FROM RAY BLACKPORT
WED. OCT. 6/82

OCCURRENCE AND DISTRIBUTION OF HAZARDOUS ORGANIC CHEMICALS IN THE LEACHATE PLUMES OF SANITARY LANDFILLS IN THE PROVINCE OF ONTARIO, CANADA

by

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ABSTRACT

Ground water samples of leachate plumes of sanitary landfills were characterized for potentially hazardous organic chemicals. The three sanitary landfills investigated are located near the towns of Borden, Woolwich, and North Bay, respectively, in the province of Ontario, Canada. Concentration profiles were established vertically and horizontally, using multilevel sampling devices. Chlorinated solvents, aromatic hydrocarbons, phenols, aromatic and aliphatic carboxylic acids, miscellaneous industrial compounds including nitrogen-containing compounds and plasticizers, and biogenic compounds such as terpenes were detected. Concentrations were generally in the µg/ℓ range, for the main compounds in the 100 µg/ℓ range or above.

At two of the sites (Woolwich and North Bay) many trace compounds seemed to be present throughout the plume suggesting mobility and stability of these compounds under the prevailing anoxic conditions. The adsorption capacity of the sandy aquifers was too low for effectively retaining many of the trace

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chemicals. Evidence for mobility and stability was found for 1,2- and 1,4-dichlorobenzene, tri- and tetrachloroethylene, 1,1,1-trichloroethane, several aromatic hydrocarbons including benzene, toluene, ethylbenzene, naphthalene, and others. For other aromatic hydrocarbons the data suggested selective removal. Included here are xylenes and 1,2,4-trimethylbenzene. Several nitrogen-containing chemicals presumably derived from wastes of a tire manufacturer were found 80 m away from the landfill.

High concentrations of 1,1,1-trichloroethane and trichloroethylene in lower levels of the aquifer at Woolwich suggested two-phase transport of the liquids to the bottom of the aquifer. Type and amount of ground water contamination varied between the sites depending on the wastes buried and on management of the site.

At the Borden site where wastes were periodically incinerated and construction debris constituted most of the waste, contamination was low. However, it is believed that conditions at the Woolwich and North Bay sites are quite typical for the many sanitary landfills in operation.

INTRODUCTION

Landfilling has long been the major disposal method for domestic and industrial wastes. Unfortunately, many of the thousands of landfills, active or abandoned, have been operated with little regard for the dangers of ground water contamination. In recent years, the number of sites where leachate from sanitary landfills is known to contaminate the underlying aquifer has been increasing, but only a few cases have been studied in detail with regard to geochemical processes (Baedecker and Back, 1979a, b; Cherry, 1982). However, only a few studies have addressed the occurrence of potentially hazardous organic chemicals in leachates of sanitary landfills (Dunlap et al., 1976).

To assess the impact on the water quality at a given site, several questions must be answered: (1) what are the potentially harmful constituents in the leachate? (2) what are the local hydrogeologic conditions? and (3) what is the significance of attenuating factors such as biological and/or chemical degradation, adsorption, ion exchange, precipitation, and hydrodynamic dispersion? For any given real situation, all these questions are extremely difficult to answer and the design of mitigating measures, such as leachate barriers and contaminant removal, must rely largely on the trial and error approach.

Since the 1970s, the hydrogeology group at the University of Waterloo has been engaged in research activities designed to provide an improved understanding of the behavior of landfill-derived contaminants. Several sites have been instrumented and the shapes of the leachate plumes have been delineated. Furthermore, the distributions of a broad range of water quality characteristics have been determined and processes affecting dispersion, geochemical and biogeochemical contaminant attenuation are being studied.

The study summarized here has been conducted as a joint effort between the Water Quality Control Research Laboratory at Stanford University and the Earth Science Department at the University of Waterloo. Its prime objective was to characterize the leachate plume with respect to trace organics at three different landfills. The three sites, Borden, North Bay, and Woolwich, are located in Ontario, Canada. They have been under investigation for their hydrogeological conditions and the major characteristics of the leachate plume have been established. A further objective was to attempt to determine the distribution of trace organic concentrations within the plume. Here we report on the first preliminary results of this study, which, it should be emphasized, are primarily qualitative in nature.

SUMMARY OF SITE DESCRIPTIONS

In the following the main features of the three sites are summarizerd to the extent needed to evaluate the trace organics data. More details have been reported by Cherry (1982) and in reports cited there.

Borden

The Borden site is an abandoned sanitary landfill situated on an unconfined aquifer of glacio-fluvial sand. It is located within the confines of the Air Force Base, approximately 80 km NW of Toronto. Leachate composition, migration, and distribution are known in exceptional detail. The site, which was operated from 1940-1973 received mainly wood and construction debris. It has been estimated that about 80% of the deposited refuse consists of this category. The remainder is supposed to consist of domestic and commercial wastes. Although refuse was periodically burned, generally on-site management was insignificant. The aquifer appears to be heterogeneous, containing too many lenses to be adequately delineated. The porosity of the aquifer material was 0.38 and the hydraulic conductivity was estimated to be in the range of 1×10^{-3}-5×10^{-3} cm/s. The velocity of the groundwater was estimated to be on the order of 1 m per day.

The contour of the plume as determined from chloride data is depicted in Figure 1. Also shown is the area where wastes are buried and the locations of the observation wells. Wells P3-25 and the injection site were analyzed to obtain background values for the ground water of the area.

Woolwich

The Woolwich landfill is located in the northwestern part of the Regional Municipality of Waterloo, Ontario. It is situated on a deposit of glacio-fluvial sand which is generally about 30 m thick and rests on a deposit of relatively impervious clayey till. The landfill occupies approximately 3.5

hectares, of which 75% have been filled since operation began in the mid-1960s. The site has received rural and municipal, as well as some industrial wastes from a nearby tire manufacturer. The landfill is covered with sand only. Rain and snow melts infiltrate the deposited refuse and after migrating through the unsaturated zone disperse with the underlying ground water 10 to 15 m below. The monitoring network included 36 bundle piezometers, each having eight to nine individual piezometers at different depths between the water table and the bottom of the aquifer. The plume has been delineated using chloride and conductance. Figure 2 indicates the shape of the plume as determined from chloride data. It extended about 600 m to the south and to the southeast of the landfill. The vertical profiles available suggest that nearly the entire saturated zone of the aquifer was contaminated. A background sample was obtained from piezometer 0-D, located about 50 m east of the north end of the landfill.

North Bay

The North Bay site, operational since 1962, is located near the City of North Bay in north-central Ontario on the Precambrien Shield. The landfill lies on a deposit of bedded glacio-fluvial sand which is devoid of carbonate minerals. The aquifer is bordered by a layer of siltey-sandy glacial till on top of biotite gneiss. The aquifer is comprised of sand and occasional gravel and silt lenses that were deposited in meltwater streams during the late Pleistocene.

The site received domestic, commercial, and small quantities of industrial wastes. Dewatered sludge from the sewage treatment plant has been deposited regularly on the top of the completed segments of the landfill. The area receives an average of 80 cm of precipitation per year which penetrates through the cover and transports the leachate into the underlying groundwater

stream underneath. Figure 3 depicts the leachate plume delineated with Cl^- and the sampling locations. A background sample was obtained from a multi-level observation well located south of the leachate pond, about 50 m away from the boundary of the plume. The plume has reached its maximum extent possible and was at a steady state (local equilibrium) with respect to most major ions (except NH_4^+ and K^+). It stretched from the landfill where the leachate disperses into the ground water to the discharge area where the leachate-contaminated ground water emerges in an area of springs.

Comparison of the Three Sites

Leachate strength was highest close to or underneath the landfill and generally decreased in direction of the flow. The center of the plume tended to be lowered with increasing distance. At the Woolwich and Borden sites, concentrations were distinctly higher underneath the oldest part of the landfills. Conditions appeared to be anoxic at all three sites as indicated by the occurrence of methane and hydrogen sulfide. Concentrations of sulphate (SO_4^{2-}) and nitrate ions (NO_3^-) were low except at the Borden site where SO_4^{2-} concentrations were found to be exceptionally high (> 4 g/ℓ underneath the landfill). This was attributed to the occurrence of large amounts of gypsum and anhydrite at this landfill (Cherry, 1982).

At none of the sites did the hazardous inorganic elements (As, Cd, Cr, Pb, Se, Ag) included in the primary drinking water standards of Canada and the United States (E.P.A.) exceed the specified standards, except for barium and mercury, for which no data were available. Iron and manganese were the only transition metals, metalloids, or heavy metals found in concentrations above the specified limits of the primary or secondary drinking water standards. Formation of sulfide, hydroxide, and carbonate phases and adsorption on solids of the aquifer was presumed to be the controlling factor for the occurrence of these elements.

Dissolved organic carbon (DOC) was found to occur at elevated levels throughout the plumes and indicated that most of the materials measured as DOC were mobile. Preliminary investigations indicated that the leachate of the North Bay site contained chloro- and dichlorobenzene, alkylated benzenes, and many other potentially harmful organics.

SAMPLING AND ANALYSIS

Sampling

Samples were taken in order of increasing concentration to reduce the possibility of cross-contamination. Background samples were taken first, leachate from close to the landfill last. Prior to sampling, one to two gallons of wellwater was removed to ensure that the sample was representative of the groundwater. A peristaltic pump was used to suck water into a 2-ℓ suction flask. Teflon tubing was inserted into the piezometer tubes and was connected to the flask. The pump was connected after the flask so that the sample came in contact with only Teflon and glass. Two 1-ℓ samples were taken at each sampling location for analysis of acids, phenols, neutrals (including purgeables), and bases. In addition one or several 50-mℓ samples were taken for volatile organics analysis. The 50-mℓ vials were taken by inserting a Teflon tube into the piezometer, thereby using the tube as a bailer. The content of the tube was drained into the vials, displacing several volumes of sample before capping the vial, air-tight and free of head space.

Where the water table was too deep for sampling by suction, samples were taken by inserting a Teflon tube into the piezometer and applying pressure to it by means of a specially fabricated adapter (Cherry et al., 1982). Samples tended to develop gas bubbles as they were brought to the surface. This might have caused some loss of certain volatiles. Between sampling locations, the

equipment was rinsed with deionized water and with the water to be sampled. Samples were packed in cooled containers and shipped by air-freight to Stanford University and stored under refrigeration until analyzed, which normally occurred within a week.

Analytical Procedures

Volatile halogenated organics with one and two carbons were analyzed by pentane extraction followed by electron-capture GC analysis (Henderson et al., 1980). Purgeables were analyzed using a closed-loop stripping (CLS) procedure (Grob and Zürcher, 1976). Heavily contaminated samples were diluted by a factor of five with purified water prior to CLS analysis. Base/neutrals and acid/phenols were analyzed using a method similar to EPA method 625 (Federal Register, 1979) modified as follows: two-liter continuous extractors were used for the methylene chloride extraction (Continental Glas Blowing Corp., Richland, NY 08350). Base/neutrals (B/Ns) were extracted at pH 11, acid/phenols (A/Ps) were extracted subsequently at pH 2. The acid/phenol extracts were methylated with diazomethane for improving GC separation. A fused silica (J & W Scientific, Rancho Cordova, CA 95670) SE-52 capillary column (50 m, 0.3 mm i.d., 0.25 μm film thickness) was used for GC/MS analysis. Concentrations were estimated based on the peak height relative to the peak height of the internal standard using the most intense ions for compounds not included in the priority pollutant list (Keith and Telliard, 1979). The concentrations given were not corrected for differences in extraction efficiencies and differences in the detection sensitivities. These corrections might change the absolute concentrations given by more than an order of magnitude. Nevertheless, in the absence of such corrections, comparisons of values from different locations are possible. Chloride ions (Cl^-) were analyzed titrimetrically using the mercuric nitrate method (Standard Methods, 1976). Total

organic carbon (TOC) was measured with a Model DC-80 TOC Analyzer (Envirotech-Dohrmann, Santa Clara, CA 95050) according to the instructions of the instrument manufacturer.

RESULTS AND DISCUSSION

Borden

Table 1 summarizes the volatile organics data measured along the axis of the plume and at the injection well. Only four volatile compounds were detected: chloroform ($CHCl_3$), carbon tetrachloride (CCl_4), trichloroethylene (TCEY), and tetrachloroethylene (PER). Only CCl_4 and TCEY were present in concentrations above trace levels in more than one well. $CHCl_3$ was found above the detection limit at the injection site and at trace levels (< 0.1 µg/ℓ) in most other wells within the plume. PER was detected as a trace only at the injection site and at the organic piezometer. TCEY and CCl_4 were found in quantifiable amounts in most wells but their presence did not seem to be related to the presence of the leachate. Background values measured at P3-25 were not significantly different from the concentrations measured in samples from within the plume. The only clear exception was a high TCEY value measured at P2-33. The high TCEY value there coincided with a high Cl^- concentration (359 mg/ℓ). However, in general no clear correlation between the Cl^- and the trace organics concentrations appeared to exist. At the organic piezometer nearby, the Cl^- concentration was 261 mg/ℓ, but no TCEY was found. Comparing the TOC and the trace organics data shows that the distribution of the two is quite different. At P2-33, the well with the highest TCEY concentration, TOC was only 18.7 mg/ℓ, twice the background level of P3-25. The same general conclusions could be drawn from the vertical profiles obtained at 77-6, 77-25, and 77-40. There is no indication of higher trace organics concentrations at levels of higher Cl^- concentration.

Another vertical profile was established at T-4 on 12/16/81 (Table 2). There the concentrations of TCEY was detected significantly above background and the Cl^- concentrations were high (237 mg/ℓ). At level 7 no TCEY was found although the Cl^- concentration was similarly high. At level 10, the concentration was significantly lower and only a trace of TCEY was detected, but CCl_4 was measured at a slightly elevated concentration.

The data shown in Tables 1 and 2 indicate that these contaminants had a distribution within the plume which was quite different from those of TOC and Cl^-. The more random distribution of CCl_4 and TCEY was presumably due to random burial of small amounts of these solvents. In each case a small separate plume may have formed. Two-phase transport by gravity could explain high CCl_4 concentrations in layers where the leachate concentration was low.

Detailed characterization by GC/MS using closed-loop stripping and methylene chloride extraction seemed to indicate that relatively few compounds of industrial origin were buried. The concentrations of those identified were present at levels close to the background values found at P3-25 and at the injection site. As was observed for the volatiles, the distribution of the compound appeared to be random and was quite different from that observed for Cl^- and TOC. Di-ethyl-phthalate was measured in all wells tested, but because phthalic acid esters are ubiquitous, trace concentrations are difficult to interpret. Thus these data are suspect and must be interpreted with caution. Triphenylphosphate, which is a fire retardant, was found in one of the background samples (injection site) at a level similar to those at 77-25. Thus it was difficult to evaluate whether leaching of this compound into the ground water occurred. Benzothiazole was found in well 77-25-2 but not in any other. The presence of elemental sulfur is interesting as it is known to participate in redox reactions (Stumm and Morgan, 1981). Assuming pH 6.5 and

equilibrium conditions, a pε value in the range of -2 can be inferred. This was consistent with the reduced conditions observed within the plume. The fatty acids palmitic, stearic, and linoleic are present in all living cells and are found widely in the environment. Their estimated concentrations do not indicate a significant contamination by the leachate. Conspicuous was the absence of large amounts of short-chain fatty acids which are formed as by-products of anaerobic degradation and often constitute a major fraction of the DOC in leachates (Chian and DeWalle, 1977).

The aromatic hydrocarbons detected (Table 3) are components of gasoline, No. 2 fuel oil, and other petroleum products. Some are used as solvents and intermediates. The concentrations observed within the plume were generally very low and close to the detection limit. In general, a significant contamination of the ground water through leaching of anthropogenic organics did not seem to occur. But because only a limited number of wells have been analyzed, no firm conclusions can be drawn, however. The aquifer might have been contaminated in areas which have not been investigated.

Woolwich

At the Woolwich site, two vertical profiles were measured for volatile organics, one at well M4 and another one at PDML nearby. The data are shown in Table 4. At M4, the concentration profile was relatively even for $CHCl_3$, TCEY, and PER. However, 1,1,1-trichloroethane (TCEA) appeared to be enriched in the bottom layer (level 9). Here, the concentration was about 10 times higher than at levels 5, 6, and 7. This was in contrast to the Cl^- concentrations, which were 303 mg/ℓ, 144 mg/ℓ and 182 mg/ℓ for levels 5, 6, and 7, respectively, but only 25.5 mg/ℓ at level 9. This suggested that Cl^- and 1,1,1-TCEA had different sources and consequently, that Cl^- could not be used to determine dilution of the 1,1,1-TCEA plume.

At PDML a similar observation was made. Again the botton layer (level 6) had the lowest Cl^- and the highest 1,1,1-TCEA concentration. At level 6, the 1,1,1-TCEA concentration was about 20% higher than in the upper levels. TCEY seemed to follow the trend of 1,1,1-TCEA. A possible explanation for this anomaly was that these chlorinated solvents, which are heavier than water, migrated to the bottom of the aquifer as a separate phase. Once they reached the bottom they might have slowly leached into the ground water stream and formed a separate plume. The mechanisms and conditions which might affect two-phase transport of solvents heavier than water through porous media have been discussed by Schwille (1981).

Samples from wells W-D, M4-5, M9-8, and M17-8 were taken to evaluate a horizontal profile. M4-5 and M9-8 seemed to be located close to the same source streamline and thus were suitable for a quantitative comparison. Following Cl^- analysis it was apparent that M17-8 was outside the plume and probably lay on a separate streamline.

Table 5 summarizes the Cl^-, TOC, and trace organic data obtained from these wells. At W-2, all volatiles were present at concentrations close to or below the detection limit except for $CHCl_3$ (0.64 µg/ℓ) which was significantly above the detection limit. The $CHCl_3$ concentrations within the plume seemed somewhat lower. At M4-5, the concentrations of 1,1,1-TCEA, TCEY, and PER increased markedly indicating that substantial amounts of these compounds were released by the landfill. The concentrations of $CHCl_4$ and 1,1,2-TCEA seemed to increase only to a minor extent. 1,1,1-TCEA decreased from M4-5 to M9-8 as did the Cl^- concentration, but with TCEY, the opposite trend was observed. Its concentration was significantly higher at M9-8 60 m downstream. This suggested that the plume of Cl^- and TCEY had little resemblance. PER was detected only at M4-5 but not at M9-8. The TOC data suggested effective

attenuation between M4-5 and M9-8. The TOC to Cl^- ratio decreases from 6.7 to 2.2 between these two wells. This suggested that factors other than hydrodynamic dispersion--such as biodegradation--might have been effective in reducing organic carbons. M17-8 was low in Cl^-, TOC, and in all organics measured specifically. None of these parameters indicated a significant impact by leachate at this well.

Table 5 also shows the distribution of aromatic hydrocarbons, phenols, alkylphosphates, carboxylic acids, and nitrogen-containing compounds. At M4-5 four of the carboxylic acids listed in Table 5, benzoic through 3-phenylpropanoic acid, were present at concentrations above the dynamic range of the instrument. At M9-8 the same compounds were detected but at concentration levels orders of magnitude lower. This rapid apparent attenuation might be due to microbial degradation. Some aromatic acids including benzoic acids are known to be degraded under anaerobic conditions to methane and carbon dioxide (Clark and Fina, 1952; Healy et al., 1980). Palmitic and stearic were the major long-chain fatty acids detected. Their concentrations were significantly above background at M4-5 but appeared to have been attenuated by M9-8. Linoleic acid was found only at trace levels. The two dicarboxylic acids, benzenedicarboxylic and nonanedioic, were found at high concentrations at M4-5, but at or below the detection limit at M9-8. Possible mechanisms for this removal are microbial degradation, adsorption onto soil particles, or precipitation as heavy metal salts. Two chlorinated aromatic acids were detected: the structure of one with an apparent molecular weight (MW) of (228) remains unknown, the other was tentatively identified as a dichlorohydroxybenzoic acid. These compounds might be metabolites of chlorinated aromatics. It appears that they are mobile to some degree and that they are not degraded further readily. Both these compounds were detected downstream at M9-8.

The nitrogen-containing compounds were minor constituents. The data suggest that they are leaching from the landfill, as none of these compounds were found in the ground water upstream. The nitrogen-containing compounds benzonitrile, methylbenzonitrile, aniline, tetramethylthiourea, and cyanobenzoic acid might have originated from wastes of a tire manufacturing plant, which was in operation years ago. Benzonitrile, methylpyridine, aniline, and possibly, tetramethylthiourea are used in tire manufacturing as intermediates or accelerators. Cyanobenzoic acid might be an oxidation product of methylbenzonitrile. The data are insufficient to discern attenuation, but their occurrence at M9-8 indicates that these compounds are mobile and not readily degraded under the presumably anaerobic conditions prevalent in the aquifer.

The acid/phenol fraction contained numerous other compounds including aliphatic and cyclic carboxylic acids, some of which could be tentatively identified (Table 6).

Other compounds detected appeared to be polycyclic carboxylic acids, but no reference spectra could be found and they remain unknown. It is suspected that the decomposition of plant material produces many of these materials as they do not appear to be of industrial origin. Some of the compounds listed in Table 6 appeared to contain nitrogen and we suspect that they too were constituents of the buried tire manufacturing wastes.

North Bay

Vertical Distribution: At location G a piezometer and an upper G and a lower G' multilevel device have been installed. Samples from the piezometer (G pz) were analyzed for organics along with samples from the bottom layer (G'-9) and from the top layer (G-1) (see Table 7). The Cl^- concentration in piezometer G (pz G) was close to that of G-5 and G-6, but was significantly different from that at the top and at the bottom. This suggests that the

leachate plume was concentrated in the center layers of the aquifer as expected from data obtained previously (Cherry, 1982). The volatile organics concentrations did show a different pattern, however. In the G pz and in the top layer (G-1), only traces were detected. Yet, in the bottom layer (G'-9), which appeared to contain the lowest lechate concentration, the TCEY concentration was 14 µg/ℓ, significantly above background. PER and 1,1,1-TCEA followed the same trend. Their concentrations were above the detection limit only at G'-9.

Horizontal Distribution: In spite of the high TCEY concentration at G'-9, all concentrations downstream were below the limit of 0.1 µg/ℓ and no TCEY plume could be discerned. It is possible, however, that this compound migrated with the bottom layer. Since little mixing is expected to occur, it might not have dispersed into the center levels of the leachate plume where the samples were taken. Traces of $CHCl_3$ and 1,1,1-TCEA were also detected but their low concentrations did not seem significant.

The low Cl^- and TOC concentrations at O-4 indicated that the plume did not extend to this well. The trace organics data were consistent with this observation. Most concentrations were near or below the detection limit.

Analysis of the ground water samples for purgeable compounds with the CLS procedure indicated the presence of significant amounts of aromatic hydrocarbons, chlorinated benzenes, and terpenes. Also detected were miscellaneous chemicals of industrial origin. Figures 4 and 5 show the reconstructed ion chromatograms of samples G pz and AAA-5. Identifications--some of which are still tentative—are given in Table 8. They are based on computer-aided matching of the unknown spectra with reference spectra included in the EPA/NIH reference library (Heller and Milne, 1978) incorporated in the software of the INCOS data system and comparison of elution sequences determined by Kappeler, 1976; Zürcher and Thüer, 1978).

The mixture was very complex and prevented complete chromatographic resolution of the extract. For instance, p- and m-xylene co-eluted and could only be measured as the sum of the two compounds. Likewise, 1,2-dichlorobenzene co-eluted with a compound tentatively identified as cineole.

1-chlorooctane and 1-chlorododecane were added as surrogate standards for quantitation. Response factors were determined only for the aromatic hydrocarbons and the chlorobenzenes. Concentrations of the other compounds were only estimated by comparing the peak heights with the peak heights of the surrogate standards.

Based on the relative abundance of the various components, the hydrocarbons detected were presumed to derive from waste petroleum products deposited at the landfill (Zürcher and Thüer, 1980). Chlorobenzene and o- and p-chlorobenzenes are used as solvents besides miscellaneous other uses. The terpenic compounds with the elemental composition $C_{10}H_xO_1$ (x = 20, 18, 16; y = 1) that were tentatively identified are geochemical markers for plant material (Streibl and Heirout, 1969) and presumably derived from buried plant material. Tert-octylphenol and tert-octylphenolmonoethocylate are used as detergents and as emulsifiers. Their occurrence has been reported previously (Giger et al., 1981; Sheldon and Hites, 1979). Tributylphosphate is used as a plasticizer, and dimethylsulphoxide is used as a solvent.

Figure 5 depicts the chromatogram of the CLS extract of the AAA-5 sample. It indicated that numerous compounds were persistent and were able to migrate from the landfill to the leachate spring 800 m away. By comparing the profiles of the two chromatograms, significant changes in the composition of the extracts could be noted. Camphor (22) and an unknown (23), p+m-xylene (6) and o-xylene, which are major peaks in the G pz sample were close to or below the detection level at AAA-5. Other peaks which significantly decreased were

1,2,4-trimethylbenzene (13), d-fendione (21), 1-i-propyl-4-methylcyclohexanol (24), and menthol (25).

Conversely, minor components in G pz were relatively major in AAA-5. Chlorobenzene (4), ethylbenzene (5), and 1-methyl-4-(1-methylethyl)-7-oxabicyclo-[2,2,1]heptane (15) were the major components of the CLS extract at AAA-5. Other components which were relatively more abundant (as judged from their peak heights) were i-propylbenzene (8), n-propylbenzene (9), 1-ethyl-3-methylbenzene (12), indan (19), naphthalene (26), and the C_4-benzenes (17). The compounds "tert"-octylphenol, octylphenolmonoethoxylate, tributylphosphate, and the unknowns 33, 37, and 38 were present in about the same relative amounts relative to the main components. This suggested that these compounds were persistent under the prevailing geochemical conditions.

To evaluate persistence and attenuation on a more quantitative basis samples from wells in between M-9 and LL-9 were analyzed for a wide range of compounds. Background values (well O-4) were low but traces of benzene, toluene, ethylbenzene, and chlorobenzene were detected. These might stem from diffuse sources. At G pz where the strength of the leachate was greatest the main components (ethylbenzene, xylenes, 1,2,4-trimethylbenzene and naphthalene) camphor and an unknown 23 were detected in the 100 µg/ℓ range. The sum of the individual components was estimated to be in the range of 3-4 mg/ℓ, close to solubility limit for No. 2 fuel given by Zürcher and Thüer (1978) and Kappeler (1976).

With distance, the concentrations of both chlorinated and nonchlorinated hydrocarbons decreased steadily with few exceptions. An unknown ethylphenol isomer was attenuated to levels below the detection limit by well LL-9. Carboxylic acids were detected throughout the plume. A tendency towards lower concentrations with greater distance was noted as for the other compounds.

Benzoic acid appeared to behave unusually, as it decreased to levels below the detection limit but increased again towards AAA-5. We suspect that this might be due to simultaneous formation and removal processes. Benzoic acid is a common intermediate in the anaerobic degradation of many benzoic compounds (Crawford, 198?). Conspicuous was the absence of phenylacetic acid (C_1-benzoic). Carboxylic acids appeared to be the major components of the extract. Extraordinarily big amounts of diazomethane were consumed during methylation. Previous studies on the composition of leachates of sanitary landfills indicated that short-chain fatty acids comprised 49% of the TOC of the sample investigated by Chian and DeWalle (1977).

To obtain a better picture for attenuating processes other than dispersion, the observed pollutant concentrations were corrected for dilution using Cl^- as a conservative tracer. A conservative behavior of a pollutant is indicated if the pollutant to Cl^- ratio remains constant throughout the plume (assuming that background values are sufficiently low, leaching rates or rate changes are the same for pollutant and Cl^-). Nonconservative behaviors involving formation or removal is indicated if the ratio pollutant to Cl^- ratio increases or decreases, respectively.

Table 10 summarizes the ratios of the pollutants to the Cl^- concentrations at G pz, M-9, LL-9, and AAA-5. The data are quite variable but several trends appear to be significant. Benzene, ethylbenzene, naphthalene, and the methylnaphthalenes appeared to be attenuated to a lesser degree than o/m/p-xylene, 1,2,4-trimethylbenzene. These data suggested that the xylenes and 1,2,4-trimethylbenzene were attenuated by factors other than hydrodynamic dispersion. The data on toluene were variable. It decreased between G pz and M-9, but increased again between LL-9 and AAA-5, but it is not clear whether these changes are significant.

The selective apparent removal of aromatic hydrocarbons is interesting and can perhaps be explained by microbial degradation, which tends to be selective. Physico-chemical processes are not expected to affect selectively the fate of these chemicals to such a marked degree. The physico-chemical characteristics which might affect adsorption and retention, such as water solubility and the octanol/water partition coefficient, do not seem different enough to explain these marked differences in attenuation behavior. Because their composition in the waste petroleum products is assumed to be fairly constant, selective microbial removal and perhaps formation mechanisms might be effective. Formation processes might also be significant. The formation of 4-methyl-i-propylbenzene and p-methane from a terpenic compound, α-pinene, has been demonstrated to occur in wood stumps covered by peat (Skrigan, 1963). The process involved appears to be decarboxylation, dehydrogenation and/or hydrogenation with or without rearrangement of the carbon skeleton (Streibl and Herout, 1969). In general reduction processes make the compounds more hydrophobic and more amenable to removal by sorption onto the aquifer material. If these processes should occur to a significant extent, accumulation of hydrocarbons derived from plant materials should occur. Testing of this hypothesis could be interesting from a geochemical point of view.

The chlorinated benzenes did not show any tendency to be attenuated beyond dispersion as indicated by their relatively constant ratios along the flow path of the plume. The ratio tended to increase even, which may be due to a decrease in the leaching rate of these compounds. The changes are small, however, and the data will need to be verified. The tendencies for the carboxylic acids appeared to be similar. It decreased between G pz and M-9 but appeared to increase again between LL-9 and AAA-5. It was not clear whether these variations were significant.

The apparent selective attenuation of these aromatic hydrocarbons might have been due to microbial processes but more data are needed to verify these findings. Formation of certain hydrocarbons as discussed by Streibl and Herout (1964) was also considered and could be significant.

The relative concentrations of the chlorinated benzene compounds remained fairly constant, indicating that attenuating factors other than hydrodynamic dispersion were not effective. The relative concentrations of C_3-benzoic and 2-methylbutanoic acid appeared to decrease whereas dehydroabiatic acid appeared to be persistent. The relative concentrations of benzoic and, less distinctly, C_2-benzoic acid showed a minimum along the flow path. Whether these observations are significant needs further investigation.

SUMMARY AND CONCLUSIONS

The leachate plumes of landfills were characterized with respect to potentially hazardous organic chemicals. Significant contamination with chemicals included in the list of priority pollutants (Keith, 1979) were found at two of the three sites. The prioriity pollutants identified included halogenated solvents, TCEY, PER, CCl_4, $CHCl_3$, 1,1,1- and 1,1,2-TCEA, chlorobenzene, 1,2- and 1,4-dichlorobenzene, aromatic hydrocarbons, including benzene, toluene, ethylbenzene, naphthalene, acenaphthene, and fluorene, several alkylphthalates, and phenol. The data suggested that these compounds have the potential to migrate in the subsurface environment as indicated by their occurrence hundreds of meters away from the landfills. Phenol and perhaps fluorene was the only priority pollutants detected which seemed to be attenuated by factors other than hydrodynamic dispersion. This was attributed to a low adsorption capacity of the sandy aquifer and to unfavorable microbial conditions. TCEY, 1,1,1-TCEA, and PER have also been shown to be persistent

under anaerobic conditions in laboratory experiments (Bower et al., 1981). A large number of aromatic acids including C_n-benzoic acids was detected. Their presence was explained by partial microbial oxidation of petroleum-derived hydrocarbons. The water-soluble fraction of No. 2 diesel fuel has been shown to be degraded by adapted microorganisms in a simulated aerobic ground water environment (Kappeler, 1976). Their occurrence suggested that certain zones of the landfills are suitable for aromatic hydrocarbon degradation, presumably in zones where air has access to the refuse. We have shown that significant amounts of potentially hazardous materials were leaching into the ground water from sanitary landfills considered typical for many of the thousands which are in operation.

The data obtained for TCEY and 1,1,1-TCEA suggested two-phase flow to the bottom of the aquifer. Further study of this phenomenon is needed because it might have important implications for evaluating the potential of groundwater contamination in the vicinity of sanitary landfills. It would also have to be considered in the operation and regulation of sanitary and hazardous waste landfills. Deeper aquifers previously considered safe could be affected, making them unusable for human consumption.

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TABLE 1. BORDEN 11/1/81: CHLORIDE, TOC, AND VOLATILE ORGANIC DISTRIBUTION

			77-6				77-25			77-40		
Location	P3-25	Inj.Site	1	2	P2-33	Org.pz.	1	2	3	1	2	3
Chloride, mg/ℓ	5.2±1.4	5.6±1.2	5.6±1.0	102.7±1.1	359± -	260.8±2.1	4.7±1.7	136.5±3.1	3.9±0.5	4.6±0.6	95.7±3.7	5.5±1.0
TOC, mg/ℓ	9.1	2.1	n.a	43.0	18.7	16.01	n.a.	15.1	6.4	n.a.	14.3	n.a.
Chloroform, µg/ℓ	< 0.1	0.22±0.11	< 0.1	< 0.1	< 0.1	< 0.1	n.d.	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Carbontetrachloride, µg/ℓ	0.20±0.04	0.25±0.11	0.13±0.01	0.10±0.01	0.18±0.07	0.18±0.11	< 0.1	0.1±0.03	0.12	0.11	0.1±0.03	0.1
Trichloroethylene, µg/ℓ	0.22±0.29	< 0.1	0.40±0.03	0.29±0.06	3.4±0.07	n.d.	0.15	> 0.1	0.14	0.11	< 0.1	< 0.1
Tetrachloroethylene, µg/ℓ	n.d.	< 0.1	n.d.	n.d.	n.d.	< 0.1	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Number of Analyses	3	2	2	2	2	3	1	2	1	1	2	1

n.a.: not analyzed; n.d.: not detected; < 0.1: trace below 0.1.

TABLE 2. BORDEN 12/16/81: VERTICAL PROFILE AT T-4

Well Level	4	6	7	10
Chloride	237.7 ± 2.9	237.0 ± 6.1	244.8 ± 2.7	72.8 ± 2.7
Trichloroethylene, µg/ℓ	0.97 ± 0.16	0.37 ± 0.057	n.d.	0.03
Carbontetrachloride, µg/ℓ	< 0.01	< 0.01	0.1	0.15
Number of Samples	4	3	2	2

n.d.: not detected; < : trace detected but not quantified.

TABLE 3. BORDEN 11/11/81: NEUTRAL AND ACIDIC COMPOUND DISTRIBUTION
(Concentrations in µg/ℓ)

Well	P3-25	Inj.Site	77-6-2	P2-33	Org.pz.	77-25-2	77-25-3	77-40-2
Aromatic Hydrocarbons (n)	1	2	2	2	1	2	1	2
Benzene	0.8	1.2±0.95	2.6±0.02	2.8±1.3	1.0	1.7±1.8	0.75	0.8±0.15
Toluene	0.3	< 0.1	< 0.2	0.3±0.03	0.8	1.0±0.7	0.9	0.7±0.5
Ethylbenzene	< 0.2	n.d.	< 0.2	< 0.2	0.2	0.3±0.1	0.3	0.2±0.13
p+m-Xylene	< 0.2	< 0.2	< 0.2	< 0.2	0.3	0.5±0.56	< 0.2	0.4±0.32
Anthracene (Phenanthrene)	0.2	0.2	0.1	n.d.	0.1	0.3	n.d.	< 0.1
Miscellaneous (n)	1	1	1	1	1	1	1	1
Triphenylphosphate*	n.a.	0.3	0.1	n.d.	n.d.	0.3	0.4	< 0.1
Di-ethyl-phthalate*	8.1	6.7	2.7	0.5	2.7	4.6	12.3	0.7
Benzothiazole*	n.d.	n.d.	n.d.	n.d.	n.d.	0.7	n.d.	n.d.
Sulfur (S_8)*	n.d.	n.d.	> 100	n.d.	n.d.	n.d.	n.d.	n.d.
Acids (n)*	1	1	1	1	1	1	1	1
Palmitic*	n.a.	3.2	2.3	6.6	13.4	2.9	7.2	6.7
Stearic*	n.a.	1.2	0.8	3.9	6.3	0.9	2.3	2.1
Linoleate*	n.a.	0.3	0.1	0.7	2.5	0.2	0.2	0.2

n.a.: not analyzed; n.d.: not detected; (n): number of analyses.
*Semi-quantified as internal standard (no response factor).

TABLE 4. WOOLWICH: VERTICAL PROFILES

WELL M4, 10/23/81

Level	5	6	7	9
Chloride,, mg/ℓ	303	144	182	25.5
Halogenated Organics, µg/ℓ				
Chloroform	0.38±0.17	0.34±0.08	0.38±0.008	0.37±0.01
1,1,1-Trichloroethane	5.4±2.8	4.3±0.08	9.1±0.4	68.1±4.6
Carbon tetrachloride	0.017±0.004	0.017±0.003	0.2	n.d.
Trichloroethylene	2.9±0.7	2.6±0.3	2.9±0.5	1.1±0.3
1,1,2-Trichloroethane	0.07±0.003	0.05±0.02	0.05±0.005	< 0.01
Tetrachloroethylene	1.7±0.4	0.86±0.39	1.5±0.55	0.79±0.09

WELL PDML, 11/ /81

Level	1	2	3	4	5	6
Chloride, mg/ℓ	153.5±3.1	152.2±1.0	132.0±13.4	153.8±2.2	111.5±1.3	33.4±2.2
1,1,1-Trichloroethane, µg/ℓ	133	110	140	140	139	179
Trichloroethylene, µg/ℓ	0.59	0.57	1.08	1.03	1.05	1.22

n.d.: not detected; < : trace detected but not quantified.

TABLE 5. WOOLWICH: CHLORIDE, TOC, AND TRACE ORGANICS DISTRIBUTION†

Well	W-D	M4-5	M9-8	M17-8
Chloride, mg/ℓ	13.1	303	215	16.1
TOC, mg/ℓ	23.5	2040	472	6.4
Volatiles (n)†				
Chloroform	0.64±0.003	0.38±0.008	0.13±0.01	0.35±0.01
1, ,1-Trichloroethane	0.01±0.005	9.1±0.4	5.3±3.2	0.11±0.03
Carbontetrachloride	0.03±0.01	0.2±0	0.03±0.01	0.01±0.001
Trichloroethylene	< 0.01	2.9±0.5	5.3±2.2	n.d.
1,1,2-Trichloroethane	n.d.	0.05±0.005	0.19±0.02	n.d.
Tetrachloroethylene	< 0.01	1.5±0.55	n.d.	0.01±0.004
Aromatic Hydrocarbons				
Toluene	0.21	140	14	n.d.
Ethylbenzene	n.d.	98	0.08	n.d.
p/m-Xylene	n.d.	17	n.d.	n.d.
o-Xylene		12	0.1	n.d.
Phenols*				
Phenol	n.d.	460	n.d.	n.d.
Methylphenol isom.	n.d.	610	63	n.d.
Ethylphenol isom.	n.d.	17	11	n.d.
ar-Chloromethylphenol isom.	n.d.	13.6	n.d.	n.d.
Alkylphosphates*				
Tributylphosphate	n.d.	1.2	0.4	n.d.
Triethylphosphate	n.d.	15	10	n.d.
Carboxylic Acids*				
Benzoic	< 0.1	> 10^3	17	< 0.1
Methylbenzoic isom.	n.d.	> 10^3	30	n.d.
Dimethylbenzoic isom.	n.d.	> 10^3	3.5	n.d.
Phenylacetic	n.d.	>10^4	> 10^2	0.3
3-Phenylpropanoic	n.d.	> 10^4	1.9	n.d.
4-Phenylpropanoic	n.d.	9.7	0.8	n.d.
Palmitic	1.7	42	1.8	1.7
Stearic	0.8	8.8	1.2	0.8
Linoleic	n.d.	0.1	0.1	0.1
Benzenedicarboxylic isom.	n.d.	6.1	1.1	n.d.
Nonanedioic	n.d.	68	n.a.	n.d.
Chlorinated unknown (MW 228?)	n.d.	5.4	0.4	< 0.1
Dichloromethoxy benzoic	n.d.	0.2	0.2	n.d.
Nitrogen Containing*				
Benzonitrile	n.d.	n.a.	2.5	n.d.
Methyl benzonitrile isom.	n.d.	0.8	8.8	n.d.
Aniline	n.d.	n.a.	9.9	n.d.
Tetramethylthiourea	n.d.	19	12	n.d.
Cyanobenzoic acid isom.	n.d.	n.d.	34	n.d.

n.d.: not detected; n.a.: not analyzed.

*Semi-quantified as internal standard (no response factor).

† [illegible] given in µg/ℓ, except chloride and TOC, which are in mg/ℓ.

TABLE 6. WOOLWICH: MISCELLANEOUS COMPOUNDS TENTATIVELY IDENTIFIED AT M4-5*

Monocarboxylic	Dicarboxylic
n-pentanoic	nonanedioic
1-methylpentanoic	decanedioic
n-hexanoic	undecanedioic
1-ethylpentanoic	unsaturated
n-hepatanoic	$C_{17}H_{31}COOH$ (2DB)
1-ethylhexanoic	$C_{17}H_{33}COOH$ (1DB)
1-methylpentanoic	
n-dodecanoic	**Nitrogen-Containing Compounds**
cyclohexanoic	cinnoline
2-methylcyclohexanoic	benzothiazole
	N-propyl-ar-methylbenzamid
Miscellaneous	
cyclohexanone	

DB = double bond.

*Compounds other than those included in Table 5.

TABLE 7. NORTH BAY: VERTICAL PROFILE OF CHLORIDE AND VOLATILES*

Location	G pz	G1	G5	G6	G'9
Chloride, mg/ℓ	710	197	728	721	101
Trichloroethylene, µg/ℓ	< 0.1	< 0.1	n.a.	n.a.	14
Tetrachloroethylene, µg/ℓ	n.d.	< 0.1	n.a.	n.a.	0.75
1,1,1-Trichloroethane, µg/ℓ	< 0.1	< 0.1	n.a.	n.a.	0.13
Carbontetrachloride, µg/ℓ	n.d.	< 0.1	n.a.	n.a.	< 0.1
Chloroform, µg/ℓ	< 0.1	< 0.1	n.a.	n.a.	< 0.1

n.d.: not detected; < : trace detected but not quantified;
n.a.: not analyzed.

TABLE 8. IDENTIFICATION OF CHEMICALS IN SAMPLES G pz AND AAA-5

1. Benzene
2. Toluene
3. Dimethylsulphoxide
4. Chlorobenzene
5. Ethylbenzene
6. p + m-Xylene
7. o-Xylene
8. i-Propylbenzene
9. n-Propylbenzene
10. 1-Ethyl-3-methyl-benzene, 1-Ethyl-4-methyl-benzene
11. 1,3,5-Trimethylbenzene
12. 1-Ethyl-2-methyl-benzene
13. 1,2,4-Trimethylbenzene
14. 1,4-Dichlorobenzene
15. 1-Methyl-4-(1-methylethyl)-7-oxabicyclo[2,2,1]heptane ($C_{10}H_{18}O$)
16. 1,2,3-Trimethylbenzene
17. C_4-Benzene
18. 1,3,3-Trimethyl-2-oxabicyclo[2,2,2]octane ($C_{10}H_{18}O$), cineole
    a. 1,2-Dichlorobenzene
19. Indan
20. 1-Chloro-n-octane (Internal Standard)
21. 1,3,3-Trimethyl-bicyclo[2,2,1]heptan-2-one ($C_{10}H_{16}O$), d-Fenchone
22. 1,7,7-Trimethyl-bicyclo[2,2,1]heptan-2-one ($C_{10}H_{16}O$), camphor
23. Unknown, spectrum similar to 8-methyl-1,8-nonanedial
24. 1-i-Propyl-4-methyl-cyclohexanol ($C_{10}H_{20}O$)
25. 5-Methyl-2-i-propyl-cyclohexanol ($C_{10}H_{20}O$), Menthol
26. Naphthalene
27. 3,6,6-Trimethyl-bicyclo[3,1,1]heptan-2-one ($C_{10}H_{16}O$)
28. 2-Methylnaphthalene
29. 1-Methylnaphthalene
30. Phenylether
31. C_2-Naphthalene
32. 1-Chloro-n-dodecane (Internal Standard)
33. Unknown, 145 (100%), 41 (60%), 57 (45%), 20 (25%), 127 (20%)
34. Octylphenol
35. Tributyl Phosphate
36.* Unknown, 59 (100%), 109 (48%), 166 (39%)
37.* Unknown, 145 (100%), 215 (20%), 127 (10%)
38.* Unknown, M^+ 346 (10%), 253 (100%), 331 (25%)
39. Octylphenolmonoethoxylate

A. Tetrahydronaphthalene
B. C_1-Indanes
C. C_1-Tetrahydronaphthalenes and C_2-Indanes

*Unknowns are characterized by their most abundant ions. Values in parentheses indicate relative abundance. M^+ = apparent molecular ion.

TABLE 9. NORTH BAY 10/25/81: CHLORIDE, TOC, AND TRACE ORGANICS DISTRIBUTION

Well	0-4	G pz	M-9	LL-9	AAA-5
Chloride, mg/ℓ	2.4	710	184	96.5	77.9
TOC, mg/ℓ	3.3	600	205	109	79
Aromatic Hydrocarbons, µg/ℓ					
Benzene	0.3	47	4.5	2.1	2.1
Toluene	0.2	59	0.8	0.6	3
Ethylbenzene	0.1	480	30	26	14
m/p-Xylene	< 0.1	820	60	13	0.5
o-Xylene	n.d.	510	13	2	0.6
1,2,4-Trimethylbenzene	< 0.1	220	75	40	0.6
Naphthalene	n.d.	110	21	10	3
2-Methylnaphthalene	< 0.1	20	5.6	2	1
1-Methylnaphthalene	0.1	13	3.4	1.6	0.8
Acenaphthene†	n.d.	0.9	1.2	0.1	0.2
Fluorene†	n.d.	1.2	0.7	n.d.	n.d.
Chlorinated Benzenes, µg/ℓ					
Chlorobenzene	0.3	33	17	16	16
1,2-Dichlorobenzene	0.2‡	13	5.6	2.8	4.8
1,4-Dichlorobenzene	< 0.1	40	10	7	7
Phenol*, µg/ℓ					
Ethylphenol isom.	n.d.	6.3	1.8	n.d.	n.d.
Carboxylic Acids*, µg/ℓ					
Benzoic	n.a.	8.8	n.d.	< 0.1	1.0
C_2-Benzoic	n.a.	25	6.5	4.2	0.8
C_3-Benzoic	n.a.	7.3	2.3	1.9	0.1
Methylbutanoic	n.a.	238	37	25	13
Dehydroabietic	n.a.	15.5	1.9	0.6	0.6

n.a.: not analyzed; n.d.: not detected; <: trace detected but not quantified.

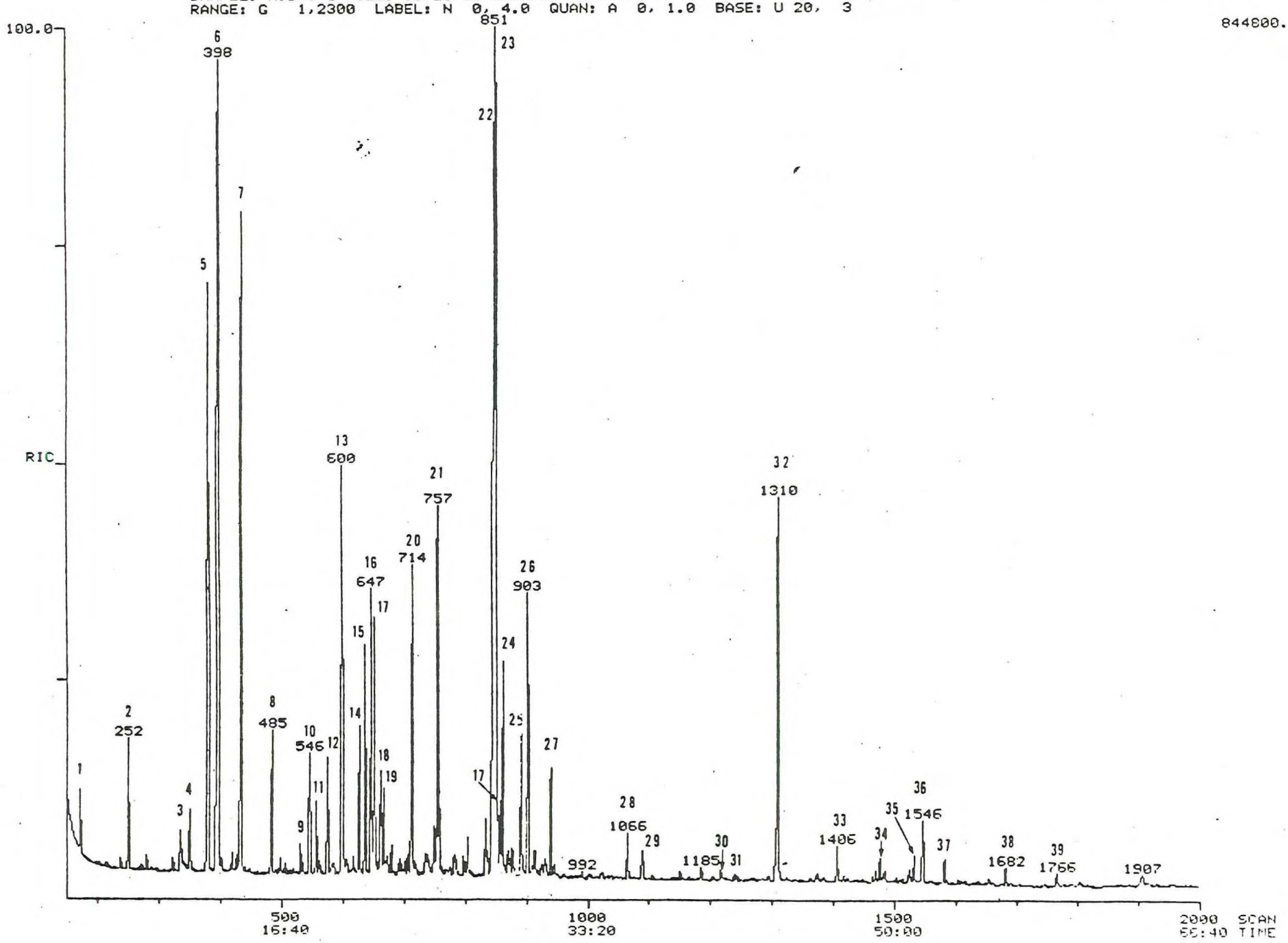
*Semi-quantified as internal standard (no response factor).

†Compounds found in B/N analysis, semi-quantified as 3,6-dimethylphenanthrene.

‡Interference with cineole possible.

TABLE 10. NORTH BAY 10/25/81: TRACE ORGANICS TO CHLORIDE ION RATIO (ng/ℓ:mg/ℓ)

Location	G pz	M-9	LL-9	AAA-5
Aromatioc Hydrocarbons				
Benzene	66	24	65	26
Toluene	83	4	6	38
Ethylbenzene	780	160	260	180
m/p-Xylene	1100	330	130	7
o-Xylene	720	71	21	8
1,2,4-TMB	310	410	410	8
Naphthalene	150	110	100	38
2-MeNaphthalene	28	30	21	13
1-MeNaphthalene	18	18	16	10
Chlorobenzenes				
Chlorobenzene	46	92	165	205
1,2-Dichlorobenzene	18	30	29	61
1,4-Dichlorobenzene	56	54	72	90
Phenol				
Ethylphenol isom.	8	9	-	-
Acids				
Benzoic	12	-	-	12
C_2-Benzoic	35	35	4	10
C_3-Benzoic	10	12	1.9	1.3
2-Methylbutanoic	330	210	260	170
Dehydroabietic	21	10	6	8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02/07/82 22:28:00
SAMPLE: N.BAY G-PIED. 10/25/81 5/1DIL. IS-200UG/L
RANGE: G 1,2300 LABEL: N 0, 4.0 QUAN: A 0, 1.0 BASE: U 20, 3
DATA: CLS13 #1
CALI: GCAL282B #4
SCANS 150 TO 2000
100.0
844800.
RIC
851
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398
22
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13
600
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1310
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647
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903
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1907
992
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1000
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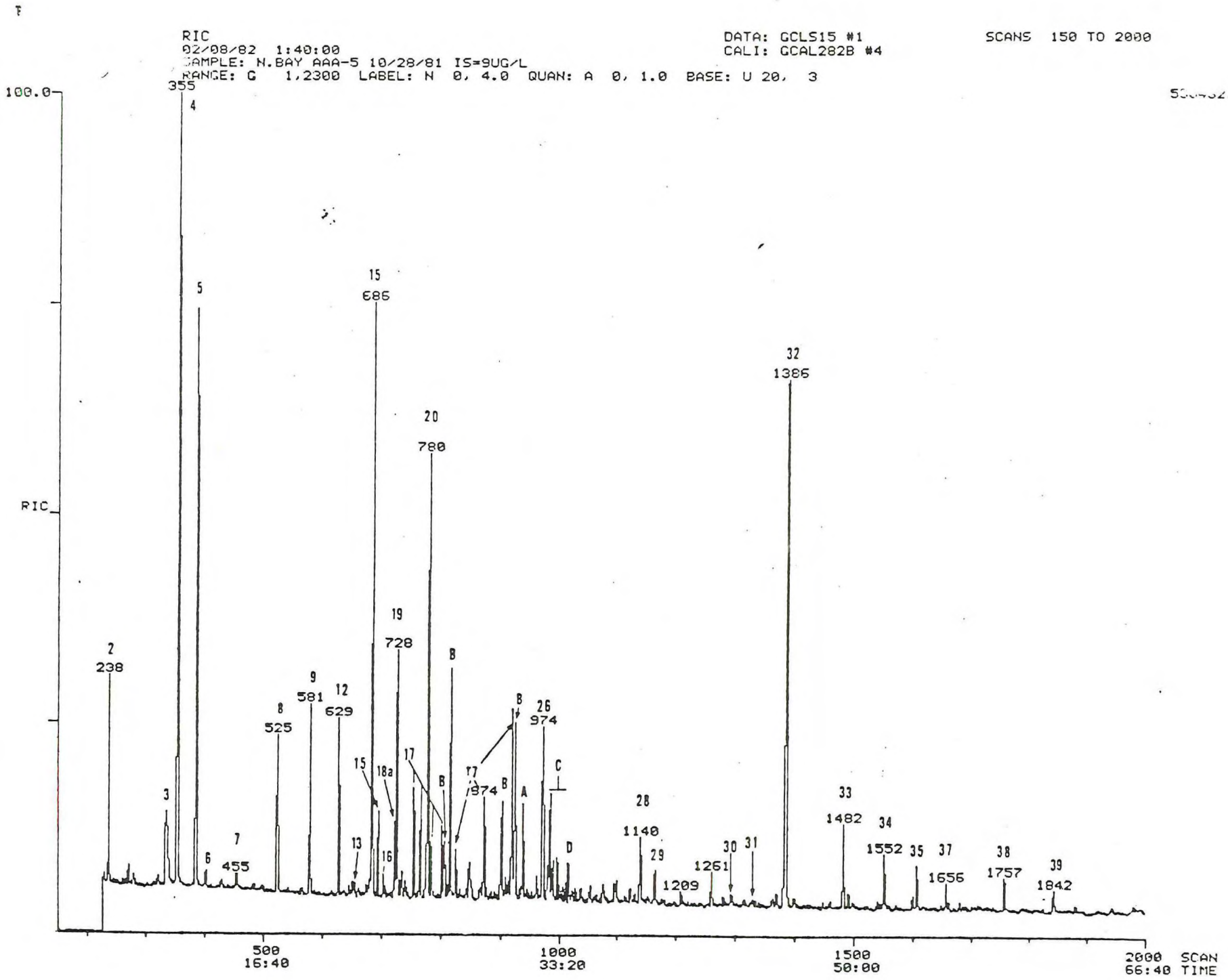
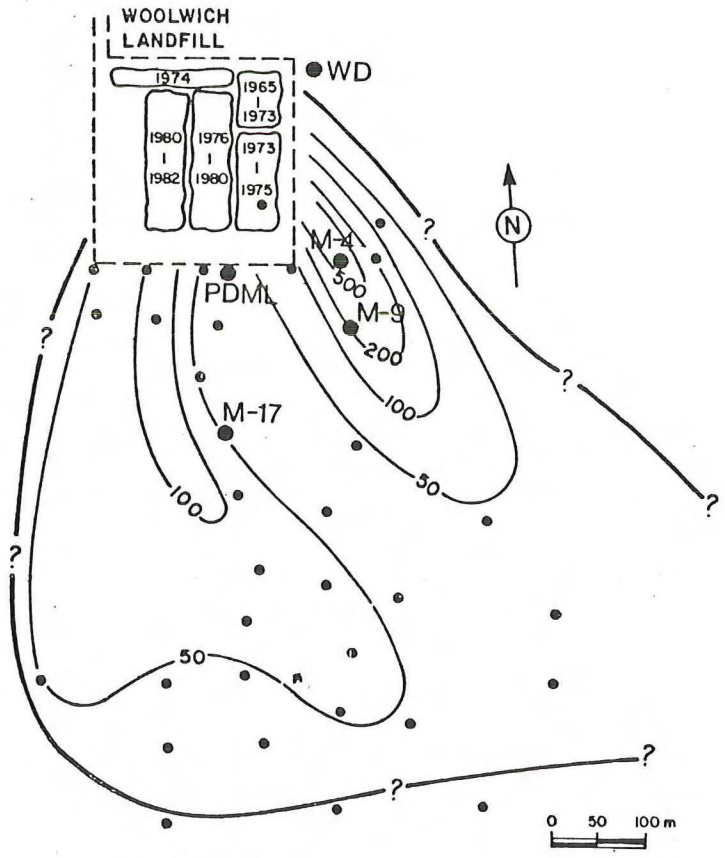
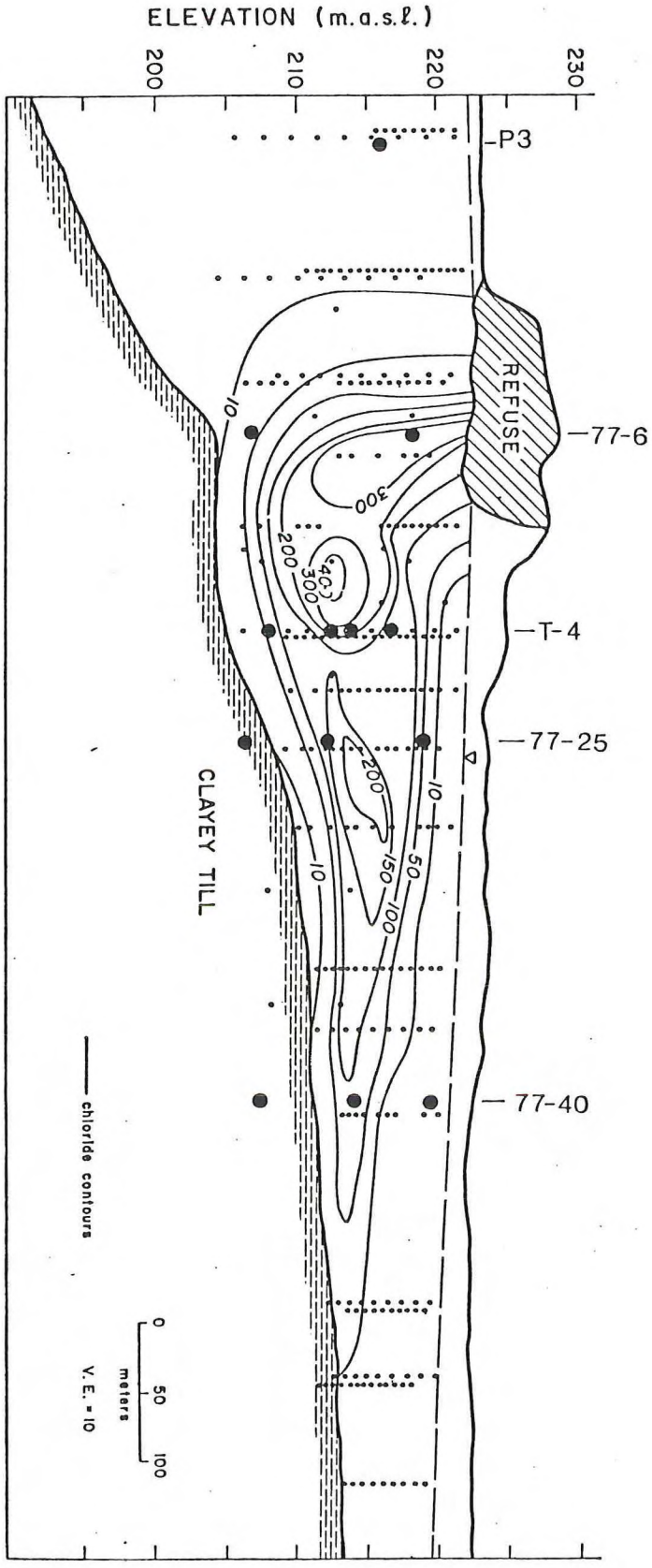
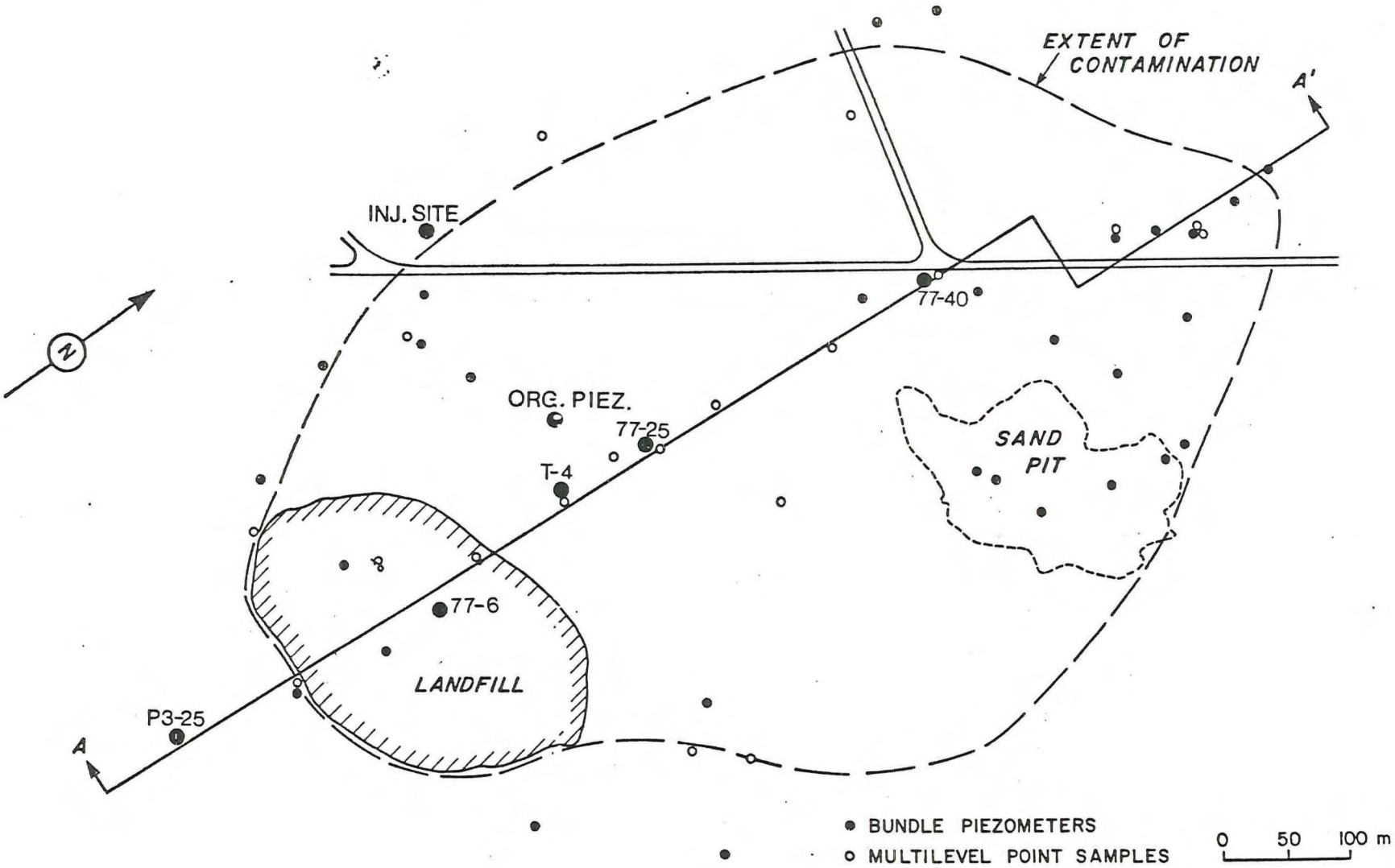
2000 SCAN
55:40 TIME


RIC
02/08/82 1:40:00
SAMPLE: N.BAY AAA-5 10/28/81 IS=9UG/L
RANGE: G 1,2300 LABEL: N 0, 4.0 QUAN: A 0, 1.0 BASE: U 20, 3
DATA: GCLS15 #1
CALI: GCAL282B #4
SCANS 150 TO 2000
100.0
RIC
355
4
5
15
686
32
1386
20
780
19
728
2
238
9
581
12
629
8
525
B
26
974
B
15
18a
17
B
17
874
B
A
C
3
7
455
6
13
16
D
28
1140
29
1209
1261
30
31
33
1482
34
1552
35
37
1656
38
1757
39
1842
500
16:40
1000
33:20
1500
50:00
2000 SCAN
66:40 TIME


WOOLWICH
LANDFILL
1974
1965
1973
1980
1982
1976
1980
1973
1975
WD
M-11
PDML
M-9
M-17
500
200
100
50
100
50
?
N
0 50 100 m

Cl^- CONTOUR


ELEVATION (m.a.s.l.)
200
210
220
230
P3
REFUSE
77-6
T-4
77-25
77-40
CLAYEY TILL
10
300
200
300
(AC)
200
10
150
50
100
10
chloride contours
0
50
100
meters
V. E. = 10


EXTENT OF CONTAMINATION
A'
INJ. SITE
77-40
N
ORG. PIEZ.
77-25
T-4
SAND PIT
77-6
LANDFILL
P3-25
A
BUNDLE PIEZOMETERS
MULTILEVEL POINT SAMPLES
0 50 100 m