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MEMORANDUM

To: Andrew Ryder
Western Geopower
Vancouver, BC

Date: February 7, 2005

From: Roger Henneberger

Subject: South Meager Project – Results of MC-7 Completion Testing

Introduction

Completion testing of well MC-7 was conducted during February 4-7, 2005, after the well was drilled to its total depth of 3,291 m. This memorandum presents a description of the testing, and an initial evaluation of its results.

Testing Activities

The history of testing activities is summarized in Table 1. The tests included the following principal components:

- measurement of a static temperature/pressure profile (TP01), approximately 10 hours after circulation (to displace the drilling mud in the wellbore with water) was stopped;
- an injection test, during which a temperature/pressure profile (TP02) was measured while injecting water, and downhole (P03) and surface pressures were monitored while injecting water at 4 different rates and during the subsequent pressure fall-off period; and
- measurement of a static temperature/pressure profile (TP04) approximately 36 hours after injection was stopped.

Comparison of the characteristics of MC-7 with the results of well MC-6 indicated little likelihood that production could be induced in MC-7 before the well was allowed to recover thermally for a period of weeks to months. Therefore, no attempt was made to air-lift the well during the completion testing, as was done for MC-6.

Results

Temperature and Pressure Profiles

Measured temperature and pressure profiles are shown in Figure 1. All of the surveys reflect substantial cooling of the near-wellbore environment by circulation and injection during and

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after drilling; therefore, they do not indicate stable formation temperatures. The maximum measured temperature was approximately 216°C, at bottomhole in the final survey (TP04). The pressure surveys indicate a static water level at about 540-550 m depth, similar to but slightly shallower than the water level in MC-6.

Comparison of the temperature profile measured while injecting (T02) with the prior static survey (T01) indicates that most of the water injected exited the wellbore at depths shallower than about 1,600 m. However, the timing of survey T02 was such that the thermal front created by injecting would not have reached deeper levels before temperatures were measured there, if the fraction of water exiting the wellbore at these levels were small. Survey T04 shows that some cooling by injection took place down to at least 3,000 m depth, and probably as far down as the zone of minor circulation loss at about 3,080 m. It appears that virtually no water was injected below 3,080 m depth.

Survey T04 also indicates that permeable zones are likely present in the vicinity of 900 m and 1,500 m depth, where minor inflection in the temperature profile occur. These depths do not coincide with any observed circulation losses; conversely, a circulation loss observed at 1,004 m depth is not reflected in the temperature profiles. Overall, the temperature profiles suggest the presence of multiple, minor permeable zones in MC-7, distributed at various depths between the casing shoe (at 870 m) and about 3,080 m, rather than the presence of a small number of more highly permeable zones.

Rapid heat-up between 800 m and 1,400 m depth caused a minor temperature reversal to appear in survey T04. It is too early to tell whether this is an artifact of differential cooling (by injection), or a real reversal that will persist once the well has heated fully. However, it provides strong evidence that the well is quite hot in this shallow interval.

The profile of survey P02 reflects the pressure increase caused by injection. The response of MC-7 to injection is discussed in the following section.

Injection testing

Figure 2 shows the data collected during the injection test, as a function of time. The test was conducted by injecting at 4 different rates (roughly 46 m^3/hr, 73 m^3/hr, 94 m^3/hr and 120 m^3/hr, in that order) for a minimum of about 2 hours at each rate. Pressures were monitored during and after injection, at the surface and (for most of the period) downhole.

The injection rate was determined from the rig's pump stroke counter (injection actually began when the well was filled with water, using a different pump, between 6:00 and 7:00 AM on February 5; detailed rate data are not available for this period, but the average rate was about 45 m^3/hr). Data for both the stroke rate (as strokes per minute, or SPM) and the pumping pressure were obtained from the CHIMO system, which recorded at variable intervals as small as one

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second. The data shown in Figure 2 have been thinned to minimum intervals of 5 seconds, to facilitate data processing.

Downhole pressure data were obtained from survey P03, in which a mechanical pressure sensor was hung in the well at 2,500 m depth. The chart from the sensor was read at selected time intervals, the largest being about 10 minutes and the smallest about 1 minute. The downhole data provide a more accurate reflection of the response of the well and the reservoir to injection, but they are less detailed and accurate. The pumping pressures represent a reasonable approximation to wellhead pressure, but are available only when the well is filled and the pumps are operating, and are subject to the effects of temperature variations over the length of the wellbore as injection proceeds.

Figure 3 shows a comparison of recorded pumping pressures and downhole pressures (with the downhole pressures normalized to facilitate the comparison). For the most part, there is good agreement between the two data sources with respect to the pattern and magnitude of observed pressure changes. Therefore, the pump-pressure data are useful for estimating the response during the period before downhole pressure data were collected.

The following observations can be made from the data presented in figures 2 and 3:

- A pressure increase was observed in response to each increase in injection rate. However, during each rate step, both the downhole pressure and the surface pressure tended to decline over time. This indicates a general trend of improvement in the well's injectivity characteristics with continued injection, a phenomenon which is common in geothermal wells.
- Both steady and sudden (or episodic) decreases in pressure, as well as some transitory increases, were observed in the different rate steps. A particularly large and sudden decrease was observed during the third (94 m^3/hr) rate step (Figure 3). The reason for this behavior is uncertain, but it may be related to the opening and (in some cases) blockage of fractures in response to injection.
- The pressure did not stabilize during any of the rate steps, indicating that the injectivity of the well would continue to improve with further injection.

The changing pressure response of MC-7 makes it impossible to define precisely a single injectivity behavior for the well. However, the approximate behavior can be estimated from the pressure response observed during each rate step. These data are summarized in Figure 4, which shows the deduced pressure increase (with respect to the hydrostatic condition) as a function of injection rate. In Figure 4, the blue curve shows pressure changes calculated from pumping pressures, and assuming a static water level at 546 m depth (as indicated by pressure survey P04). The green and red curves are calculated from downhole pressure changes at 2,500 m

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depth, with respect to the static pressure indicated by surveys P03 and P04, respectively. The single point corresponding to an injection rate of 2.8 l/s is based on Precision Drilling's estimate that MC-7 was losing water at that rate (about 10 m^3/hour) while circulating after the drilling mud was displaced from the well on February 4.

For each rate step, the pressure change was calculated from the pressure observed at or near the end of the step. For the third (94 m^3/hr) step, the change was also calculated using pressure just prior to the large pressure drop in mid-step; this is reflected in the step-down in each curve at about 26 l/s.

The following points emerge from the data presented in Figure 4:

- The pressure changes calculated from the different data sources agree quite well, and therefore provide a reliable indication of the well's injectivity behavior (at least at specific points in time).
- The curve defined by the deduced pressure changes does not extrapolate to zero pressure change. This indicates that the well has a high "threshold" of injectivity; that is, a relatively large pressure increase is required to achieve the first increment of injection, whereas, at higher injection rates, the incremental or marginal injectivity index (injection rate divided by pressure change) is much greater.
- The data imply an overall injectivity index of about 0.4 l/s/bar (33 l/s divided by 80 bar). However, at injection rates above 5 to 10 l/s (20-35 m^3/hr), the incremental injectivity index is close to 1.3 l/s/bar, while at lower rates it is probably much lower than 0.4 l/s/bar.

Discussion

The results of completion testing indicate that MC-7 is similar to MC-6 in its thermal and permeability characteristics. Figure 5 shows a comparison of selected temperature profiles measured in MC-6 and MC-7, including the profile measured in MC-6 on February 6 (at which point the well was probably at or close to complete thermal recovery). As this figure shows, the two wells had quite similar temperature profiles at comparable stages of heat-up. Therefore, it can be expected that anywhere from 30°C to more than 100°C of further heat-up will take place over most or all of the interval below 800 m depth in MC-7 as the well recovers, with the largest increases occurring in the shallower part of the interval. As discussed above, it is not yet certain whether MC-7 may ultimately exhibit a minor temperature reversal near 1,000 m depth. The presence of a liner in MC-6 (which tends to induce convection within the wellbore) could be obscuring such a reversal in that well; MC-7, which has no liner, may provide an opportunity to learn more about the temperature structure of this part of the geothermal reservoir.

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An injectivity index of roughly 1.0 l/s/bar (1.1 gpm/psi) was calculated for MC-6 during its completion testing. This is higher than the overall injectivity index of 0.4 l/s/bar calculated for MC-7, but comparable to the incremental injectivity index described above for higher injection rates. Based on the observed behavior of MC-7, it is likely that both wells would show increases in injectivity index (and probably productivity index as well) with additional, sustained injection.

Recommendations

Although wells MC-6 and MC-7 have similar characteristics (as discussed above), MC-6 appears to have encountered somewhat greater permeability, and is therefore more likely than MC-7 to be productive. On this basis, MC-7 is a better candidate to be sidetracked, if it is decided that this will be done to one of the two wells. In any case, it would not be worthwhile to attempt a production test of MC-7 without first allowing the well to heat up to a nearly stable condition; this would probably require about two months of thermal recovery (without further injection).

As noted above, MC-7 may provide valuable information about temperatures in this part of the field (possibly to a greater degree than MC-6, whose temperature profile is probably affected by the presence of a liner). It is therefore important that MC-7 be re-surveyed in a condition as close to thermal equilibrium as is practical. If it is decided to sidetrack MC-7, then a survey run just before commencing the sidetrack operation would be appropriate (in which case MC-6 should be re-surveyed during the same visit of the logging service company).

Either MC-6 or MC-7, or both, might be improved by some type of stimulation, the simplest and least expensive method being injection over as long a term as possible. However, undertaking a stimulation operation at this point would create a delay in production testing and, possibly, drilling operations, and therefore it is something best left for future consideration.

Table 1. History of Completion Testing Activities, Well MC-7 (February 2005)

Date/Time		Code	Activity
From	To		
	2 Feb 21:00	D	Drill to total depth of 3,291.0 m
2 Feb 21:00	3 Feb 14:00		Circulate, survey and pull out of hole
3 Feb 14:00	4 Feb 06:30		Stage in hole to bottom, displacing mud with water
4 Feb 06:30	4 Feb 20:30		Circulate caustic and high-vis sweeps, flush hole with water; pull out of hole
4 Feb 20:30	4 Feb 22:45	S	Rig up Challenger Wireline and run sinker bar to 3,290 m
4 Feb 22:45	5 Feb 06:00		Run static temperature/pressure survey to 3,288 m (TP01)
5 Feb 06:00	5 Feb 07:00	I	Fill well with 45.3 m^3 water (start of injection test)
5 Feb 07:00	5 Feb 07:19		Run in hole with temperature/pressure tools to 850 m (TP02); close pipe rams
5 Feb 07:19	5 Feb 08:30		Inject water at 47-48 SPM; monitor rate and pump pressure with CHIMO system
5 Feb 08:30	5 Feb 13:30		Run temperature/pressure survey to 3,280 m while continuing to inject 47-48 SPM
5 Feb 13:30	5 Feb 13:52		Make up pressure tool, run in hole and hang at 2,500 m (P03), injecting 47-48 SPM
5 Feb 13:52	5 Feb 15:28		Continue to inject at 47-48 SPM)
5 Feb 15:28	5 Feb 17:24		Increase injection rate to 76 SPM and maintain
5 Feb 17:24	5 Feb 19:32		Increase injection rate to 97-100 SPM and maintain
5 Feb 19:32	5 Feb 19:38		Shut off pumps to permit increase in injection rate
5 Feb 19:38	5 Feb 22:12		Begin injecting 126 SPM and maintain
5 Feb 22:12	6 Feb 10:16		Stop injection; monitor pressure falloff at 2,500 m
6 Feb 10:16	6 Feb 11:15		Pull pressure tool out of hole (end of injection test)
6 Feb 11:15	6 Feb 20:00	T	Allow well to recover thermally (run static T/P survey in MC-6 during this period)
6 Feb 20:00	6 Feb 20:30		Run sinker bar to 3,291 m
6 Feb 20:30	7 Feb 06:50		Continue thermal recovery period
7 Feb 06:50	7 Feb 14:40	S	Run static temperature/pressure survey to 3,280 m (TP04) (end of completion testing)

Codes: D = Drilling; S = Static survey; I = Injection testing; T = Thermal recovery

Figure 1. MC-7 Temperature/Pressure Surveys (February 4-7, 2005)

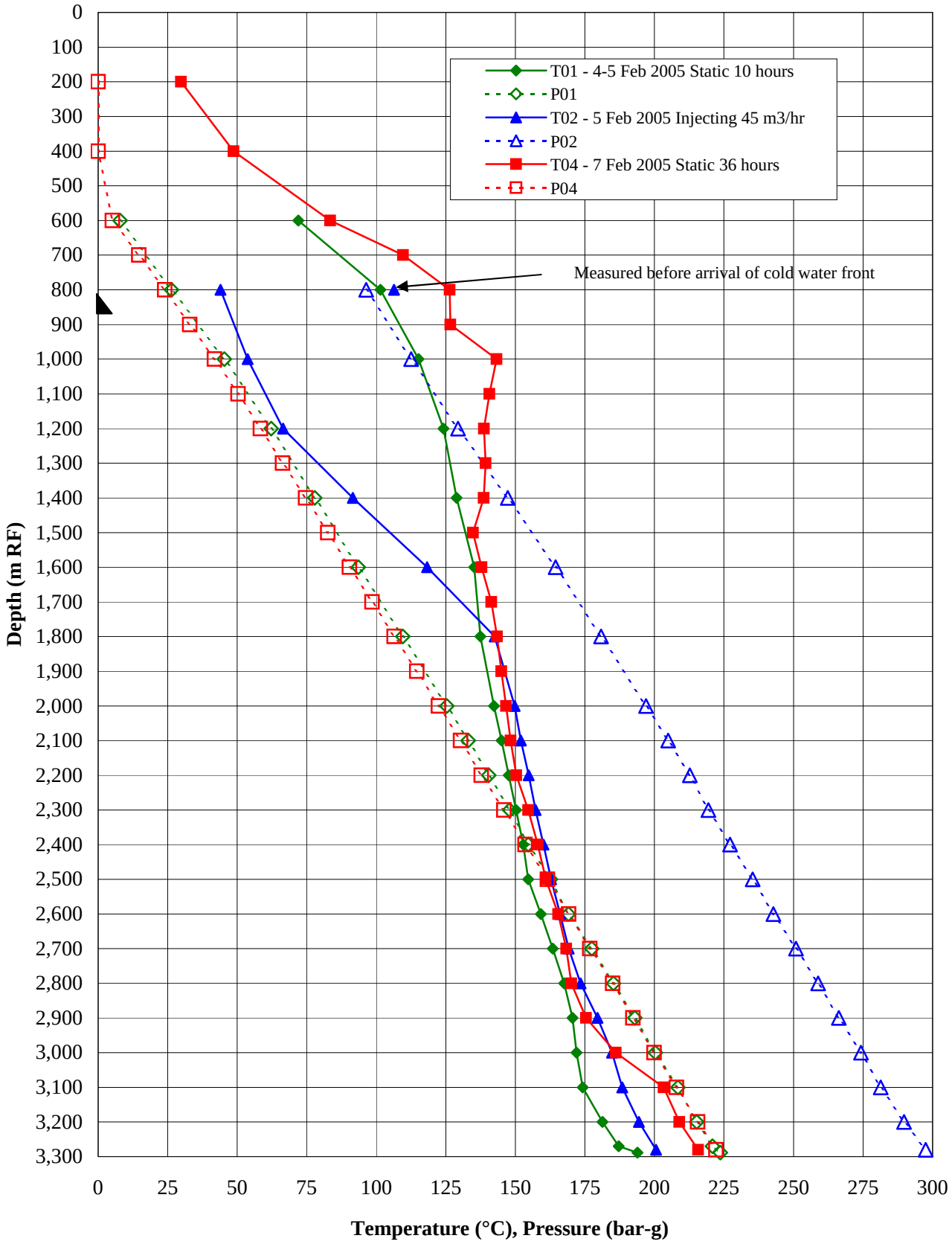

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Figure 2. Summary of Injection Test Results, Well MC-7 (February 5-6, 2005)

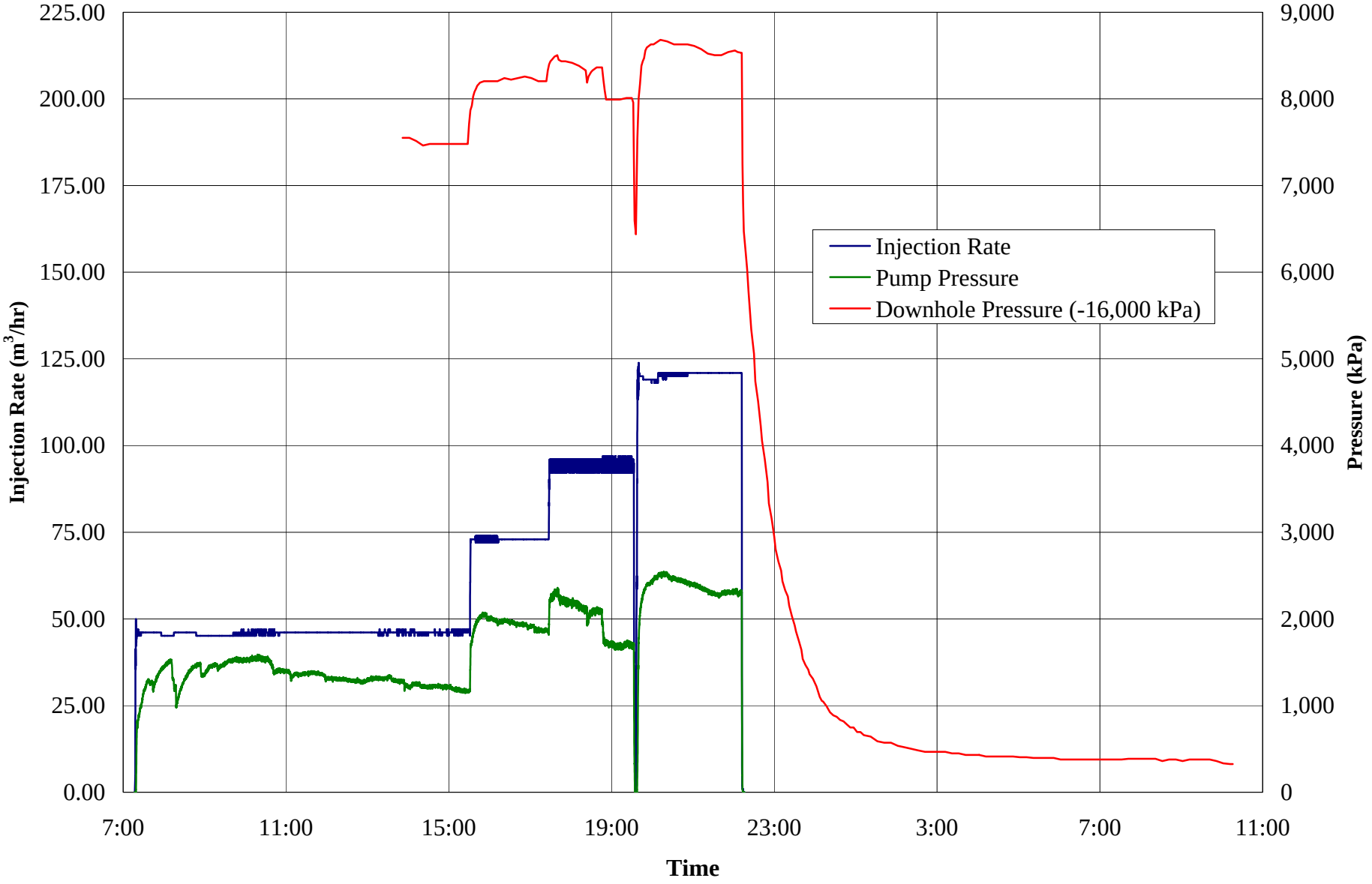

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Figure 3. Detail of Monitored Pressures, Injection Test of MC-7

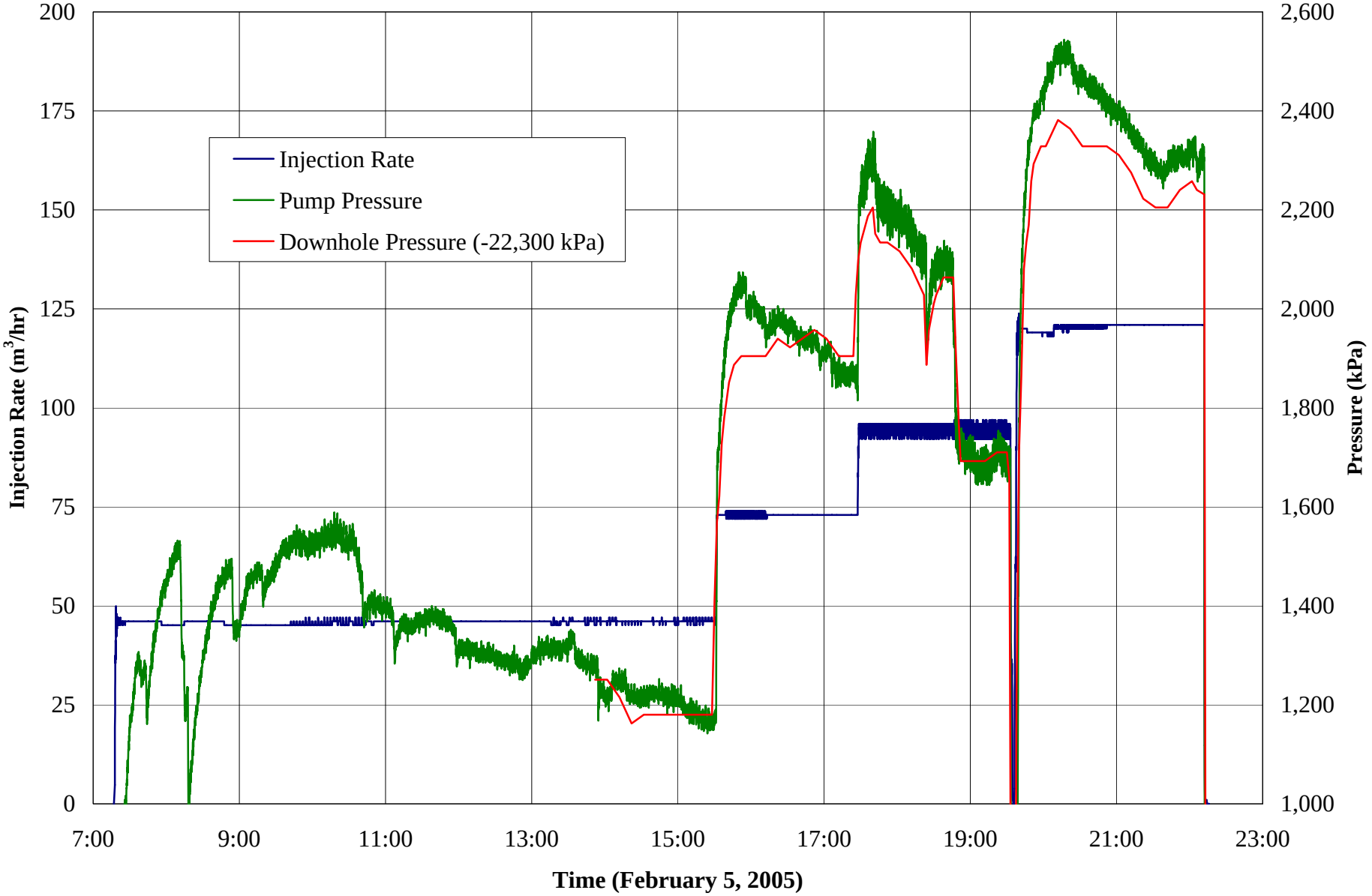

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Figure 4. Pressure Increase vs. Injection Rate, Well MC-7 (February 4-6, 2005)

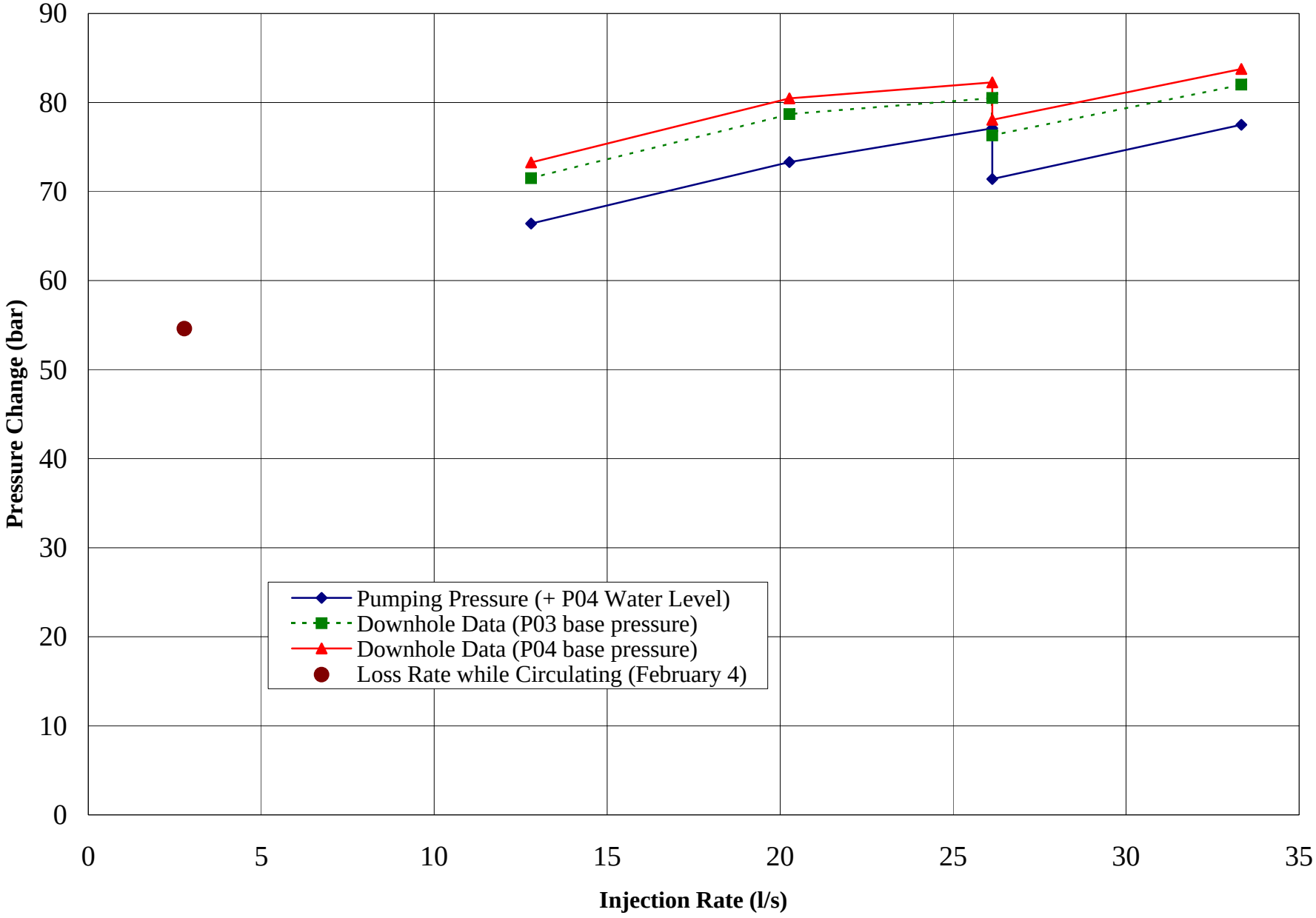

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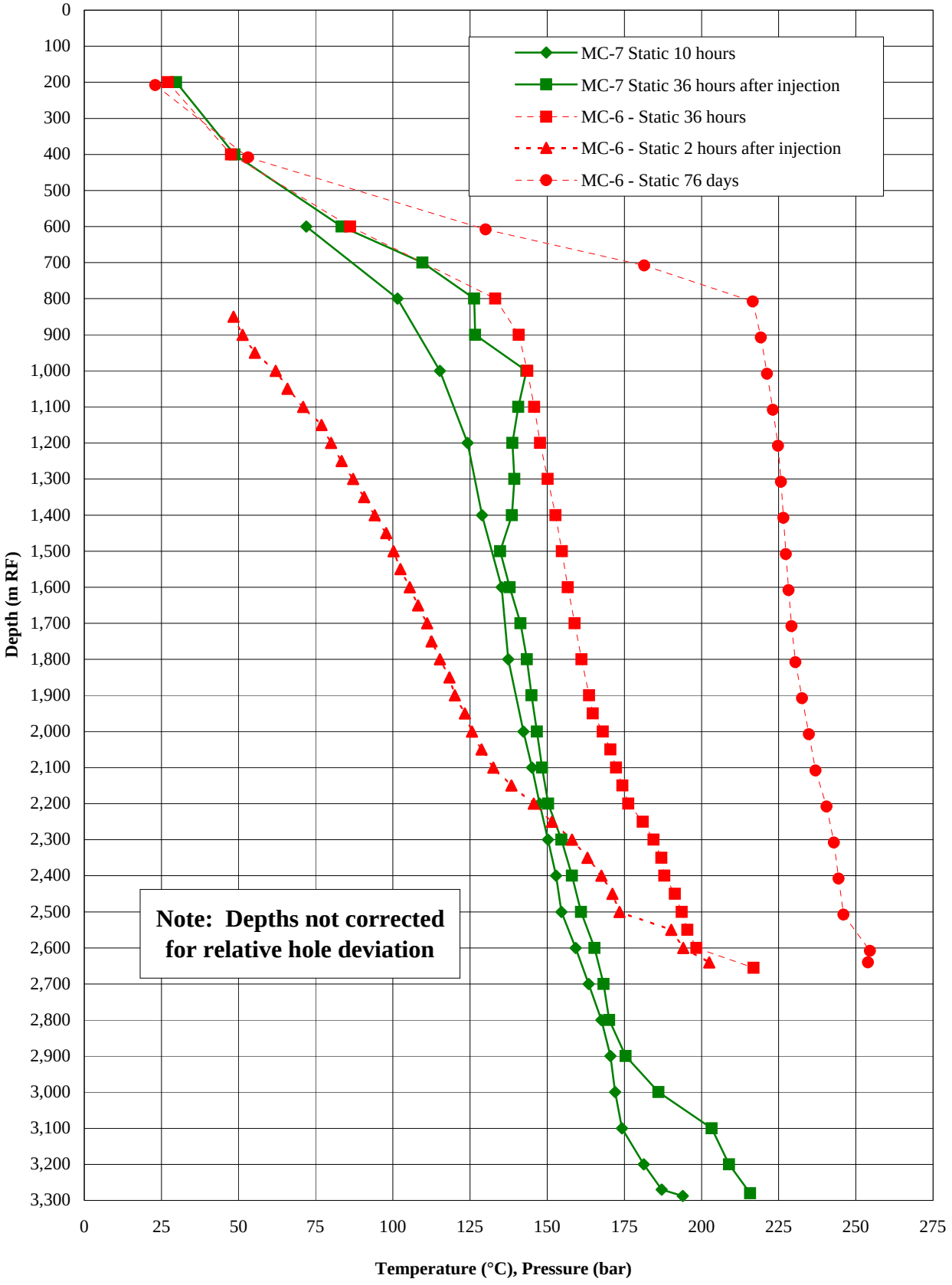
Figure 5. Comparison of MC-6 and MC-7 Temperature Surveys



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