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PERMEABILITY OF MESAVERDE SANDSTONE SAMPLES: PROJECT RULISON

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ABSTRACT

The permeability (K) of preshot Rulison samples was measured as a function of net confining pressure. These sandstone samples represent gas-bearing sands located at a depth of ~8400 ft. The measurements were made for comparative studies with measurements and calculations from other sources.

EXPERIMENTAL PROCEDURE

Permeability measurements were conducted using equipment and techniques developed in previous studies with other sandstones.[1,2] Current data acquisition is greatly facilitated through the partial use of a small computer control system which will eventually operate and control the permeability apparatus. Although computer control of the apparatus is not yet functional, the FOCAL programming routines, the signal converters for pressures and flow transducers, and the recording and output features of the system are usable.

For sample preparation, a 1-in. diam × $1\frac{1}{2}$-in. long cylindrical sample is removed from the field-retrieved core sample. The ends of the sample are faced off and attached to end adapters for tubing connection. A flexible plastic jacket is cast around the sample, which allows it to be submerged in an autoclave. Dry nitrogen is then passed axially through the sample while it is subjected to various confining hydraulic pressures. Appropriate pressure and flow measurements are taken. Net confining pressure (NCP), which is the oil pressure minus mean gas pressure, was varied from 300 to 9500 psi. The in situ NCP is 5250 psi. Sample water saturation at time of measurement varied from 12 to 17% of the void volume, compared with the in situ value of 50%. Nitrogen gas pressures as high as 1250 psi were required to produce sufficient flow through the samples at the high confining pressures.

RESULTS

A linear reduction in K to 30% of its initial value is observed as the NCP is increased to 3000 psi. Additional increase in NCP to 9500 psi reduces absolute permeability more slowly to about 5% of its initial value. The horizontally cut samples have higher K's than equivalent vertically cut samples. This reflects the geological conditions of the gas-bearing sands, perhaps to the orientation of bedding planes.

Table 1. Permeability (K) of Rulison samples, unconfined and at 5250 psi.

Sample	Water saturation, % of void volume	K (unconfined), μD	K (at 5250 psi), μD	K (estimated, at 5250 psi and 50% water saturated), μD
8400 hor	—	25.0	—	—
8400 vert	16.9	7.7	1.4	0.3
8404 hor	12.0	21.3	2.5	0.4
8404 vert	12.2	16.5	1.8	0.3
8404 (USBM[3])	12.0	73.5	6.1	1.3 (measured)
8404 (Core Lab., Inc.[4])	dry	150	—	—

Table 1 lists the values of K at unconfined conditions and at an NCP of 5250 psi, which represents conditions at 8400 ft where the sands are located. The percentage water saturation after sample measurement is also listed. The permeability at 50% water saturation is estimated from the experimental data and from the effect of water on permeability in similar studies with Gasbuggy sandstones.[2]

Figures 1-3 show the effect of confining pressure on permeability. Unconfined or initial permeability is the extrapolated value at zero confining pressure The secondary curves show the hysteresis effect with confining pressure. Recovery is gradual and only 80% complete after three days. Complete recovery is probably never attained, due to permanent deformation of the rock matrix. Figure 4 shows the "slip" contribution to permeability first noted by Klinkenberg, and hence the Klinkenberg correction to permeability for gas pressure.[5] In these measurements the effect is small (Fig. 4), especially when compared with the normal spread in permeability measurements. Therefore, no corrections were made for slip.

As noted in Table 1, the permeability results in this paper are considerably lower than those from other sources. The reasons are not obvious. Perhaps the effect of sample size is important. Infrequent but significant flow paths can be excluded in preparing a few small random samples. Insufficient sampling could then result in permeability values which deviate considerably from the mean.

Calculations based on production flow and well pressures by Montan[6] indicate in situ K of ~8 μD. This is considerably higher than any of the above sample measurements made at simulated in situ conditions. Measurements made for Project Gasbuggy produced similar results. That is, in situ K was 10 μD,[7] compared with 0.7 μD[2] estimated from laboratory measurements. In situ permeability is not unexpectedly higher, in that permeability based on in-place flow includes the effect of flow mechanisms on every scale within the reservoir, not just those restricted to small samples. In general, the Rulison samples are not appreciably different from Gasbuggy or Wagon Wheel sandstone samples in terms of both absolute permeability and permeability response to confining pressure.

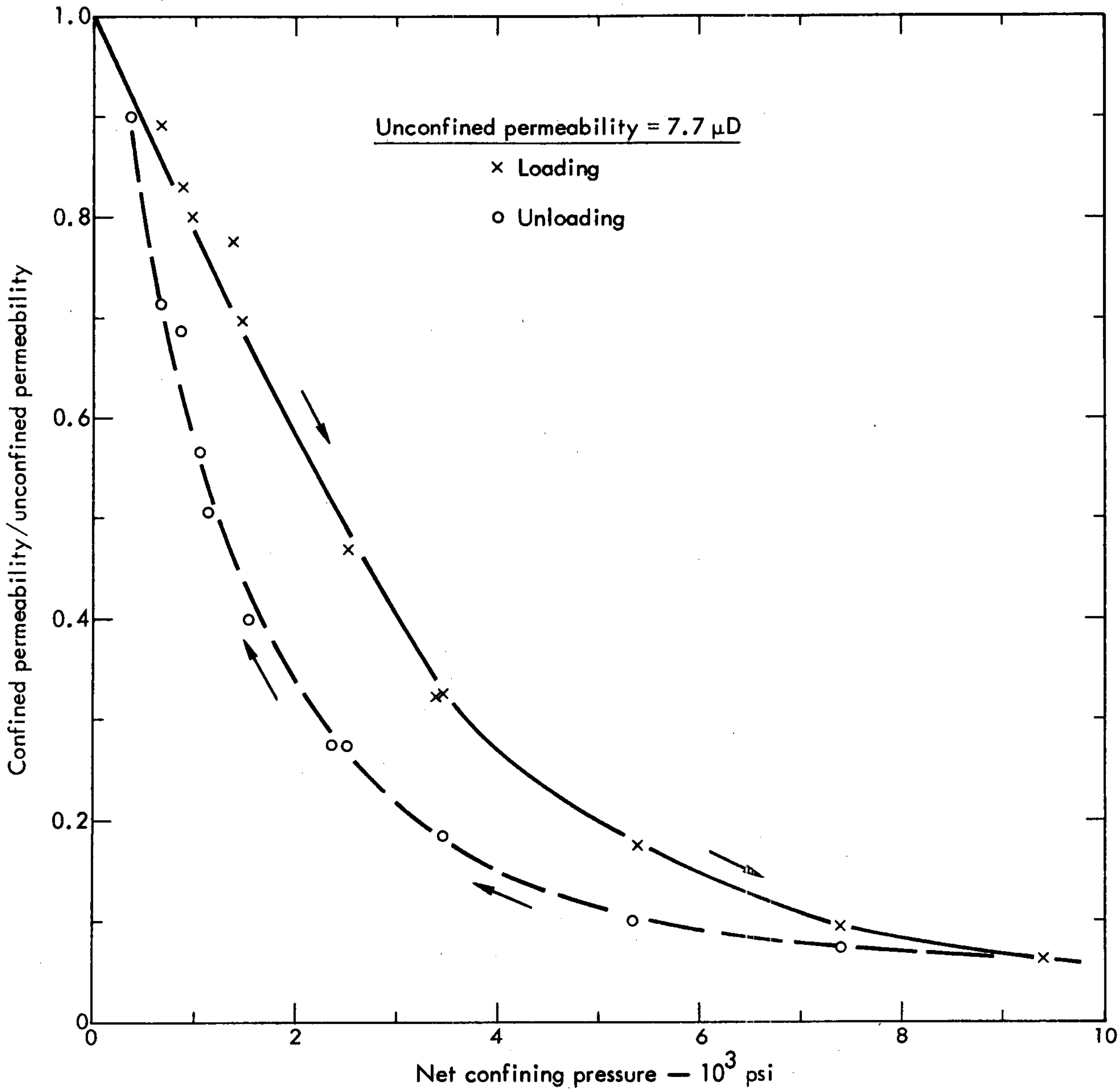

Fig. 1. Effect of net confining pressure on permeability for sample 8400 vert (Rulison).

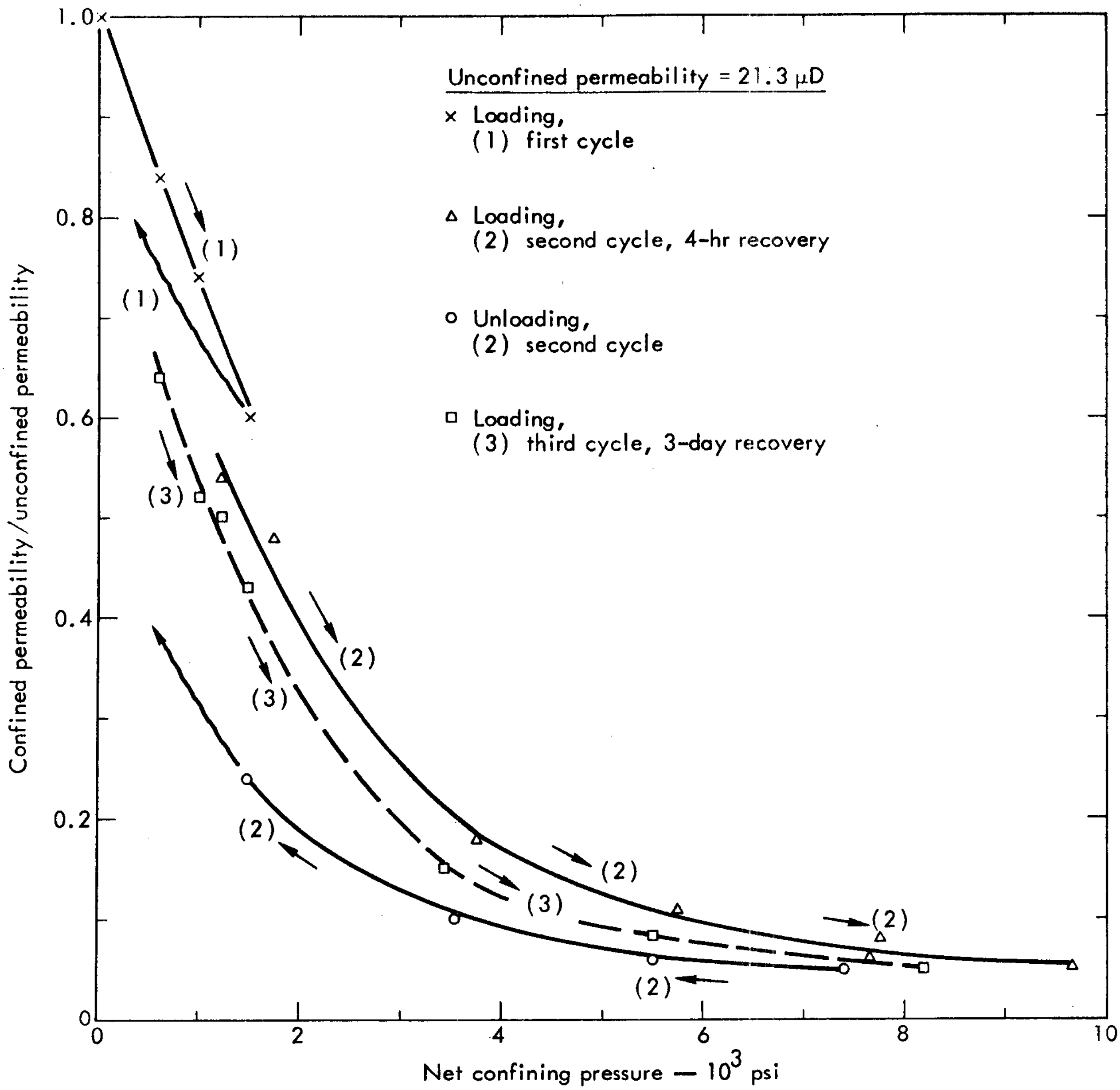

Fig. 2. Effect of net confining pressure on permeability for sample 8404 hor (Rulison).

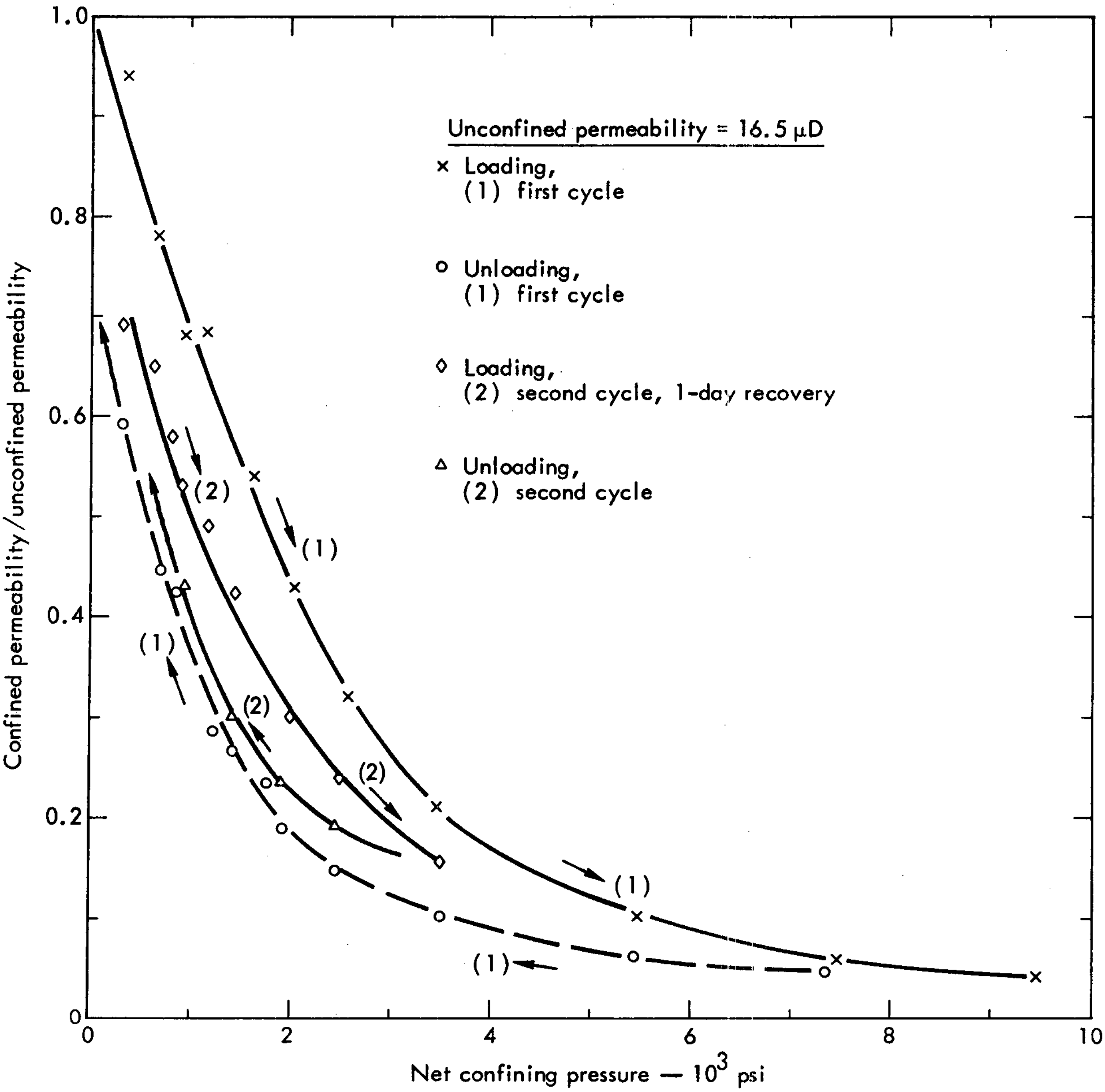

Fig. 3. Effect of net confining pressure on permeability for sample 8404 vert (Rulison).

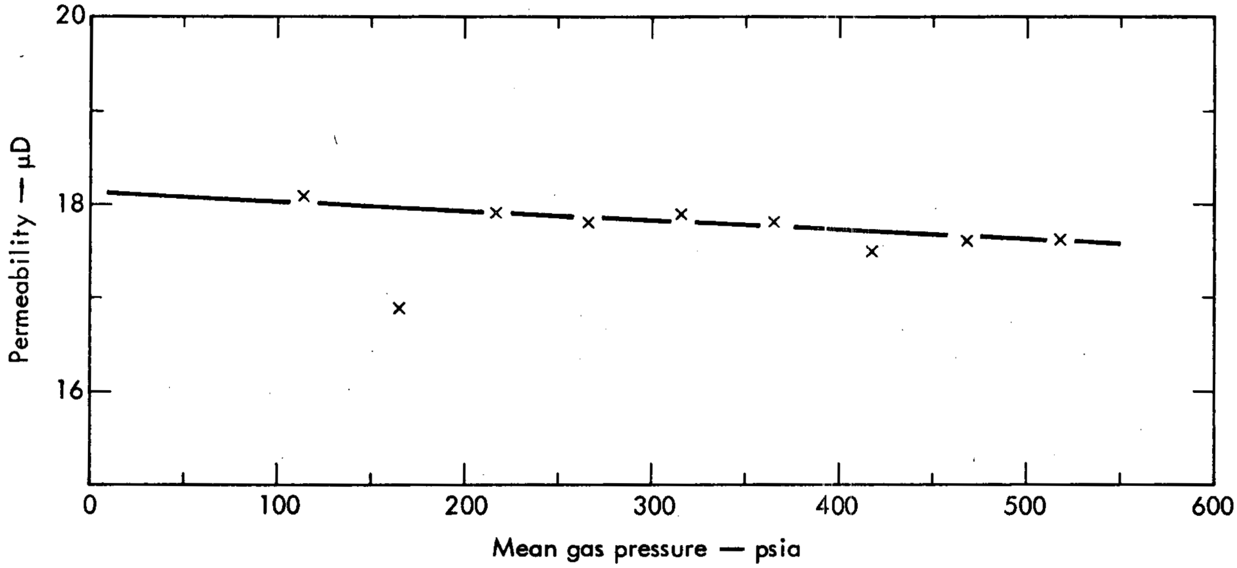

Fig. 4. Permeability at 600 ± 4 psi NCP as a function of mean dynamic gas pressure for sample 8404 hor (Rulison).

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