Proceedings Eighth Workshop Geothermal Reservoir Engineering
Stanford University, Stanford, California, December 1982
SGP-TR-60

# EFFECTS OF CONTAMINATION BY GEOTHERMAL DRILLING MUD ON LABORATORY DETERMINATIONS OF SANDSTONE PORE PROPERTIES: AN EVALUATION

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## INTRODUCTION.

Numerous studies have been presented, mainly in the petroleum literature, about permeability impairment of reservoir formations due to rock/drilling fluid interactions. For example, Glenn et al;(1957) showed that mud particles can invade to an appreciable depth into the pores of a porous medium, form a "filter cake" in the pores, and cause a substantial reduction in the permeability of the invaded zone. Drilling muds contain water and dissolved salts that can cause reductions in permeability attributed to clay minerals which expand or disperse upon contact with water (Alexander and Johnson, 1949) that is less saline than the connate water (Jones, 1964; Atwood, 1964, Monaghan et al; 1959). Other studies showed that permeability reduction due to salinity changes, can also occur in formations containing only nonexpandable clays, such as illite or kaolinite, and that permeability impairement can be caused by changes in PH (Mungan, 1965). Experiments designed for geothermal conditions indicated that formation damage depends on the composition of the drilling mud, temperature and stagnation time (Ennis et al; 1979). These and other studies (e.q. Abrams, 1977; Nicholson, 1978) demostrated that permeability reduction is site-specific, in the sense that it depends strongly on the compatibility of the rock/drilling fluid system.

We are initiating research to evaluate formation damage related to drilling fluids used in Mexican geothermal fields. The initial work, reported in this paper, has been done on Berea sandstone for two reasons: a) to save valuable reservoir drill cores while developing and turning experimental techniques, and b) for comparison with results from other investigations, since Berea sandstone has been extensively studied and used in permeability impairment research This paper focuses on the magnitudes of permeability reductions associated with high-temperature rock/geothermal drilling fluid interactions, and on the possibility of restoring the unperturbed permeability to reservoir drill cores for its measurment in the laboratory.

## EXPERIMENTAL METHOD.

Two sets (A and B) of experiments were conducted. In both of them the permeabilities of specimens extracted from two samples, one corresponding to each set, were measured before and after contamination with drilling fluid at simulated geothermal borehole conditions. The specimens of set A were then subjected to a washing process widely used in the petroleum industry, and their permeabilities remeasured. In this way the fraction of the initial permeability restored by washing was evaluated.

With set B the depth of invasion by mud particles, and permeability restoration by mechanical treatment were investigated. One end of each (cilindrical) specimen was wire-brushed, and then the permeability of the specimen was remeasured. This sequence was then repeated for the other end. Next, a thin slice was cut from one end, and the permeability of the shortened specimen was measured again. This process was repeated, alternating the ends of the specimen, several times.

The use of several specimens in each set of experiments was intended to statistically compensate for inhomogeneities in the samples.

Permeabilities to nitrogen were determined at room temperature by means of a Core Lab gas permeater. These measurements were then corrected for Klinkenberger slippage to obtain absolute permeabilities. Before the permeability measurements the specimens were oven-dried at 100°C for 24 hours. Porosities were measured by the liquid vacuum saturation method.

Interaction of the rock specimens with drilling fluid at simulated geothermal borehole conditions was achieved with the experimental set up illustrated in Fig. 1. The specimens were loaded into a stainless steel pressure cell. Subsequently the drilling fluid was added at ambient temperature, and the cell was sealed. The pressure was then raised (by means of pressurized nitrogen) before heating to avoid flashing the drilling fluid. Once the temperature and pressure planned for the experiment were achieved, their values were achieved, their values were kept constant for fixed periods. The conditions chosen for both sets of experiments are shown in Table 1.

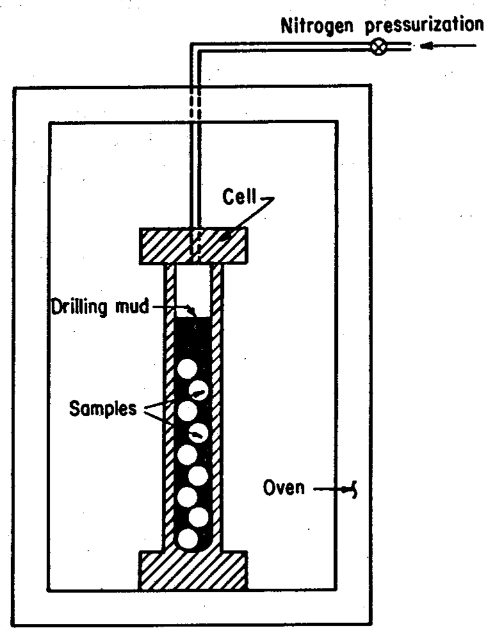


FIGURE 1- EXPERIMENTAL SETUP FOR ROCK/DRILLING FLUID.

The selected drilling fluid is commonly used in the geothermal field of Cerro Prieto for the depth range 300-2000 m. (Domínguez, 1982; A. Fernández and M. Flores, 1982). Its composition is given in Table 2. Other properties of the fluid (API norm RP 13B) are given in Table 3. After contamination the excess mud adhered to the specimens was removed by means of a wet rag.

Table 1. Experimental Parameters.

| Parameter | Set A | Set B |
|---|---|---|
| Pressure (psi) | 1600 | 400 |
| Temperature (°C) | 200 | 150 |
| Stagnation time (hs) | 6 | 20 |

Table 2. Composition of the drilling fluid.

| Component | Weight (%) |
|---|---|
| Tap water | 76 |
| Rock cuttings | 13 |
| Bentonite | 7 |
| Diesel oil | 3 |
| Lignite | 1 |
| NaOH | <0.1 to adjust pH to 9.0 |

Table 3. Rheological Characteristics of the Drilling Fluid.

| | |
|---|---|
| Density | 1.14 g $cm^{-3}$ |
| Marsh viscosity | 47 s/l |
| Plastic viscosity | 13 cps |
| Yield point | 5 lb/100 $ft^2$ |
| Initial gel strength | 0' = lb/100 $ft^2$ |
| Final gel strength | 10' = 2 lb/100 $ft^2$ |
| API filtration | 13 ml/30 min, |
| Mud cake thickness | 3 mm |

Washing was done with methanol in a Core Lab centrifuque operating at 1000 rpm during 12 hs.

Petrological studies by X-Ray diffraction and thin sections were conducted on specimens reserved for this purpouse. For X-Ray diffraction samples were prepared by grinding the material into a very fine powder in an agate mortar. The powdered sample was pressed on a glass holder, ready to be X-Rayed. Crystalline phases were identified by powder X-Ray diffraction with a Siemens diffractometer (D 500) with Ni, filtered Cu $k\alpha 1$ $\alpha 2$ radiation. The scanning speed of the goniometer was 2°2θ/min. Phase identification was carried out from the ASTM powder diffraction file.

Thin sections were prepared using the standard lamination technique. Petrographic analysis were conducted with a petrographic microscope (Carl Zeiss) with polarized light capability and up to 1250 X magnification.

## RESULTS AND DISCUSSION.

The initial permeabilities measured in clean specimens from core sample A are shown in Fig. 2 as a function of the specimen's position in the core. It will be noticed that there is a marked change of permeability along the core sample. The regression line shown has an associated correlation coefficient equal to 0.9285; its slope is 0.462 md/cm. The standard deviation of the data points (circles) with respect to the regression line equals 5.18 md, or about 4 percent. The data points illustrated with triangles were not included in the correlation. These points correspond to specimens which under/went saturation with distilled water and then a drying cycle before their permeability to nitrogen was measured. We attribute the observed permeability impairment in these specimens to clay swelling, which could not be removed by the 24 hours, 100°C drying cycle.

The permeabilities measured after the rock specimens interacted with the drilling fluid at simulated borehole conditions are presented in Table 4. The specimens appearing in Fig. 1 but missing in this table were used for experiments no reported in this paper. Table 4 also shows the permeabilities recorded after the washing process. The results are presented as fractions of $k_{regr}$, the permeabilities of the clean specimens as obtained from the regression line of Fig. 2. From Table 4 the average fractional permeability of the contaminated samples is 0.704, with a standard deviation equal to 0.054, or 7.7 percent. It will be noticed that the washing process seems to have impaired the permeabilities even further: the mean fractional permeability of the washed specimens is 0.656, with a standard deviation equal to 0.056, or about 8.5 percent. With only ten cases, the observed differential between both mean fractional permeabilities is not statistically compelling. Therefore the differential is taken only as indicative that the washing process could actually reduce the permeability. What is certain though, is that washing with methanol did not improve the permeabilities.

Table 4. Permeabilities after contamination and washing for core sample A.

| Sample # | Position (cm) | regr (md) | cont / regr | wash / regr |
|---|---|---|---|---|
| 1 | 1.85 | 112.35 | .751 | .689 |
| 2 | 5.65 | 114.10 | .835 | .779 |
| 3 | 13.02 | 117.51 | .700 | .654 |
| 4 | 20.53 | 120.98 | .662 | .608 |
| 5 | 24.17 | 122.66 | .661 | .589 |
| 6 | 31.70 | 126.14 | .719 | .703 |
| 11 | 57.67 | 138.13 | .677 | .618 |
| 12 | 65.16 | 141.59 | .679 | .626 |
| 13 | 68.85 | 143.30 | .687 | .652 |
| 14 | 76.38 | 146.78 | .670 | .642 |

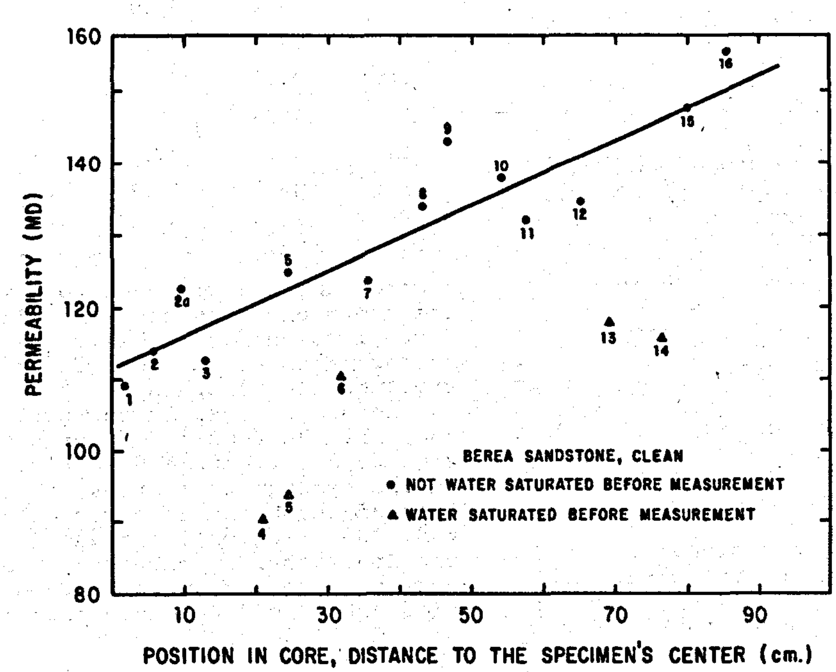


FIGURE 2.- PERMEABILITY vs. POSITION IN CLEAN CORE SAMPLE A.

Having evaluated the amount of permeability reduction associated with the rock/drilling-fluid interaction at geothermal borehole conditions, and the effectiveness of the washing process, the question remains as to what actually caused the observed permeability impairement. We investigated the penetration of drilling fluid particles by means of petrological thin sections studies and by X-Ray diffraction. Samples for these studies were taken from the flat ends of cilindrical specimens (identified by the letter a after their label numbers) which were subjected to contamination and washing simultaneously with the specimens used for permeability measurements. The results of our semiquantitative analysis are shown in Table 5. The minerals in this Table are arranged in order of decreasing abundance. We were unable to find evidence of invasion of the porous medium by particles from the drilling fluid. Electron scanning micrographs are planned for future work.

Table 5. Results of semiquantitative petrological analysis for core sample A.

| SAMPLES | MAINS COMPONENTS |
|---|---|
| | CLEAN SAMPLES |
| 2a,5a,15a | Quartz, feldspars, chlorite, dolomite, mica, calcite* |
| 3a | Quartz, feldspars, dolomite, chlorite, mica, plagioclase? calcite* |
| 7a, 13a | Quartz, feldspars, chlorite, dolomite, mica (illite T), calcite* |
| 9a, 11a | Quartz, feldspars, chlorite (clinochlore), dolomite, mica, calcite* |
| | CONTAMINED SAMPLES |
| 2a,3a,13a | Quartz, feldspar, dolomite, chlorite (clinochlore), mica, calcite* |
| 5a, 11a | Quartz, chlorite, feldspar, dolomite, mica, calcite* |
| | WASHED SAMPLES |
| 5a | Quartz, feldspar, chlorite (clinochlore), dolomite, mica, calcite* |
| 13a | Quartz, chlorite (clinochlore), feldspar, dolomite, mica, calcite* |

*Low concentration.

As complement to this study we measured the porosities of the clean and washed specimens. Turbidity was observed in the water used for these measurements. The corresponding results are shown in Table 6. Unlike the results reported for permeability, no sistematic variation of porosity with position along the core was found to exist. The average porosity and standard deviation for the clean specimens are 18.11% and 0.45% respectively; the corresponding values for the washed specimens are 17.7% and 0.40% respectively. Although the evidence is not statistically compelling due to the relatively modest number of cases considered, a slight decrease of porosity is indicated for the washed samples. This indication taken together with the results of our petrological studies sugest clay swelling as a possible explanation for the porosity reduction.

Table 6. Porosities of clean and washed specimens from core sample A.

| Sample # | Porosity (%) $\phi$clean | $\phi$wash |
|---|---|---|
| 1 | 19.1 | 17.6 |
| 2 | 17.6 | 17.8 |
| 2a | 17.5 | 16.7 |
| 3 | 18.0 | 17.8 |
| 3a | 17.5 | 17.5 |
| 4 | 18.3 | 17.7 |
| 5 | 18.2 | 17.9 |
| 5a | 18.3 | 17.4 |
| 6 | 18.1 | 18.0 |
| 11 | 17.8 | 17.6 |
| 11a | 17.7 | 17.8 |
| 12 | 18.3 | 18.4 |
| 13 | 18.4 | 17.9 |
| 13a | 18.1 | 17.3 |
| 14 | 18.7 | 18.2 |

Core sample B was used to investigate the depth of invasion by drilling fluid particles, and permeability restoration by mechanical treatment. The mechanical treatment (wire-brushing and slicing) has been described in the preceeding section. The results of set B of experiments are summarized in Fig. 3. Whithin the experimental error, the permeability of the blank specimen was unaffected. The fractional permeabilities of the four other specimens decreased in average to 0.735, with a standard deviation equal to 0.068 upon contamination with drilling mud. The agreement of these values with those found for set A is excellent. Therefore, we deduce that

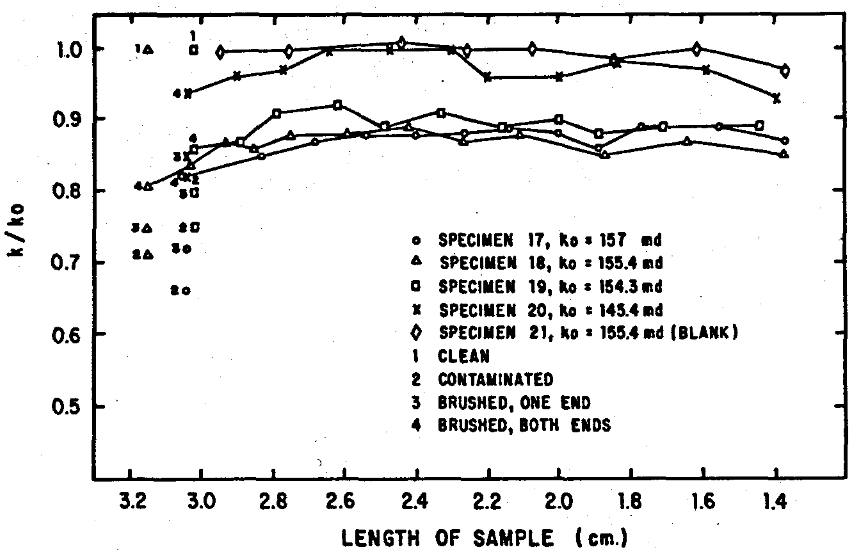


**FIGURE 3.- EFFECTS OF WIRE-BRUSHING AND SLICING ON THE PERMEABILITIES OF SPECIMENS FROM CORE SAMPLE B.**

possible permeability impairment effects associated with the different pressures, temperatures and stagnation times corresponding to sets A and B must be small for the conditions of our experiments.

The effect of brushing the ends of the specimens is important: in every case it accounts for most of the permeability restoration. Slicing the ends of the specimens increases the permeability slightly at first, but very rapidly a stabilized permeability value is reached. The average stabilized fractional permeability, about 0.91, is significantly higher than 0.656, the value corresponding to the washing process.

For the conditions of the experiments reported in this paper, our results of set B indicate that permeability impairement is due to two distinct phenomena. Surface blocking accounts for about two thirds of the permeability reduction. And some other mechanism, operating in the whole rock, not just in the surface, acounts for the rest of the permeability impairement. Based on the presence of mica, and expandable clay, in any samples (Table 5), and on the turbidity of the water observed during our porosity determinations, we suggest clay swelling and dispersion as responsible for the later mechanism.

CONCLUSIONS.

The following conclusions may be reached from our work with Berea sandstone and a drilling fluid used in the Cerro Prieto geothermal field for the depth range 300-2000 m.

1) Permeability reduction due to rock/drilling fluid interaction at geothermal borehole conditions is of the order of 30 percent for the system studied. This result in insensitive to pressure, temperature, and stagnation time within the range of parametrs explored.

2) Two mechanisms are responsible for permeability impairment. One acting on a thin surface layer, accounts for approximately two thirds of the total effect. The other is distributed in the bulk of the rock, and accounts for about one third of the total permeability impairment.

3) About 90 percent of the original permeability can be restored by mechanical means (wire-brushing and cutting). This removes the permeability damage associated with the "surface mechanisms", but does not affect that due to the "bulk mechanism".

4) Washing contaminated specimens with methanol does not restore their permeability in any discernible way, and may actually cause further permeability impairement.

AKNOWLEDGEMENTS.

We thank Ing. Guillermo Barroso at IIE for providing the Berea cores and some of the equipment and materials used in this work. Juan Flores F., drafted the figures. We also aknowledge the collaboration of Ing. Antonio Rodríguez G. at Instituto Mexicano del Petróleo for washing the samples. The present investigation forms part of the Cooperative Geothermal Program between Instituto de Investigaciones Eléctricas and Stanford University.

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