

## CLAY-COATING REDUCTION OF PERMEABILITY DURING OIL-SAND TESTING

**Key Words**—Chlorite, Coating, Oil sand, Permeability, Petroleum reservoir.

While making a series of permeability test measurements on an Alberta oil-sand which were to be used in a computer simulation of steam stimulation or steam drive (an *in situ* recovery technique discussed by Kendall (1977)), an unexpected decrease in permeability was observed. The cause of the permeability drop during the test procedure was the main objective of this study.

### EXPERIMENTAL

#### *Test procedure*

In the test procedure used, a 7.62 cm diameter × 12.7 cm long core of Cold Lake oil-sand was sealed in a test chamber under 13.6 atm constant compacting pressure. The sealed core was cleaned and 10% NaCl brine was pumping through the core at room temperature. The measured absolute permeability was 1100 md. The chamber was then heated to 66°C. Clean Cold Lake heavy-oil was pumped through the chamber for one day. At this temperature, the heavy-oil permeability was 580 md. The chamber was heated to 149°C for one day, and the permeability to heavy-oil was found to decrease to 175 md. A mixture of heavy-oil and brine was then pumped through the chamber, gradually reducing the amount of heavy-oil until only brine was present. The core was cleaned again when the temperature was brought down to room temperature. The absolute permeability to brine was now 234 md whereas it had been 1100 md at the beginning of the test.

#### *Samples and methods*

Samples from the injected fluid “inlet” end of the tested core, the injected fluid “outlet” end of the tested core, and of a cleaned “fresh” oil-sand which provided an unaltered reference for comparison were examined. Portions of the samples were ground and examined by X-ray powder diffraction for random bulk mineral identification. An oriented aggregate of the <0.8- $\mu\text{m}$  and the 0.8–2- $\mu\text{m}$  size fractions was examined to determine the clay mineralogy. Portions of the samples were inspected with an AMRAY 1400 scanning electron microscope to observe pore throats.

### RESULTS

The bulk minerals found in the fresh, inlet, and outlet samples by X-ray powder diffraction were quartz, feldspar, and clay minerals. No evidence of changes in the

bulk mineral assemblages after the test was observed. Most of the <0.8- $\mu\text{m}$  and the 0.8–2- $\mu\text{m}$  minerals in the three samples consisted of quartz, feldspar, chlorite (Dean, 1983), illite, and smectite, but quartz and feldspar were especially abundant in the 0.8–2- $\mu\text{m}$  fraction. No evidence of newly formed minerals nor changes in the clay mineral composition were observed in either size fraction. Newly formed smectites or zeolites, which can cause serious permeability drop during *in situ* recovery of Alberta oil-sand (Perry and Gillott, 1979; Boon, 1980), were not observed.

Scanning electron microscope examination showed that the fresh sand grains were covered by clays except at grain contacts (Figure 1). The clay-coating consisted of two different layers: an inner massive layer and an outer chlorite layer (Figure 2). Figure 3 shows the inner massive clay-coating from the inlet sample peeling off the sand grains. Figure 4 shows the pore throats in the outlet sample filled with the peeled-off clay-coating.

### DISCUSSION

The investigation indicates that the unexpected permeability drop was caused by clay-coatings peeling off the sand grains and plugging the pore throats. The critical step appears to have been the heating from 66°C to 149°C because in that temperature range the heavy-oil permeability dropped from 580 md to 175 md. Also, the sand grain orientation may have been dis-

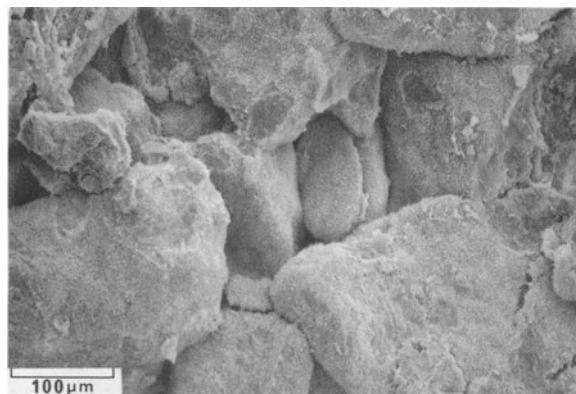


Figure 1. Scanning electron micrograph of the surface of fresh sand grain coated by clays, except at grain contacts.

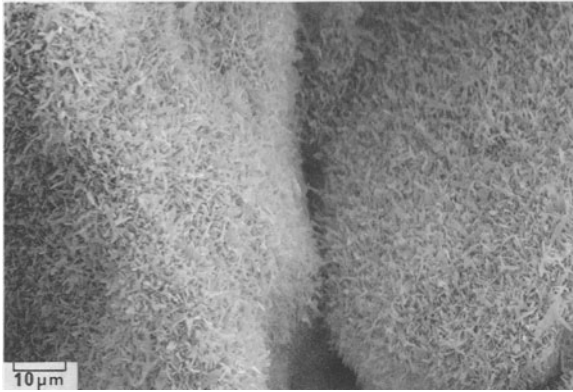


Figure 2. Scanning electron micrograph of the outer chlorite layer on fresh sand grains.

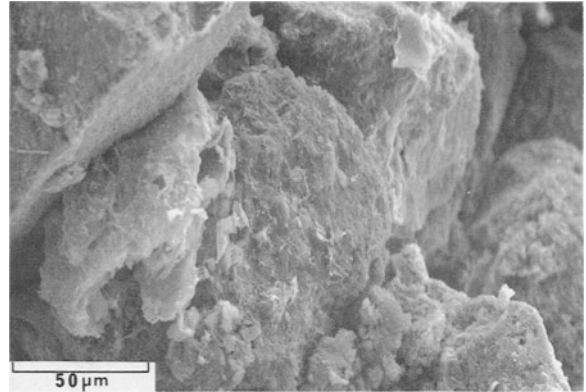


Figure 3. Scanning electron micrograph of the inner massive clay-coating peeling off sand grains.

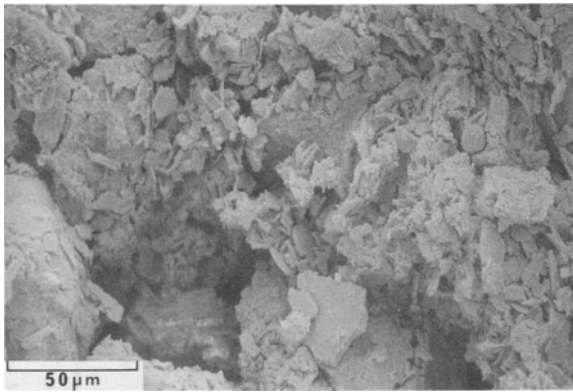


Figure 4. Scanning electron micrograph of stripped clay-coating plugging the pore throats.

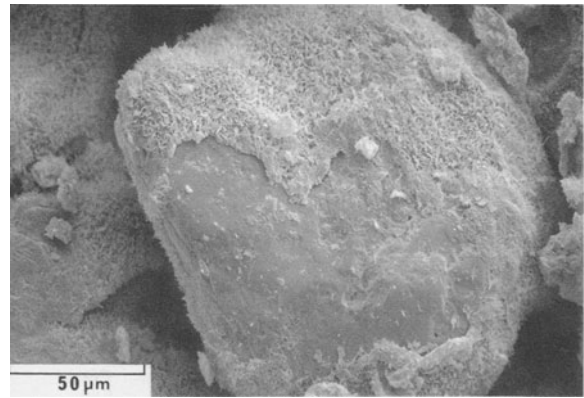


Figure 5. Scanning electron micrograph of fresh sand grain showing the clay-coating partially stripped from grain.

turbed during coring, packing, or heating; the stripping seems have started at the exposed grain-to-grain contacts (Figure 5). Thus, the peel-off mechanism was probably due to the weakening of the grain-coating bond at 149°C.

The high viscosity of the heavy oil may have caused the coating to peel off. The viscosity of Cold Lake heavy-oil decreased, however, from 277 centistokes at 66°C to about 14 centistokes at 149°C. Consequently, if the high viscosity of the oil was responsible for stripping the coating, the process should have occurred at 66°C and not at 149°C. Therefore, the stripping was probably not due to the viscosity of the heavy oil at 149°C. The vaporization of the water may have pulled off the clay-coating at 149°C; however, the pore fluid pressure was maintained at 6.8 atm to prevent vaporization of the water in the system at 149°C. The expansion of water, either from the dehydration of smectite or from brine squeezed into the boundary area probably did not contribute significantly to the loosening of the coating at 149°C. The weakening mech-

anism was likely due to the differential thermal expansion of grain and coating.

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#### REFERENCES

- Boon, J. A. (1980) An experimental-statistical study of mineral transformations during *in situ* recovery of bitumen from various oil sand deposits in Alberta, Canada: *Proc. 3rd Int. Sym. on Water-Rock Interaction, Edmonton, Canada, 1980*, B. Hitchon, ed., Alberta Res. Council, Edmonton, 97-99.

- Dean, R. S. (1983) Authigenic trioctahedral clay minerals coating Clearwater Formation sand grains at Cold Lake, Alberta, Canada: *Program Abstracts 20th Meeting Clay Min. Soc., Buffalo, New York, 1983*, p. 79. (Abstract).
- Kendall, G. H. (1977) Importance of reservoir description in evaluating *in situ* recovery methods for Cold Lake heavy oil. Part 1. Reservoir description: *Bull. Can. Pet. Geol.* **25**, 314–327.
- Perry, C. and Gillott, J. E. (1979) The formation and behaviour of montmorillonite during the use of wet forward combustion in the Alberta oil sand deposits: *Bull. Can. Pet. Geol.* **27**, 314–325.

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