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July 26, 1988

TO ALL INTERESTED PARTIES

Re: Region of Halton Landfill Hearing.

Please find enclosed a copy of a report, dated June 22, 1988, to Geocon Inc., from the University of Western Ontario Geotechnical Research Centre. This report may be used in reply evidence by the Town of Milton.

DAVID ESTRIN

K. Clarke

Per: K. Clarke

KC:vw

Geocon Inc.

geotechnical consultants

Lavalin

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1988 06 22

Geocon Inc.
3210 American Drive
Mississauga, Ontario
L4V 1B3

Attention: Ms. Janet Haynes

Dear Sirs:

Re: Hydraulic conductivity testing on compacted Halton Till and compacted weathered Queenston Shale

Hydraulic conductivity tests have been carried out on two compacted soil samples. It is understood that the test data are to be used to assist in forming an opinion of their suitability for use as barrier materials for retardation of domestic waste leachate migration. The two samples were identified as follows:

1. A bag sample of brown clayey silt till (identified as Halton Till and received on March 28, 1988).
2. A bag of air dry, brown, broken and weathered shale (identified as Queenston Shale and received on March 31, 1988).

Two types of tests were required on each sample, as follows:

1. A fixed ring test with a static vertical effective stress, σ'_v, of about 100 kPa on the samples; and
2. A flexible membrane (triaxial) test with an all round effective stress, σ'_3, of about 100 kPa.

For both sets of tests the hydraulic gradient, i, was to be as low as practical and preferably about 20.

Each sample was also subjected to a preliminary mineralogical assessment and to a Harvard Miniature compaction test for comparison to previous Proctor tests by others. The compaction tests were required to establish suitable compaction procedures for the hydraulic conductivity test specimens.

1.0 Description of Samples

The Halton till arrived in bags labelled T.P. 1 and consisted of brown clayey silt with a weak to modest dry strength. The sample was identified as a combined till sample from Site F.

The Queenston shale arrived as a well graded air dry mixture of weathered, broken, medium reddish brown shale fragments varying in size from 5 cm to fine silt sized soil.

Both samples were highly reactive to dilute HCl indicating abundant carbonate.

Detailed descriptions are presented in Table 1.

2.0 Compaction Tests

The Harvard Miniature compaction test results for both the Halton till and the Queenston shale are presented on Figure 1. Since the mold for these tests is only 62.35 cm^3 in size (33.36 mm diam.), stones larger than 2 mm were removed from the Halton Till sample and the Queenston Shale was crushed by hand with a rubber tipped pestle to sizes less than 2 mm. Distilled water was added to both samples to bring them to the required molding water content. The testing protocol is presented in Appendix I of this report.

The two curves presented on Figure 1 present Harvard Miniature compaction data similar to Proctor results (by others) which are summarized in

Table 2. It was therefore concluded that the hydraulic conductivity test specimens would be compacted up to 2% wet of "Harvard" optimum using the Harvard Miniature compaction rod to simulate kneading compaction in the field. According to the saturation lines on these plots, the saturation state should be about 95% for these compaction conditions using the value of specific gravity measured on each sample.

The data points for the compacted specimens used for the hydraulic conductivity testing are also plotted on Figure 1 as Points #1 to #3. Point #3 for the two Halton Till specimens plots at its expected location whereas the two Queenston Shale specimens (Points #1 and #2) are slightly more dense than anticipated. Slight variations in composition, gradation, specific gravity, etc. associated with crushing, mixing and sampling make such scatter inevitable. All four samples, however, were quite satisfactory for k testing.

3.0 Hydraulic Conductivity Tests

3.1 Fixed Ring Method

The fixed ring hydraulic conductivity tests were run on 2 cm thick specimens compacted into 54 mm diameter permeameter cells using the same rod and the same energy per mass of soil used for the Harvard Miniature compaction tests. A static effective stress of 100 kPa was applied to the porous stone on top of the sample by means of a spring-loaded cell cap. The permeant, which consisted of ordinary tap water, was forced through the specimens using computer-controlled, constant flow rate equipment developed at Western. Two flow rates were employed, one producing a gradient of 30 to 50 and the other producing a gradient of 400 to 600 depending on the properties of the sample. Flow was maintained until the continuously measured k was deemed constant. Further details are presented in Appendix I.

3.2 Flexible Membrane (Triaxial) Method

The specimens for triaxial hydraulic conductivity testing were compacted into a 50 mm diameter mold using the same methods described for the fixed ring tests. The samples were removed from the mold, fitted with a greased double membrane and installed in a triaxial cell for saturation at a back pressure of 50 kPa, followed by isotropic consolidation to $\sigma_3' = 100$ kPa. Once the rate of consolidation had reduced to a negligible value, the inlet pressure at the top end of the triaxial specimen was increased to generate flow from the top to the bottom of the sample. Both the influent and effluent flow volumes were measured and the test continued until the two flow rates were as similar as practical. A low gradient of ~ 20 was employed for both tests. Further details of the test procedure are presented in Appendix I.

3.3 Halton Till Results

A plot of hydraulic conductivity, **k**, versus pore volumes of fluid passed through the sample is presented on Figure 2 for the Halton Till compacted at $\omega_o = 19.4\%$ (data point #3 on Figure 1). At a very slow flow rate of 6.0×10^{-6} mL/s, a stable average **k** of 5.2×10^{-9} cm/s was obtained after 8 days of flow corresponding to a gradient of 50 and a max seepage drag at the bottom of the sample (J_{max}) of 10 kPa. The long slow drop in **k** is a feature of this equipment and represents a combination of system compliance and loss of influent into air space in the compacted sample (i.e. increased saturation from its original calculated S_o value of ~ 96% shown in Table 3).

Increasing the flow rate to 89×10^{-6} mL/s produced a final **k** of 6.9×10^{-9} cm/s with a corresponding gradient of ~ 560 and J_{max} of ~ 110 kPa. The k_f is actually higher at the larger gradient than it was at i = 50. This probably is a result of gas compression under the influence of the higher fluid pressure which compensated for the 0.125 mm of sample consolidation caused by the seepage drag (Figure 2b). This phenomenon is somewhat similar to the increased saturation produced by the back pressures applied in the triaxial tests.

Plots of cumulative influent and effluent flow versus time for the triaxial **k** test on the Halton Till are presented on Figure 3. The **k** values calculated for each final flow rate are $k_{influent} = 9.5 \times 10^{-9}$ cm/s and $k_{effluent}$ = 7.08 x 10^{-9} cm/s. The two flow curves are not quite parallel and therefore the test had not quite reached equilibrium even though it had run for 11 days when terminated. The fact that both curves seem to be changing slope towards parallelism suggests a final equilibrium k of ~ 8 x 10^{-9} cm/s.

The high gradient fixed ring k value of 7 x 10^{-9} cm/s is quite similar to the averaged triaxial value of 8 x 10^{-9} cm/s.

3.0 Queenston Shale Results

A plot of hydraulic conductivity, **k**, versus pore volumes of fluid passed through the sample is presented on Figure 4 for the Queenston Shale compacted at ω_o = 14.9% (data point #1 on Figure 1). At the slow flow rate of 6 x 10^{-6} mL/s, a k of 7 to 8.5 x 10^{-9} cm/s was obtained after 8 days of flow at a final gradient of ~ 30 and a J_{max} of 6 kPa.

Increasing the flow rate to 89 x 10^{-6} mL/s produced a slight increase in the k to a final value of 9.6 x 10^{-9} cm/s at a corresponding gradient of 405. As in the fixed ring test on the Halton till, this increase in **k** is attributed to greater saturation of the samples under the influence of the higher influent pressure. This was in spite of the small decrease in void ratio indicated by the 0.087 mm of settlement caused by drag forces during seepage which amounted to 80 kPa at the base of the sample.

Plots of cumulative influent and effluent flows versus time for the triaxial test performed on compacted Queenston shale are presented on Figure 5. The k values calculated for each final flow rate are $k_{influent}$ = 1.2 x 10^{-8} cm/s and $k_{effluent}$ = 9.6 x 10^{-9} cm/s. If the two k values are averaged as was done for the Halton Till a suggested equilibrium value of k = 1.06 x 10^{-8} cm/s is calculated. This is very similar to the high gradient value of 0.96 x 10^{-8} cm/s obtained by fixed ring testing.

4.0 Mineralogical Assessment

The preliminary mineralogical assessment consisted of the following tests:

i) x-ray powder diffraction on pulverized, air dry whole soil or whole rock samples;

ii) dispersion in very dilue NaOH solutions and x-ray diffraction of the oriented fines, water-wet, air dried, glycerol treated and heated to 550°C for 30 min;

iii) same as item (ii) except K^+ saturated;

iv) gasometric analyses for total carbonate content using the Chittick apparatus.

4.1 Halton Till

The powder trace (Figure 6) used in combination with the carbonate (Chittick) analyses indicate the following very approximate composition:

Calcite and dolomite	~ 33%
Quartz	~ 14%
Feldspars	~ 23%
Clay minerals	~ 30%

The oriented traces (Figure 7a) indicate that the clay minerals consist of abundant illite (1.0 nm peaks) plus chlorite which has been extensively weathered to a swelling clay (1.4 - 1.5 nm) so that no distinct 1.4 nm peak is obtained by oven drying at 550°C. The ragged nature of the illite peak and its presence at 1.01 nm rather than 1.00 nm suggests some interlayering with a swelling phase.

Potassium saturation of the fines (Figure 7b) produces some reduction in the size of the 1.52 nm smectite peak and a shift to 1.42 nm but does not collapse it in the water-wet state. Air drying, however, causes significant collapse indicating that the swelling clay is borderline in charge between vermiculite and smectite. This soil is of similar mineralogy to other soils in Ontario presently believed to be performing satisfactorily as clay barriers against domestic waste leachate migration.

4.2 Weathered Queenston Shale

The powder trace (Figure 6) used in combination with the carbonate (Chittick) analyses suggest the following very approximate composition.

Calcite and dolomite	~ 22%
Quartz	~ 29%
Feldspars	Nil
Clay minerals	45-55%

The oriented traces (Figure 8a) indicate that the clay minerals consist of abundant illite, moderate chlorite and a trace amount of swelling clay. The chlorite in the shale produces a distinct 1.40 nm peak on heating to 550°C unlike the weathered Halton till.

Potassium saturation of the shale fines (Figure 8b) has little effect on the traces producing no major collapse of any peaks although the slight amount of smectite shown by the traces on Figure 8a seems less evident. The mineralogy of the shale suggests that it is a potentially suitable liner material provided it is adequately comminuted in the field either by the compaction process or by crushing and wetting before compaction.

5.0 Concluding Remarks

I trust that this preliminary assessment of these two potentially suitable liner materials is adequate for your present purposes.

Yours truly,
GEOTECHNICAL RESEARCH CENTRE

R.M. Quigley, P.Eng.
Professor

RMQ:em

Attachments: Tables 1 to 4
Figures 1 to 8
Appendix 1

Table 1. Description of Test Samples

Sample	Description
Halton Till	Medium brown, air dry clayey silt till having a modest dry strength. Yellowish to reddish colour on surface of some chunks, freshly broken surfaces appear mottled. Some fracture surfaces coated with a whitish material and others coated with a brown stain. All particles highly reactive to dilute HCl. Carbonate ≈ 33% on two specimens. As received water content ≈ 13.4%. Specific gravity, D_R = 2.75 (2.764, 2.742).
Queenston Shale	Well graded air dry mixture of broken, weathered, medium reddish brown shale containing scattered lumps of dry soil up to 2 cm in diameter. Shale fragments vary from silt sizes to tabular chunks up to 5 cm in diameter and 1 cm thick. All particles coated with a more yellowish looking silt. Freshly broken fragments a darker, medium brown shale. Shale fragments moderately to highly reactive to dilute HCl. Carbonate ≈ 19% and 25.5% on two specimens. As received water content 6 to 8.5%. Specific gravity, D_R = 2.74 (two measurements).

Table 2. Compaction Data

Sample	γ_d(max) (pcf)	ω_{opt} (%)	Type Compaction	Source
Halton Till				
Till (Site F)	111.1	16.7	Std. Proctor	J. Haynes (phone - Mar. 31, 1988)
Combined till (Site F)	114.1	17.25	Harvard* Miniature	U.W.O. (this report)
Queenston Shale				
Weathered shale (Site F)	118.6	13.4	Std. Proctor	Geocon (Mar. 1988)
Weathered shale	124.0	12.8	Std. Proctor	Golder report to Morrison Beatty (June 1980)
Weathered shale	119.3	14.25	Harvard Miniature	U.W.O. (this report)

*Mold height = 71.38 mm, diam = 33.36 mm, volume = 62.35 cm^3; soil compacted in 5 layers, 20 tamps/layer, using an 0.142 kN (32 lb) spring; contact pressure of 12.5 mm diam. rod = 1160 kPa.

Table 3. Geotechnical Characteristics of Compacted Soil/Shale Samples before Hydraulic Conductivity Testing

Soil Characteristic	Halton Till		Queenston Shale	
	Fixed Wall	Triaxial	Fixed Wall	Triaxial
Moisture content ω_o (%)	19.4	19.4	14.9	15.5
Void Ratio e_o	0.557	0.556	0.418	0.428
Dry density ρ_{do} (Mg/m³)	1.767	1.767	1.932	1.919
Saturation S_o (%)	~ 96	~ 96	~ 98	~ 99
Sample volume V_o (mL)	45.8	196.4	45.8	117.2
Pore Volume PV_o (mL)	16.4	70.2	13.5	35.1

Table 4. Geotechnical Characteristics of Compacted Soil/Shale Samples during and after Hydraulic Conductivity Testing

Soil Characteristic	Halton Till		Queenston Shale	
	Fixed Wall	Triaxial	Fixed Wall	Triaxial
Applied static effective stress (kPa)	σ'_v = 100	σ'_{3C} = 100	σ'_v = 100	σ'_{3C} = 100
Volume change due to[(1)] static stresses (mL)	- 0.786	- 4.29	- 0.426	- 3.25
Volume change due to seepage (mL)	- 0.286	-	- 0.199	-
Final average moisture content ω_f (%)	18.2	18.4	14.3	15.4
Final void ratio e_f	0.520	0.529	0.399	0.425
Final dry density $\rho_{d(f)}$ (Mg/m³)	1.809	1.800	1.959	1.922
Final Saturation S_f (%)	~ 96	~ 96	~ 98	~ 99

(1) Directly measured in fixed wall tests; inferred from water of consolidation in triaxial tests.

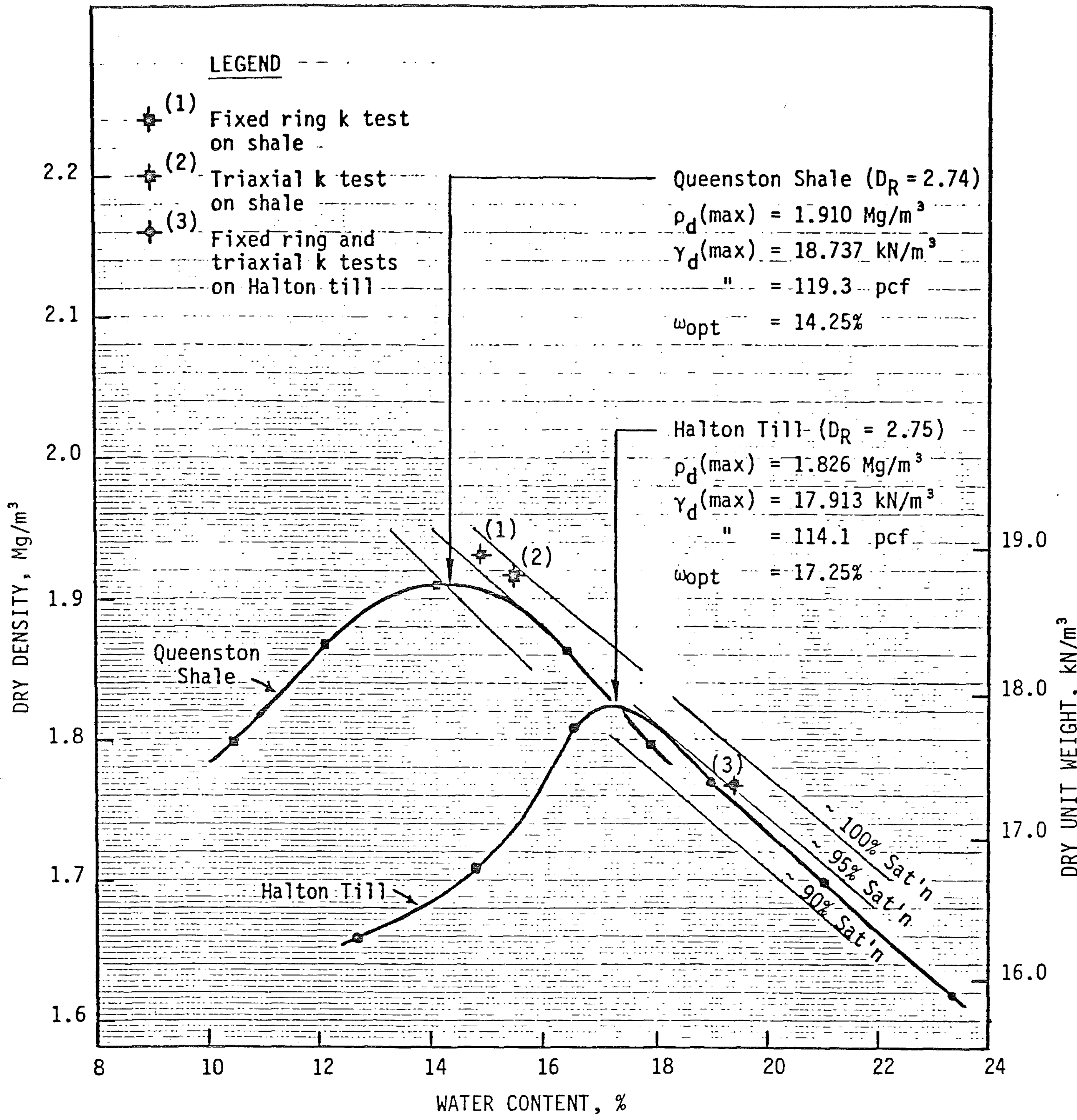

FIGURE 1. HARVARD MINIATURE COMPACTION CURVES FOR HALTON TILL AND QUEENSTON SHALE TEST SAMPLES

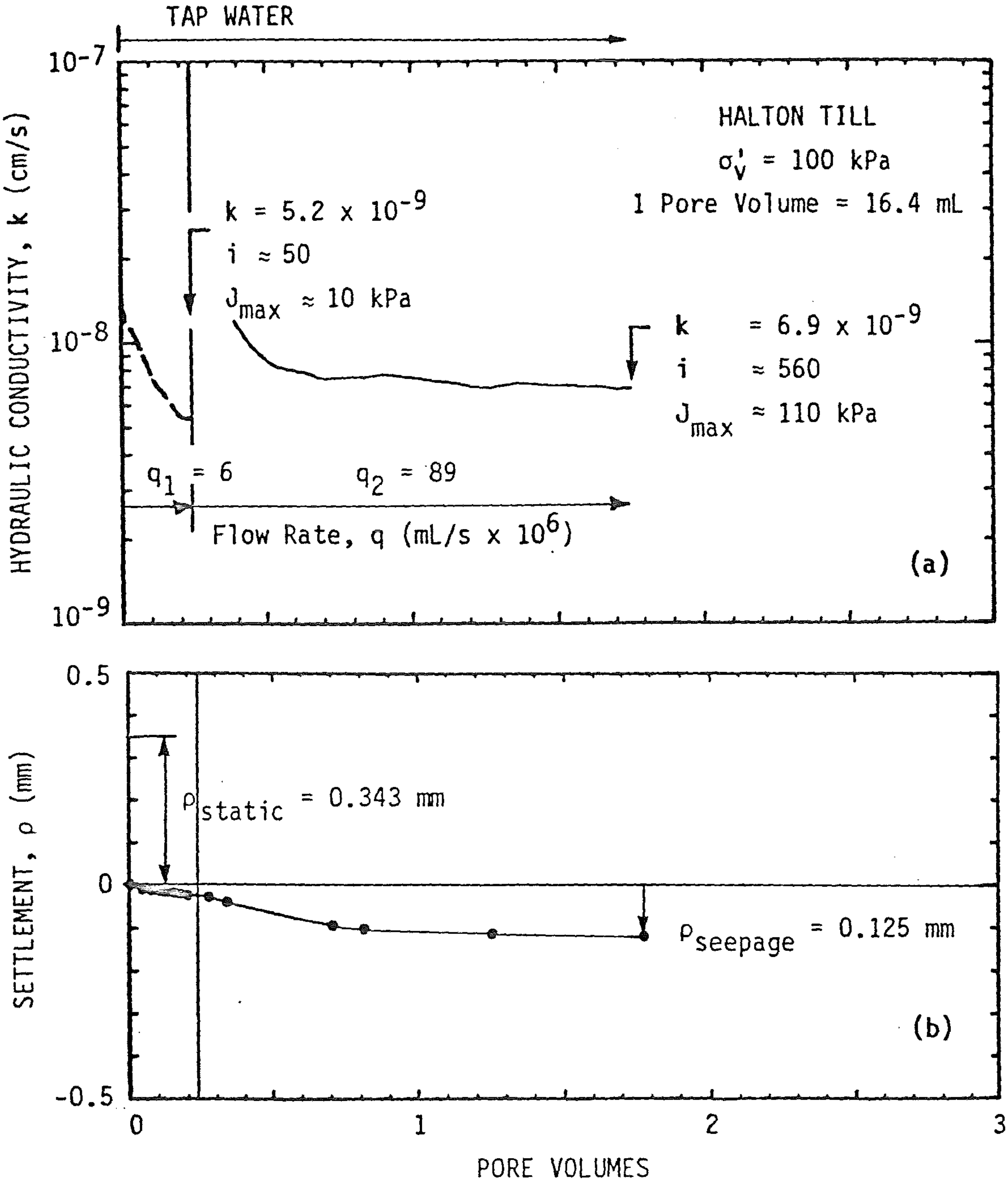

FIGURE 2. FIXED-RING, CONSTANT FLOW RATE, HYDRAULIC CONDUCTIVITY TEST RESULTS ON HALTON TILL:
(a) k VS PORE VOLUMES PASSED THROUGH;
(b) SETTLEMENT VS PORE VOLUMES DURING TESTING

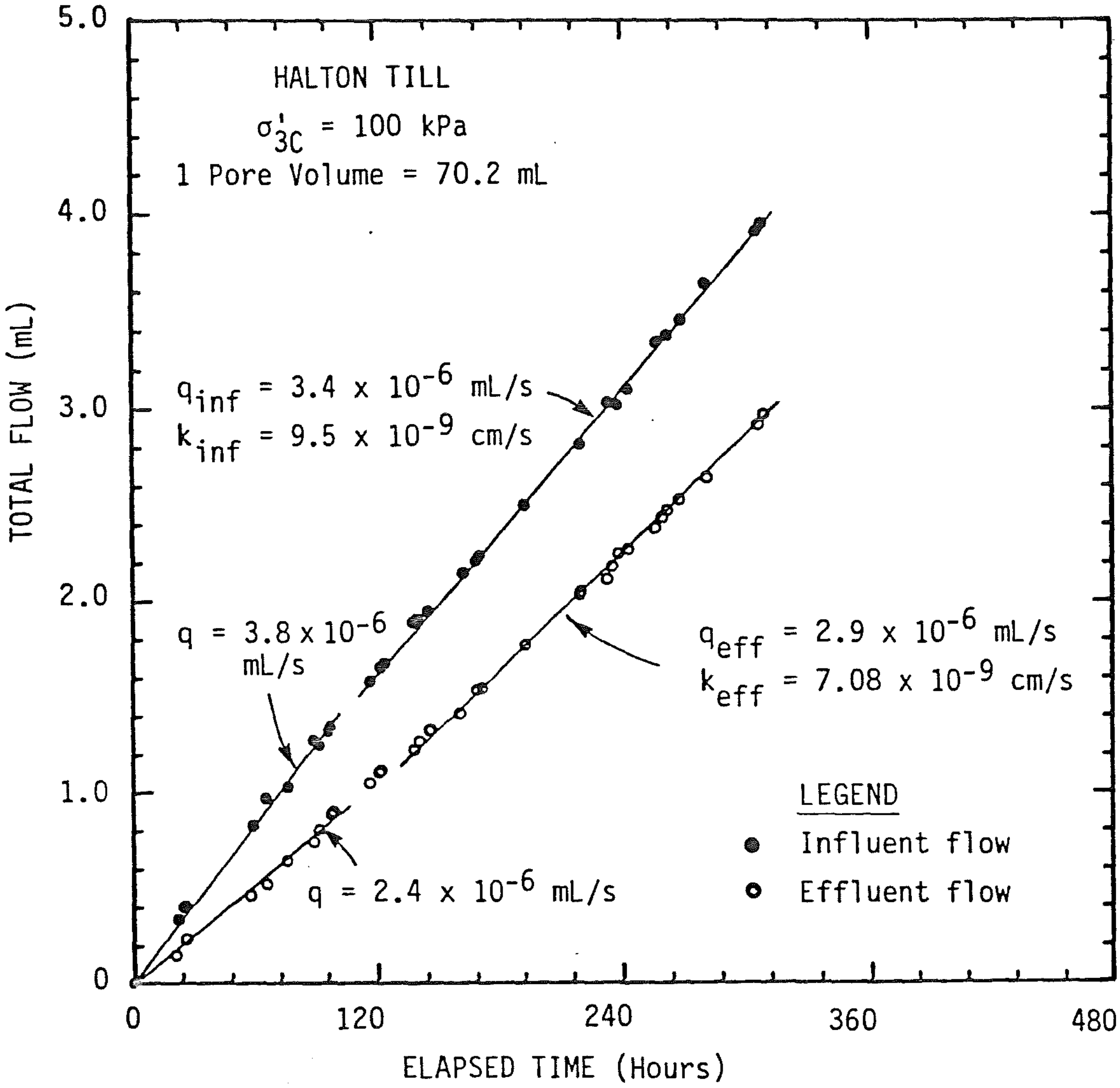

FIGURE 3. INFLUENT AND EFFLUENT FLOW VS TIME FOR COMPACTED HALTON TILL PERMEATED WITH DISTILLED WATER IN A TRIAXIAL CELL (FLEXIBLE WALL TEST, i ≈ 20)

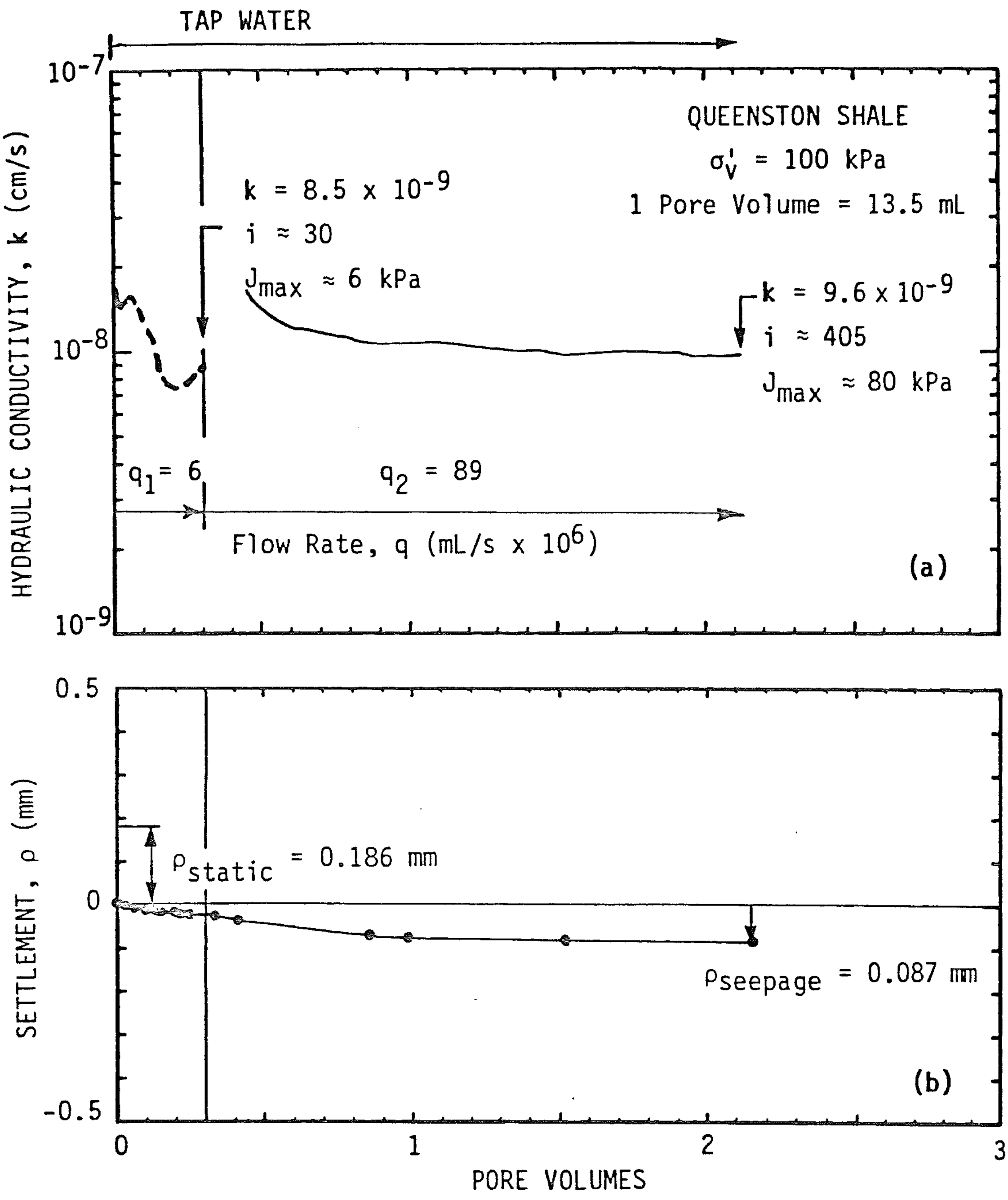

FIGURE 4. FIXED RING, CONSTANT FLOW RATE, HYDRAULIC CONDUCTIVITY TEST RESULTS ON QUEENSTON SHALE
(a) k VS PORE VOLUMES PASSED THROUGH
(b) SETTLEMENT VS PORE VOLUMES DURING TESTING

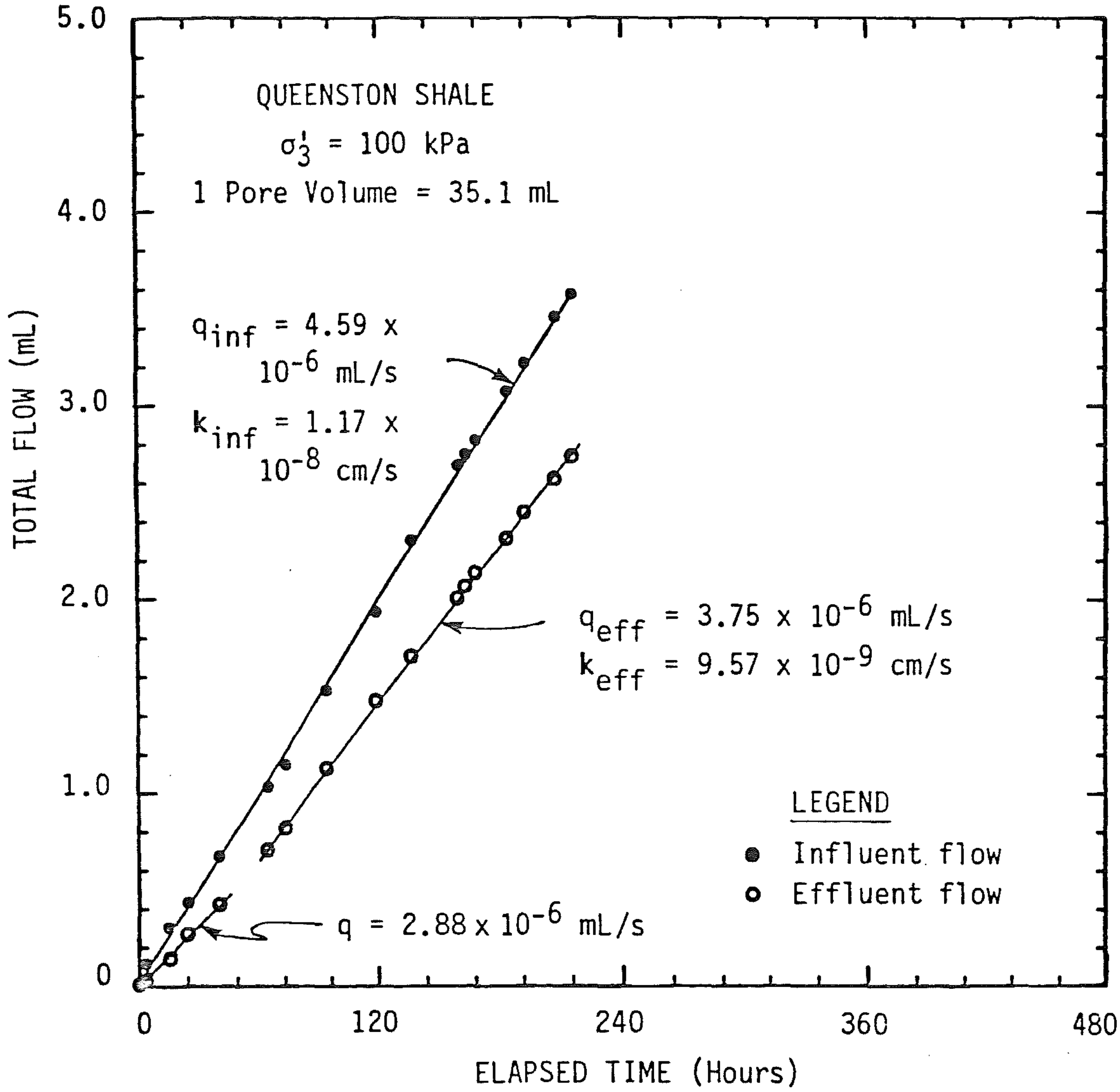

FIGURE 5. INFLUENT AND EFFLUENT FLOW VS TIME FOR COMPACTED QUEENSTON SHALE PERMEATED WITH DISTILLED WATER IN A TRIAXIAL CELL (FLEXIBLE WALL TEST, i ≈ 20)

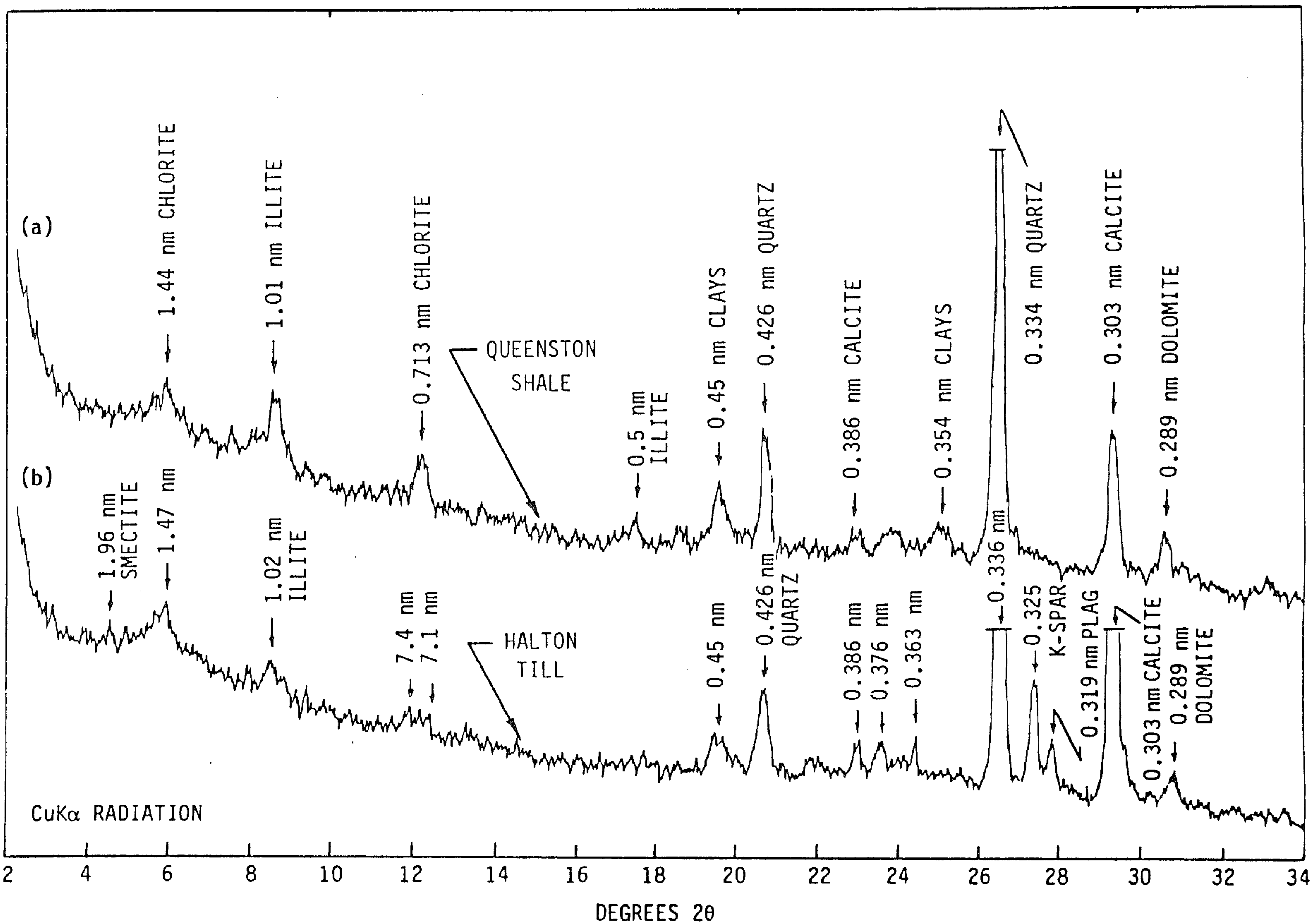

FIGURE 6. X-RAY POWDER PATTERNS OF PULVERIZED WHOLE SOIL SAMPLES OF HALTON TILL AND QUEENSTON SHALE TEST SAMPLES

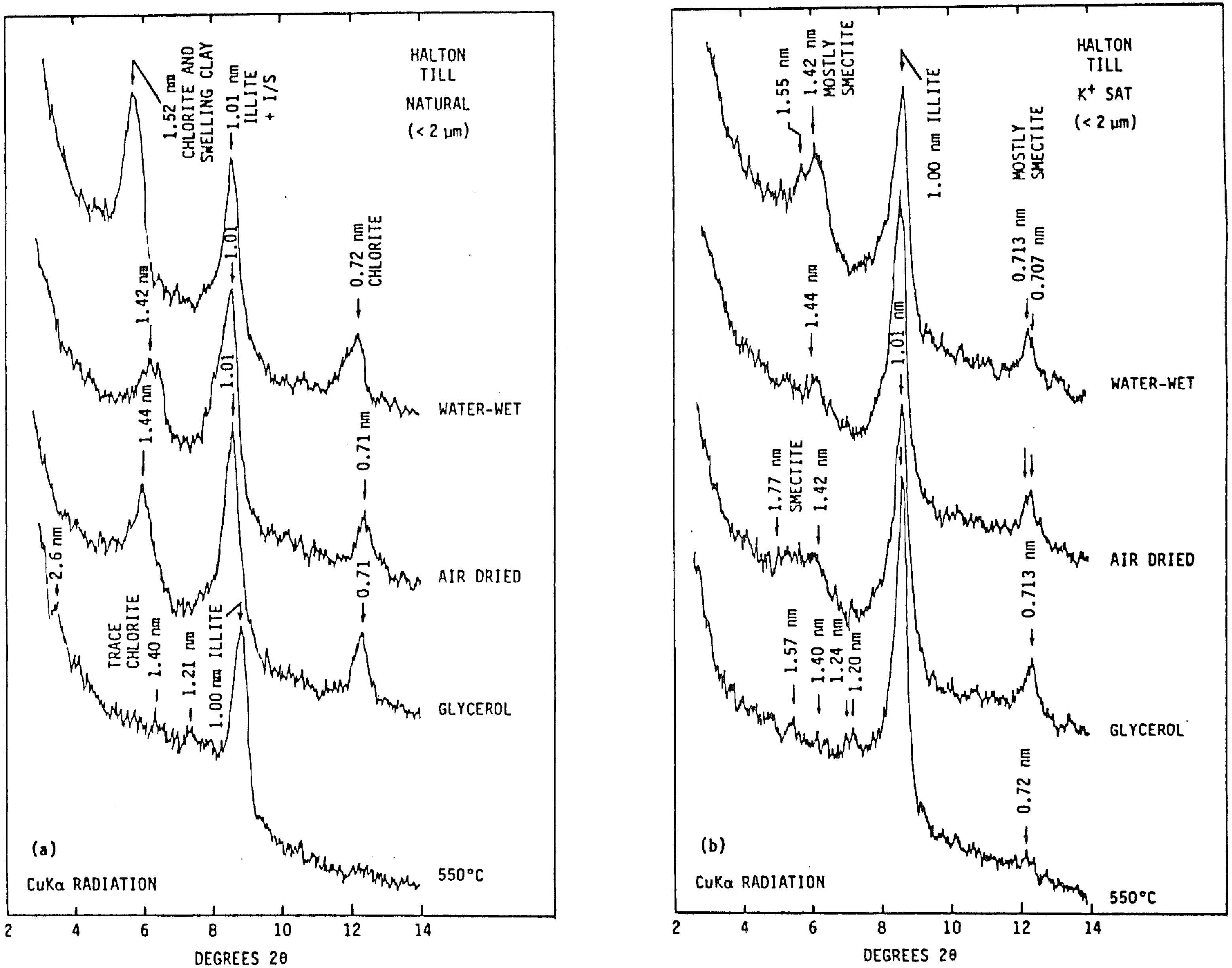

FIGURE 7. X-RAY TRACES OF ORIENTED, < 2 μm FINES OF HALTON TILL: (a) UNTREATED EXCEPT FOR VERY DILUTE NaOH IN DISTILLED WATER FRACTIONATION; (b) K^+ SATURATED

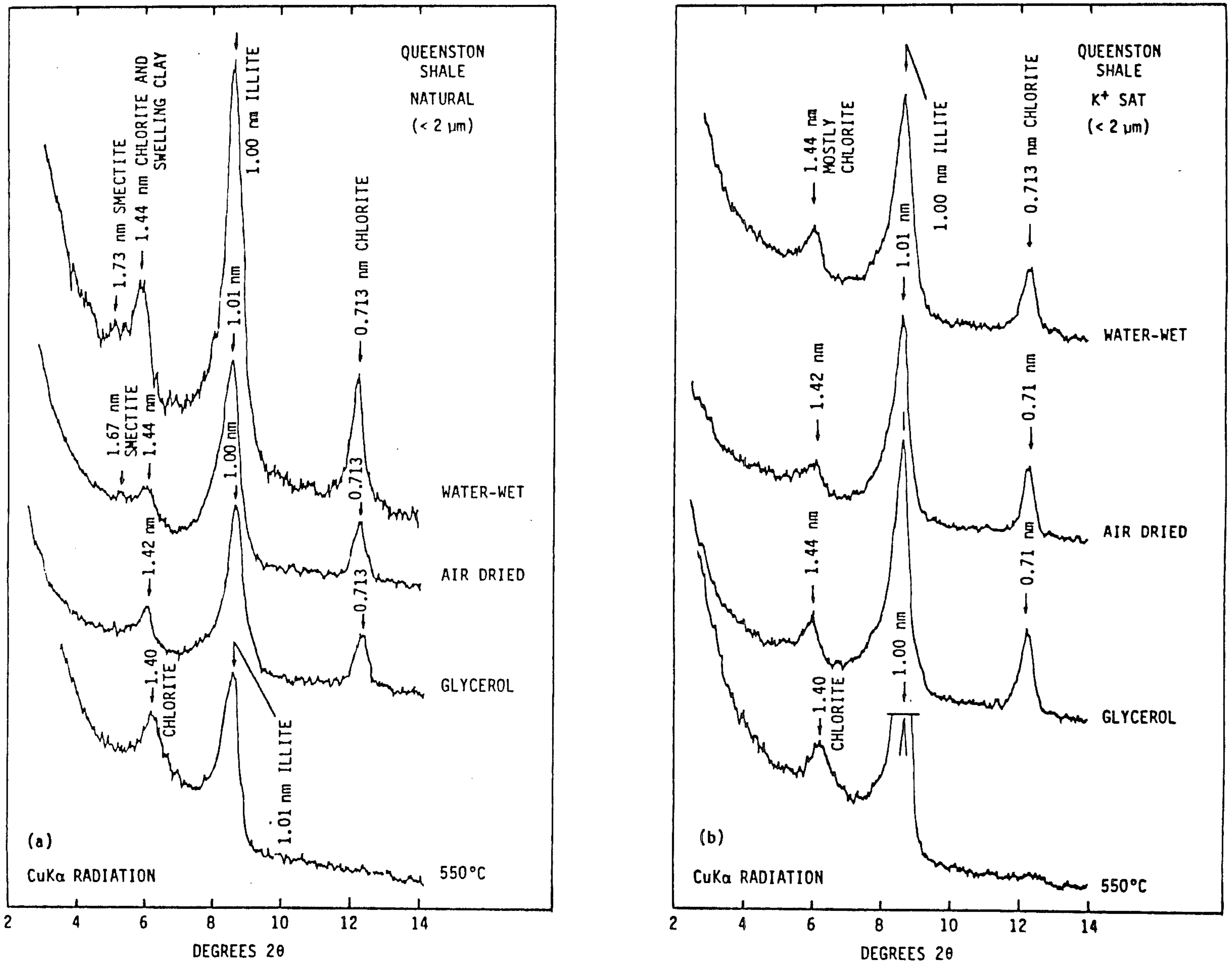

FIGURE 8. X-RAY TRACES OF ORIENTED, < 2 μm FINES OF QUEENSTON SHALE: (a) UNTREATED EXCEPT FOR VERY DILUTE NaOH IN DISTILLED WATER FRACTIONATION; (b) K^+ SATURATED

APPENDIX 1

TESTING PROTOCOLS

1. Harvard Miniature Compaction
2. Fixed Ring Hydraulic Conductivity
3. Triaxial Hydraulic Conductivity

1. Harvard Miniature Compaction Test

This test involves compaction of samples into a small, 62.35 cm^3 mold using a spring-loaded 12.5 mm diameter rod pushed many times into the soil to simulate kneading compaction. The procedures used are those outlined in Procedures for Testing Soils, ASTM Committee D-18, April 1958; "Suggested method of test for moisture-density relations of soils using Harvard compaction apparatus", S.D. Wilson, pp. 133-135.

Briefly, each test specimen is allowed to equilibrate with water at least overnight, then compacted in five layers in a 71.38 mm high mold. For the tests employed in this series, 20 prods per layer were applied using a 0.142 kN spring.

Experience in our laboratory has shown that for the clayey soils of southern Ontario, the above procedures produce compaction densities and optimum water contents very close to those obtained by Proctor compaction (Quigley, R.M., 1978. Compaction-strength-stabilization properties of weathered surface clays of southwestern Ontario, Ontario Ministry of Transportation and Communication Research Report #RR 215, 36 p.).

2. Fixed Ring Hydraulic Conductivity

2.1 Soil Compaction

The soil was compacted in stainless steel, fixed ring permeameters having a 5.4 cm inside diameter. A 12.5 mm diameter Harvard Miniature rod mounted with a 0.142 kN (32 lb) spring was used to compact the soils in three layers using 30 prods/layer. The upper surface was then trimmed producing a sample 2 cm in thickness.

Although the compaction energy/mass of soil is similar to that employed in the Harvard miniature compaction test, the presence of only three layers means that more energy is transferred to the lower layers during compaction and occasionally greater densities may be obtained as more air is apparently expulsed from the samples during compaction. This may have been the case for hydraulic conductivity test specimen #1 for the

Queenston shale (Figure 1) which appears to be ~ 97% saturated when plotted with the compaction data and had a calculated value of ~ 98% (Table 3). Alternatively, a sample of slightly different composition may have been taken from the bulk sample. The more "plastic" Halton till was not influenced by the number of layers (Point #3, Figure 1).

In comparing results from one test to another, especially for the shale, it should be remembered that the shale arrived in variably weathered broken chunks so small variations in specific gravity and compaction behaviour would be expected due to difficulties with sample mixing and sampling.

2.2 Soil Permeation

Once trimmed, a vertical consolidation pressure, σ'_v, of 100 kPa was applied to the top of the sample by means of a spring-loaded cell cap. Volume changes were measured by a dial gauge mounted on the permeability cell.

Following overnight consolidation, the permeameter cells were filled with tap water and connected to the piston system forcing the permeant through the samples at the selected constant flow rate, q. The induced head drop across the sample, Δh_t, was monitored by a pressure transducer and values of hydraulic conductivity, **k**, were calculated according to Darcy's law:

$$\mathbf{k} = \frac{q \times Th}{\Delta h_t \times A} = \frac{q}{iA}$$

where Th and A are the sample thickness and cross-sectional area, respectively. The test specimens are weighed after testing to determine an approximate value of percent saturation.

3. Triaxial Hydraulic Conductivity

3.1 Soil Compaction

The test soil was compacted in a 5 cm inside diameter, brass cylinder in layers of ~ 1 cm thickness using 30 prods per layer, which provides a compaction energy per mass of soil similar to the Harvard miniature compaction tests presented on Figure 1. The soil sample was then extruded, trimmed to the desired thickness and placed in a standard triaxial cell. The lateral surface of the specimen was sealed by two latex membranes separated by a layer of high vacuum grease. The triaxial cell was then assembled and filled with distilled water. A pressure of 50 kPa was applied to both the cell and back pressure lines and the pore pressure response checked until the pore pressure parameter B was greater than 0.96. The cell pressure, σ_3, was then raised to its final value of 150 kPa producing an isotropic consolidation pressure, σ_3', of 100 kPa. Both ends of the sample were allowed to drain. All pressure lines were connected to a mercury/water constant pressure system.

The compacted Halton till was tested using a specimen height of ~ 10 cm. The compacted Queenston shale was tested using a specimen ~ 6 cm high to expedite consolidation which took 4 days for the till and 2 days for the shale. The Halton till had the same initial density as for the fixed wall test with a data point close to the Harvard compaction curve (Point #3, Figure 1). The compacted shale also had a density close to that for the fixed wall test (Point #2 compared to Point #1), but again plotted above the compaction curve suggesting close to 98% saturation which calculations showed to be the case (~ 99%, Table 3).

3.2 Soil Permeation

Following consolidation, the pore pressure acting on the top of the sample was raised to produce a constant downward hydraulic gradient, i, of 20. Influent and effluent flows were monitored using volume change devices until reasonably constant flow rates, q, were established. The hydraulic conductivity was then calculated using

$$k = \frac{q}{iA}$$

where A is the cross-sectional area of the sample.

In this type of test the sample is not rigidly confined so that creep and stress release effects may cause changes in the length and cross-sectional area of some test specimens. It may thus take a very long time for the influent and effluent flows to equalize. Practical considerations such as the necessary level of accuracy balanced against cost determine when the test is terminated.