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CONTAMINANT MIGRATION THROUGH CLAY BELOW A DOMESTIC WASTE LANDFILL SITE, SARNIA, ONTARIO, CANADA

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ABSTRACT

The results of field and laboratory investigations of a domestic waste landfill overlying a 30 m deep natural clay deposit are presented.

Migration profiles of soluble constituents from the leachate, through the underlying clays, are presented for 1983 when the landfill was about 15 years old. Migration from the landfill is believed to have occurred for approximately 15 years, since the refuse attained saturation shortly after placement due to the construction practices employed.

Porewater concentration versus depth plots show that sodium, calcium, magnesium and chloride have migrated 0.7 to 1.0 m from the interface compared to an estimated advective advance of only 3.5 cm. Calculated values of the sodium adsorption ratio decrease from ~ 40 at the interface to ~ 12 about 0.5 m below the interface suggesting that up to 40% of the clay-exchange sites should be occupied by Na^+ near the interface, however, subsequent exchange experiments indicate that Na^+ is only adsorbed in minor quantities.

A preliminary study of heavy metal migration from the landfill suggests that migration has only occurred over a distance of 20 cm from the interface.

Preliminary measurements of dissolved organic carbon in the porewater indicate migration of organic substances to a depth of approximately 0.9 m.

INTRODUCTION

The design of a landfill facility situated in a hydro-geologically unsuitable area requires installation of a relatively impermeable liner, such as clay, to provide a final barrier between the landfill and any underlying pervious strata. Design of such a clay liner should be based on field measurements of pollutant migration through clay, in addition to numerical predictions and laboratory studies. Since investigation of an in situ clay liner could seriously disturb its integrity and promote contamination, landfills situated on thick natural clay deposits are more suitable for study. This paper presents additional results of continuing studies under way at such a landfill site near Sarnia, Ontario.

GEOLOGY AND SOIL MINERALOGY

The 30 m thick, homogeneous silty clay at Sarnia, Ontario is believed to be a waterlain till of late Wisconsin age composed mostly of rock flour obtained by glacial erosion of Silurian and Devonian carbonates and shales from the Lake Huron basin. A slight downward flow gradient exists in the area, and at the landfill site under study, piezometric observations indicate a small groundwater mound in the refuse and a steady downward flow velocity of approximately 0.24 cm/a in the till. In situ measurements of till hydraulic conductivity yielded values of about 1.5×10^{-8} cm/s at an in situ water content of 20-25%. Extensive studies of the geology and mineralogy of the site are summarized by Quigley and Ogunbadejo (1976) and Quigley and Crooks (1983). The hydrogeology was described by Goodall and Quigley (1977).

The soil in the 3 m zone directly below the waste is a carbonate-rich clayey silt containing 40% of < 2 μm sizes. The composition is approximately as follows: ~ 34% carbonate, ~ 25% illite, ~ 24% chlorite, ~ 15% quartz and feldspar, ~ 2% smectite. The effective cation exchange capacity is about 30 meq/100 g measured on the < 74 μm fraction.

PREVIOUS STUDIES

Two previous papers (Goodall and Quigley, 1977 and Crooks and Quigley, 1984) presented studies dealing with the migration of water soluble cations from the leachate through the underlying clays when the site was 6 and 12 years old. Both studies attributed the migration of Na, K, Ca and Mg to chemical diffusion. In the Crooks and Quigley study, profiles for Na^+ and $C\ell^-$ suggested migration by diffusion to depths of 1 to 1.5 m below the interface. Since man-made liners for domestic waste landfills are rarely greater than 1.2 m thick, the above field data indicate that a chemical flux of Na^+ and $C\ell^-$ will exit from most liners within 10 to 15 years of placement.

This paper presents concentration versus depth profiles for porewater and exchangeable cations (Na^+, K^+, Ca^{2+}, Mg^{2+}) and porewater chloride now that the site is 15 years old. Preliminary profiles for heavy metal (Cu, Zn, Fe, Pb) migration and organic carbon dissolved in the porewater are also given.

CATION (Na^+, K^+, Mg^{2+}, Ca^{2+}) MIGRATION

Porewater and exchangeable cations were determined for two boreholes (designated BH83-2 and BH83-9) and the results are presented in Figs. 1 and 2. Sample preservation techniques and laboratory testing procedures are described in Crooks and Quigley (1984). Exchangeable cations on < 74 μm untreated soil were determined using the silver thiourea exchange method of Chabbra (1975).

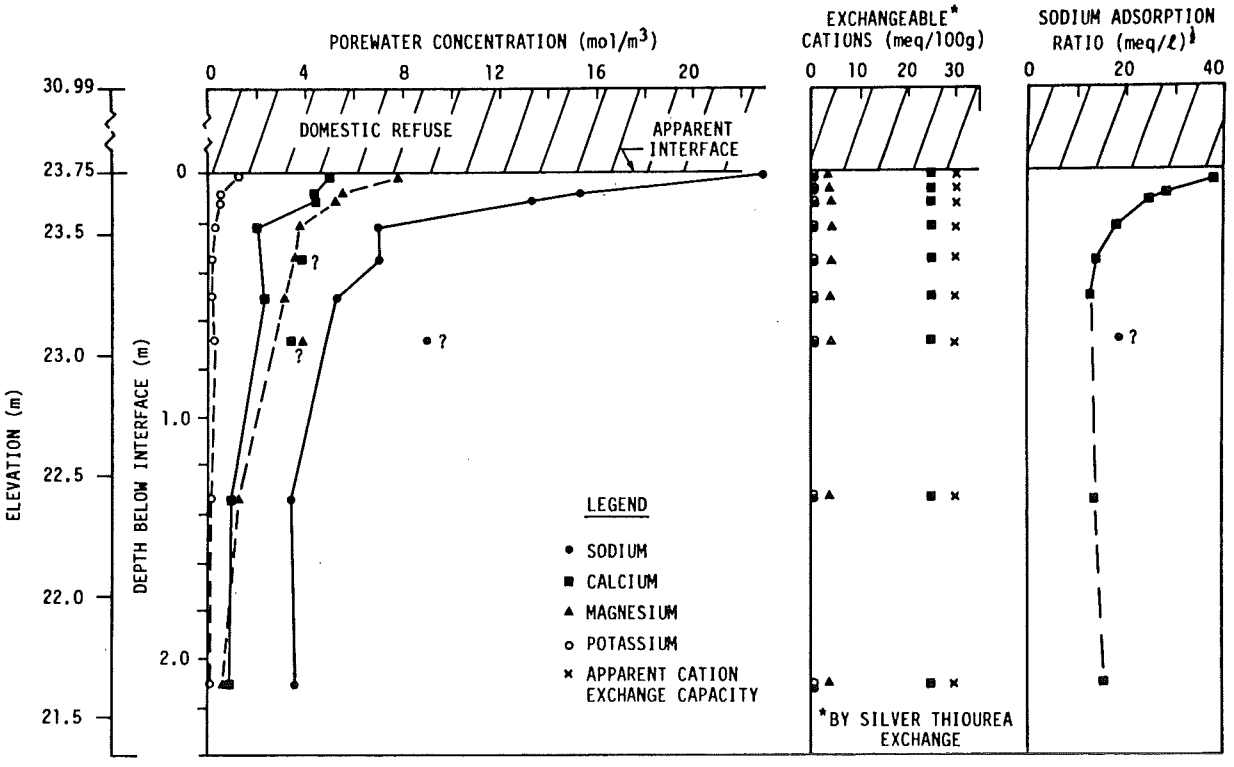

FIG. 1. POREWATER CATION CONCENTRATION, EXCHANGEABLE CATIONS AND SODIUM ADSORPTION RATIO (S.A.R.), BH83-2

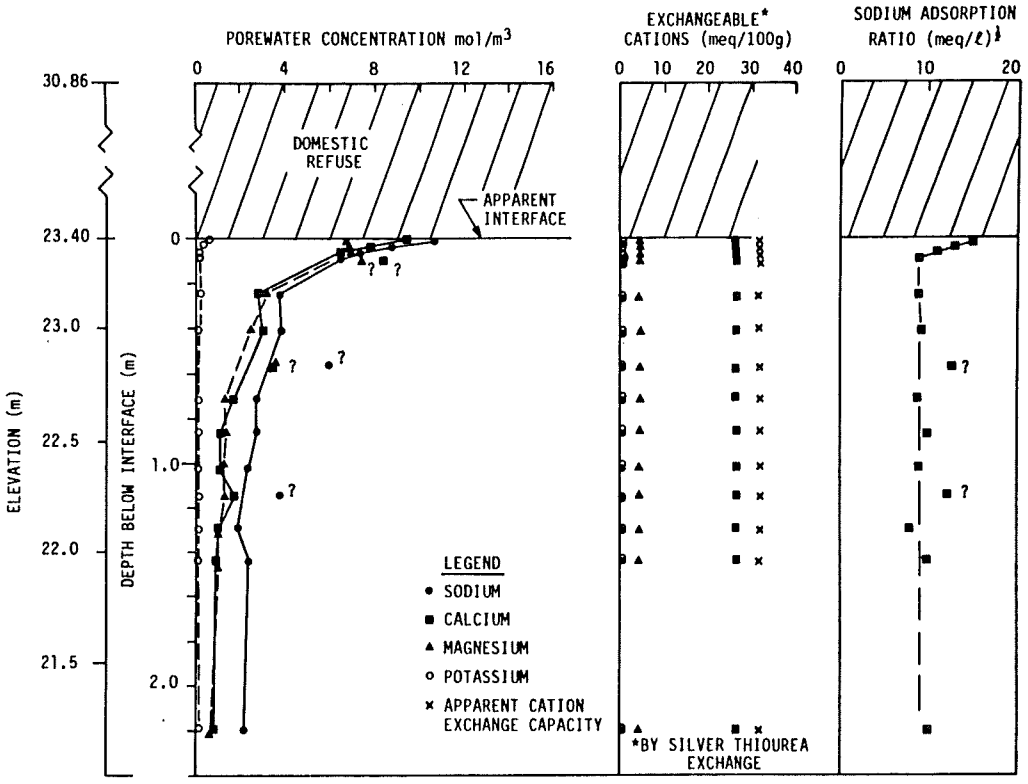

FIG. 2. POREWATER CATION CONCENTRATION, EXCHANGEABLE CATIONS AND SODIUM ADSORPTION RATIO (S.A.R.), BH83-9

The results for t = 15 years indicate that cation migration has occurred to depths of 0.7 to 1.0 m at these particular locations in the landfill. Previous results by Crooks and Quigley (1984) for boreholes located some distance away suggested that migration had occurred to a depth of approximately 1.5 m below the refuse/soil interface. It is believed that spatial variability in the refuse composition produces somewhat different migration profiles throughout the site. This phenomenon is illustrated by the migration profiles presented here for two boreholes located 7 m apart. Although the maximum depth of migration in both boreholes is similar, the maximum cation values at the refuse/soil interface are significantly different, e.g. Na^+ concentration of 23 mol/m^3 in BH83-2 compared to 10.6 mol/m^3 in BH83-9, both values at the interface. In both boreholes the dominant porewater cation is sodium.

Calculated sodium adsorption ratios (S.A.R.) versus depth often reflect the adsorbed cation distribution in the soil clay mineral fraction. Calculated S.A.R. values decrease from 40 at the interface to 12 at a depth of 0.5 m in BH83-2 (Fig. 1), suggesting that in this 0.5 m interval up to 40% of the clay exchange sites should be occupied by Na^+. Subsequent work using silver thiourea exchange indicated that calcium is the dominant adsorbed ion and that only minor amounts of Na^+ are adsorbed on the clay minerals. This situation may arise if the Na^+ concentration of the original leachate is not high enough to promote Na^+ for Ca^{2+} exchange, or if the clay exchange sites are preferentially occupied by other species such as heavy metal cations.

A similar but less significant decrease in S.A.R. for BH83-9 is shown in Fig. 2.

CHLORIDE MIGRATION

A porewater chloride migration profile was obtained for BH83-2, and is shown in Fig. 3. Chloride migration has apparently occurred to a depth of ~ 1 m.

A limited amount of analytical work was performed using this profile to obtain "best-fit" values of effective diffusion coefficient, D. The analytical solution used is that given by Ogata (1970) for the case of one-dimensional diffusion (without advection) from a constant source, and is applicable in our situation due to the negligible advection component (V_s = 0.24 cm/a) of transport from the landfill. The choice of the value for the interface concentration is somewhat difficult. Measured Cl^- leachate values of 86 mol/m^3 were obtained by Crooks and Quigley (1984), however the use of this value was shown to significantly overpredict the measured curve, although the maximum depth of migration could be modelled. Field observations of the zone of intermixed refuse and soil found above the undisturbed soil stratum suggest that the 'effective' interface for leachate migration may be as much as 30 cm above the location of undisturbed soil. Two profiles (A and B on Fig. 3) using different values of effective diffusion coefficient, D = 1 x 10^{-6} cm^2/s and D = 2 x 10^{-6} cm^2/s, were calculated from the analytical solution with C_o = 86 mol/m^3 and an 'effective' interface position located 25 cm above the apparent interface.

The use of D = 2 x 10^{-6} cm^2/s predicts the maximum depth of migration, although some overestimation of the upper part of the curve is obtained.

It has also been suggested that the appropriate value of initial concentration for use in the analytical solution is actually the maximum measured value in the profile, and that the 'effective' interface may be taken as the apparent interface. A third profile (C) calculated using this assumption, with a value of D = 1 x 10^{-6} cm^2/s, is also presented on Fig. 3. This profile exactly reproduces the upper 0.2 m of the measured profile, and predicts the maximum depth of migration, however this does not constitute a valid approach when reliable leachate concentration values are available. The "best-fit" value of D = 2 x 10^{-6} cm^2/s is comparable to the value of 3 to 6 x 10^{-6} cm^2/s given by Crooks and Quigley (1984) and to a value of 3 x 10^{-6} cm^2/s given by Desaulniers et al (1981).

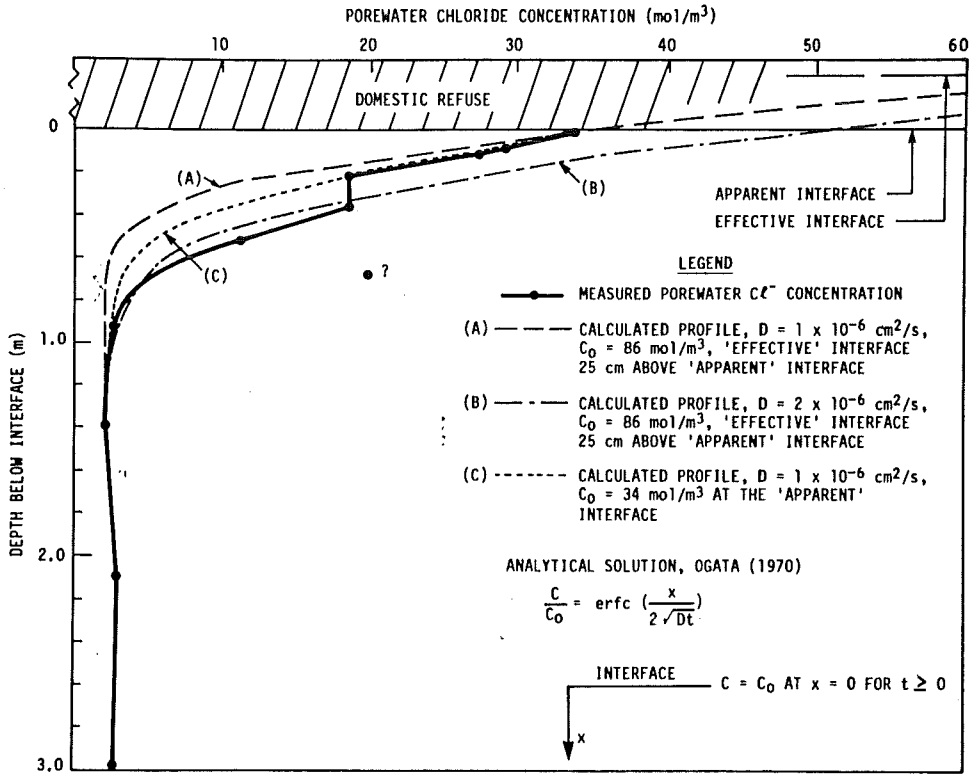

FIG. 3. MEASURED POREWATER CHLORIDE CONCENTRATION AND CALCULATED PROFILES, BH83-2

HEAVY METAL MIGRATION

Concentration profiles for Cu, Zn, Fe and Pb are presented in Fig. 4. These concentrations represent total acid extractible heavy metals both adsorbed and within the crystal structure of the clay minerals and other soil constituents. If the straight line portions of these profiles are considered to represent background or original in situ values, then the four metals have all migrated to a maximum depth of about 20 cm below the apparent interface.

The cumulative Cu, Zn and Pb concentrations are calculated to be 0.5 meq/100 g above their background values and these species could be adsorbed on the clay minerals without affecting the cation exchange measurements shown on Figs. 1 and 2. The amount of Fe in excess of background amounts to 34 meq/100 g which corresponds to the apparent exchange capacity of the soil. Obviously, this element is not adsorbed in these amounts and is possibly present as authigenic iron carbonate. Selective dissolution analyses are in progress to determine the mode of occurrence of the heavy metals.

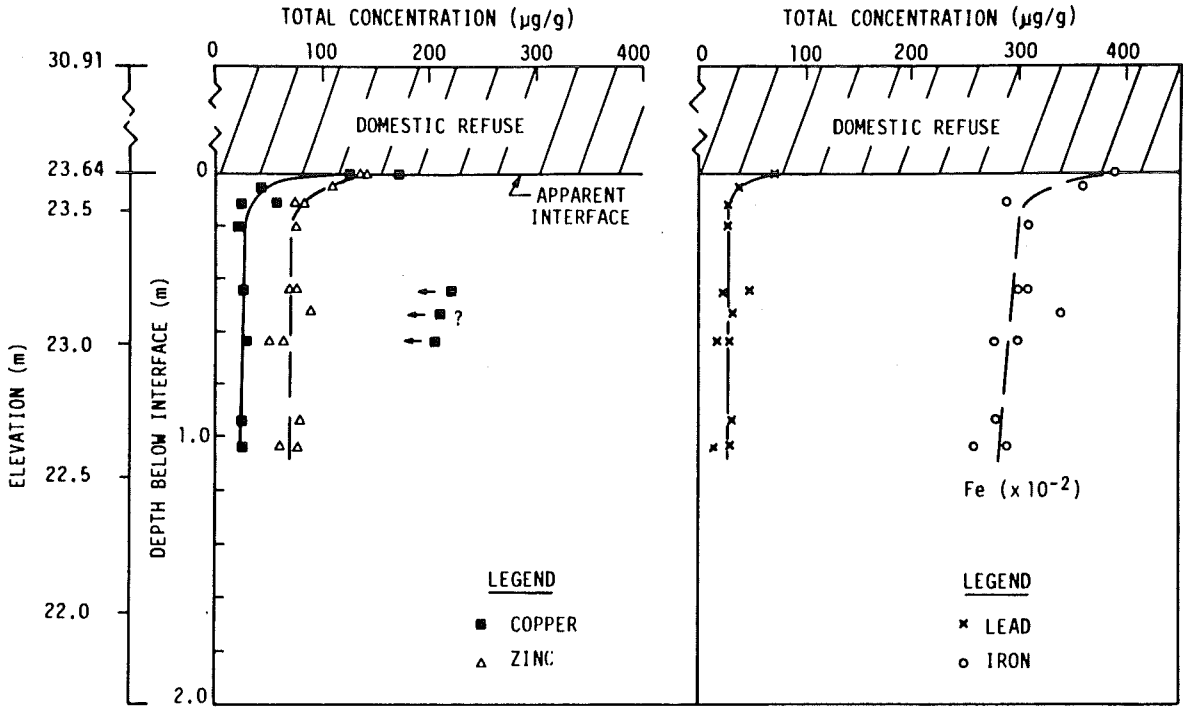

FIG. 4. TOTAL CONCENTRATION OF HEAVY METALS (COMBINED ANALYSIS U.W.O. AND X-RAY ASSAY LABORATORIES LTD.), BH83-7

DISSOLVED ORGANIC CARBON

A preliminary investigation of the migration of organic substances from the landfill was performed by measuring dissolved organic carbon (DOC) concentrations in the soil porewater. The borehole used for this study

contained significant quantities of petroleum product in the interface region and overlying refuse, which would tend to produce measurable migration of organic carbon in the soil porewater. The DOC profile is shown in Fig. 5 and indicates that migration has occurred to a depth of approximately 0.9 m. The measured concentrations reach a maximum value (41 mol/m^3) at a depth of 0.1 m from the apparent interface. This zone of lower DOC concentrations may result from bacterial activity in the soil or may simply indicate that the effective interface is 0.1 m below the one chosen. Similar results for DOC migration from the landfill were obtained by Crooks (1981) when the landfill was 12 years old.

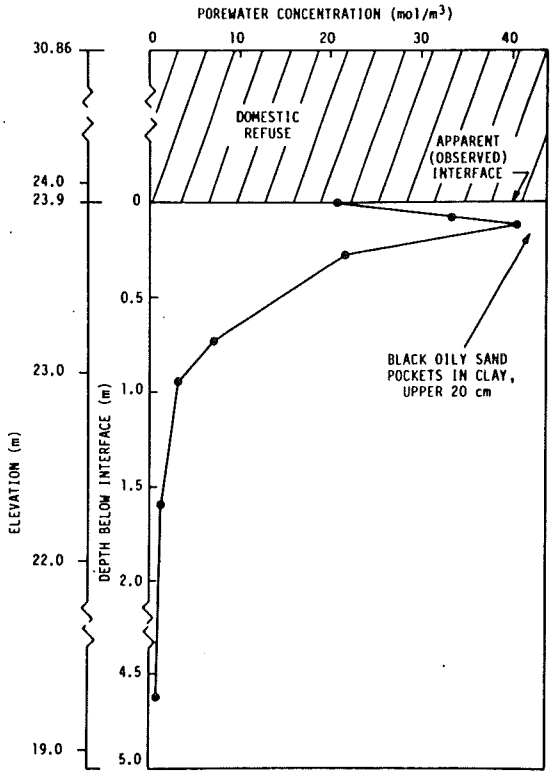

FIG. 5. POREWATER DISSOLVED ORGANIC CARBON, BH83-14 AND BH83-3

SUMMARY

Results of continuing studies at a 15 year old landfill situated on clay have been presented and indicate that migration has reached a depth of approximately 1 m. Cation (Na^+, K^+, Mg^{2+}, Ca^{2+}) migration has reached a depth of 0.7 to 1 m, as has $C\ell^-$ migration (depth ~ 1 m). Heavy metal (Cu, Zn, Fe, Pb) migration has occurred to a depth of about 20 cm below the interface. Dissolved organic carbon (representative of organic species) has migrated about 0.9 m. A limited amount of analytical work suggests the measured $C\ell^-$ profile may be predicted using an effective diffusion coefficient $D = 2 \times 10^{-6}$ cm^2/s in an expression for one-dimensional diffusion.

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