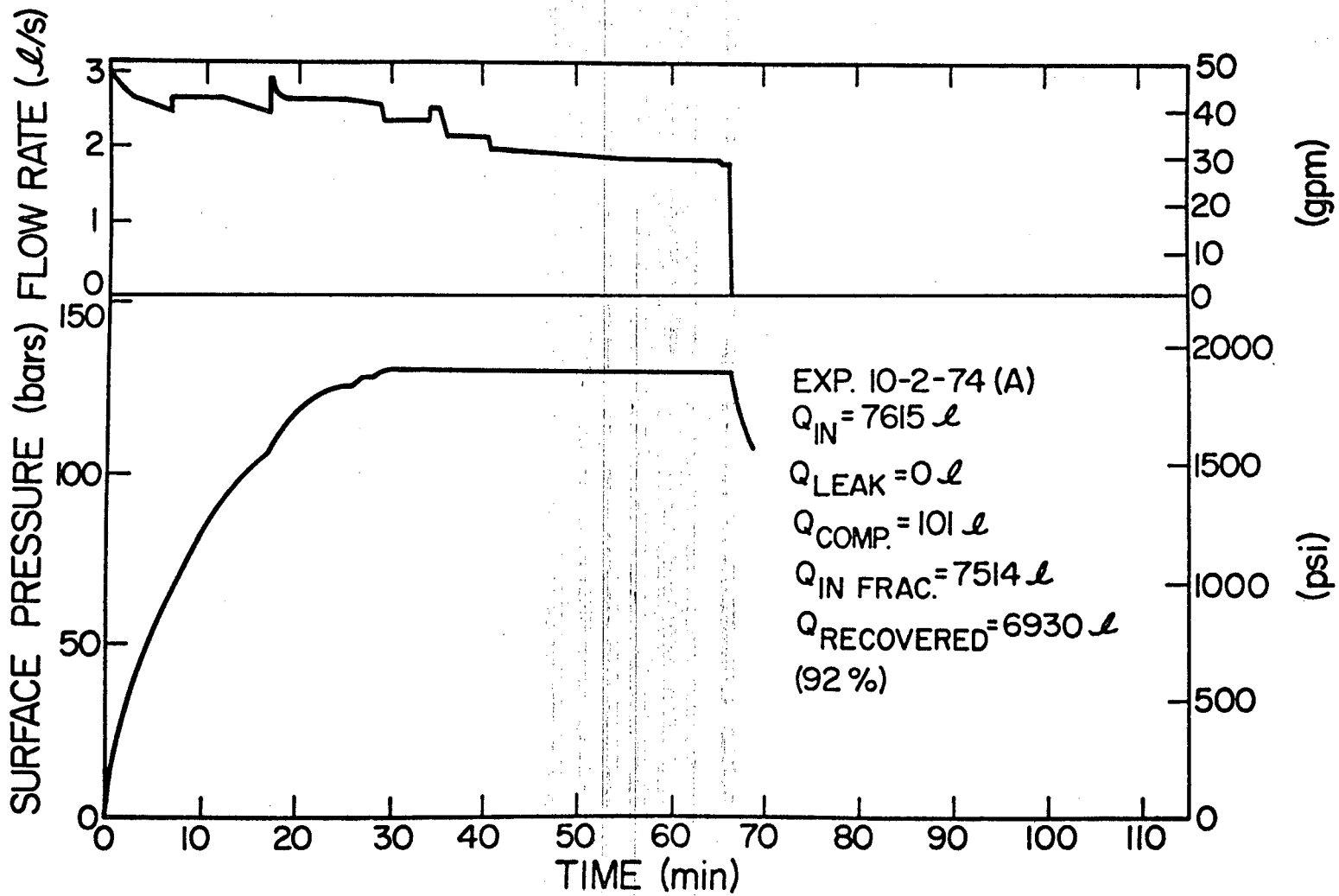




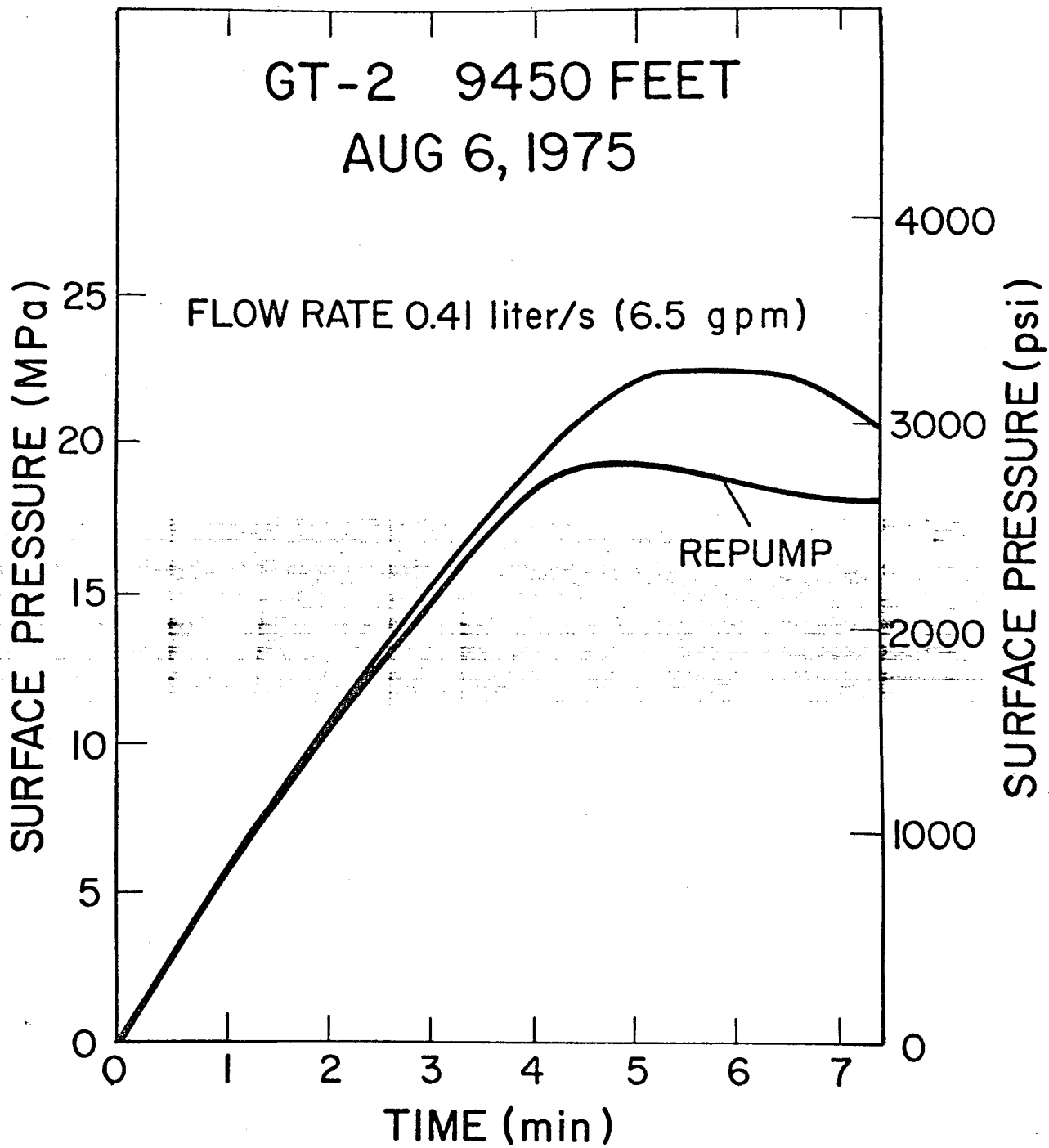




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GT-2 9450 FEET
AUG 6, 1975



GT - 2 9550 FEET

AUG 6, 1975

FLOW RATE 0.4l liter/s (6.5 gpm)

