

TRACING OF INJECTION USING GASES DERIVED FROM LOST-CIRCULATION MATERIALS AT THE MATSUKAWA GEOTHERMAL FIELD, JAPAN

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ABSTRACT

Tracer testing using alcohols were conducted in the Matsukawa vapor-dominated reservoir since 2000 (Fukuda et al., 2005). In addition to the alcohols, two unexpected gases were detected by gas chromatography during the test conducted on well M-14 prior to the completion of the drilling. We concluded that the gases were derived from lost-circulation materials (LCMs) used for the drilling of well M-14, which was confirmed by heating experiments of the LCMs in the laboratory. The LCMs were products of cottonseed hull and pulp. The LCM-derived gases were found in all the monitoring wells in the Matsukawa vapor-dominated reservoir, although the alcohol tracer was detected in the only two production wells. The return curves and arrival times were obtained by the monitoring of the LCM-derived gases and they showed that the fluid flowed from the southwest to the northeast within the system; this flow direction is consistent with the previous study of the pressure distribution (Hanano and Matsuo, 1990).

With the results obtained during the monitoring, we concluded that the LCM-derived gases can be used as a tracer to detect the breakthrough of the drilling fluid in the vapor-dominated reservoir.

INTRODUCTION

Tracer testing using alcohols were conducted in the Matsukawa vapor-dominated reservoir since 2000 (Fukuda et al., 2005 and 2006). One of the tests was conducted on a newly drilled production well M-14 prior to its completion. The aim of this test was to predict the interference induced by the introduction of the production of well M-14, because this well is located closest to the upflow zone in the system. A mixed tracer composed of 650 kg ethanol and 1,290

kg isopropanol was injected into well M-14 using drill pipe set close to the main fracture on 18 May 2001.

In the analysis of alcohols in the steam condensate with gas chromatography, two unexpected gases were found in addition to the alcohols. These gases were found in all the monitoring wells in the period of the tracer test although the alcohols were detected in only two wells located closest to the injection well. We assumed that the unexpected gases originated in lost-circulation materials (LCMs) because (1) they were used in well M-14 up to three days prior to the tracer injection, (2) no other artificial materials were injected into any wells except for the tracer and the LCMs injected into well M-14, and (3) the LCMs are organic material which can release gases by heating. We therefore conducted heating experiments of LCMs in the laboratory in order to confirm whether the LCMs generated the unexpected gases observed in the monitoring samples. We also monitored the amount of those gases in the samples in order to evaluate whether they could be used as a tracer in the vapor-dominated reservoir.

EXPERIMENT

Heating Experiments of LCMs

We prepared the materials used for the drilling of well M-14 as follows:

- LCMs: Telstop-P, Telstop-G, and Mud Seal (Telnite Co., Ltd.),
- bentonite—the main component of drilling mud,
- drilling mud sampled from well M-14.

Telstop-P and Telstop-G are made from cottonseed hull, and the former is the smashed product. Mud Seal is a pulp product and bentonite is a clay

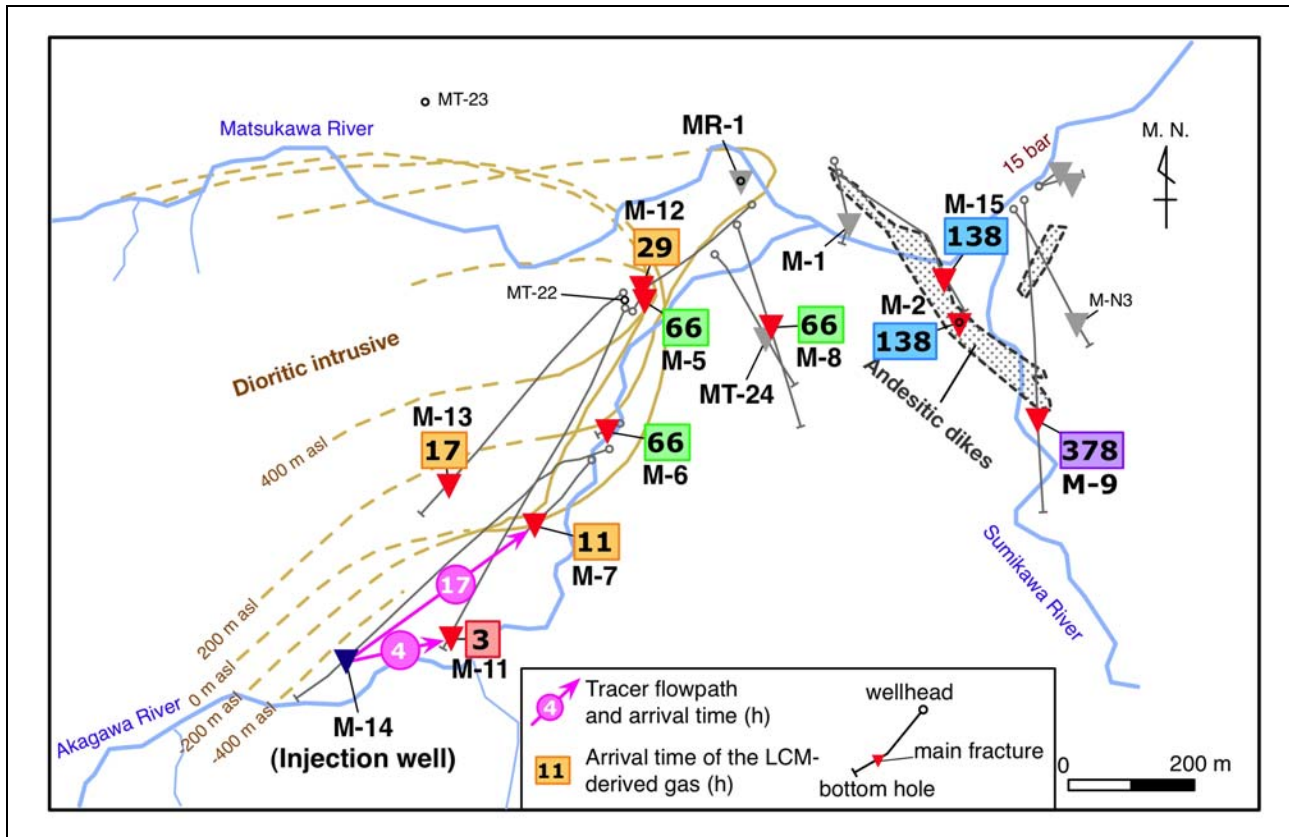


Figure 1. Well trajectories of the Matsukawa geothermal field. The arrival times of the LCM-derived gas and the alcohol tracer are displayed.

compound composed primarily of montmorillonite. In addition to these materials, ethanol and isopropanol were also tested.

Each of the materials except the drilling mud was put in Teflon containers having a volume of approximately 30 ml, and the containers were filled up with distilled water and capped. Subsequently, the containers were set in the stainless-steel cases to keep the Teflon containers capped tightly, and then moved to an ordinary electric furnace. The heating temperature was 150°C and heating durations were 112 hours for the LCMs, bentonite, and the drilling mud sample, and 131 hours for the alcohol solutions. The amounts of the materials used in the experiment were as follows:

- Telstop-P: 0.6 g,
- Telstop-G: 0.7 g,
- Mud Seal: 0.4 g,
- bentonite: 1.0 g,
- ethanol and isopropanol: 0.1 ml each.

The drilling mud was doubly diluted and then used for filling up the container.

Sampling of Steam Condensates

Samples were collected from wells M-2, M-5, M-6, M-7, M-8, M-9, M-11, M-12, M-13, and M-15; the well trajectories are shown in Figure 1. A cooling coil was connected to the steam line and 100 ml of steam condensate was collected into a screw-cap bottle. The sample was treated with 0.1 ml of 5% zinc acetate solution to precipitate hydrogen sulfide to protect the gas chromatograph. The wells were sampled approximately once an hour to six hours at the beginning of the monitoring, once a day after three days, once several days after 12 days until eight weeks; the last samples were taken after about three months from the tracer injection.

Analytical Method

Analyses were performed on a Shimadzu GC-14B gas chromatograph equipped with a flame ionization detector (FID). Separation was achieved with a 3 m x 3 mm column containing 80/120 mesh Carboxen (SPELCO), and the carrier gas nitrogen. Samples of steam condensates and solutions obtained in the heating experiments were injected into the gas chromatograph directly by an auto injector.

RESULTS AND DISCUSSION

Detection of LCM-Derived Gases by Gas Chromatography

The output of the gas chromatograph is provided as a chromatogram, which is a spectrum of the detection signal and retention time as shown in Figures 2 to 5. A chemical component in the sample appears as a peak with the specific retention time on the chromatogram. The peak area is proportional to the amount of the component in the sample.

Figure 2 shows the chromatograms of the samples taken from wells M-11 and M-14; the sample of well M-14, which had been the injection well only during the tracer testing, was collected after the beginning of its production. These chromatograms show the two peaks of the unexpected gases at the retention times of 3.7 min and 7.9 min in addition to those of alcohols (ethanol and isopropanol). The peaks with the retention time of 7.9 min are much larger than those with the retention time of 3.7 min and those of the alcohols.

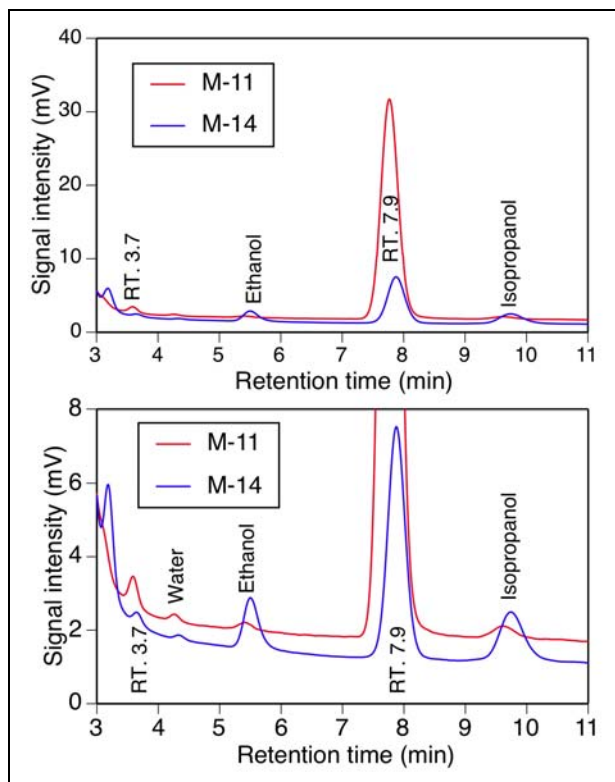


Figure 2. Chromatograms of the samples collected from wells M-11 and M-14. The unexpected gases (LCM-derived gases) are recognized at the retention times of 3.7 min and 7.9 min, respectively. RT means retention time.

The chromatograms of the solutions heated together with the LCMs are shown in Figure 3a and each of the chromatograms displays the peaks at the retention times of 3.7 min and 7.9 min as in the case of the well samples. In contrast, the solution heated together with bentonite does not have the peaks at 3.7 min and 7.9 min on the chromatogram (Figure 3b).

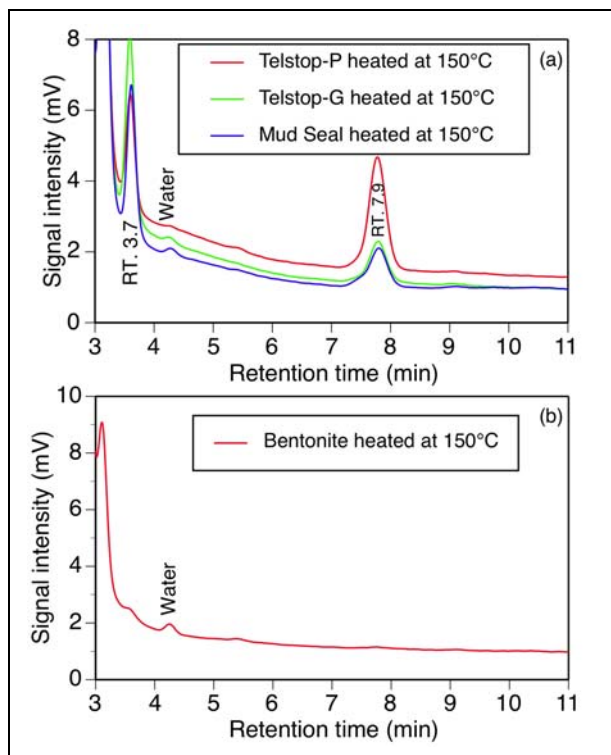


Figure 3. Chromatograms of the solutions heated together with (a) LCMs and (b) bentonite. The former has peaks at the retention times of 3.7 min and 7.9 min, although the latter has no peak at those retention times.

Figure 4 shows the chromatograms of the heated and non-heated drilling mud samples. The heated mud sample shows the peaks at 3.7 min and 7.9 min more clearly. This indicates that heating encouraged the generation of those gases from the LCMs contained in the drilling mud.

The chromatograms of the heated alcohol solutions are shown in Figure 5. They display the tiny peaks with the retention times of 3.7 min and 7.9 min (Figure 5b). These peak heights (< 0.5 mV) are extremely smaller than those of the alcohols (ca. 330 to 500 mV); this means that the amounts of those gases generated from the alcohols is practically negligible.

On the basis of the heating experiments and the fact that the unexpected gases were found in the samples collected before the tracer injection as described later, we concluded that the unexpected gases were generated from the LCMs heated in the fractures

around the wellbore. We call these gases the "LCM-derived gases."

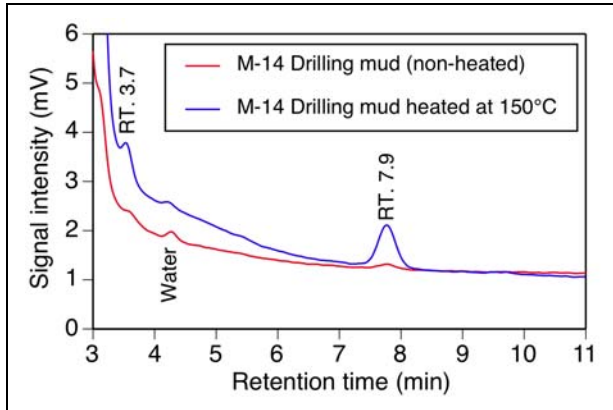


Figure 4. Chromatograms of the heated and non-heated drilling mud samples used for well M-14. The heating process encouraged the generation of the gases with the retention times of 3.7 min and 7.9 min.

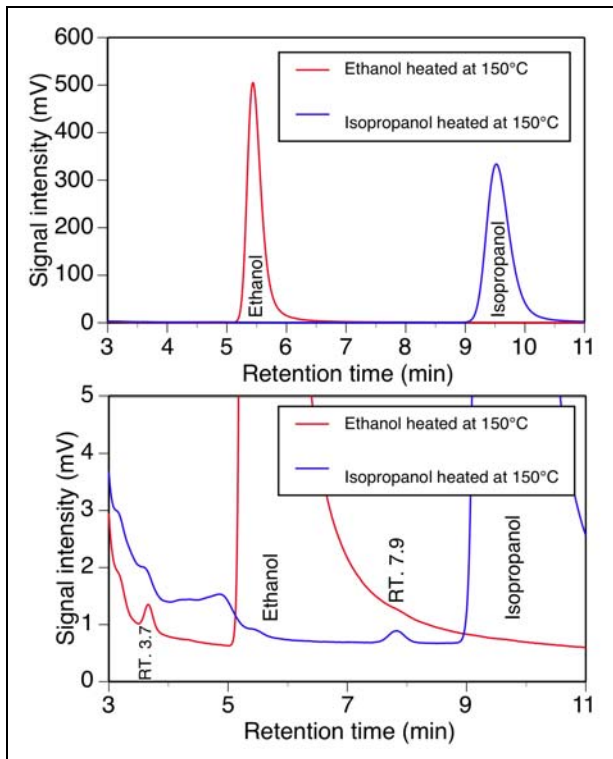


Figure 5. Chromatograms of the heated alcohol solutions. Extremely small peaks are recognized at the retention time of 3.7 min and 7.9 min.

Returns of the LCM-Derived Gases

Hereafter, we refer to the LCM-derived gas with the retention time of 7.9 min because its peak on the chromatogram was more obvious than that with the

retention time of 3.9 min. The LCM-derived gas was found in all the monitoring wells although the tracer was detected in the only two wells (Fukuda et al., 2005); this means that the LCM-derived gas flowed much further than the tracer. The reason for the difference in the flow distance can be explained as follows. The tracer could flow downwards in the vapor-dominated region because the liquid tracer has a higher density than vapor. Thus, only a small amount of alcohol vapor could escape from the downflow and reach the wells close to the injection well. In contrast, the solid LCMs could stay in the fracture around the wellbore and then be heated. This process could encourage the generation of the LCM-derived gas in the fracture. Furthermore, the amount of the LCMs used (ca. 5,460 kg) was larger than that of the tracers (1,940 kg in total). All of these factors indicate that the LCM-derived gas could be generated more efficiently than the alcohol vapor in the fracture around the wellbore.

The peak area of the chromatogram was used instead of the concentration for the monitoring of the LCM-derived gas, because the LCM-derived gas was not identified as the specific chemical species and the concentration was not calculated using a proper standard, and also because the peak areas are proportional to the concentrations of the gases. The histories of the peak areas are shown in Figure 6. Extremely small peak areas (less than 8,000 pixels) of the LCM-derived gas were observed in wells M-7 and M-11 before the tracer injection. This indicates that the small amount of the LCM-derived gas arrived at the wells before the tracer injection. Subsequently, the peak area of the LCM-derived gas and the concentrations of tracers rapidly increased nearly simultaneously as shown in Figure 7. Because the tracer was injected at a depth close to the main fracture using drill pipe and a high capacity pump in a short period of time (5 min), we concluded that this process triggered the strong flow from well M-14 to the other wells.

Wells M-7 and M-11 closest to well M-14 showed the earliest rises and the sharpest peaks of the return curves, and the more distant wells displayed the later rises and broader peaks (Figure 6). This behavior of the LCM-derived gas is similar to that of the general tracers. Now we define the arrival time of the LCM-derived gas and the tracer as the elapsed time from the tracer injection to the appearance of the rise of the return curves. As shown in Figure 1, the arrival times display the fluid flow from southwest to northeast. This flow direction is consistent with the pressure gradient of the reservoir (Hanano and Matsuo, 1990). Figure 8 shows the relationship between the flow distance and the arrival time of the LCM-derived gas. The velocities of the LCM-derived gas are calculated in the range of 3 to 82 m/h, and they could reflect regional differences in the physical properties of the reservoir such as permeability and pressure gradient. Future work will include the

numerical modeling using these data obtained from the monitoring of the LCM-derived gas.

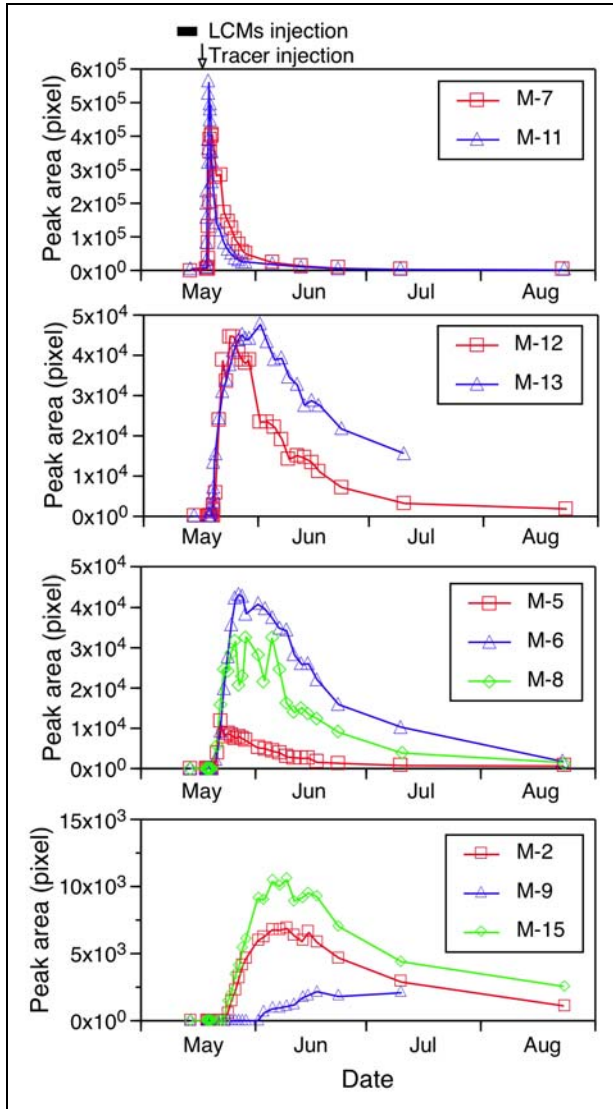


Figure 6. Return curves of the LCM-derived gas. The peak areas of the chromatograms are used instead of the concentrations (see text).

The breakthrough of the drilling fluid is a common and sometimes serious problem in some Japanese geothermal fields. The measurement of turbidity of the produced brine has been used as an indicator of the breakthrough only in liquid-dominated reservoirs. Meanwhile, the monitoring of the LCM-derived gas is applicable also to vapor-dominated reservoirs in cases where the LCMs are used.

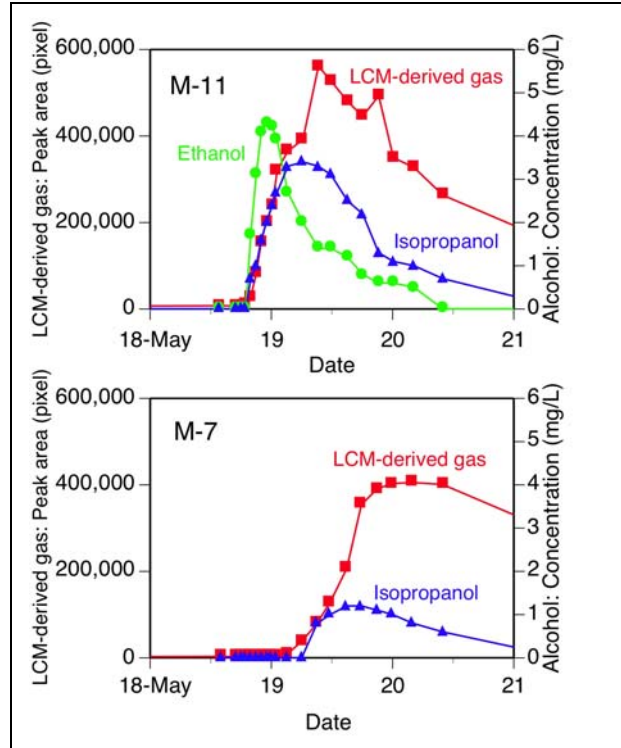


Figure 7. Return curves of the LCM-derived gas and the alcohols for wells M-7 and M-11 in the first three days after the tracer injection. The peak area of the LCM-derived gas and the concentration of the tracer rapidly increased nearly simultaneously.

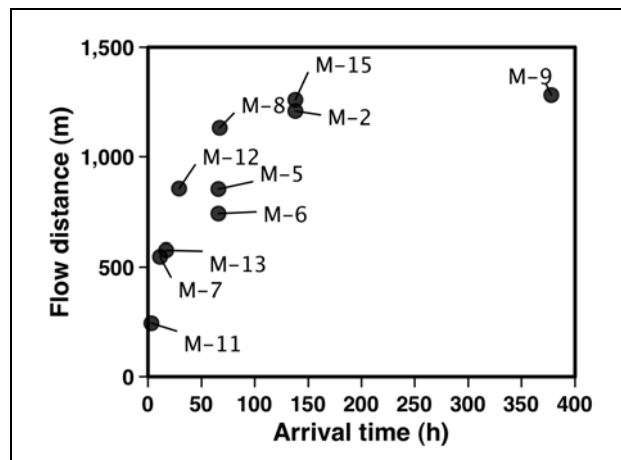


Figure 8. The relationship between the arrival time and the flow distance of the LCM-derived gas.

CONCLUSIONS

Two unexpected gases detected together with alcohols were analyzed during the alcohol tracer testing conducted on well M-14 in the Matsukawa

vapor-dominated reservoir. We concluded that the gases were generated from the lost-circulation materials (LCMs) used for the drilling of well M-14, because the gases were detected in the solutions heated together with the LCMs in the laboratory. We call these gases the "LCM-derived gases."

The LCM-derived gas was detected in all the monitoring wells, although the tracer was detected in the only two production wells closest to the injection well M-14. On the basis of comparison of the arrival times between the LCM-derived gas and the tracer, it is concluded that the tracer injection triggered the flow of the LCM-derived gas from well M-14.

The arrival times of the LCM-derived gas indicate that fluid flows from southwest to northeast consistent with the previous study of the pressure gradient in the system.

With the results obtained, we concluded that the LCM-derived gas can be used as a tracer to detect the breakthrough of drilling fluid in the vapor-dominated reservoir.

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