Soil Gas Containing VOCs
Entering Homes Near
Hazardous Lands

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ABSTRACT

The entry of soil gas volatile organic compounds (VOCs) into houses has been recognized as a contributing factor in the degradation of indoor air quality. Typically, houses which are affected by soil gas VOCs are situated in close proximity to hazardous lands, i.e. landfill sites, lands affected by contaminated groundwater plumes, hydrocarbon spills, etc. Although there are hundreds of evaluations carried out yearly to assess the impact of soil-gas VOCs indoors, very few studies typically address the VOC concentration variability over time or the factors which influence this variability. Coupled to this problem is the presence of ubiquitous indoor or outdoor sources of VOCs. As a result of these difficulties, many investigations are far from accurate.

This study was designed to develop a practical protocol to evaluate the impact of soil gas VOCs on indoor air. The method used, monitored the temporal concentration variability of methane and oxygen in the ambient air and the subsurface as well as the driving forces which influenced the variability. Using this data, it was concluded that barometric fluctuations produced a bidirectional airflow across the subsurface envelope. By sampling VOCs indoors during high flux periods and during time periods when the airflow was directed towards the soil, the contribution of soil gas VOCs can be subtracted from other sources. This allows investigators the possibility of identifying the origin of VOCs found indoors, as well as allowing the completion of more accurate risk assessments.

DISCLAIMER

This study was conducted by CH2M HILL ENGINEERING LTD. for Canada Mortgage and Housing Corporation under Part IX of the National Housing Act. The analysis, interpretations, and recommendations are those of the consultants and do not necessarily reflect the views of Canada Mortgage and Housing Corporation or those divisions of the Corporation that assisted in the study and its publication.

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EXECUTIVE SUMMARY

The entry of soil gases such as radon, water vapour, methane and volatile organic compounds (VOCs) into houses has been recognized as a contributing factor to the degradation of indoor air quality. Although much has been learned about appropriate sampling methodologies and entry mechanisms of radon, methane and water vapour, relatively little has been published concerning VOCs under similar conditions. Typically, houses which are affected by soil-gas VOCs are situated in close proximity to hazardous lands, i.e. landfill sites, and lands affected by contaminated groundwater plumes, or hydrocarbon spills. The problem of VOC soil gas entry is widespread, especially near hydrocarbon spills on landfill sites; many investigations are carried out yearly.

Unfortunately many of these investigations show a general failure on behalf of investigators to account for VOC concentration variability, possibly due to a lack of knowledge of the mechanisms which affect soil gas entry. Coupled with this problem is also the presence of other ubiquitous indoor or outdoor VOCs, such as emissions from automobiles, vegetation, building materials, etc. The main problem with ubiquitous sources is that many of the compounds found in the environment resemble contaminants found in landfills, groundwater contamination, etc. This makes the task of assessing soil gas impacts from contaminated lands extremely difficult.

Because several VOCs, which typically occur in landfills, gasoline, etc. are known or suspected carcinogens at very low concentrations, a need arose to develop a precise but simple method for sampling and analysis of indoor air for the evaluation of soil gas sources. The approach used here incorporates basic knowledge of soil gas entry mechanisms, which are applicable for example for methane, coupled with an innovative approach to separate ubiquitous sources. This method will allow investigators to assess soil gas impacts with minimal analytical effort. This work was completed by CH2M HILL ENGINEERING LTD. for Canada Mortagage and Housing Corporation under a grant provided through the External Research Program.

The main cause of soil gas entry is due to elevated soil gas pressures underneath the building. Elevated soil gas pressures may result due to: declining barometric pressure, depressurization of basement by negative return ducts of forced air furnaces, stack effects (induced by indoor/outdoor temperature differences), etc. By sampling for VOCs at a time of soil gas influx, for example during a barometric pressure decline, the sample would contain contamination from indoor sources as well as soil gas sources. Conversely when the barometric pressure rises, airflow in the house is directed to the soil . If an air sample is retrieved at this time, contamination indoors would reflect typical indoor sources. By subtracting indoor contamination from contamination present during soil gas influx, the impact of soil gas VOCs can be evaluated. This technique was applied successfully to two unoccupied houses, one with significant soil gas entry, one with minimal soil gas entry.

Two factors which could further complicate the evaluation procedure in occupied houses includes: slow VOC desorption from surfaces inside houses, and to a lessor extent variable VOC background sources. These two factors were not addressed in the scope of this work. In order to overcome the dilemma caused by slow desorption, mass transfer models may be used to determine the appropriate time for sampling background concentrations. The second problem of variable indoor sources such as the use of cleaning solvents, etc. could be deliberately minimized during the testing period, or simply more background samples could be taken to evaluate this variability. Neither of these factors are insurmountable, however, they do remain to be tested.

The contribution of this research is two-fold. It will enable future investigators to optimize indoor air sampling strategies for the practical evaluation of soil gas entry. As well, it will allow investigators to complete more accurate risk assessments on houses affected by hazardous lands.

RESUME

L'infiltration de gaz souterrains tels le radon, la vapeur d'eau, le méthane et les composés organiques volatils (COV) à l'intérieur des habitations est reconnue comme facteur préjudiciable à la qualité de l'air. On en a certes appris beaucoup sur les méthodes d'échantillonnage appropriées et les mécanismes d'infiltration du radon, du méthane et de la vapeur d'eau, mais assez peu d'informations ont été diffusées au sujet des COV dans des conditions semblables. Généralement, les maisons touchées par les COV sont situées à proximité de terrains à risques, c'est-à-dire de décharges ou de terrains frappés par des panaches de nappe phréatique contaminée, ou des déversements d'hydrocarbures. L'infiltration des COV est répandue, surtout près des déversements d'hydrocarbures dans les décharges; bon nombre d'enquêtes s'y effectuent chaque année.

Malheureusement, bon nombre de ces enquêtes ne tiennent généralement pas compte de la variation de la concentration des COV, peut-être en raison du manque de connaissances des mécanismes influant sur l'infiltration des gaz souterrains. S'y ajoute la présence d'autres COV présents partout à l'intérieur ou à l'extérieur, comme les émanations provenant des automobiles, de la végétation, des matériaux de construction, etc. Le principal problème que posent ces substances omniprésentes, c'est que de nombreux composés que l'on retrouve dans l'environnement ressemblent à des polluants qui se retrouvent dans les décharges, les nappes phréatiques contaminées, etc. Cela rend la tâche d'évaluer les répercussions des gaz souterrains à partir des sols contaminés extrêmement difficile.

Puisque plusieurs COV, émanant généralement des décharges, de l'essence, etc., sont reconnus comme ou soupçonnées d'être cancérigènes à des concentrations très faibles, il a fallu élaborer une méthode précise mais simple d'échantillonnage de l'air intérieur et d'analyse de sa teneur en gaz souterrains. L'approche retenue ici fait appel à une connaissance fondamentale des mécanismes d'infiltration des gaz souterrains, valables notamment pour le méthane, juxtaposée à une méthode innovatrice de distinguer les substances omniprésentes. Cette méthode permettra aux enquêteurs d'évaluer les effets des gaz souterrains moyennant une analyse minimale. La firme CH2M HILL ENGINEERING LTD. s'est chargée d'exécuter ces travaux que lui avait confiés la Société canadienne d'hypothèques et de logement dans le cadre de son Programme de subventions de recherche.

L'infiltration des gaz souterrains est principalement causée par les pressions élevées des gaz souterrains sous un bâtiment, qui sont attribuables à la baisse de la pression

atmosphérique, à la dépressurisation du sous-sol du bâtiment que suscitent les conduits de reprise du générateur-pulseur, à l'effet de tirage (provoqué par l'écart des pressions intérieure et extérieure, etc.). En prélevant la teneur des COV lors de l'afflux des gaz souterrains, par exemple en période de baisse de la pression atmosphérique, l'échantillon prélevé renfermerait des contaminants de l'air intérieur et des gaz souterrains. Par contre, lorsque la pression atmosphérique monte, le mouvement d'air de la maison se fait en direction du sol. Le prélèvement d'un échantillon d'air en pareille circonstance refléterait la composition type des contaminants à l'intérieur. En soustrayant les contaminants intérieurs de ceux qui sont présents au cours de l'afflux des gaz souterrains, on peut évaluer l'incidence des COV des gaz souterrains. Cette technique a été appliquée avec succès dans le cas de deux maisons inoccupées, l'une ayant subi d'importantes infiltrations de gaz souterrains et l'autre peu.

Il existe deux facteurs susceptibles de compliquer davantage la méthode d'évaluation des maisons occupées : d'une part, la désorption lente des COV à partir des surfaces à l'intérieur des maisons, et, d'autre part, dans une moindre mesure, les sources variables des COV. La portée des présents travaux ne s'étendait pas à ces deux facteurs. Pour surmonter le dilemme causé par la faible désorption, les modèles de transfert massique peuvent servir à déterminer le temps approprié pour effectuer l'échantillonnage des concentrations de base. Le deuxième problème des sources variables intérieures, résultant notamment de l'emploi de solvants de nettoyage, etc., pourrait délibérément être réduit au cours de la période d'essai, ou simplement davantage d'échantillons de base pourraient être prélevées pour en évaluer la variabilité. Ni l'un ni l'autre de ces facteurs sont insurmontables, mais demeurent à être testés.

La contribution de cette recherche comporte deux volets. Elle permettra à d'autres enquêteurs d'optimiser les stratégies d'échantillonnage de l'air intérieur en vue d'une évaluation pratique de l'infiltration des gaz souterrains. De même, elle permettra aux enquêteurs de se livrer à des évaluations plus justes des risques dans les maisons touchées par des terrains à risque.

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Section 1
INTRODUCTION

STATEMENT OF THE PROBLEM

The entry of soil-gas pollutants into basements has been recognized as a contributing factor in the degradation of indoor air quality. Most of the current understanding of soil-gas entry into houses has been derived through research aimed at pollutants such as radon, methane, and water vapour. Although much has been learned about appropriate sampling methodologies and entry mechanisms of such gases, relatively little has been published concerning VOCs under similar conditions.

Typically houses which are affected by soil-gas VOCs are situated in close proximity to hazardous lands, ie. landfill sites (Walsh et al, 1987; Garbesi, 1988; U.S.EPA, 1988), near contaminated groundwater plumes (Schatz and Smith, 1990), or petroleum hydrocarbon spills (O'Connor et al, 1984; Dunlap, 1984). In addition to these studies, many more unpublished investigations are carried out yearly especially near gasoline spills, and landfill sites.

One of the most important lessons learned through the study of typical soil-gas pollutants (radon, methane) is that soil-gas concentrations indoors can be extremely variable in time and space. This variability are due to factors such as: the persistence of the source, the pressure differential across the sub-grade envelope, the size of the leakage area, and the air exchange rates (White, 1989). Unfortunately many investigations which have centred on the assessment of VOC entry, typically do not address or at least do not report on the concentration variability or the factors which influence this variability (CH2M HILL, 1992). This lack of detail concerning concentration variability may be due to financial constraints, the need for relatively sophisticated equipment, and a lack of trained personnel. Exceptions include more scientifically based studies carried out by Garbesi (1988) and Garbesi and Sextro(1988).

Coupled to the problem of variable concentrations is the presence of ubiquitous indoor and outdoor sources. Various ubiquitous VOC sources have been cited in the literature including: emissions from automobiles, industrial activity, natural vegetation (Rasmussen,1992), building materials, and activities of occupants (White et al, 1988; Pellizzari et al, 1987). Many of the compounds originating from these and other sources may be similar to those compounds typically detected in petroleum contaminated soil or landfills.

Several investigations have had an appreciation for the dilemma of ubiquitous sources and consequently have implemented various practical approaches. One approach is based on establishing concentration gradients between the ambient air in the basement, first and successive floor living spaces (e.g. Schatz and Smith, 1990). Providing the flux of contaminants into the house at the time of measurement is sufficiently high, and negligible ubiquitous sources are present, such an approach may be adequate to provide the necessary data. However, such conditions are rarely present. A second approach depends on source identification. Once the selected indicator compounds are found, sampling of the indoor air and analysis for the target compounds are carried out. Such an approach is commonly carried out for cases involving landfill gas infiltration. Although such an approach can be successful when coupled with knowledge of subsurface pathways, and well-defined pressure gradients (e.g. Garbesi, 1988), in most investigations where expedience is a requirement, such information is not available. When subsurface pathways or pressures are not well defined, when concentrations have been severely decayed or influenced by retardation, chemical reactivity and biological degradability, the evaluation of soil gas impacts becomes far more difficult.

OBJECTIVES

The objectives of this study were:

- to develop a practical protocol to evaluate the impact of soil gas VOCs on indoor air given typical concentration variability found indoors.
- to determine optimum sampling times for the evaluation of soil gas VOCs indoors, using ambient and sub-slab methane, and oxygen concentrations and pressures as indicators.

The potential contribution of this research is two-fold:

- to enable future investigators to optimize indoor air sampling strategies for the practical evaluation of soil gas entry (i.e. source identification); and
- to allow future investigators to complete more accurate risk assessments on houses affected by hazardous lands.

Section 2

METHODOLOGY

This research was conducted on a group of vacant townhouses in Kitchener, Ontario. The townhouses are currently owned by Canada Mortgage and Housing Corporation (CMHC) and have been the focus of previous research by CMHC Research Division (CH2M HILL, 1989; CH2M HILL, 1990a). The townhouse complex consists of 81 separate units, arranged in 14 different housing blocks ranging from 3 to 12 units per block. The layout of the site as well as locations of soil gas monitors used in this and previous investigations is shown in Figure 1. The houses are all two storey structures with full basements containing natural gas-fired water heaters and forced air furnaces. The houses are built out of wood frame construction with brick veneer, and have basements consisting of poured concrete walls and floors. Each basement contains a sump area, however, all sumps are dry and generally are capped with a plastic fitting.

The townhouse site is located on a site where previously a thin layer (~2 to 3 m) of municipal refuse had been deposited. Recognizing that methane could be a problem, passive vents connected to perforated drainage pipes, laid next to the building foundation, were installed at the time of construction to mitigate potential methane problems. However, the scheme proved unsuccessful, as methane was found to migrate indoors. Other remedial schemes such as gas collection systems on and around the site also proved inadequate.

Two housing units on the site were selected for this study, units 71 and 48. Prior to this study, two investigations by CH2M HILL (1989, 1990a) found that methane had infiltrated into both of these units. The highest observed methane concentration in unit 71 was 27,500 ppm; the highest observed methane concentration into unit 48 was 100 ppm in these two studies.

The approach to sampling for this study was developed on historical data from the above two studies (CH2M HILL 1989, 1990a) and from more recent specific unpublished data from unit 71 (CH2M HILL 1990b). All of the data indicated a high degree of variability in the indoor air concentrations. Primarily, the data from unit 71 suggested that soil gas influx was primarily due to pressure differentials induced by barometric fluctuations (Fugler and Adomait, 1991). Whenever barometric pressure declined rapidly, gas pressures relative to the indoor environment did not respond as quickly. Due to the time delay in response, the relative pressure gradient toward the basement envelope rose sharply, and large indoor methane concentrations were noted. Conversely, whenever a rapid rise in barometric pressure occurred, the soil gas pressure relative to the indoor air environment became negative indicating that the airflow was directed towards the soil. Accordingly, indoor methane concentrations decreased sharply. Measurement of oxygen in the soil gas under the floor slab also confirmed that the airflow direction was dependent on barometric pressures.

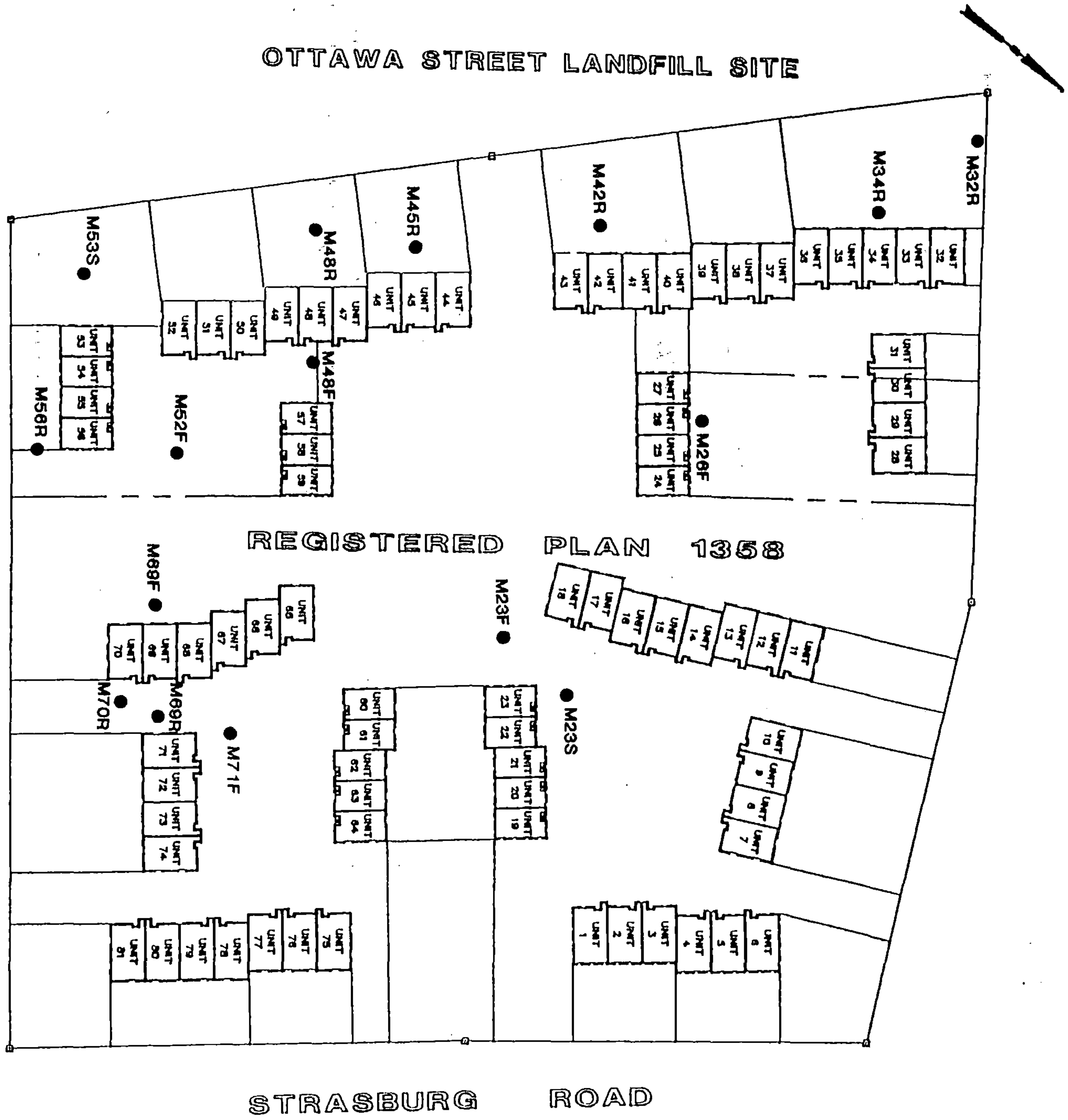

FIGURE 1:
SITE PLAN

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An understanding of the direction of airflow is important in monitoring the entry of soil gas VOCs. If the airflow is directed out of the building toward the soil, the VOC concentrations in the building will reflect indoor and inflowing outdoor VOC sources. However, if the airflow is directed towards the building envelope, VOC concentrations inside the building will reflect VOCs from indoor and soil gas sources. By sampling in both conditions, an estimate can be made for the soil gas impact on indoor air quality.

The concept of increased soil gas transport due to barometric pressure declines is certainly not new, however the application of the reverse process for the purposes of assessing background contamination has typically not been well researched. The use of barometric pressure changes for the purposes of evaluating background concentrations has the advantage of not only suppressing soil gases which might flow through the building envelope, but also limiting gases which may be released from soil surfaces in the immediate vicinity of the building. Since soil-gas emissions are minimized through landfill covers, during the period of rising barometric pressures (Bogner et al., 1987), a limited quantity of ambient contaminants will be available for entry into the building through windows, doors, etc.

It should be noted that the method of evaluation described here does not take into account the effect VOC adsorption onto surfaces inside the home. Although adsorption effects will complicate data interpretation, this problem is not insurmountable. Various mathematical models, such as used by Guo et al. (1992) which predict indoor concentrations once a source has been removed, could be used to dictate the time when a background sample should or should not be taken. If the soil-gas contaminants are present in high concentrations indoors or have extremely low desorption co-efficients, extended periods of rising barometric pressure may be necessary to achieve favourable background concentrations. In most cases however, where indoor concentrations are very low or desorption happens quickly, several air exchanges should be sufficient to achieve background concentrations.

The study was conducted in two phases. In the first phase, indoor methane concentrations, soil gas pressures relative to the indoor air environment, barometric pressures, indoor and outdoor temperatures were monitored continuously by a data logger described by Adomait and Gillham (1990). Indoor methane concentrations were based on average values; thorough mixing was accomplished with a continuously operating box fan. Periodic calibrations were carried out with portable equipment and oxygen concentrations below the floor-slab were also taken. All equipment used in this study are summarized on Table 1. Phase II commenced once the patterns for maximum/minimum soil gas entry were determined. The sampling of VOCs was conducted during periods of high influx (either when the stack effect or dropping barometric pressures were encountered), as well as when airflow was directed downward (during periods of rising barometric pressure). An additional sample of soil gas from underneath the floor was also submitted for VOC analysis. Ambient air samples were retrieved with evacuated stainless steel canisters; sub-slab air samples were retrieved with teflon tubing inserted into a small hole in the floor slab and connected to a stainless steel canister. Sub-slab samples were retrieved from only one

Table 1
List of Equipment Used in Monitoring Program

Instrument	Purpose
• Dwyer inclined Manometer; 0 - 62 Pa	pressure measurement
• Omega Px 163-00 5BD Pressure Transducer (-1244 to 1244 Pa)	continuous pressure measurement (used on soil gas probes M7OR, M69R, M48R, M48F)
• DJLP-003-A-1 Pressure Transducer (DJ Instruments Inc.) (-75 to 75 Pa)	continuous pressure measurement (used on sub-slab probes M71IA, M48IA)
• Century Organic Vapour Analyzer Model OVA 128; 0 - 10, 0 - 100, 0 - 1000 ppm	ambient indoor methane measurement
• Heath GMI Methane Detector; 0 percent LEL - 100 percent GAS	subsurface methane measurement
• Figaro Model TGS 813 Methane Sensor	continuous ambient indoor methane measurement
• Omega OL-703 Stainless Steel thermistor Probe	continuous indoor and outdoor temperature measurement
• National Mine Service Oxygen Detector	oxygen measurement
• Stainless Steel Air Sampling Canisters	analysis of VOCs
• SF_6 gas, Becton Dickenson 50 cc disposable syringe, 20 mL vacutainers	tracer tests
• Data Logger[2]	continuous recorder

Notes:

[1] Implementation of the Methane Detector is described in greater detail in Appendix B.
[2] Data Logger used in this application is described in greater detail by Adomait and Gillham (1990).

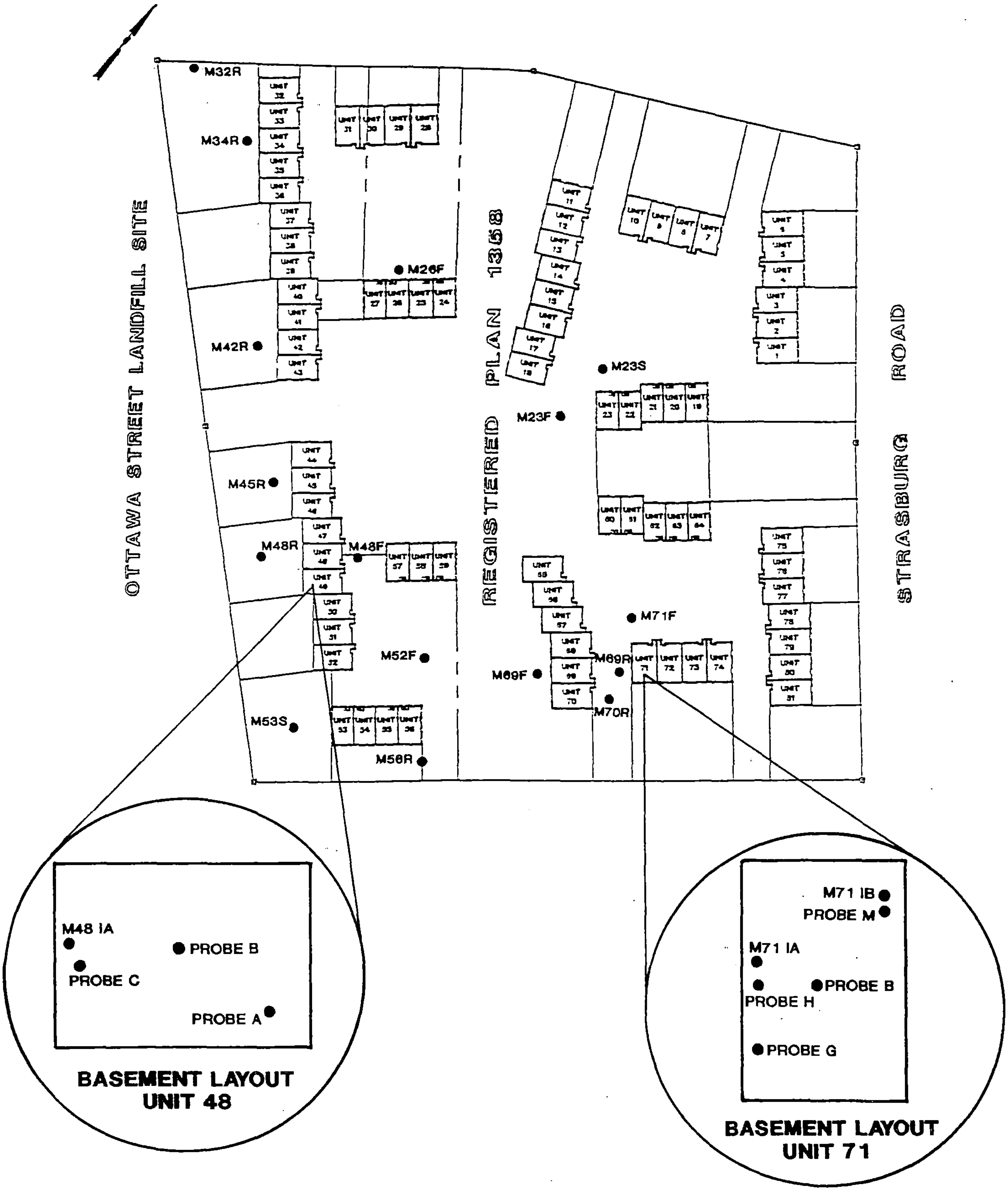
location in each unit. In total, 16 gas samples were analyzed for 41 VOCs listed in the USEPA TO-14 methods protocol (U.S. EPA, 1984). Many of the gases listed are typically found in and around landfill sites. Gas samples were submitted to Batelle Laboratories and analyzed by GC/MSD.

As part of a longer-term monitoring program at the Strasburg Road townhouses, indoor methane concentrations, inside and outside temperatures at unit 71, soil gas pressures (at three locations around/in the building envelope), and barometric pressures were monitored continuously. The three soil gas monitoring locations included a probe located 0.6 metres below the floor slab (M70IA), M69R and M70R which are located 2 and 5 metres respectively from the structure. Locations of soil gas monitors used in this study are shown in Figure 2. During the installation of the sub-slab probe and M69R, the subsurface geology was recorded. In the vicinity of unit 71, low permeability materials consisting of silts and clays overlay a coarse sand deposit. This coarse sand deposit was at the same elevation of the building foundations and intersected the sub-slab gravel layer of unit 71. Spot checks for methane, oxygen, temperatures, and pressures were also carried out weekly. When the formal monitoring program commenced in April 1991, the frequency of monitoring was increased slightly, and by early May, VOC sampling was initiated.

Based on the monitoring results, it was evident that pressure differentials induced by barometric changes were the principal cause for soil gas entry. Source concentrations also appeared to be affected by rainfall activity. VOC sampling in unit 71 was conducted during barometric lows (May 5) and also after significant rainfall activity (Oct. 10, 11). Methane concentrations were 4500, 7000, and 11500 ppm respectively on these three days.

In the second half of May 1991, the intensive monitoring began at unit 48. Two additional soil gas monitoring probes (M48F and M48R) were installed in the front and rear of unit 48. An additional probe M48IA was installed 0.9 m below the floor slab in unit 48. Refer to Figure 2 for locations. The subsurface geology was quite different compared to the subsurface near unit 71. In the vicinity of unit 48, higher permeability fine to medium sands were common for the top three metres of soil (Refer to Appendix D for geologic logs).

The initial monitoring results at unit 48 showed relatively low or non-detectable indoor and sub-slab methane concentrations at low or non-discernable pressures. Recognizing that methane, which was the most abundant soil gas contaminant, was present at such low levels, it was doubtful whether any quantifiable analysis with respect to trace VOCs would have been possible. As such, the vertical venting risers on the housing block, where unit 48 was located, were blocked near the end of May 1991. Over time, methane levels below the floor slab and indoors gradually rose. VOC sampling was conducted on June 14 and 22 when indoor methane levels rose as high as 28 and 200 ppm respectively in the early morning. From the data retrieved by the end of June 1991, diurnal variations caused by the stack effect appeared to control soil gas infiltration.



Note: Probes A,B,C,G,H,M are installed in the sub-slab gravel layer

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FIGURE 2:
LOCATION PLAN FOR SOIL GAS PROBES

The first evidence of barometric fluctuations was noted on July 28. However, given the infrequent barometric fluctuations recorded from July through August, the effects of barometric pumping could not be fully evaluated. Therefore more monitoring was completed. By September 1991, it became apparent that barometric influences were indeed a factor for methane entry into unit 48. VOC sampling was conducted in unit 48 coincident with declining barometric readings early in the morning of October 15. A barometric drop and the stack effect (caused by low outside and higher inside temperatures in the early morning hours) would have coincided at that time. The methane concentration at the time of VOC sampling was 700 ppm, well above any readings observed previously.

Air exchange rates were also conducted based on decay measurements of a hexafluoride (SF_6) tracer gas. Air exchange rates were completed by measuring the concentration of SF_6 within the basement ambient air at nearly all sampling periods for both units (71 and 48). Sampling for SF_6 was done without entering the premises by sampling ambient air through a small tygon tube inserted into the basement. Results were plotted and curve fitted with the use of MathCAD® software. Results are summarized in Appendix C.

Section 3
RESULTS

A considerable database was generated for both units 71 and 48. Table 2 summarizes the results of monitoring (detailed in Appendix A) for various indicator parameters. As seen on Table 2, indoor methane, soil gas pressure in the soil and sub-slab probes, and indoor and outdoor temperatures were measured continuously in unit 71 from February to mid-May 1991. At that time the data logger and sensors were transferred to unit 48. Continuous monitoring for most of the above mentioned parameters was continued in unit 48 until January 1992. Further spot checks in unit 71 for some parameters was also carried out in September and October 1991, coincident with greater barometric fluctuations. A brief overview of the monitoring results is given below.

Table 2
Summary of Monitoring Results from February 1991 to January 1992

	Indoor Methane		**Soil Probe Pressure**		**Sub-Slab Pressure**		**Sub-Slab Oxygen**		**Indoor/Outdoor Temperature**		**Barometric Pressure**
Unit #	**71**	**48**	**71**	**48**	**71**	**48**	**71**	**48**	**71**	**48**	-
February	✓		✓		✓		✓		✓		✓
March	✓		✓		✓		✓		✓		✓
April	✓		✓		✓		✓		✓		✓
May (1st half)	✓		✓		✓		✓		✓		✓
May (2nd half)		✓		✓		✓		✓		✓	✓
June		✓		✓		✓		✓		✓	✓
July		✓		✓		✓		✓		✓	✓
August		✓		✓		✓		✓		✓	✓
September	✓*	✓	✓*	✓	✓*	✓	✓	✓		✓	✓
October	✓*	✓	✓*	✓	✓*	✓	✓	✓		✓	✓
November		✓				✓		✓		✓	✓
December		✓				✓		✓		✓	✓
January (1st half)		✓				Þ✓		✓		✓	✓

Notes: Continuous monitoring was completed for indoor methane soil probe pressure, sub-slab pressure, indoor/outdoor temperatures, and barometric pressure.

*indicates occasions where parameters normally measured continuously were completed by spot checks.

Based on the monitoring of unit 71 during the period from February to May 1991, significant variations in indoor methane was discovered. The highest indoor levels recorded in this unit were a direct result of barometric fluctuations. Barometric declines as measured on February 13/14, 19, 22, March 6, 12, 17/18 and April 10, 21/22, all caused the influx of methane resulting in excessive concentrations on those days. In fact, methane levels indoors increased to levels of more than 1000 ppm, a criteria occasionally used to initiate some form of remedial action (CH2M HILL, 1992). Whenever barometric declines occurred on the above dates, increased soil gas pressures relative to the indoor environment were also noted at M70R, M69R, and M71IA. Positive soil gas pressures as high as 250, 525, and 450 Pa were observed at M70R on February 22, March 2, and April 21/22 respectively. Corresponding soil gas pressures underneath the floor slab at M71IA were measured at approximately 70, 80, and 70 Pa. Although subsurface oxygen concentrations were not available for all of the above dates, oxygen concentrations at M70R and M71IA (below the floor slab) on April 22, were less than 3 % by volume, typical of anaerobic environments.

Conversely, whenever a rapid rise in barometric pressure occurred, indoor methane concentrations declined. Such events were experienced on February 11, 15/16, 23, March 3, 5, 7/8, 15/16, 19/20 and April 2, 11, 16, 25. Barometric rises noted on the above dates caused negative pressures to develop in the subsurface. Negative pressures as low as -250, -375, and -380 Pa were measured at M70R during the months of February, March, and April respectively. Corresponding sub-slab pressures at M70IA were -40, -30, and -75 Pa respectively. Sub-slab oxygen measurements taken on February 16 indicated oxygen concentrations as high as 20%-by-volume a metre below the floor slab at M71IA. This was a positive indication that airflow was directed downward through the floor in unit 71.

Given the predictability of these results, VOC sampling was initiated on May 5 when another barometric decline occurred. The analytical results are shown in Table 3 for all detectable compounds identified in and under unit 71. Two samples were retrieved, one from the ambient basement air (A), the other from the sub-slab gravel layer (B). Contamination identified in sample A is a composite of indoor sources, soil gases entering the building envelope and ingested outdoor contamination. Although some of the outdoor contamination may have been due to soil gas emissions, the cumulative effect is what is of interest here. Actual contributions from each source could be obtained by retrieving an additional outdoor sample. The air exchange rate at the time of sampling was calculated at 0.72 air changes per hour.

Following the decline, the barometer rose again on May 7. Another indoor air sample was retrieved. The analytical results for sample C are shown on Table 3. The air exchange rate based on SF_6 decay was calculated at 0.48 air changes per hour.

Also shown on Table 3 are the analytical results from the October 10 and 11 sampling activity at unit 71. Due to significant rainfall activity on October 10 and declining barometric pressures on October 11, considerable soil gas was available for transport. Two sub-slab soil gas samples (D&F) were taken on October 10 and 11 to document the variability in concentrations of the target VOCs. As seen on Table 3, some variation did occur, however most values were within one order of magnitude of each other. Another indoor sample (E) was also taken on October 11; analytical results are shown on Table 3.

Table 3
Summary of VOC Analysis at Unit 71 (ppb)

Sample Number	A	B	C	D	E	F
Sample Location	amb.	sub.	amb*	sub.	amb.	sub.
Sample Date	May 5	May 5	May 7	Oct. 10	Oct. 11	Oct. 11
Sample Time	23:40	23:45	19:20	9:30	9:45	9:35
Air Exchange Rate (hr^{-1})	0.72	0.72	0.48	0.54	0.60	0.60
Methane Concentration (ppm)	4500	4500	3	7000	11500	11500
dichlorodifluoromethane	ND	ND	ND	350	9.54	400
methyl chloride	ND	ND	ND	ND	ND	0.7
1, 2-dichloro - 1,1,2,2-tetrafluoroethane	ND	3.24	ND	9.93	0.27	5.83
vinyl chloride	ND	24.7	ND	13.1	ND	16.47
1, 3-butadiene	ND	ND	ND	30.6	ND	115
ethyl chloride	20.3	3530	ND	4070	55.0	3270
trichlorofluoromethane	ND	ND	ND	ND	0.61	ND
1, 1-dichloroethene	ND	2.32	ND	2.24	ND	2.17
dichloromethane	ND	3.48	ND	8.02	0.50	ND
1, 1-dichloroethane	0.94	133	ND	147	2.37	142
cis - 1, 2-dichloroethene	ND	8.68	ND	43.0	0.23	59.4
trichloromethane	ND	0.85	0.68	8.54	0.10	2.14
1, 2-dichloroethane	ND	ND	ND	3.71	ND	5.59
1, 1, 1-trichloroethane	ND	ND	ND	ND	0.30	ND
1, 2-dichloropropane	ND	ND	ND	ND	ND	0.23
benzene	1.41	15.6	1.47	88.0	2.15	134
trichloroethene	ND	ND	ND	0.14	ND	0.20
toluene	1.68	2.31	0.99	0.24	1.53	1.10
tetrachloroethene	ND	0.36	ND	ND	ND	ND
chlorobenzene	ND	ND	ND	ND	ND	0.40
ethylbenzene	ND	ND	ND	ND	0.25	ND
m&p - xylene	ND	0.43	0.38	ND	0.68	ND
o - xylene	ND	ND	ND	ND	0.27	ND
1, 2, 4-trimethyl benzene	ND	ND	ND	ND	0.18	ND

Notes: * indicates that ambient basement air was sampled when airflow was directed towards the soil.
ND implies concentrations less than 0.1 ppb

The investigation of unit 48 was begun in mid-May 1991. As indicated previously, two soil gas monitors M48F and M48R, and one sub-slab probe M48IA were also installed. Monitoring of these newly installed outdoor monitors revealed consistent oxygen and methane concentrations for the entire May 1991 to January 1992 monitoring period. Monitor M48F had consistently low methane concentrations between of 0 to 50 ppm and 14.2 to 14.6 percent oxygen. Monitor M48R (at the rear of unit 48) had methane concentrations of 19 to 25 percent and oxygen >1.9 percent by volume. Any landfill soil gases, therefore, would likely enter via the rear side of the unit.

As indicated previously, the initial monitoring results at unit 48 showed relatively low or non-detectable indoor and sub-slab methane concentrations. From May 22 to June 11, methane concentrations indoors never exceeded 100 ppm. However, with the passive vents blocked, both sub-slab and indoor concentrations rose. The monitoring results for sub-slab methane for June (Appendix A) show an increase from 2 to 24 percent by volume in M48IA. Oxygen concentrations in M48IA dropped accordingly to approximately the 10 percent range. By August 1991, monitoring results in monitor M48IA (albeit variable), tended to vary between 20 to 30 and 4 to 10 percent for methane and oxygen respectively. In probe C installed in the sub-slab gravel layer, methane and oxygen tended to vary between 1 to 16 and 10 to 18 percent respectively. Probe B had significantly less methane (0 to 4 percent) and higher oxygen (7 to 19 percent). Probe A typically had negligible methane (<100 ppm) and some variation in oxygen levels (12 to 20 percent).

During the early stages of monitoring at unit 48, it was apparent that the stack effect was the main driving mechanism for soil gas entry. The diurnal cyclical pattern of indoor methane concentrations induced by the stack effect was observed in June and early July 1991. The monitoring data for this period (in Appendix A) shows very little correlation with barometric pressure changes but good agreement with the stack effect induced by temperature gradients. Monitoring results of sub-slab oxygen concentrations especially in probes C and B also showed similar patterns.

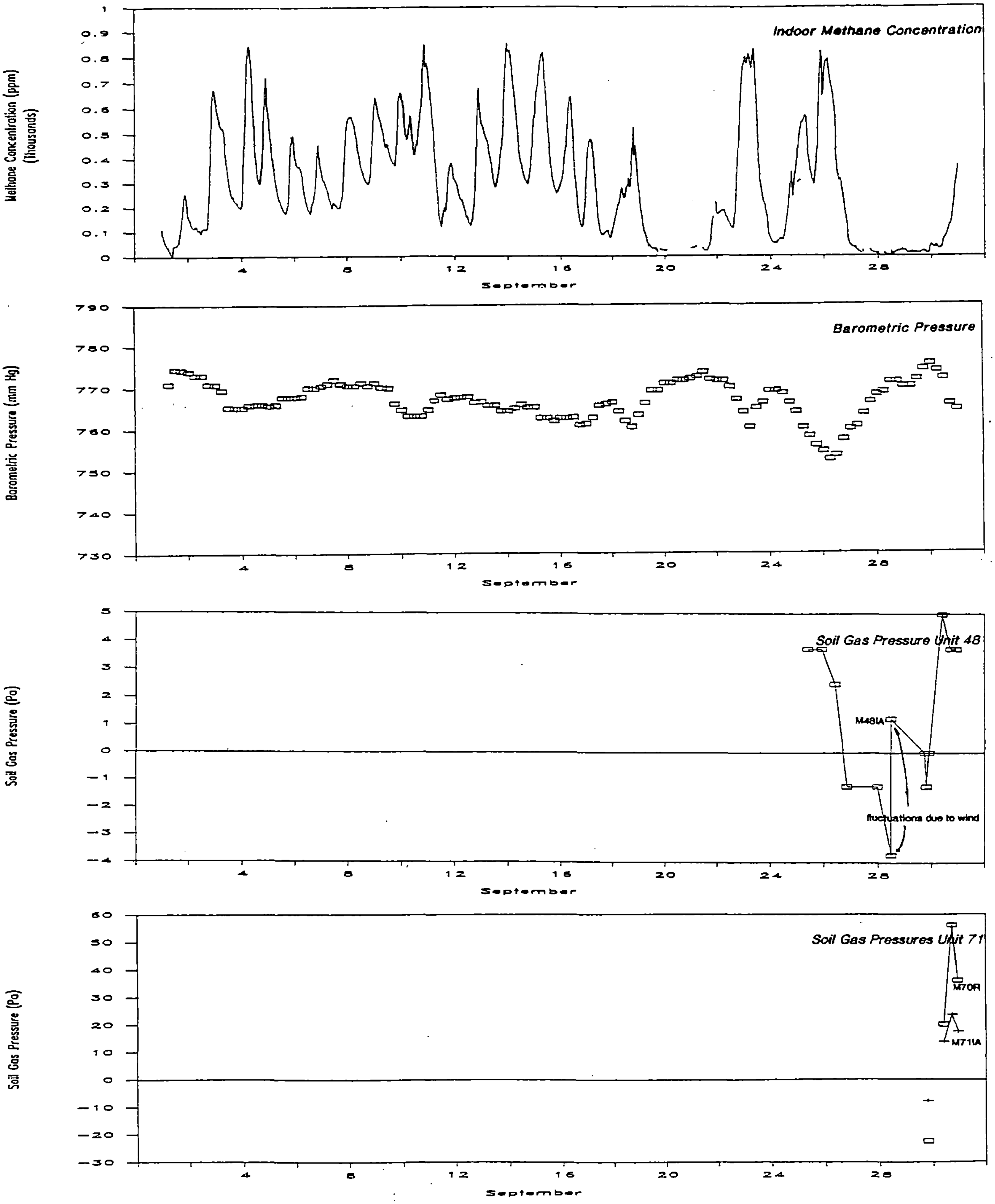
The first evidence of the barometric influence was observed on July 28. Coincident with a barometric drop, a large rise in indoor and sub-slab methane (at M48IA, probes C and B) and a sharp decline in sub-slab oxygen in probes M48IA, C and B were experienced. Similar results were also observed in varying degrees of magnitude on August 8, September 22, 25, 30, October 5, 11, and 15.

Although the indoor methane and sub-slab oxygen concentrations recorded were predictable relative to barometric pressure, the soil gas pressure data showed less predictability. Because of low soil gas pressures, and the inability of the instrumentation to measure at such low levels, the continuous pressure data could not be used to substantiate soil gas influx. For the monitoring period from May to October, 1991, continuous pressures recorded at M48R typically fluctuated around zero Pascals, well within the instrument temperature, null and sensitivity error of ±12 Pascals. Results from M48F are not displayed in the appendices, but were similar to results obtained at M48R. The results from sub-slab probe M48IA were not much better even though a more sensitive pressure transducer was used. Although slight sub-slab pressure increases were noticed with barometric declines on August 4, 14, September 12 and 14, consistent zero shift problems made much of the data from M48IA unreliable. The low soil gas pressures documented were likely due to the higher permeability soil column at unit 48, as well the large weeping tile located at the building foundations.

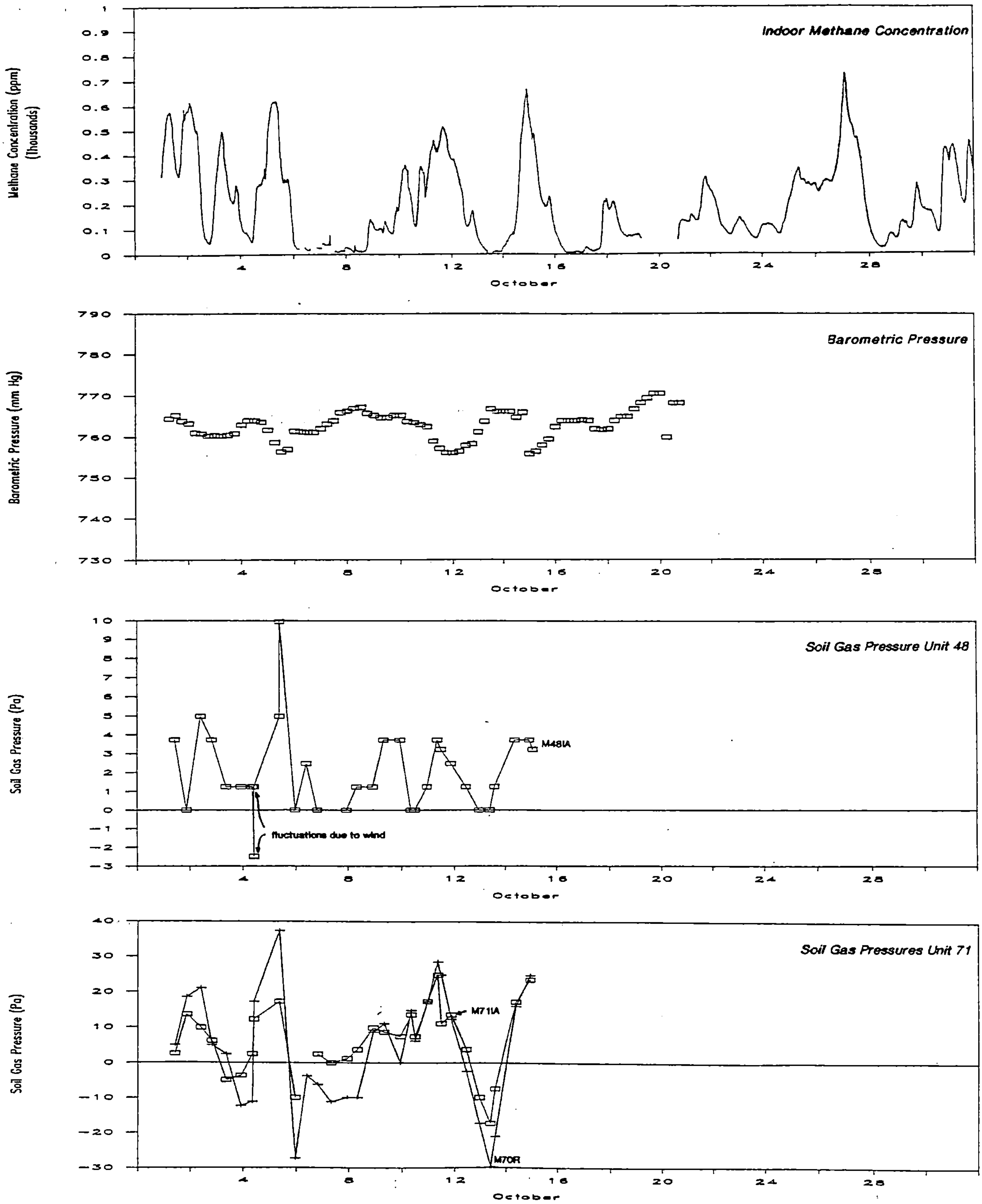
Because of the problems discussed above, a more intensive monitoring program involving spot measurements with an inclined manometer in units 48 and 71 was implemented in late September, October and December 1991. Selective data is shown graphically on Figures 3, 4 and 5 for these three months. Based on the data shown here, the sub-slab pressures in unit 71 again correlated well with barometric pressure changes. The data from unit 48 however was not as comparable. Although barometric declines, on September 30, October 5, 11, and 14, registered discernable positive pressures and corresponding elevated indoor methane concentrations in units 48 and 71, the reverse effect was not as apparent. Only a slight negative pressure developed in the sub-surface on September 27/28 due to a barometric rise of 3.7 kPa over a 48 hour period. Other smaller barometric rises on October 6, and 13 produced no measurable negative sub-slab pressure below unit 48 which was quite different than the conditions underneath unit 71 on those dates. Two other barometric rises (one small, one large) caused negative sub-slab pressures on December 9 and 18. The December data was likely influenced by frozen or wet soil surfaces in that month.

The importance of actually observing negative soil gas pressures in the subsurface was critical for the purpose of positively identifying airflow direction towards the soil. Although the monitoring of methane and oxygen does provide good qualitative data on airflow direction, there is no definable concentration values for methane and oxygen which would guarantee that the airflow was directed towards the soil. As seen from the above presentation of the results, a downward flow direction had occurred on September 27/28 when negative pressures were observed in the subsurface. For the other dates however, positive identification was not absolutely possible even when low indoor methane levels, and high sub-slab oxygen concentrations implicated downward flow. Fortunately as it turns out, no significant differences were observed in the VOC background samples to cause concern about sample integrity.

VOC samples were collected from essentially two periods: a period when the stack effect was prevalent (June), and when barometric influences were encountered (September/October). In total ten VOC air samples were analyzed; the analytical results are shown on Table 4. One ambient, and one sub-slab air sample were taken early in the morning on June 14, and 22 respectively when the stack effect was prevalent. One background sample was taken on June 24 in the afternoon. However given the elevated indoor concentration (42 ppm), a fan was connected to the indoor air for pressurization and disconnected two hours before sampling. With low indoor methane (4 ppm) and presumably few soil-gas VOCs present, sample F was obtained. No significant difference was evident between samples E and F given the detection



CH2M HILL ENGINEERING LTD. WATERLOO ONTARIO	**FIGURE 3:** **MONITORING DATA FOR UNIT 48 AND SOIL GAS PRESSURE (UNIT 71) FOR SEPTEMBER 1991**
PROJECT No. ONT29477.AO	



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PROJECT No. ONT29477.AO

FIGURE 4:
MONITORING DATA FOR UNIT 48 AND SOIL GAS PRESSURE (UNIT 71) FOR OCTOBER 1991

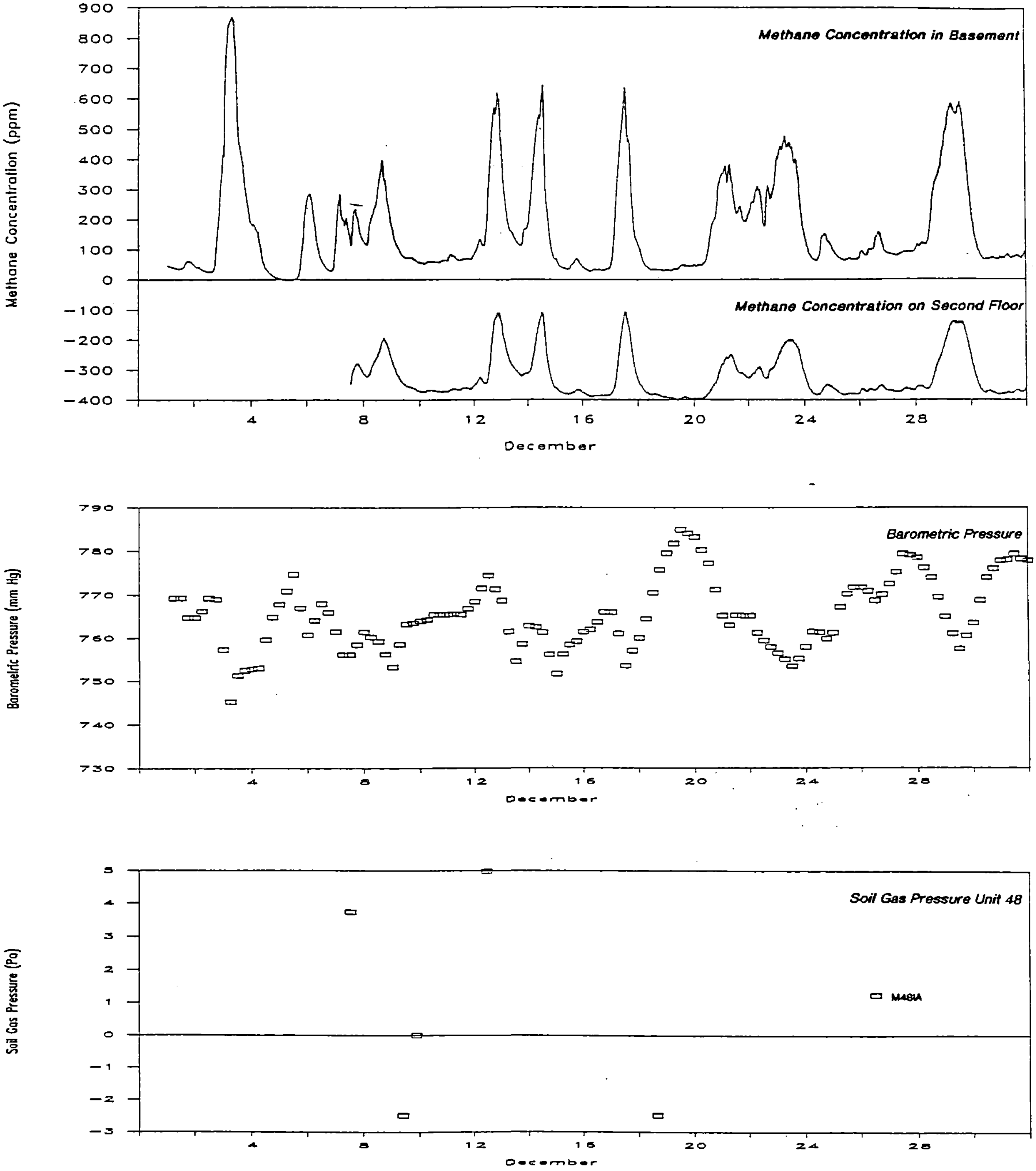

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FIGURE 5:
MONITORING DATA FOR UNIT 48 FOR DECEMBER 1991

Table 4
Summary of VOC Analysis at Unit 48 (ppb)

	A	B	C	D	E	F	G	H	I	J
Sample Location	amb.	sub.	amb.	sub.	amb*	amb.*	amb.*	amb.*	amb.	sub.
Sample Date	June 14	June 14	June 22	June 22	June 24	June 25	Sept. 29	Oct. 13	Oct. 15	Oct. 15
Sample Time	1:35	1:40	5:20	5:22	17:10	14:22	19:55	13:30	1:45	1:50
Air Exchange rate (hr^{-1})	0.36	0.36	0.54	0.54	0.24	0.36	0.48	--	0.6	0.6
Methane Concentration (ppm)	28	28	200	200	42	4	5	8	700	700
dichlorodifluoromethane	ND	ND	ND	ND	ND	ND	0.67	0.45	1.67	63.8
methyl chloride	ND	ND	ND	ND	ND	ND	0.95	0.34	ND	13.6
1,2-dichloro-1,1,2,2-tetrafluoroethane	ND	ND	ND	13.3	ND	ND	ND	ND	0.30	25.1
ethyl chloride	ND	ND	ND	194	2.70	2.75	3.67	ND	5.33	879
trichlorofluoromethane	0.62	ND	0.72	0.55	0.69	0.49	0.50	0.60	0.60	1.88
dichloromethane	0.94	0.39	ND	1.71	1.92	ND	ND	0.50	0.25	ND
1,1,2-trichloro-1,2,2-trifluoroethane	ND	ND	ND	ND	0.47	ND	0.11	ND	0.11	ND
1,1-dichloroethane	ND	0.25	ND	3.95	ND	ND	ND	ND	ND	10.0
cis-1,2-dichloroethene	ND	0.45	ND	ND	ND	ND	ND	ND	ND	ND
trichloromethane	ND	ND	ND	0.30	ND	ND	ND	ND	ND	0.73
1,1,1-trichloroethane	0.34	0.27	0.96	0.30	0.86	0.50	0.19	ND	0.46	4.06
benzene	1.04	0.68	1.31	2.27	1.35	1.01	0.93	0.97	1.10	9.10
carbon tetrachloride	ND	ND	ND	ND	ND	0.26	0.49	0.10	0.12	ND
trichloroethene	ND	0.18	ND	ND	ND	ND	ND	ND	ND	0.35
toluene	2.24	2.71	2.58	ND	2.61	1.40	0.84	1.15	0.81	0.92
tetrachlorethene	ND	0.38	0.20	0.28	0.19	ND	ND	ND	ND	0.25
chlorobenzene	ND	ND	0.15	0.23	0.37	0.57	0.95	ND	ND	ND
ethylbenzene	0.21	0.17	0.28	ND	0.25	0.24	0.13	0.13	0.14	0.33
m&p-xylene	0.75	0.57	0.83	ND	0.72	0.60	0.38	0.18	0.40	1.17
o-xylene	0.31	0.21	0.27	ND	0.28	0.20	0.13	ND	0.12	0.46
1,2,4-trimethyl benzene	0.20	0.17	0.24	ND	0.18	0.12	ND	ND	0.12	0.22
vinyl chloride	ND	ND	ND	ND	ND	ND	ND	ND	ND	2.27
1,3-butadiene	ND	ND	ND	ND	ND	ND	ND	ND	ND	2.08
1,1-dichlorethene	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.52
3-chloropropene	ND	ND	ND	ND	ND	ND	ND	ND	ND	11.6
1,2-dichloroethane	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.27
p-dichlorobenzene	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.48

Notes:
* indicates that ambient basement air was sampled when airflow was directed towards the soil
ND implies concentrations less than 0.1 ppb

limits used. Source identification will be discussed in the next section of this text. Air exchange rates based on SF_6 decay were calculated to be between 0.24 to 0.54 air changes per hour.

The final set of samples included two background (G&H), one indoor (I), and one sub-slab (J). Both background samples were taken at a time when relatively low indoor methane (5 and 8 ppm), high oxygen (18.5 and 18.5 percent) concentrations in probe C, and sub-zero or zero sub-slab soil gas pressures existed. The barometric decline on October 15 brought in positive soil gas pressures, low sub-slab oxygen concentrations, elevated indoor methane concentrations, and as seen on Table 4, a host of several VOCs including vinyl chloride, 1,3-butadiene, etc. not identified previously around unit 48 (refer to Sample J).

Section 4
ANALYSIS AND DISCUSSION

Two different scenarios of soil gas entry were examined in this study: one case involved a well defined airflow across the building envelope (i.e. unit 71), the other a more difficult case where airflow direction was not as discernable (i.e. unit 48). The analysis and discussion of VOC entry into each unit will be dealt with separately.

Unit 71

Historical data from unit 71 has long shown that soil gas entry in the form of methane has occurred. As expected, other gases such as trace VOCs have also impacted the indoor air quality. Table 3 lists 24 different trace compounds identified in and around unit 71 during this study. This includes a number of known trace landfill compounds including: 8 most commonly identified chemicals (benzene, ethylbenzene, toluene, vinyl chloride, dichloromethane, trichloroethylene, 1,2-cis dichloroethylene, and tetrachloroethylene) found in 63 landfills in California (California Waste Management Board, 1989), as well as additional trace compounds found elsewhere (California Waste management board, 1989; Behrmann et al., 1989; Young and Heasman, 1985; Vogt, 1985). Only 1,3-butadiene, which was found in the subsurface, has not been identified in the references given above. Given this comparison, it is possible, especially for the chlorinated compounds, that much of VOC contamination indoors may be due to landfill sources.

Despite the large number of compounds which were identified in and around unit 71, not all of the compounds present may be in sufficient quantities or chemically stable to have potential impacts on the indoor air. As seen on Table 3, only a few of the compounds identified were detected within the indoor air at the detection limits specified. Table 5 lists the compounds which were detected indoors in unit 71 and May 5, and October 11, 1991. The background concentration listed was determined based on the May 7 sampling round (Table 3). The results from both dates will be discussed separately; discussion of the May 7 results will take place first.

Theoretically, by subtracting the background concentration from the concentration of the sample taken during gas influx, the contribution of soil gases could be determined. Column 3 of Table 5, the corrected value, displays this number. If the background value was non-detectable, i.e. <0.1 ppb, a value of zero was assigned to the background. As seen on Table 5, several compounds from the May 5 sampling event may be regarded as soil gas sources: ethyl chloride, 1,1-dichloroethane, and toluene. Benzene appeared at an approximate concentration level of background, thereby having a corrected concentration of less than zero.

Another calculation was performed whereby the corrected concentration was divided by the sub-slab concentration. As shown on Table 5, a ratio was calculated. This ratio actually has physical significance; it represents a dilution factor of subsurface VOCs in the indoor air. If subsurface VOC compounds appear in consistent ratios under the entire floor slab, transfer indoors in a similar fashion (i.e. are not differentially adsorbed or impeded by the concrete), are not significantly adsorbed, chemically or biologically degraded, and are not subject to large sampling or analytical errors, the ratio should appear reasonably consistent. As seen on Table 5 for the May 5 sample, ethyl chloride and 1,1-dichloroethane may be regarded as having similar ratios given that both compounds had significant concentration decreases from sub-slab to ambient air. Toluene, on the other hand, did not display the large concentration decreases, and as such the ratio was significantly different. This suggests that the assigned background concentration of 0.69 ppb may been too low, given that outdoor toluene levels typically vary especially with automobile traffic. Comparing the sub-slab toluene value of 2.31 ppb with that of 1,1-dichloroethene at a sub-slab concentration of 2.32 ppb, or benzene (a structurally similar compound) at a sub-slab concentration of 15.6 ppb, and not detecting migration indoors of the latter compounds, it may be concluded that toluene present indoors was not due to soil gas influx.

Table 5
Summary of Influx Calculations for Unit 71

	Measured Concentration	Range of Background Concentration	Corrected Concentration	Sub-Slab Concentration	Ratio
May 5					
ethyl chloride	20.3	<0.1	20.3	3530	.066
1,1-dichloroethane	0.94	<0.1	0.94	133	.007
benzene	1.41	1.47	<0	15.6	<0
toluene	1.68	0.99	0.69	2.31	0.299
October 11					
dichlorodifluoromethane	9.54	<0.1	9.54	350/400	.027/.024
1,2-dichloro-1,1,2,2,-tetra-fluoroethane	0.27	<0.1	0.27	9.93/3.83	.027/.046
ethyl chloride	55.0	<0.1	55.0	4070/3270	.014/.017
trichlorofluoromethane	0.61	<0.1	0.61	<0.1	-
dichloromethane	0.50	<0.1	0.5	8.02/<0.1	.062/-
1,1-dichloroethane	2.37	<0.1	2.37	147/142	.016/.017
cis-1,2-dichloroethene	0.23	<0.1	0.23	43.0/59.4	.005/.004
trichloromethane	0.10	0.68	<0	8.54/2.14	<0
1,1,1-trichloroethane	0.30	<0	0.30	<0.1	-
benzene	2.15	1.47	0.68	88.0/134	.008/.005
toluene	1.53	0.99	0.54	0.24/1.10	2.25/.491
ethylbenzene	0.25	<0.1	0.25	<0.1	-
m&p-xylene	0.68	0.38	0.30	<0.1	-
o-xylene	0.27	<0.1	0.27	<0.1	-
1,2,4-trimethylbenzene	0.28	<0.1	0.28	<0.1	-

Notes: Ratio is calculated by dividing corrected concentration by sub-slab concentration. If sub-slab concentration is lower than detection limit (<0.1 ppb), a <0.1 value is assigned to the sub-slab concentration. At such times, the ratio is undefined.
Since two sub-slab samples were taken, two concentration values appear. This translates into a range of values under the ratio column.

The data from the October 11 sampling event and similar calculations are shown on Table 5. Consistent with higher indoor methane levels, a large number of additional VOCs have also been detected indoors. Subtracting out the background compounds based on the May 7 sample, which may or may not be appropriate depending on the variability of indoor/outdoor sources, many of the VOCs are present due to soil gas sources, as determined by the "corrected concentrations". The ratio shown on Table 5 is based on the corrected concentration divided by the concentrations of two sub-slab samples taken on October 10 and 11, 1991. Most of these ratios have values between 0.004 and 0.046 (one order of magnitude difference), with several outlying values of 0.062, 2.25, 0.491 as well as some which are negative or undefined. For those ratios between .004 and .046, the positive concentration gradient towards the indoor environment supports the origin of the contamination. It is interesting to note, that benzene has increased to such levels that its influence on indoor air can now be detected.

Several of the identified indoor compounds on October 11 listed on Table 5 do not implicate soil sources. Those compounds with values outside of the .004 to .046 range do not appear to originate directly from the soil gas. Dichloromethane with a ratio 0.062 although likely due to landfill sources may have been present in the outdoor air. This compound was identified in the background sample at unit 48 on October 13 at 0.5 ppb (Table 4). If an additional background sample around October 11 would have been taken, this problem may not have arisen. Other compounds with ratios less than zero have indoor concentrations less than background; compounds with ratios which are undefined have sub-slab concentrations less than indoor/outdoor sources - not soil gas sourced.

Unit 48

The analyzed data from unit 48 is much different from that of unit 71 because of the much lower concentrations present. Those compounds which were detected indoors are listed on Table 6 for all three sampling dates June 14, 22 and October 15. The range of background concentrations based on June 24 and 25 were compared with the June 14 and 22 analysis, whereas the background concentrations from September 29 and October 13 were compared with data from the October 14 sampling event. Some minor variations in background exist for compounds such as ethyl chloride, toluene, and m & p-xylene. Given that two background samples were collected for each sampling date, corrected calculations were calculated by subtracting the highest background concentration of each contaminant determined for each period.

As shown on Table 6, the corrected concentrations for the June 14 sampling event indicated that much of the contamination found indoors was attributable to background sources. With sub-slab VOC concentrations all less than 2.71 ppb, it is unlikely that VOC soil gases would be found indoors given typical dilution ratios calculated previously. With corrected concentrations well below the detection limit of 0.1 ppb, it may be concluded that soil gas VOCs did not impact the indoor ambient air. The definition of impact is based on a detection limit of 0.1 ppb. Because the values are at are below detection limits, it is not advisable to calculate the ratios.

Table 6
Summary of Influx Calculations for Unit 48

	Measured Concentration	Range of Background Concentration	Corrected Concentration	Sub-Slab Concentration	Ratio
June 14					
trichlorofluormoethane	0.62	0.49 - 0.69	<0	<0.1	
dichloromethane	0.94	<0.1 - 1.92	.02	0.39	
1,1,1-trichloroethane	0.34	0.5 - 0.86	<0	0.27	
benzene	1.04	1.01 - 1.35	<0	0.68	
toluene	2.24	1.40 - 2.61	<0	2.71	
ethylbenzene	0.21	0.24 - 0.25	<0	0.17	
m&p-xylene	0.75	0.60 - 0.72	.03	0.57	
o-xylene	0.31	0.20 - 0.28	.03	0.21	
1,2,4-trimethylbenzene	0.20	0.12 - 0.18	.02	0.17	
June 22					
trichlorofluoromethane	0.72	0.49 - 0.69	.03	0.55	
1,1,1-trichloroethane	0.96	0.5 - 0.86	.1	0.30	
benzene	1.31	1.01 - 1.35	<0	2.27	
toluene	2.58	1.40 - 2.61	<0	<.1	
tetrachloroethene	0.20	<0.1 - 0.19	.01	0.28	
chlorobenzene	0.15	0.37 - 0.57	<0	0.23	
ethylbenzene	0.28	0.24 - 0.25	.03	<0.1	
m&p-xylene	0.83	0.60 - 0.72	.11	<0.1	
o-xylene	0.27	0.20 - 0.28	<0	<0.1	
1,2,4-trimethylbenzene	0.24	0.12 - 0.18	.06	<0.1	
October 15					
dichlorodifluoromethane	1.67	0.45 - 0.67	1.0	63.8	0.016
1,2-dichloro-1,1,2,2,-tetra-fluoroethane	0.30	<0.1	0.3	25.1	0.012
ethyl chloride	5.33	<0.1 - 3.67	1.66	879	0.002
trichlorofluoromethane	0.60	0.5 - 0.6	0	188	0
dichloromethane	0.25	<0.1 - 0.5	<0	<0.1	<0
1,1,2-trichloro-1,2,2-trifluoro-methane	0.11	<.01 - 0.11	0	<0.1	<0
1,1,1-trichloroethane	0.46	<0.1 - 0.19	.27	4.06	0.067
benzene	1.10	0.93 - 0.97	.13	9.10	0.014
carbon tetrachloride	0.12	0.10 - 0.49	<0	<0.1	<0
toluene	0.81	0.84 - 1.15	<0	0.92	<0
ethylbenzene	0.14	0.13 - 0.13	.01	0.33	0.030
m&p-xylene	0.40	0.18 - 0.38	<0	1.17	<0
o-xylene	0.12	<0.1 - 0.13	<0	0.46	<0
1,2,4-trimethylbenzene	0.12	<0.1	.12	0.22	0.545

As soil gas concentrations increased below the floor slab, the corrected concentrations for June 22 were slightly elevated over the June 14 values. Although several compounds such as 1,1,1-trichloroethane and m & p-xylene are at the detection limit, because of the possibility of analytical error it cannot be concluded that the presence of such compounds are attributable to soil gas sources. It is not advisable to calculate ratios.

By October 15, the presence of several additional VOCs was detected beneath unit 48, as seen on Table 4. As a result, an increase in the number of VOCs was detected indoors (Table 6). Several VOCs from the October 15 sampling event had corrected values above the detection limit including: dichlorodifluoromethane (F12), 1,2-dichloro-1,1,2,2-tetrafluoroethane (F114), ethyl chloride, 1,1,1-trichloroethane, benzene, and 1,2,4-trimethyl benzene. The calculated ratios range from 0.002 to 0.067 with several outliers including: 0.545, and some values less than zero. The fact that 1,2,4-trimethylbenzene had a ratio of 0.545 may be due to its low measured concentration indoors, i.e. at the detection limit of the analytical equipment. Compounds with ratios less than zero have concentrations less than background; this implies other indoor/outdoor sources.

Summary

Based on the presentation of the above results, it does appear that the method of analysis does have some potential for the evaluation of indoor air quality near hazardous lands. In order to ensure success however, several critical components are necessary. These are discussed below.

1. Definition of airflow direction

As seen in this study, several parameters which were monitored were useful for the determination of airflow direction including methane, oxygen, and pressure, as a response to barometric or stack effects. Although methane and oxygen were useful as qualitative parameters for determining direction, the monitoring of such parameters may not always give absolute information on airflow direction. Therefore the inclusion of pressure, no matter how low, is absolutely essential. As seen in this study, especially in the case of unit 48, a definitive representation of background air quality depended on observing negative pressures in the subsurface. To obtain such a result, the use of precision instruments, no matter how labour intensive, may be necessary to obtain such a result.

2. Appreciation for Temporal Variability of Other Sources

One area which was not examined as part of this study was the variability of other sources. Temporal variability of other indoor or outdoor sources could cause difficulties in the interpretation of data especially if indoor or outdoor sources were elevated during periods of soil gas influx. Restricting indoor activities or taking additional outdoor samples would eliminate or help define potential problems, however knowledge of interfering conditions is not always possible. At minimum, the investigator should be aware of possible interferences, and should be prepared to make adjustments to the sampling program.

The problem of temporal varability of other sources can be minimized if more than one contaminant is present in the subsurface, which is most often the case. If elevated contaminants are present indoor due to other than soil-gas sources, calculation of the dilution ratio should reveal an anomoly.

3. Appropriateness of Detection Limits

Typically investigations of this sort are aimed at assessing impacts and risks on human health. In order to conduct a proper assessment, appropriate sampling procedures, at maximum influx periods, and good analytical methods are necessary achieve the required result. This study focused primarily on the timing of the sampling. Any investigator should be aware however that the sampling and analytical procedure must be geared to produce detection limits which can be used in a meaningful way. The sampling and analytical procedure used in this study, though appropriate for many TO-14 compounds, may not necessarily produce the best detection limits for other compounds of interest.

Section 5
CONCLUSIONS

The objectives of this study, as outlined in Section 1 of this report, were focused on the development of a practical protocol for the evaluation of soil gas VOCs on indoor air. Based on the results and discussion in the previous sections of this report, the conclusions are summarized below:

1. The use of barometric pressure changes to create bidirectional airflow across the subsurface envelope of a house is an effective method for determining the impact of VOC soil gases on indoor air quality. Whenever barometric decreases occur, elevated soil gas pressures result. This can cause VOC soil gases to move towards the building envelope. Conversely when barometric pressures rise, indoor air is drawn towards the soil. Sampling of indoor air at different times around the bidirectional air movement, allows investigators the possibility of identifying the origin of indoor VOCs.

2. Several parameters, when present, can be monitored to determine airflow direction across the building envelope including methane, oxygen and soil gas pressure. although gas concentrations of indicator parameters (i.e. methane or oxygen) provide good qualitative evidence of airflow direction, such data cannot easily be used to definitively inform investigators when sampling is appropriate. The definition of soil gas pressures are needed for conclusive evaluations.

3. By subtracting background concentrations from concentrations measured during periods of soil gas influx provides a convenient method of assessing soil gas impacts on the indoor air quality. Furthermore, by calculating the ratio of the corrected concentration to the sub-slab concentration gives a convenient check on the dilution factor of individual compounds. If the ratio is significantly different than the majority of the other compounds present, other sources of error have likely altered the results.

4. The evaluation of soil gas impacts presented in this report does not take into account several influencing factors such as: variable indoor/outdoor sources, adsorption, chemical or biological degradability of organic compounds indoors, or potential transfer problems of various contaminants into the indoor environment. The investigation of such factors were beyond the scope of this work.

Section 6
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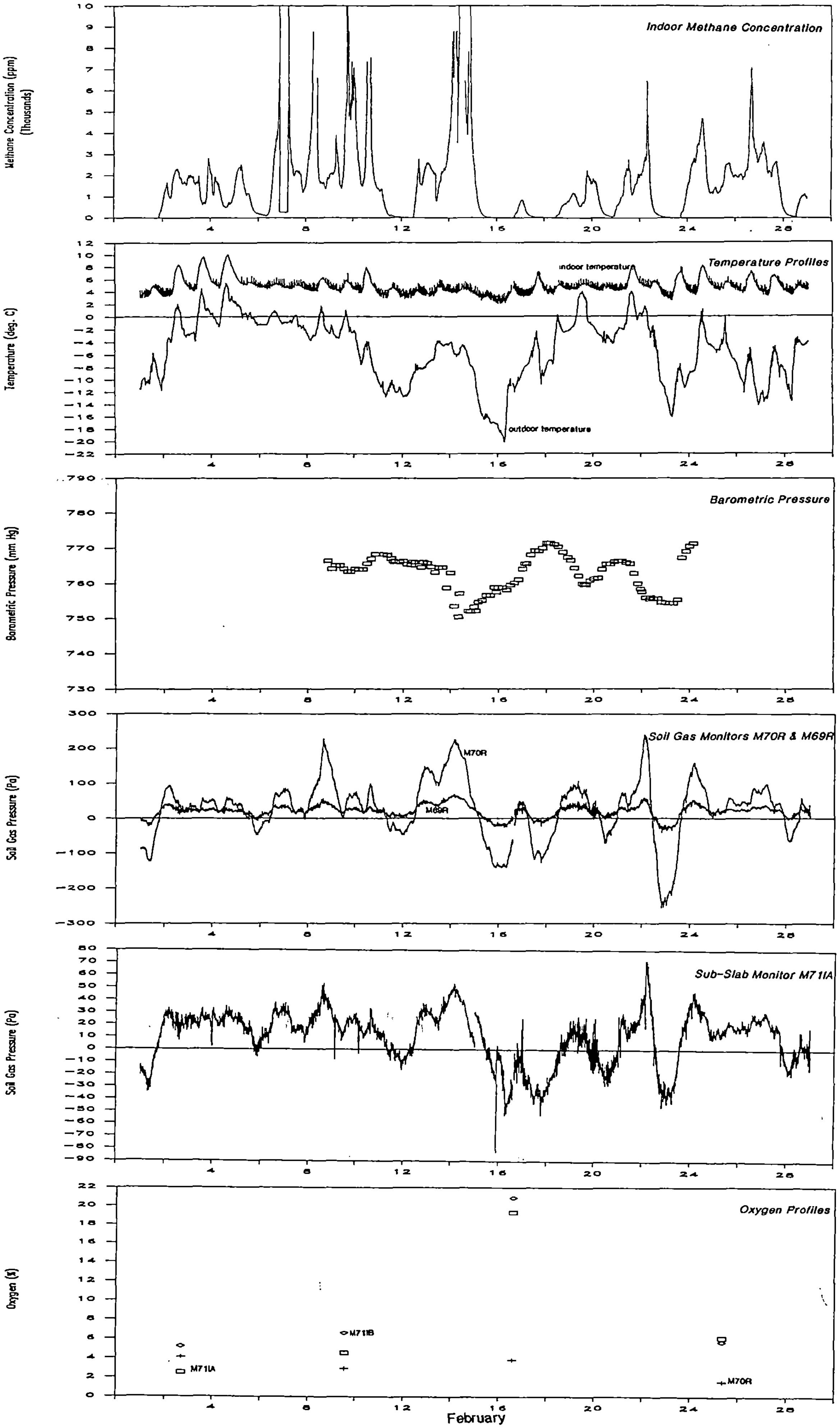
Appendix A

SUMMARY OF METHANE, OXYGEN, SOIL GAS PRESSURE, AND BAROMETRIC MEASUREMENTS



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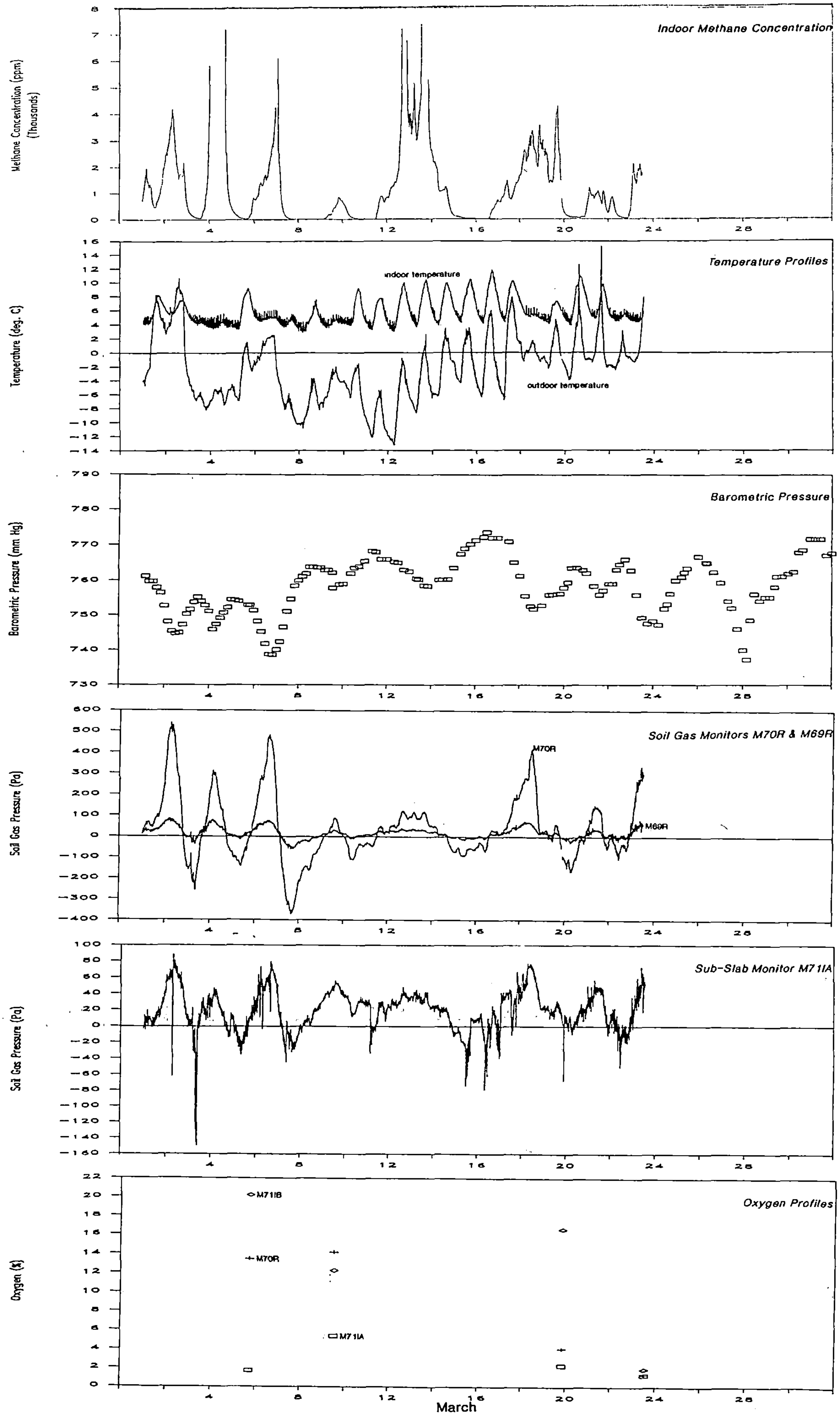

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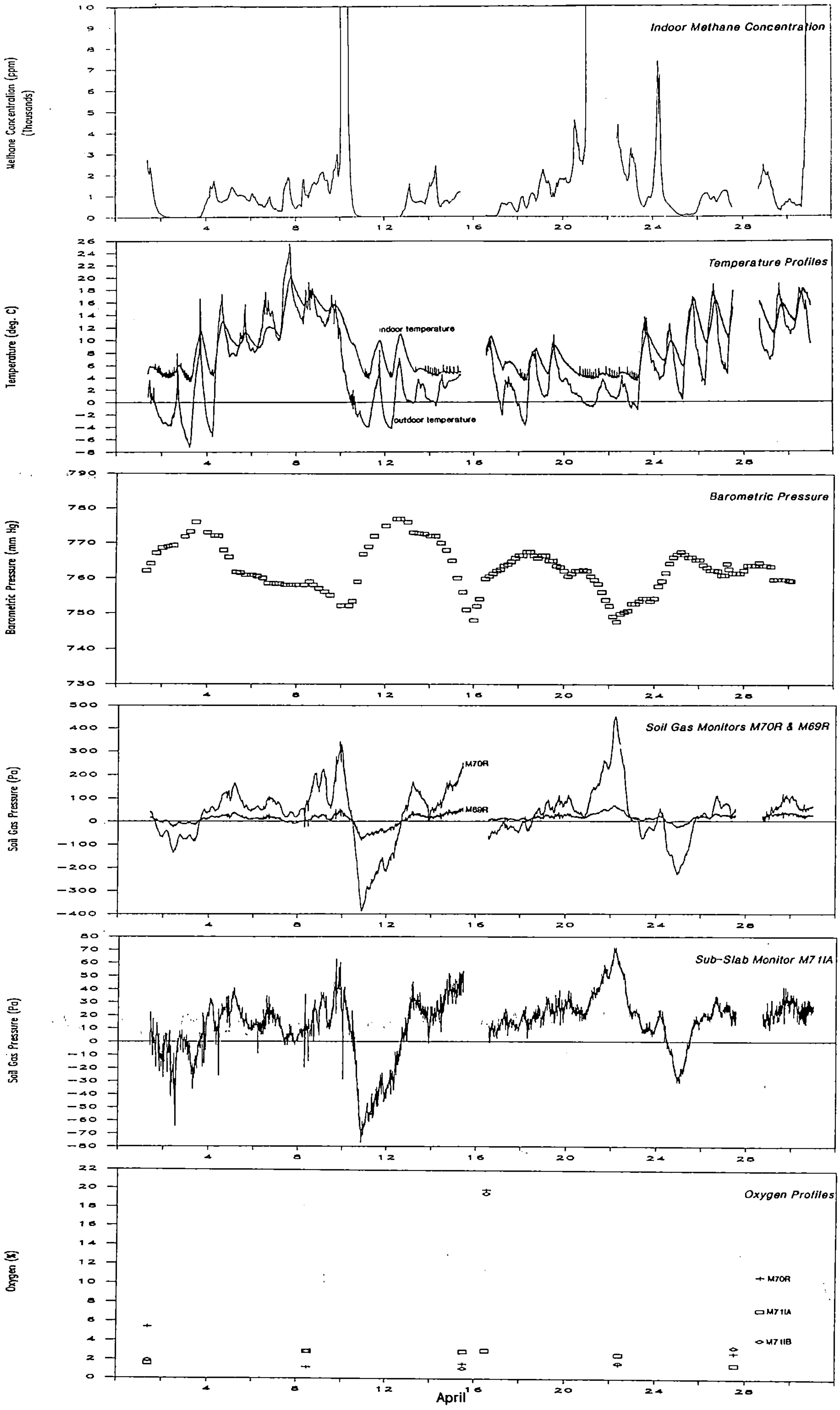

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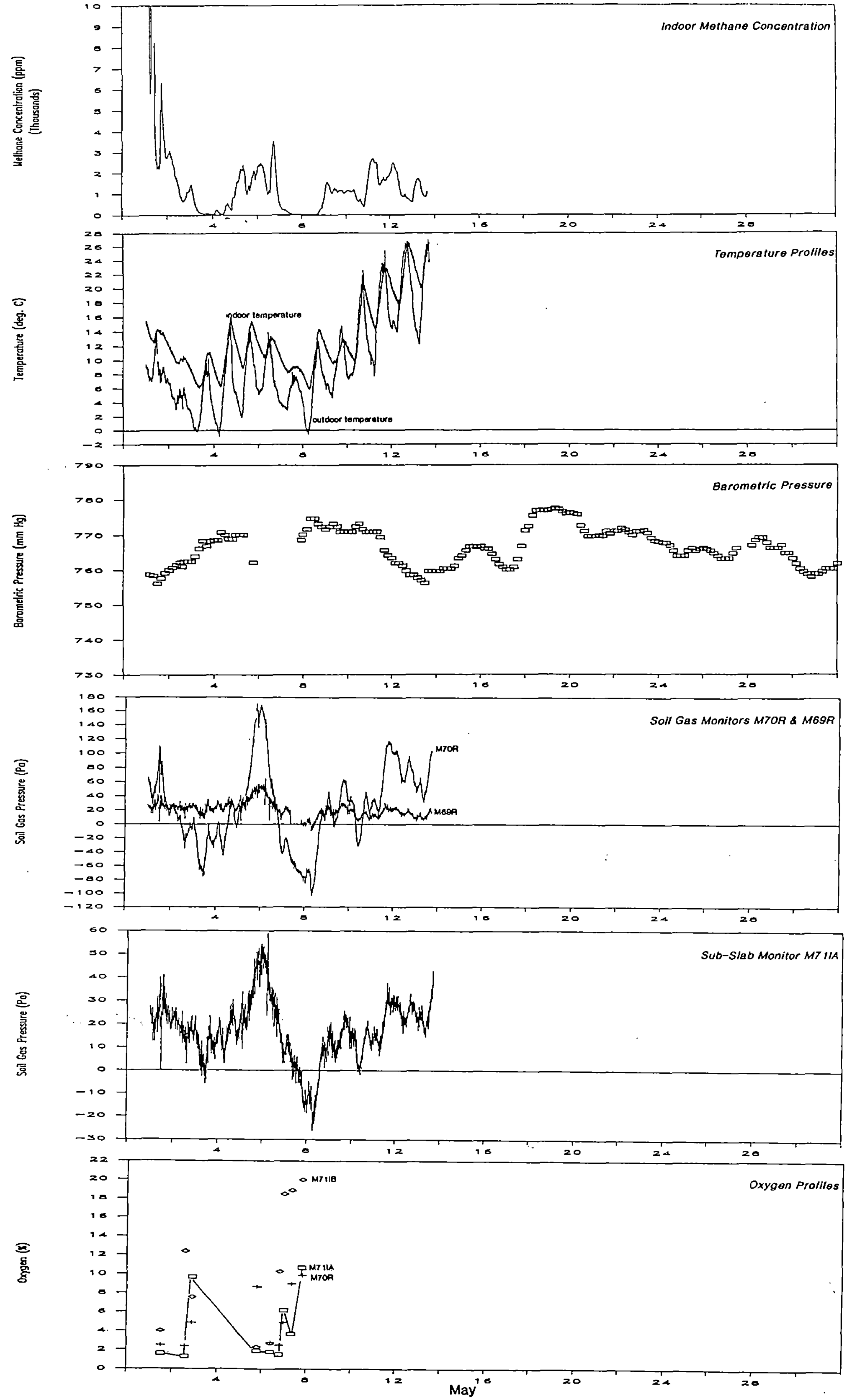

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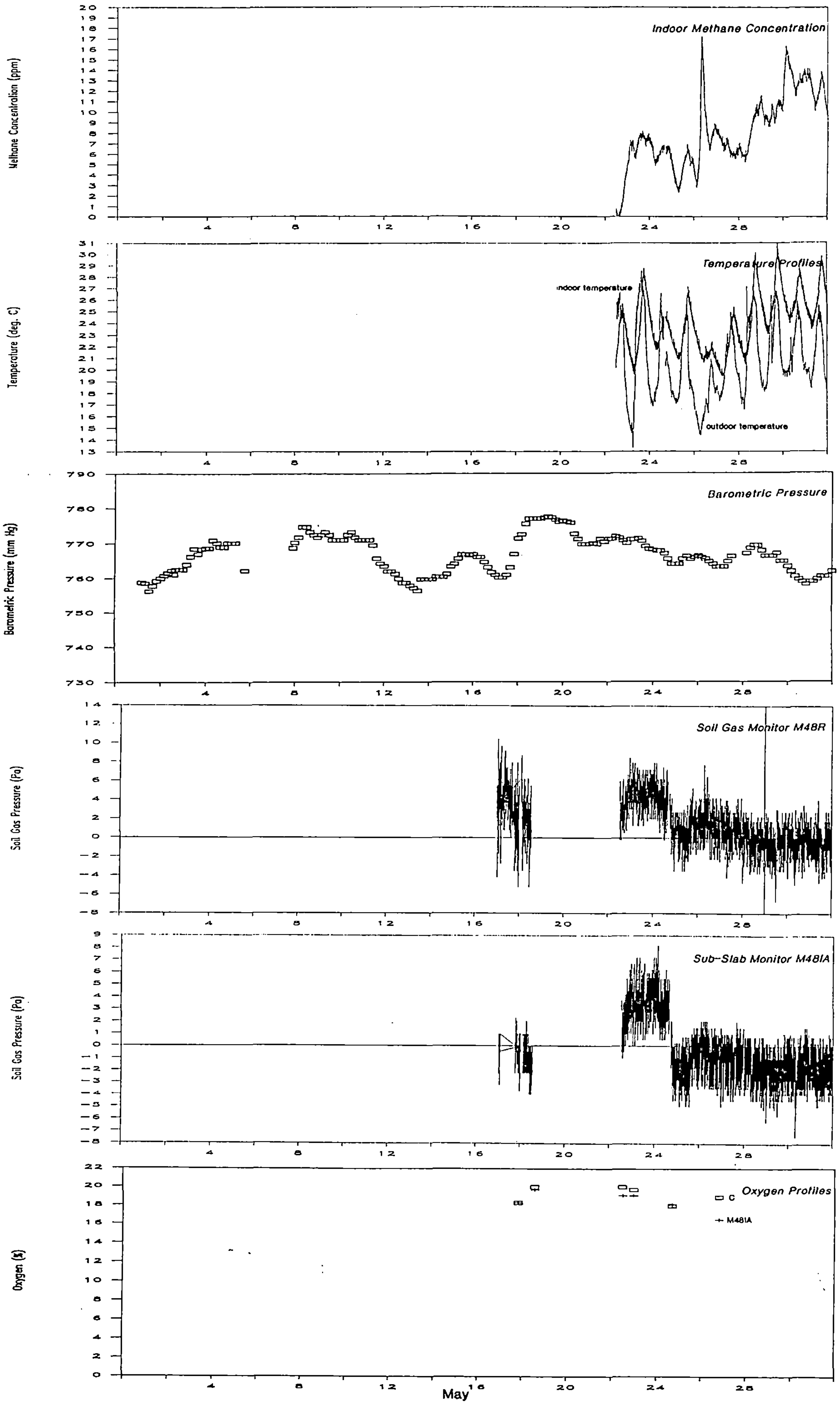

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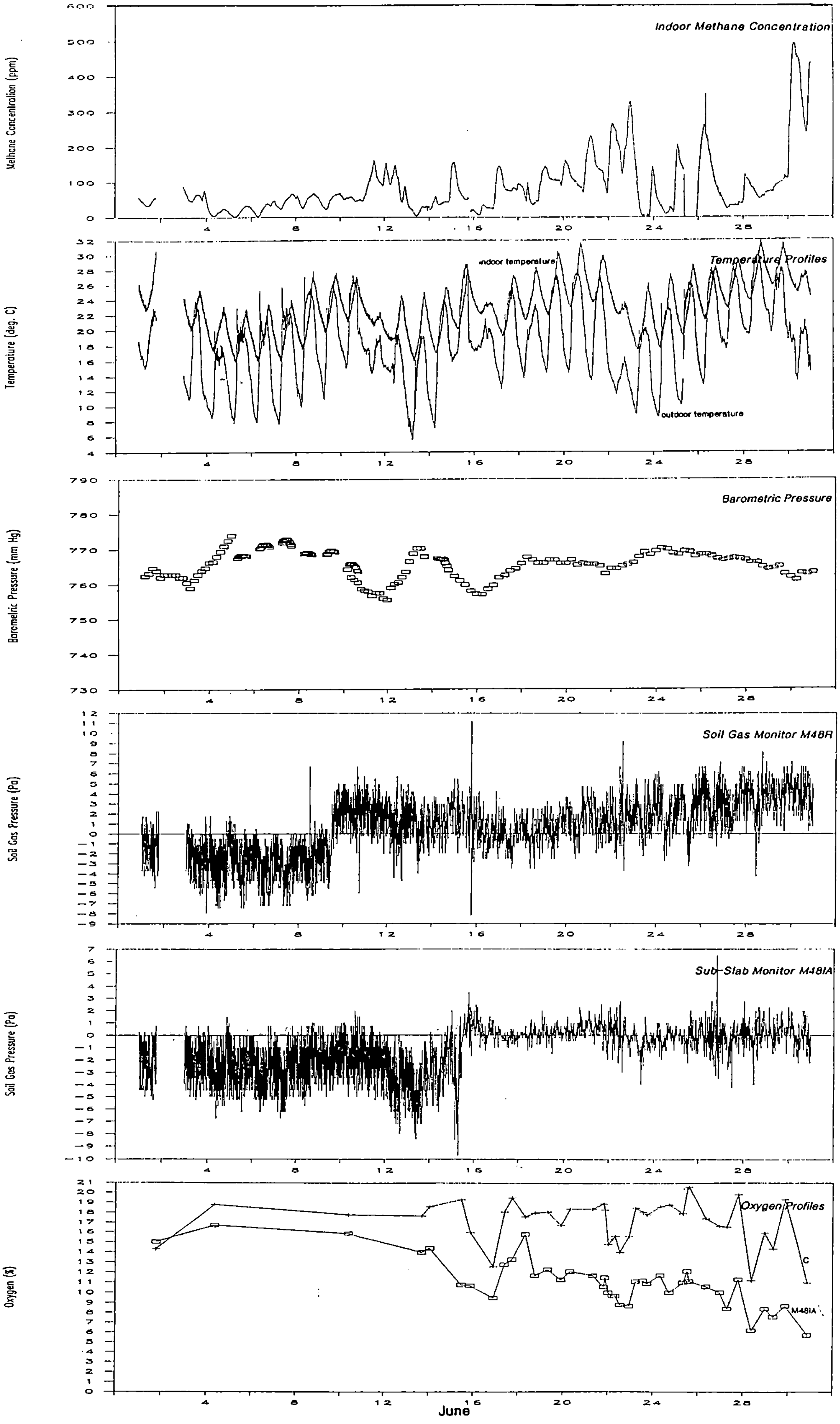
CH2M HILL



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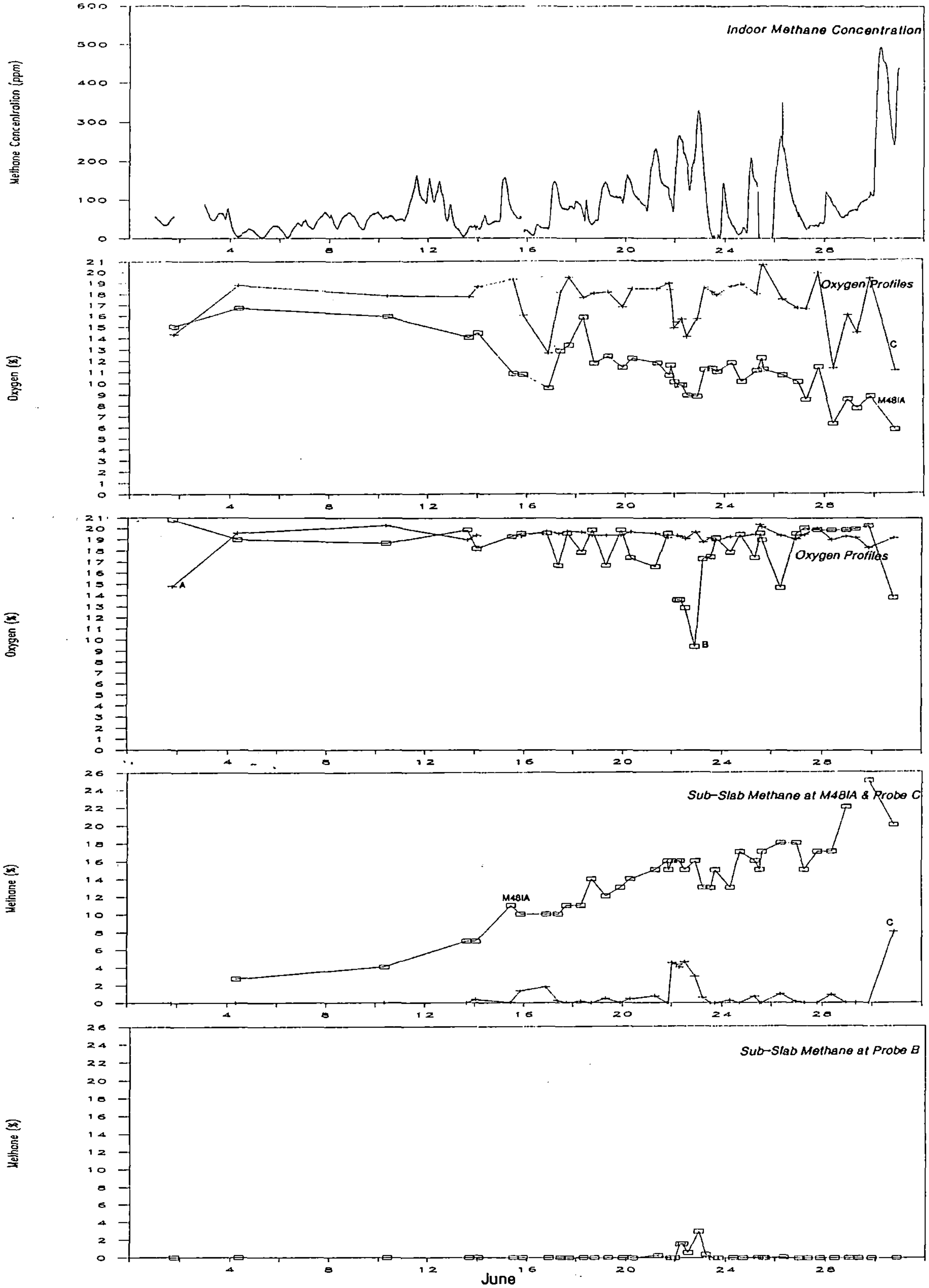

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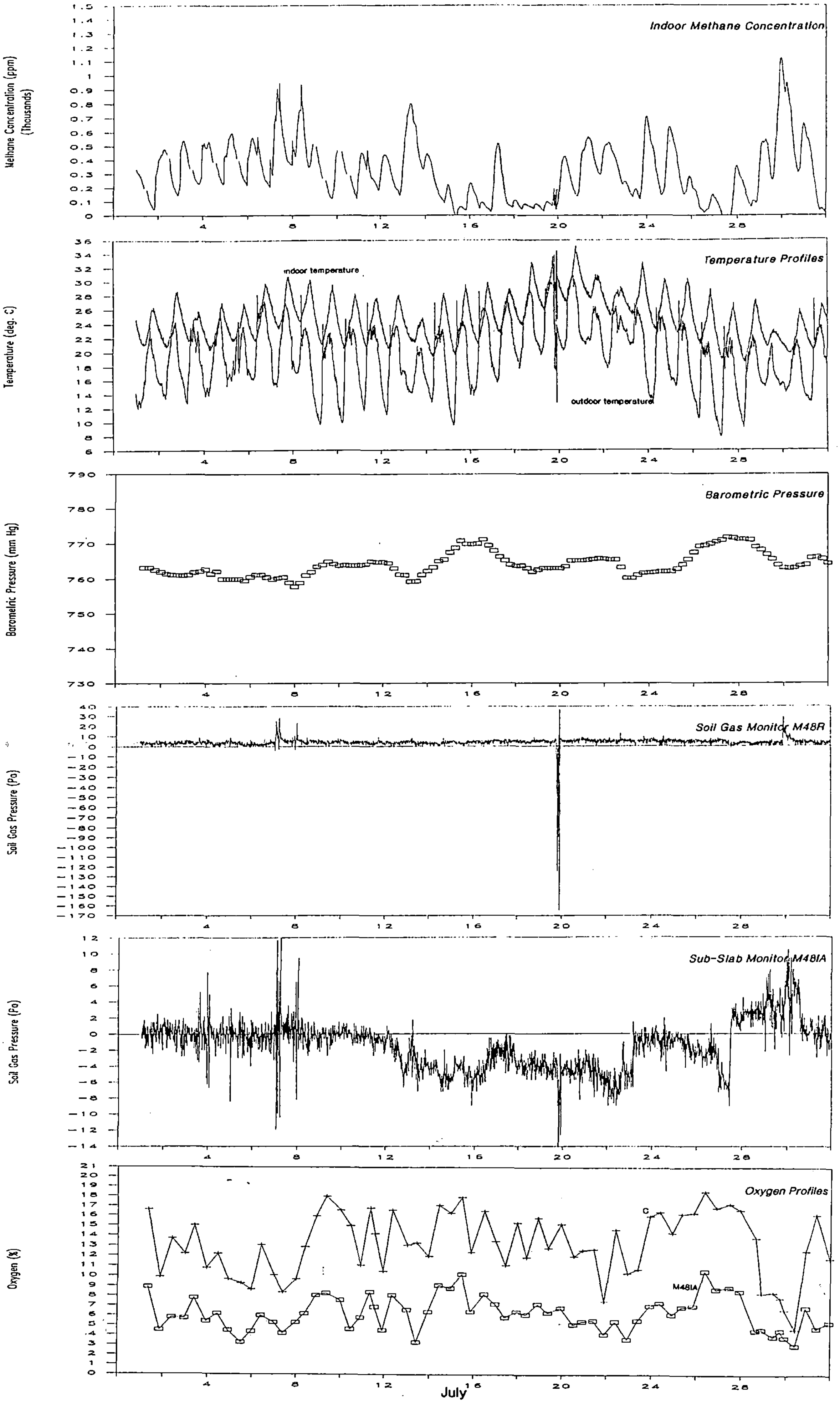

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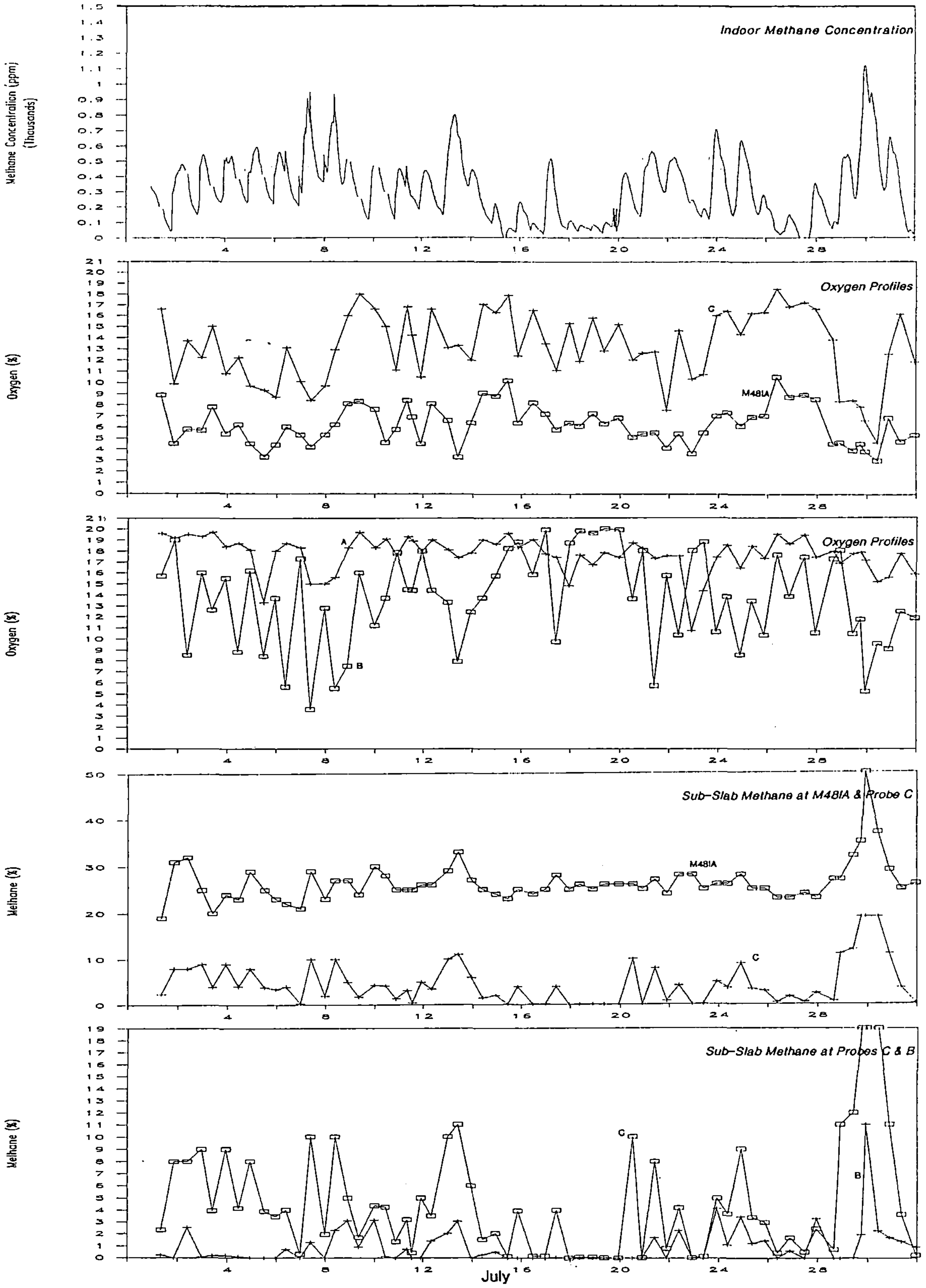

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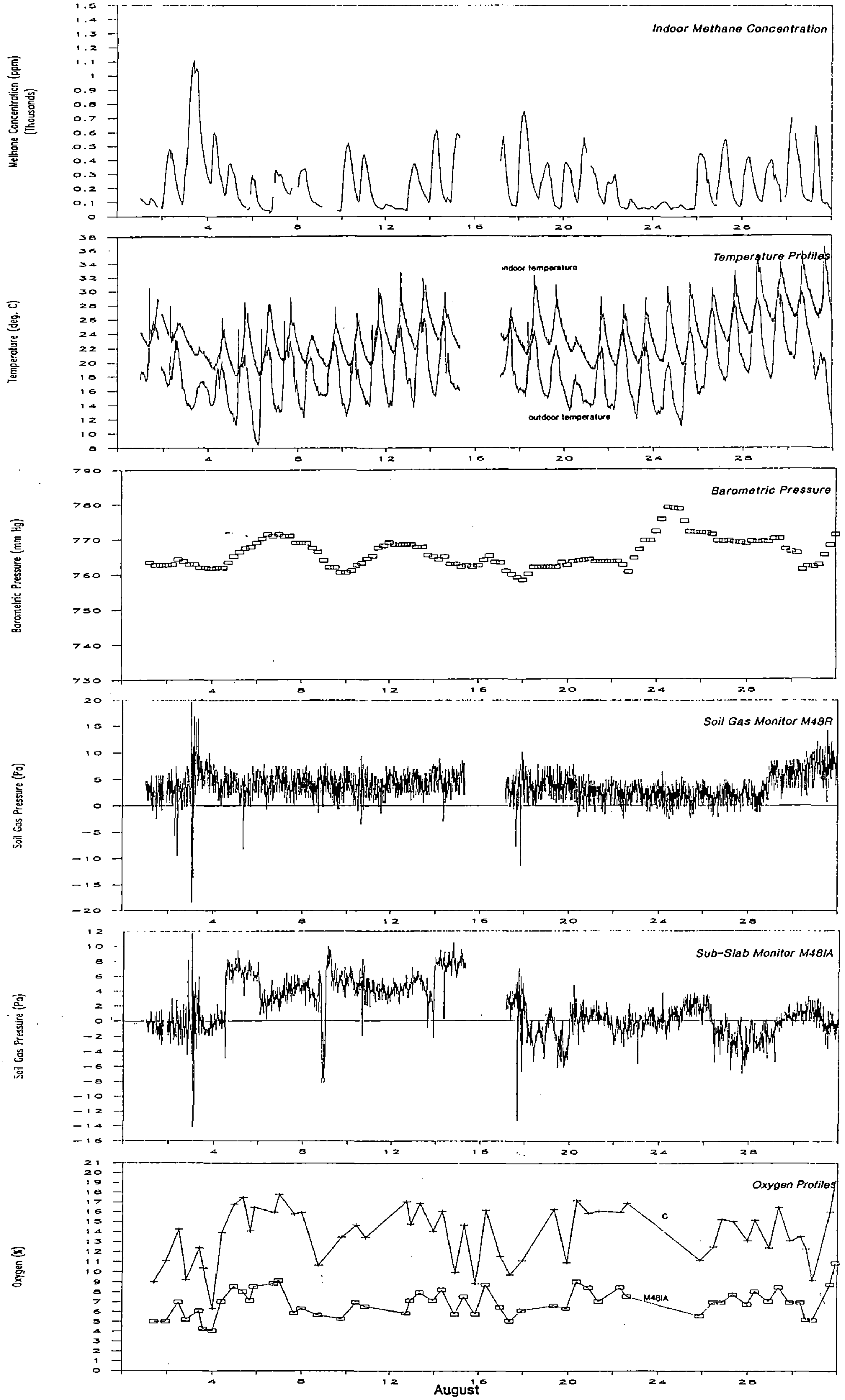

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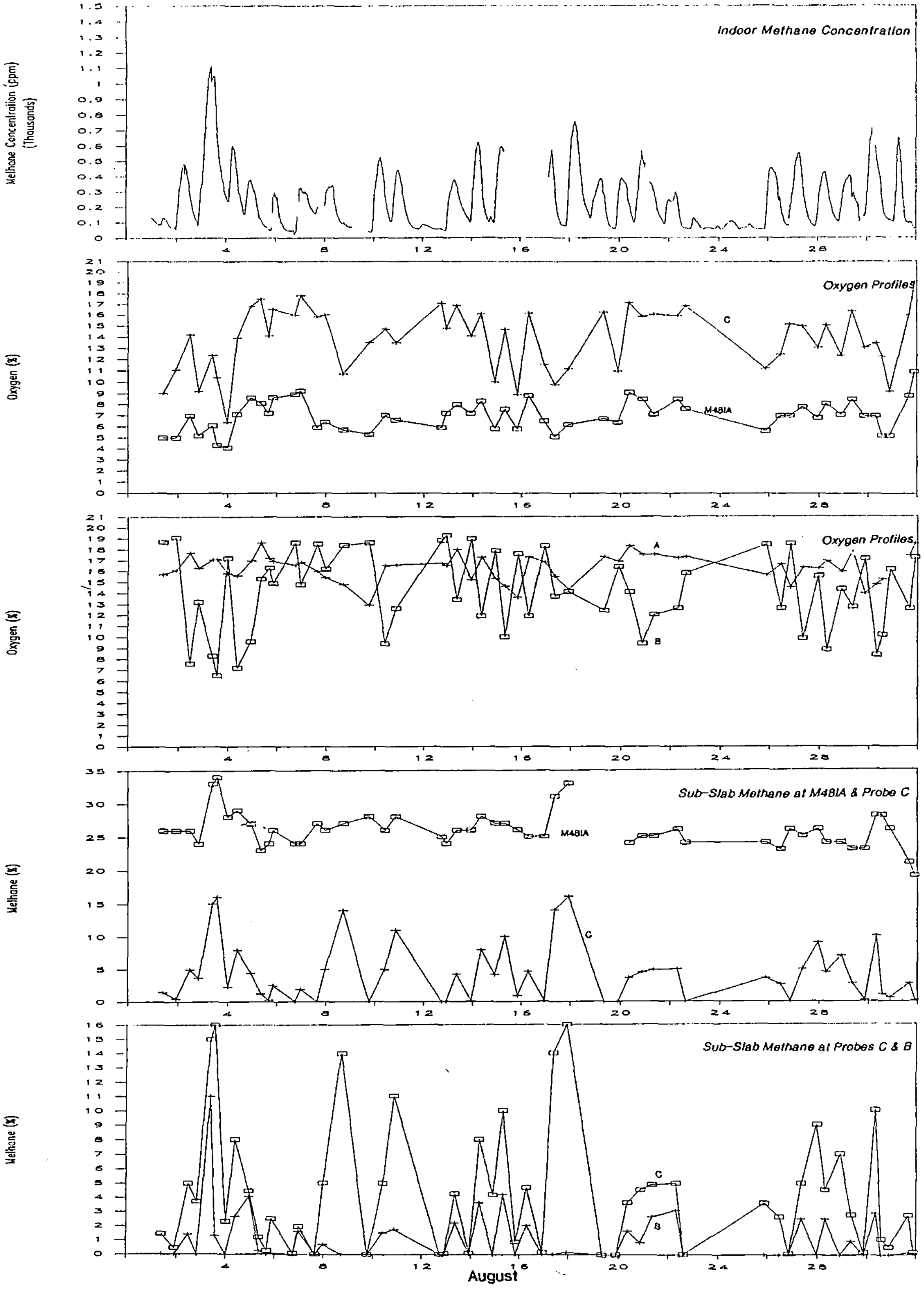

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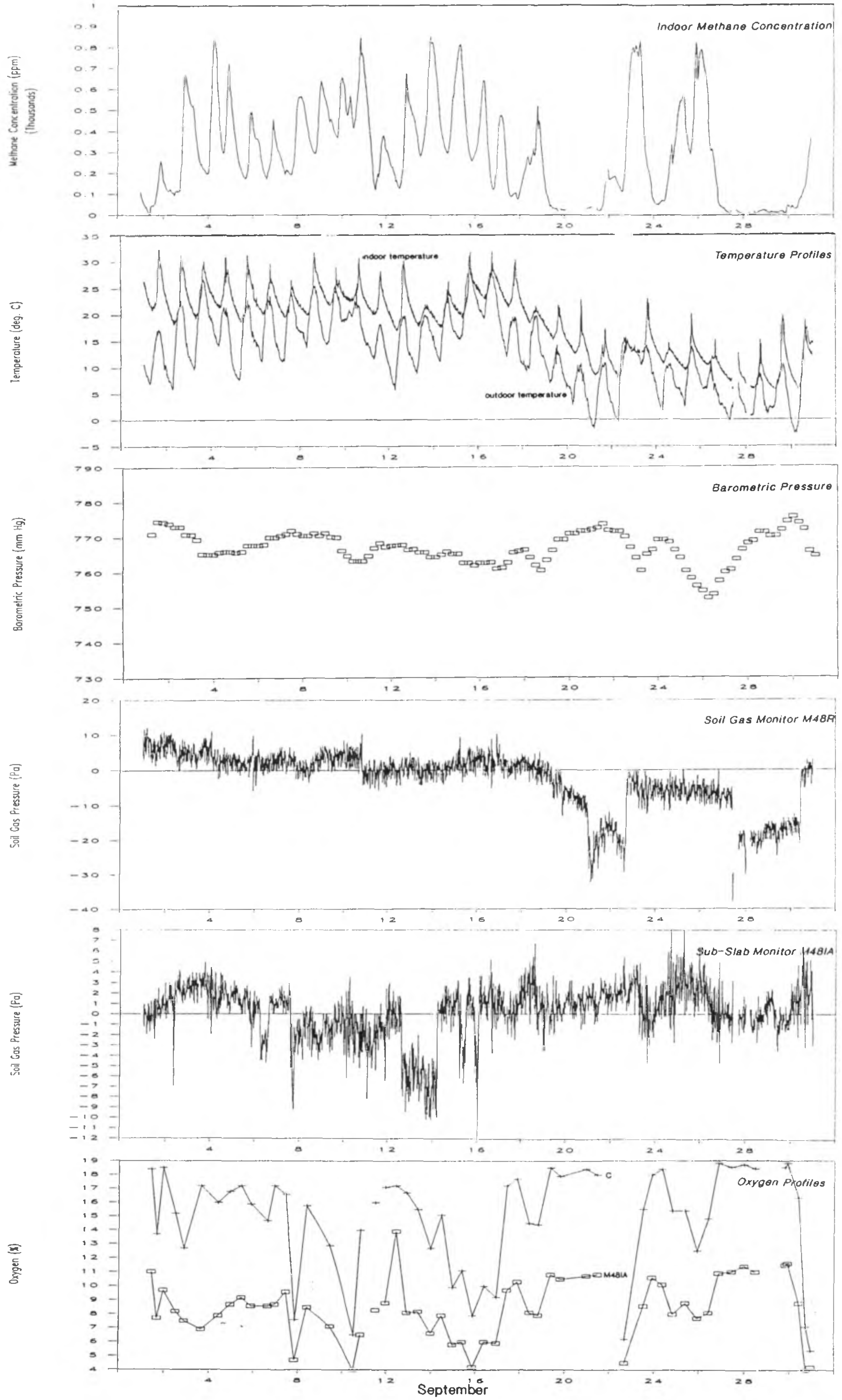

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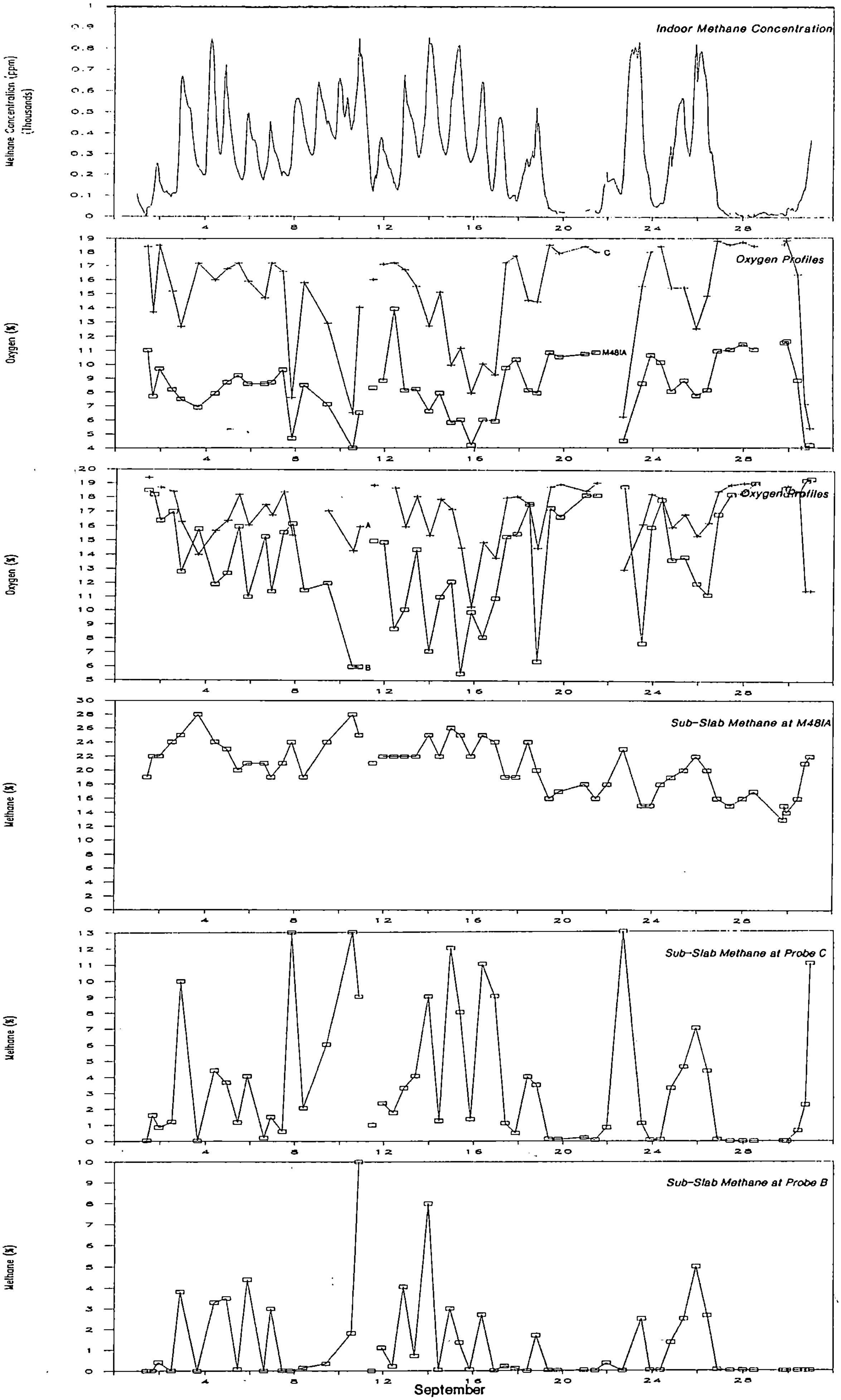

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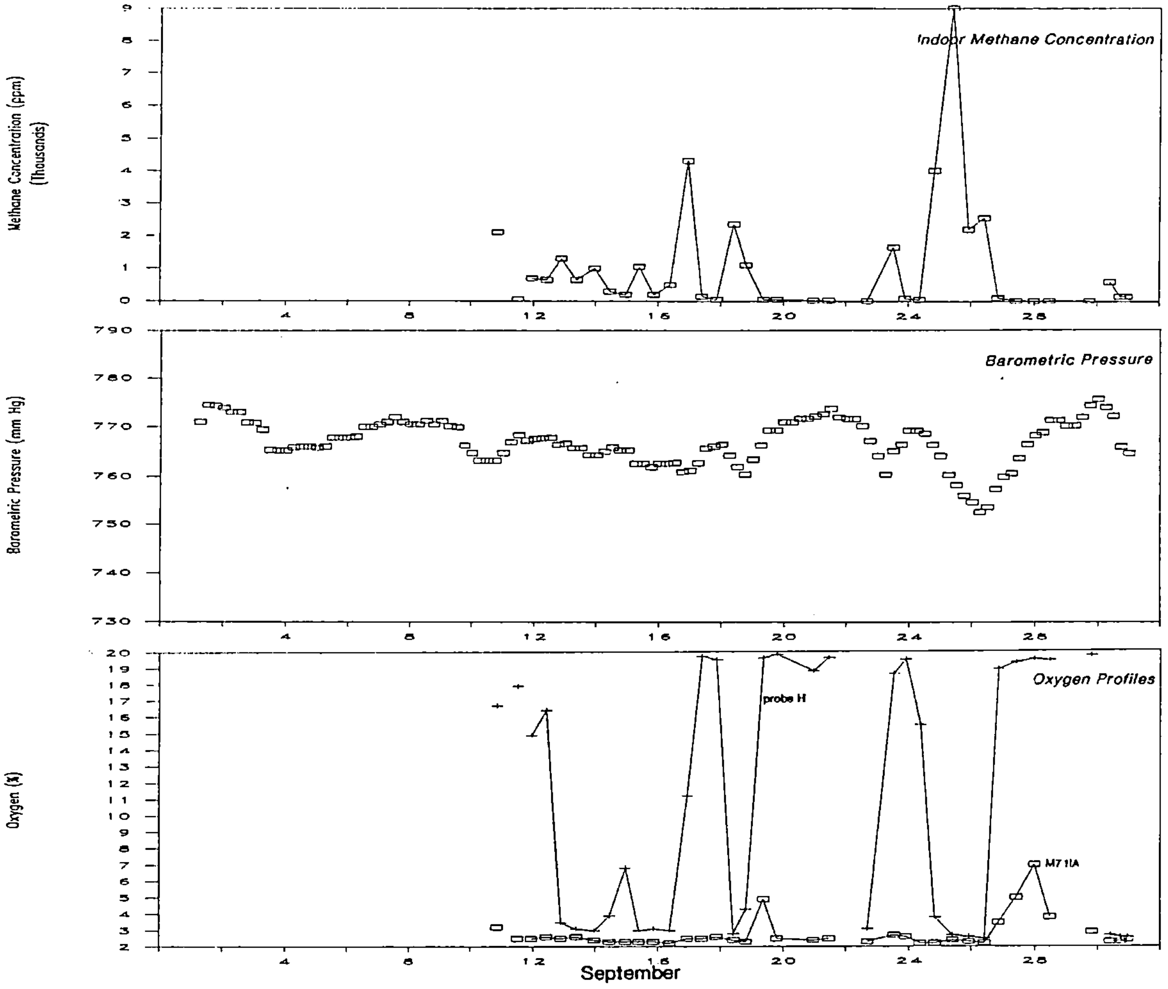

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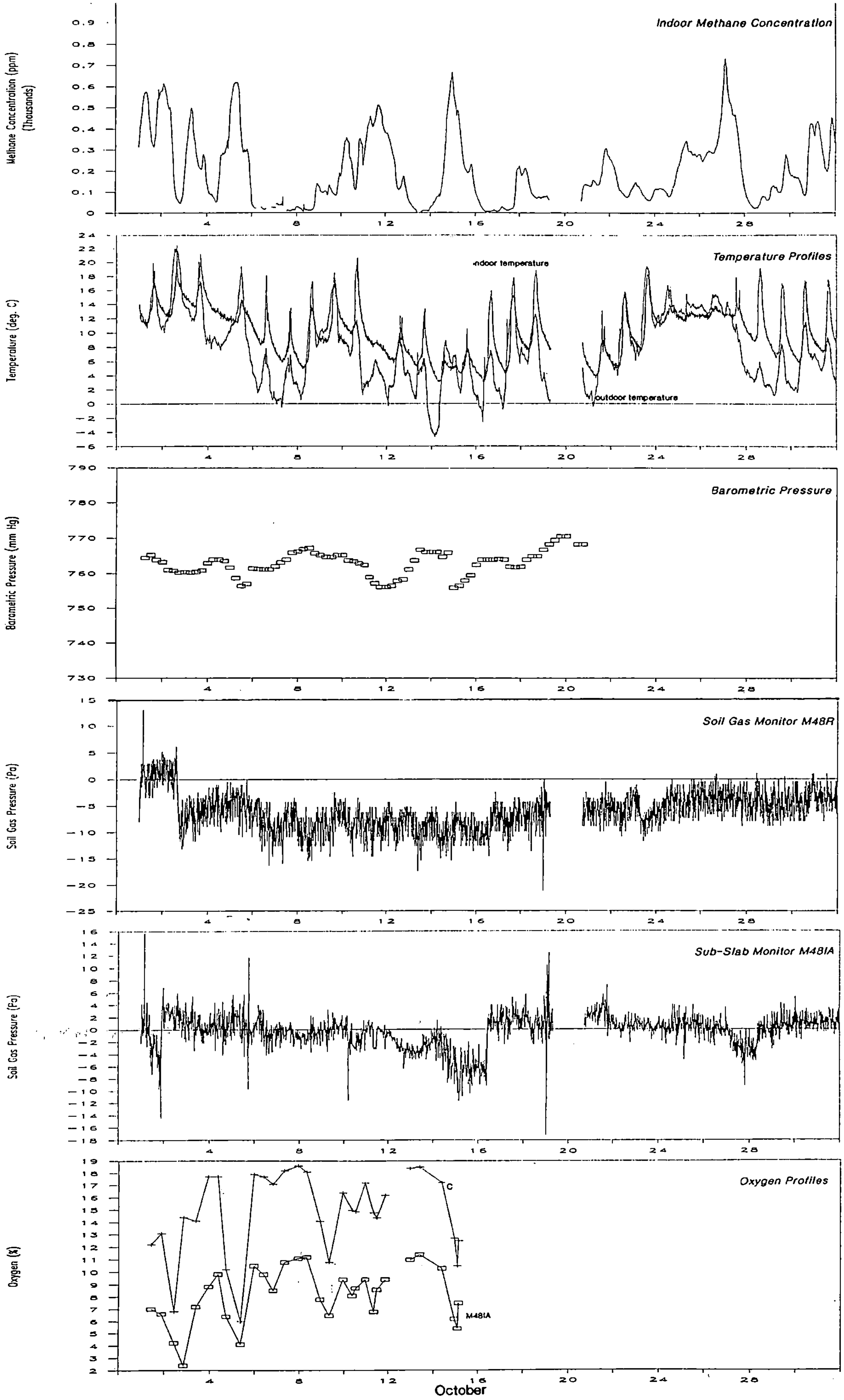

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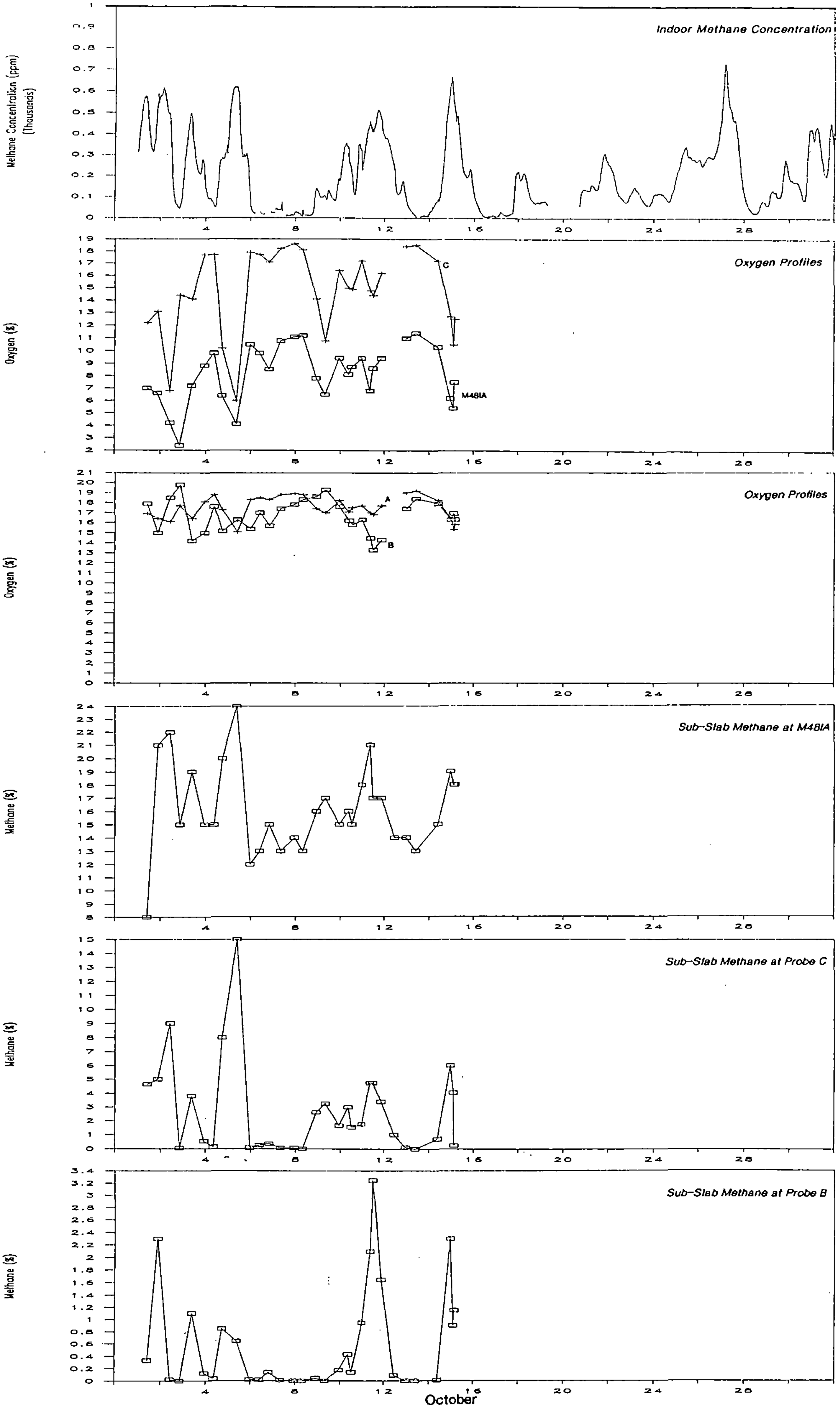

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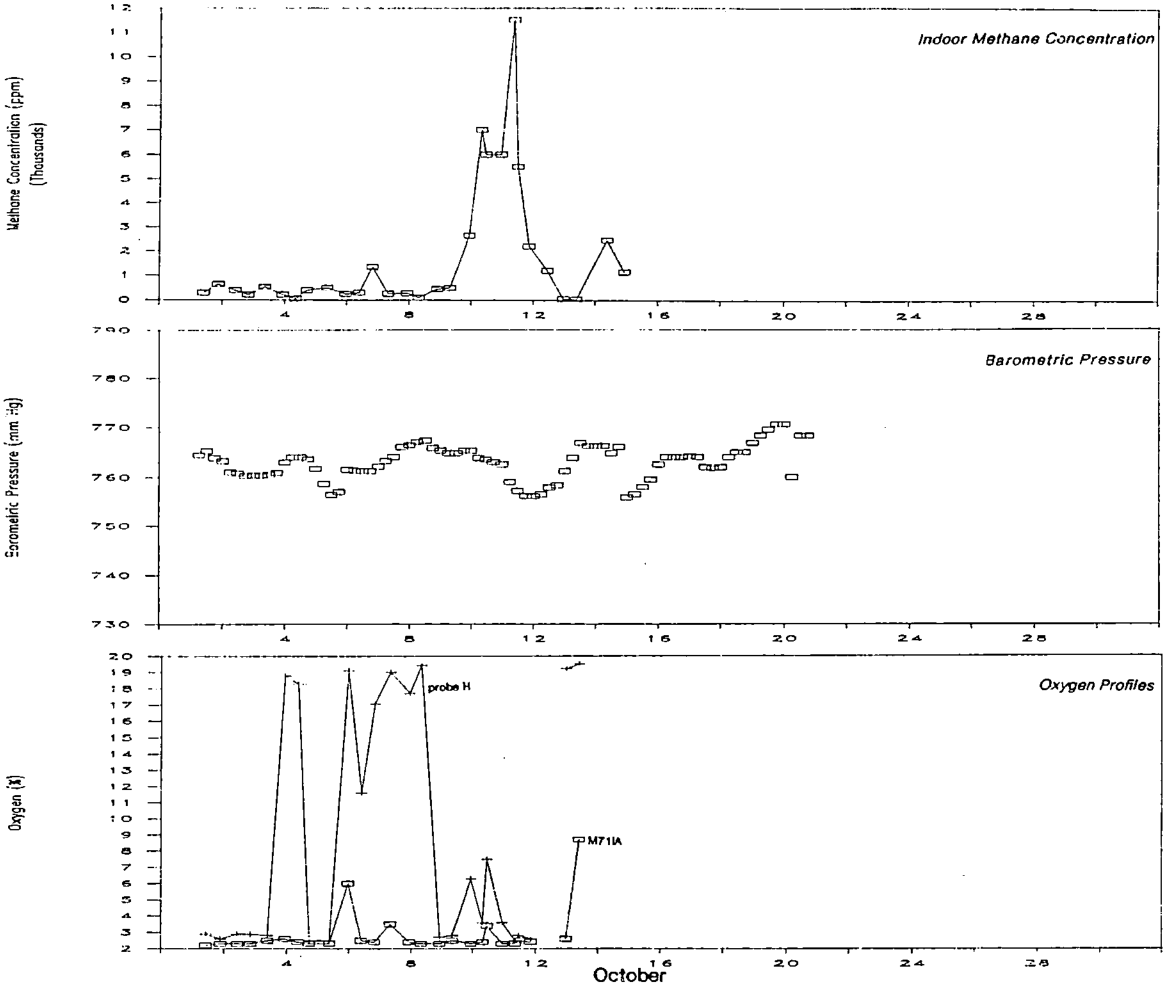

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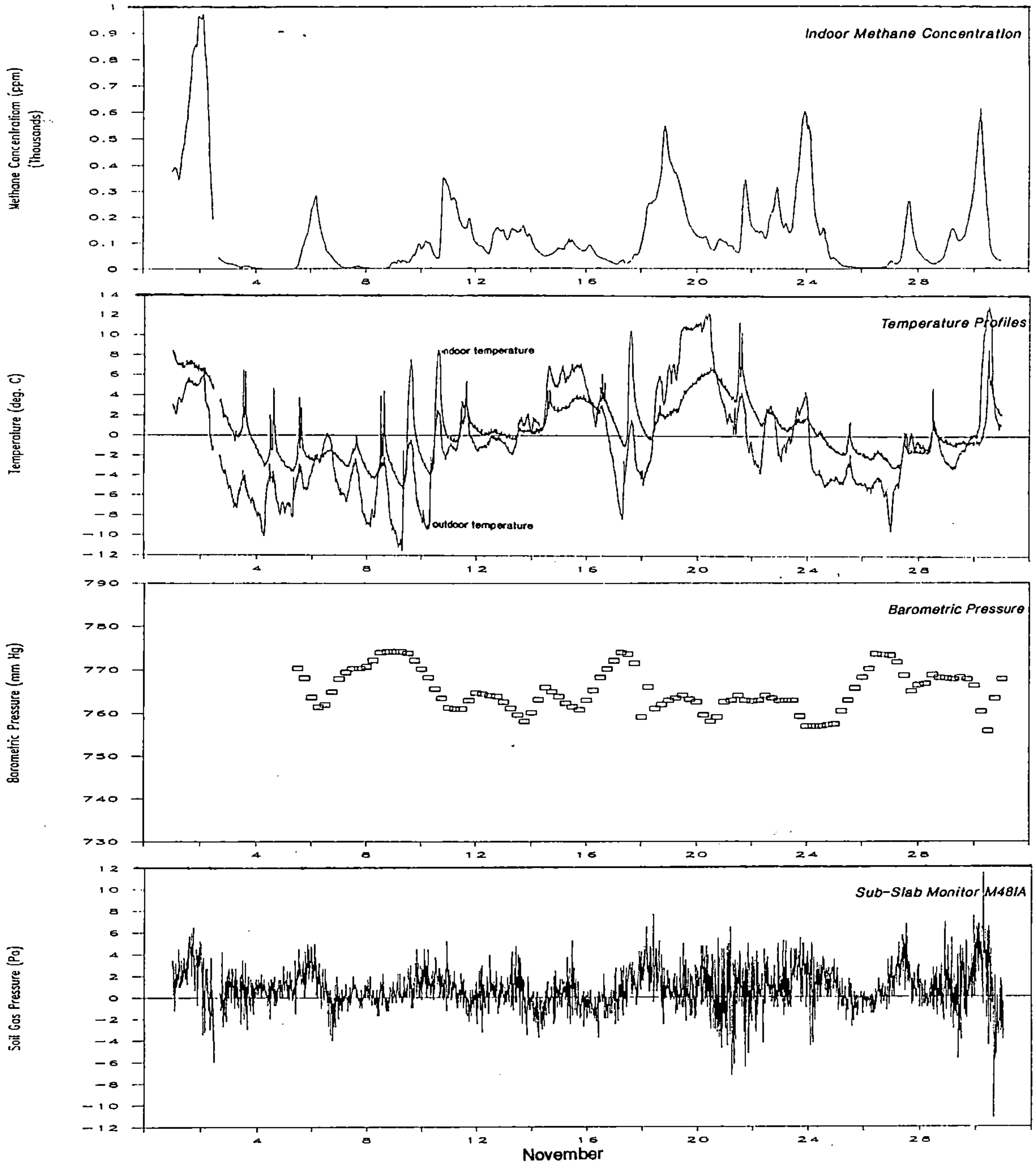
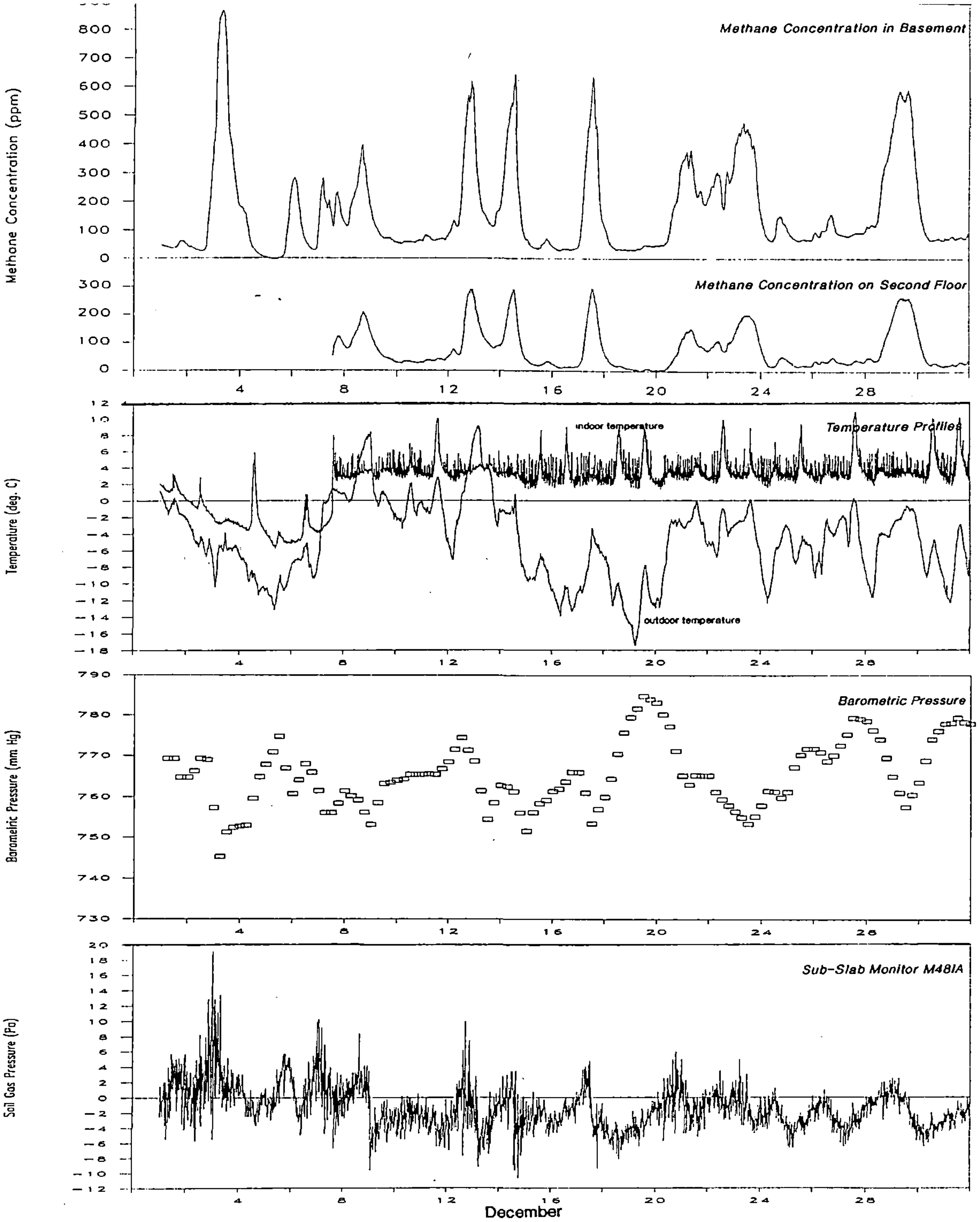
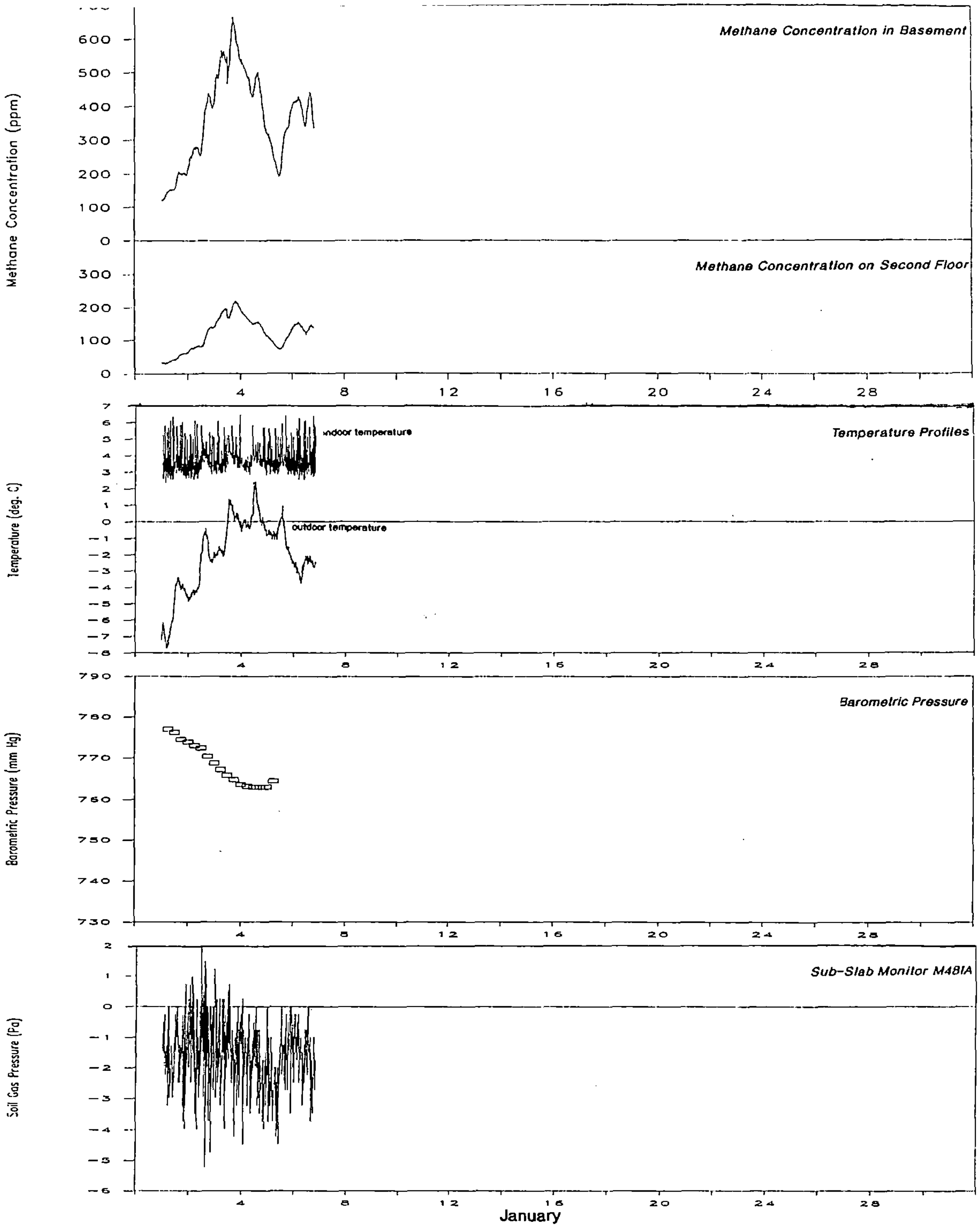


November 1991 Monitoring Data (Unit 48)



December 1991 Monitoring Data (Unit 48)



January 1992 Monitoring Data (Unit 48)

Appendix B

CALIBRATION OF FIGARO METHANE DETECTOR

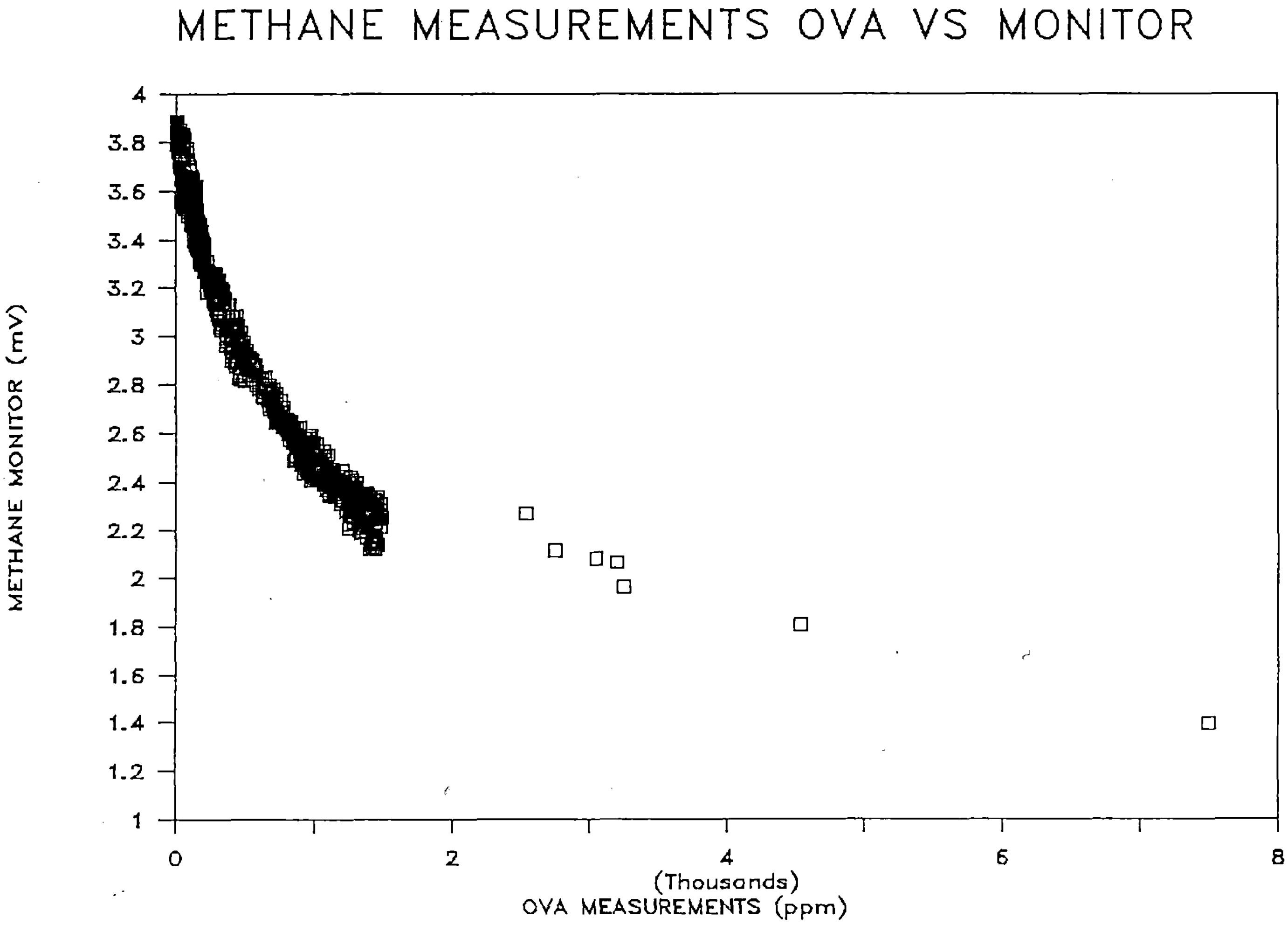
Appendix B
CALIBRATION OF FIGARO METHANE DETECTOR

The bulk of the methane measurements conducted at the site were carried out with the use of a Figaro Model TGS813 methane detector. This sensor is commonly applied for the purposes of measuring methane, however is not specific to methane. The sensor was connected to the data logger and the voltage generated by the sensor was continuously recorded. In order to correlate the voltages produced by the detector to actual methane measurement, the output form the Century Organic Vapour Analyzer was connected to another channel on the data logger, and actual methane levels were recorded. If measurements in excess of 1000 ppm occurred (as in unit 71), ambient methane concentrations as measured by the Health GMI were used for correlation purposes. The response of the sensor relative to the OVA measurements, early in the program, is shown on Figure B-1. As seen in Figure B-1, the majority of measurements were correlated with ethane concentrations less than 1000 - 1200 ppm.

The response of the detector generally had good reproducibility with only minor deviations within certain concentration ranges. minor shifts in the response curve were especially evident in the low ppm range (i.e. less than 100 ppm) as well as over 1000 ppm. Zero shift problems, higher carbon dioxide levels (Washington Dept. of Ecology, 1986), or typical instrumentation errors (Norton, 1969) are likely causes for these shifts. All errors, although not formally calculated, may have been as high as 50 ppm in the low range or as high as 200 ppm in the range above 1000 ppm. From actual spot measurements, errors were generally within ±10 percent of the full scale deflection (based on calibrated OVA readings).

Three different sets of correlated methane values were retrieved. The first set was taken in unit 71 in October and November 1990; the second set came from unit 48 in June 1991; the third set was retrieved in August and September 1991. Curve matching techniques were implemented on all three sets of data with MathCAD® software and the corresponding transfer functions were obtained. The transfer functions were then used to derive methane values with the two units.

Figure B-1.


METHANE MEASUREMENTS OVA VS MONITOR
METHANE MONITOR (mV)
4
3.8
3.6
3.4
3.2
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0
2
4
6
8
(Thousands)
OVA MEASUREMENTS (ppm)

Appendix C

SUMMARY OF AIR EXCHANGE ANALYSIS

AIR CHANGE CALCULATION - MAY 5,1991.

$\mathrm{ORIGIN} \equiv 1$

$i := 1 \,..\, 6$

$$t := \begin{bmatrix} 20 \\ 41 \\ 51 \\ 66 \\ 81 \\ 96 \end{bmatrix} \qquad c := \begin{bmatrix} 88 \\ 63 \\ 58 \\ 49 \\ 44 \\ 35 \end{bmatrix}$$

(c-vector is the SF6 concentration)
(t-vector is the time after injection)

Define the fitting function

$cc(t,\alpha,\beta) := \beta \cdot \exp(-\alpha \cdot t)$

$$\mathrm{SSE}(\alpha,\beta) := \sum_i \left[c_i - cc\left[t_i,\alpha,\beta\right]\right]^2$$

Initial guess for parameters

$\alpha := 0.007$ $\qquad \beta := 100$

Given

$\mathrm{SSE}(\alpha,\beta) \approx 0$

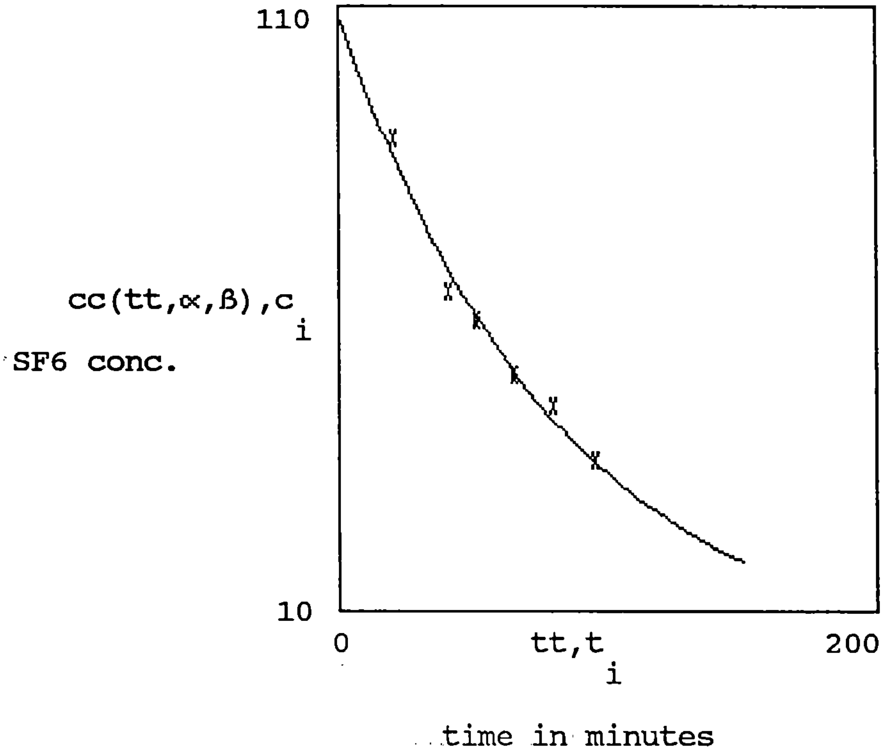
$1 \approx 1$

$\begin{bmatrix} \alpha \\ \beta \end{bmatrix} := \mathrm{Minerr}(\alpha,\beta)$

Parameters for best fit	Mean squared error
$\alpha = 0.012$ $\beta = 108.613$	$\dfrac{\mathrm{SSE}(\alpha,\beta)}{4} = 6.917$

Plot of fit:

tt := 1 ..150



AIR CHANGE CALCULATION - MAY 7,1991.

ORIGIN ≡ 1

$i := 1 \,..5$

$t := \begin{bmatrix} 25 \\ 40 \\ 55 \\ 85 \\ 100 \end{bmatrix} \qquad c := \begin{bmatrix} 77 \\ 70 \\ 61 \\ 47 \\ 43 \end{bmatrix}$

(c-vector is the SF6 concentration)
(t-vector is the time after injection)

Define the fitting function

$cc(t,\alpha,\beta) := \beta \cdot \exp(-\alpha \cdot t)$

$$SSE(\alpha,\beta) := \sum_{i} \left[c_i - cc\left[t_i,\alpha,\beta\right]\right]^2$$

Initial guess for parameters

$\alpha := 0.007 \qquad \beta := 100$

Given

$SSE(\alpha,\beta) \approx 0$

$1 \approx 1$

$\begin{bmatrix} \alpha \\ \beta \end{bmatrix} := \mathrm{Minerr}(\alpha,\beta)$

Parameters for best fit

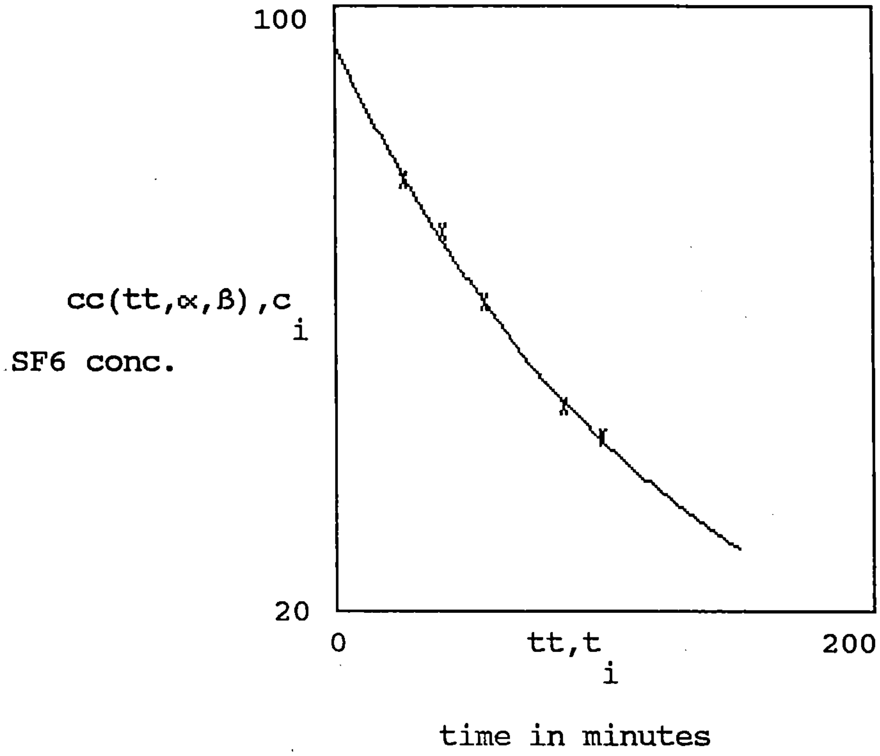
$\alpha = 0.008$
$\beta = 95.031$

Mean squared error

$$\frac{SSE(\alpha,\beta)}{4} = 0.732$$

Plot of fit:

tt := 1 ..150



AIR CHANGE CALCULATION - JUNE 14,1991.

ORIGIN ≡ 1

$i := 1 \,..6$

$$t := \begin{bmatrix} 25 \\ 40 \\ 55 \\ 70 \\ 85 \\ 90 \end{bmatrix} \qquad c := \begin{bmatrix} 100 \\ 92 \\ 84 \\ 76 \\ 69 \\ 65 \end{bmatrix}$$

(c-vector is the SF6 concentration)
(t-vector is the time after injection)

Define the fitting function

$$cc(t,\alpha,\beta) := \beta \cdot \exp(-\alpha \cdot t)$$

$$SSE(\alpha,\beta) := \sum_{i} \left[c_i - cc\left[t_i,\alpha,\beta\right]\right]^2$$

Initial guess for parameters

$\alpha := 0.007$ $\qquad \beta := 100$

Given

$SSE(\alpha,\beta) \approx 0$

$1 \approx 1$

$$\begin{bmatrix} \alpha \\ \beta \end{bmatrix} := \mathrm{Minerr}(\alpha,\beta)$$

Parameters for best fit

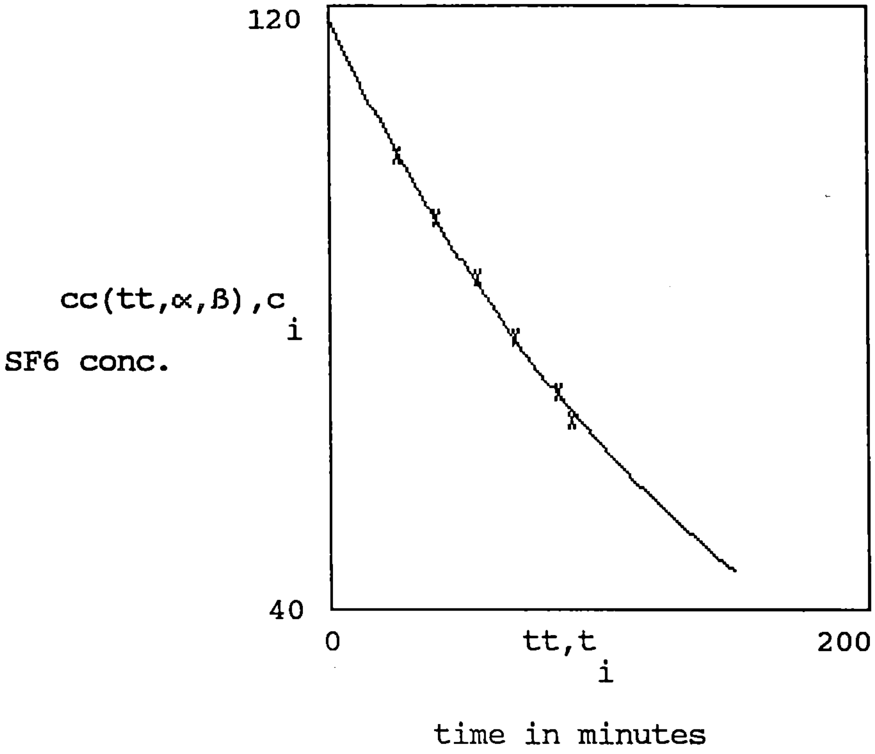
$\alpha = 0.006$
$\beta = 118.286$

Mean squared error

$$\frac{SSE(\alpha,\beta)}{4} = 0.999$$

Plot of fit:

tt := 1 ..150



AIR CHANGE CALCULATION - JUNE 22,1991.

ORIGIN ≡ 1

$i := 1 \,..5$

$$t := \begin{bmatrix} 25 \\ 40 \\ 55 \\ 85 \\ 100 \end{bmatrix} \qquad c := \begin{bmatrix} 95 \\ 81 \\ 71 \\ 54 \\ 48 \end{bmatrix}$$

(c-vector is the SF6 concentration)
(t-vector is the time after injection)

Define the fitting function

$cc(t,\alpha,\beta) := \beta\cdot \exp(-\alpha\cdot t)$

$$SSE(\alpha,\beta) := \sum_{i} \left[c_{i} - cc\left[t_{i},\alpha,\beta\right]\right]^{2}$$

Initial guess for parameters

$\alpha := 0.007$ $\beta := 100$

Given

$SSE(\alpha,\beta) \approx 0$

$1 \approx 1$

$\begin{bmatrix} \alpha \\ \beta \end{bmatrix} := \text{Minerr}(\alpha,\beta)$

Parameters for best fit

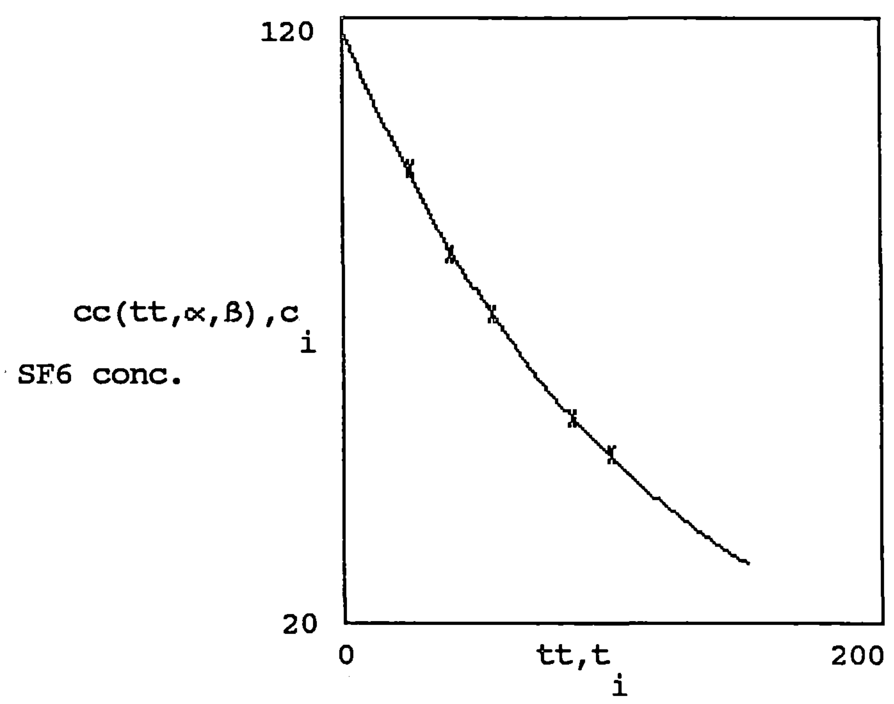
$\alpha = 0.009$
$\beta = 118.277$

Mean squared error

$$\frac{SSE(\alpha,\beta)}{4} = 0.649$$

Plot of fit:

tt := 1 ..150



time in minutes

AIR CHANGE CALCULATION - JUNE 24,1991.

ORIGIN ≡ 1

$i := 1 \,..\, 5$

$$t := \begin{bmatrix} 25 \\ 40 \\ 55 \\ 85 \\ 100 \end{bmatrix} \qquad c := \begin{bmatrix} 82 \\ 73 \\ 69 \\ 63 \\ 60 \end{bmatrix}$$

(c-vector is the SF6 concentration)
(t-vector is the time after injection)

Define the fitting function

$$cc(t,\alpha,\beta) := \beta \cdot \exp(-\alpha \cdot t)$$

$$SSE(\alpha,\beta) := \sum_{i} \left[c_i - cc\left[t_i,\alpha,\beta\right]\right]^2$$

Initial guess for parameters

$\alpha := 0.007$ $\qquad \beta := 100$

Given

$SSE(\alpha,\beta) \approx 0$

$1 \approx 1$

$$\begin{bmatrix} \alpha \\ \beta \end{bmatrix} := \mathrm{Minerr}(\alpha,\beta)$$

Parameters for best fit

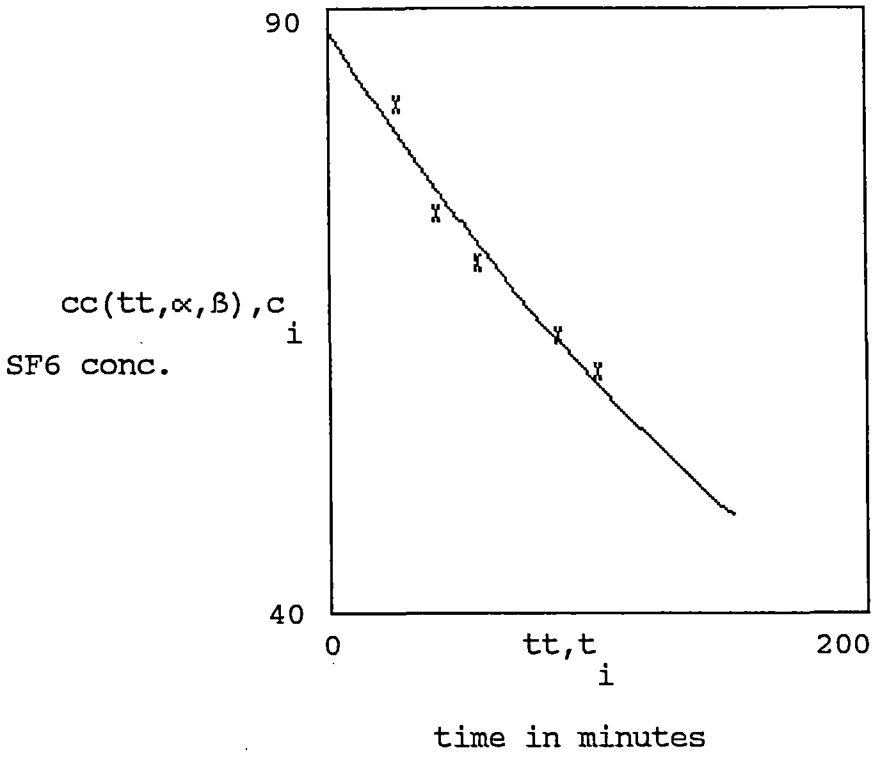
$\alpha = 0.004$
$\beta = 88.238$

Mean squared error

$$\frac{SSE(\alpha,\beta)}{4} = 3.35$$

Plot of fit:

tt := 1 ..150



AIR CHANGE CALCULATION - JUNE 25,1991.

ORIGIN ≡ 1

i := 1 ..5

$$t := \begin{bmatrix} 28 \\ 73 \\ 88 \\ 103 \\ 113 \end{bmatrix} \qquad c := \begin{bmatrix} 110 \\ 84 \\ 76 \\ 73 \\ 68 \end{bmatrix}$$

(c-vector is the SF6 concentration)
(t-vector is the time after injection)

Define the fitting function

$cc(t,\alpha,\beta) := \beta \cdot \exp(-\alpha \cdot t)$

$$SSE(\alpha,\beta) := \sum_{i} \left[c_{i} - cc\left[t_{i},\alpha,\beta\right]\right]^{2}$$

Initial guess for parameters

$\alpha := 0.007$ $\beta := 100$

Given

$SSE(\alpha,\beta) \approx 0$

$1 \approx 1$

$$\begin{bmatrix} \alpha \\ \beta \end{bmatrix} := \text{Minerr}(\alpha,\beta)$$

Parameters for best fit

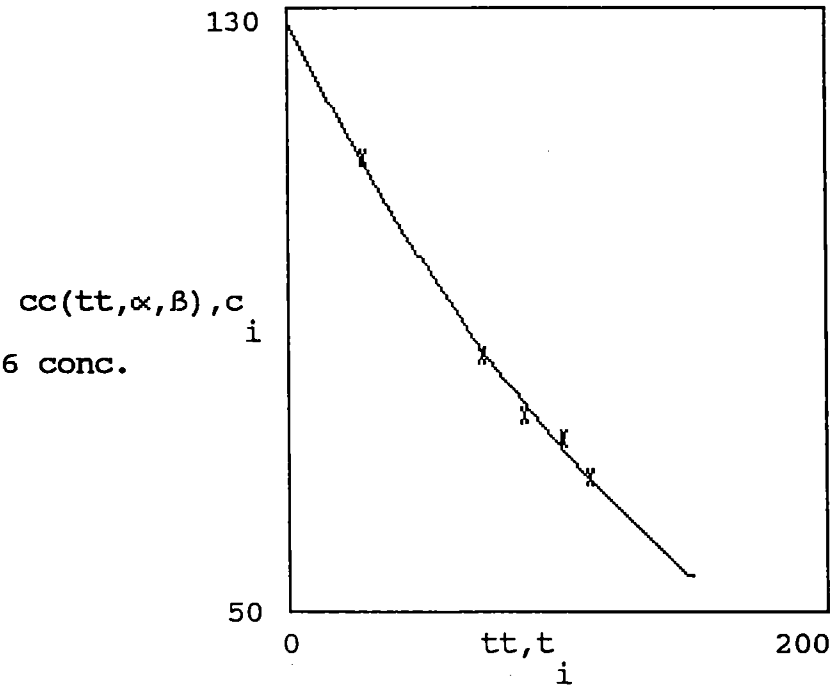
$\alpha = 0.006$
$\beta = 128.408$

Mean squared error

$$\frac{SSE(\alpha,\beta)}{4} = 1.696$$

Plot of fit:

tt := 1 ..150



time in minutes

AIR CHANGE CALCULATION - SEPTEMBER 29,1991.

ORIGIN ≡ 1

$i := 1 \,..6$

$$t := \begin{bmatrix} 27 \\ 42 \\ 57 \\ 72 \\ 87 \\ 102 \end{bmatrix} \qquad c := \begin{bmatrix} 110 \\ 98 \\ 84 \\ 77 \\ 67 \\ 60 \end{bmatrix}$$

(c-vector is the SF6 concentration)
(t-vector is the time after injection)

Define the fitting function

$cc(t,\alpha,\beta) := \beta \cdot \exp(-\alpha \cdot t)$

$$SSE(\alpha,\beta) := \sum_{i} \left[c_i - cc\left[t_i,\alpha,\beta\right]\right]^2$$

Initial guess for parameters

$\alpha := 0.007$ $\beta := 100$

Given

$SSE(\alpha,\beta) \approx 0$

$1 \approx 1$

$$\begin{bmatrix} \alpha \\ \beta \end{bmatrix} := \text{Minerr}(\alpha,\beta)$$

Parameters for best fit

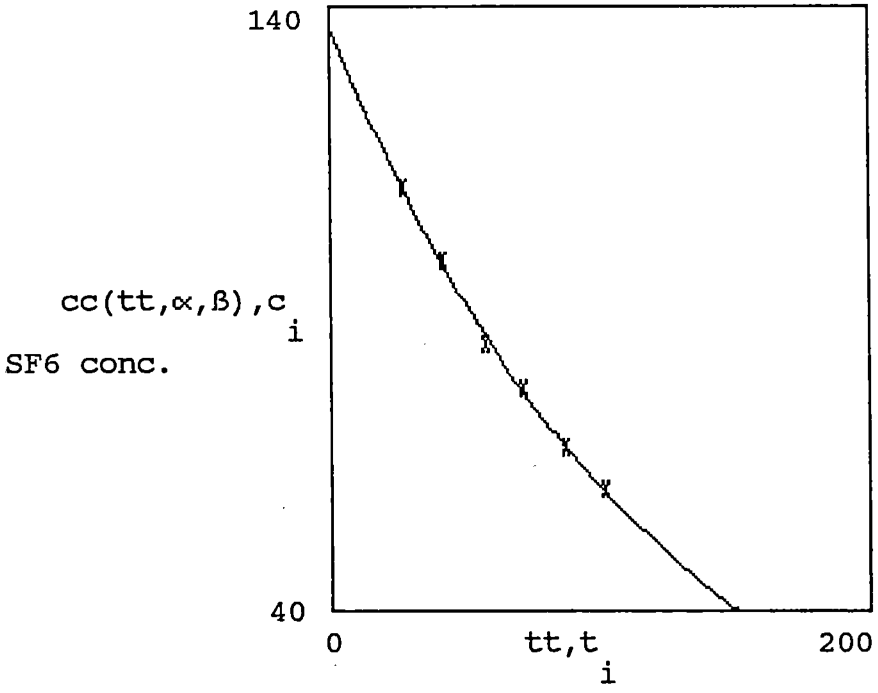
$\alpha = 0.008$
$\beta = 136.816$

Mean squared error

$$\frac{SSE(\alpha,\beta)}{4} = 1.447$$

Plot of fit:

tt := 1 ..150



time in minutes

AIR CHANGE CALCULATION - OCTOBER 10,1991.

ORIGIN ≡ 1

i := 1 ..6

$$t := \begin{bmatrix} 35 \\ 50 \\ 65 \\ 80 \\ 95 \\ 110 \end{bmatrix} \qquad c := \begin{bmatrix} 120 \\ 110 \\ 91 \\ 83 \\ 71 \\ 63 \end{bmatrix}$$

(c-vector is the SF6 concentration)
(t-vector is the time after injection)

Define the fitting function

$cc(t,\alpha,\beta) := \beta \cdot \exp(-\alpha \cdot t)$

$$SSE(\alpha,\beta) := \sum_{i} \left[c_i - cc\left[t_i,\alpha,\beta\right]\right]^2$$

Initial guess for parameters

$\alpha := 0.007$ $\beta := 100$

Given

$SSE(\alpha,\beta) \approx 0$

$1 \approx 1$

$$\begin{bmatrix} \alpha \\ \beta \end{bmatrix} := Minerr(\alpha,\beta)$$

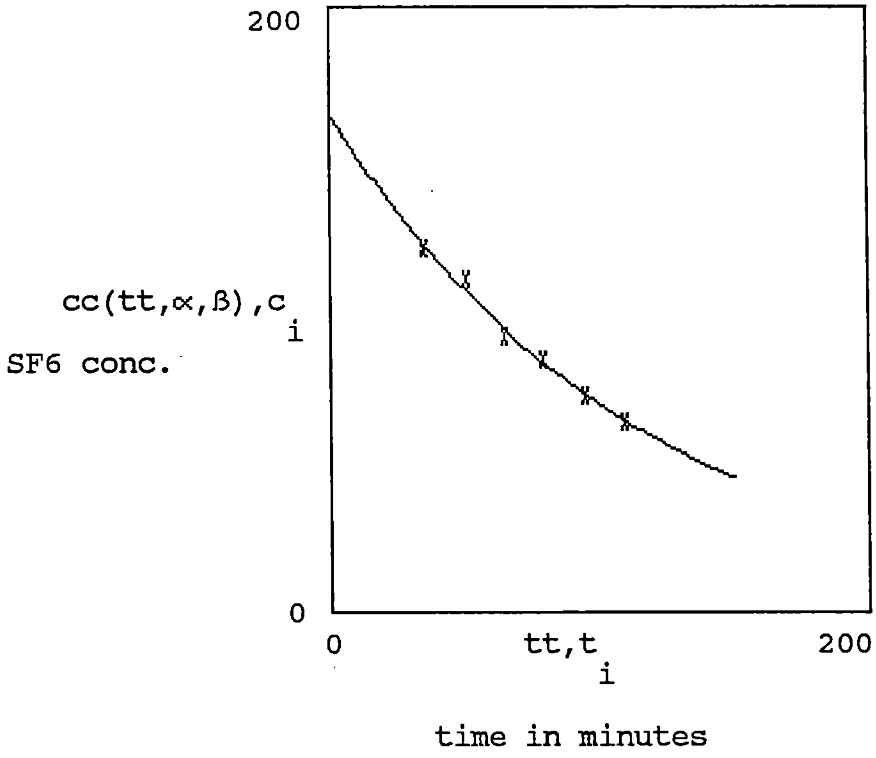
Parameters for best fit Mean squared error

$\alpha = 0.009$
$\beta = 164.905$

$$\frac{SSE(\alpha,\beta)}{4} = 5.491$$

Plot of fit:

tt := 1 ..150



AIR CHANGE CALCULATION - OCTOBER 11,1991.

$ORIGIN \equiv 1$

$i := 1 \,..6$

$$t := \begin{bmatrix} 25 \\ 42 \\ 55 \\ 70 \\ 85 \\ 100 \end{bmatrix} \qquad c := \begin{bmatrix} 110 \\ 96 \\ 82 \\ 71 \\ 58 \\ 51 \end{bmatrix}$$

(c-vector is the SF6 concentration)
(t-vector is the time after injection)

Define the fitting function

$$cc(t,\alpha,\beta) := \beta \cdot \exp(-\alpha \cdot t)$$

$$SSE(\alpha,\beta) := \sum_{i} \left[c_i - cc\left[t_i,\alpha,\beta\right]\right]^2$$

Initial guess for parameters

$\alpha := 0.007$ $\qquad\beta := 100$

Given

$SSE(\alpha,\beta) \approx 0$

$1 \approx 1$

$$\begin{bmatrix} \alpha \\ \beta \end{bmatrix} := Minerr(\alpha,\beta)$$

Parameters for best fit $\qquad$ Mean squared error

$\alpha = 0.01$
$\beta = 144.544$

$$\frac{SSE(\alpha,\beta)}{4} = 3.325$$

AIR CHANGE CALCULATION - OCTOBER 15,1991.

ORIGIN ≡ 1

i := 1 ..3

$t := \begin{bmatrix} 25 \\ 44 \\ 58 \end{bmatrix} \quad c := \begin{bmatrix} 140 \\ 120 \\ 100 \end{bmatrix}$

(c-vector is the SF6 concentration)
(t-vector is the time after injection)

Define the fitting function

$cc(t,\alpha,\beta) := \beta \cdot \exp(-\alpha \cdot t)$

$$SSE(\alpha,\beta) := \sum_i \left[c_i - cc\left[t_i,\alpha,\beta\right]\right]^2$$

Initial guess for parameters

$\alpha := 0.007 \qquad \beta := 100$

Given

$SSE(\alpha,\beta) \approx 0$

$1 \approx 1$

$\begin{bmatrix} \alpha \\ \beta \end{bmatrix} := \mathrm{Minerr}(\alpha,\beta)$

Parameters for best fit

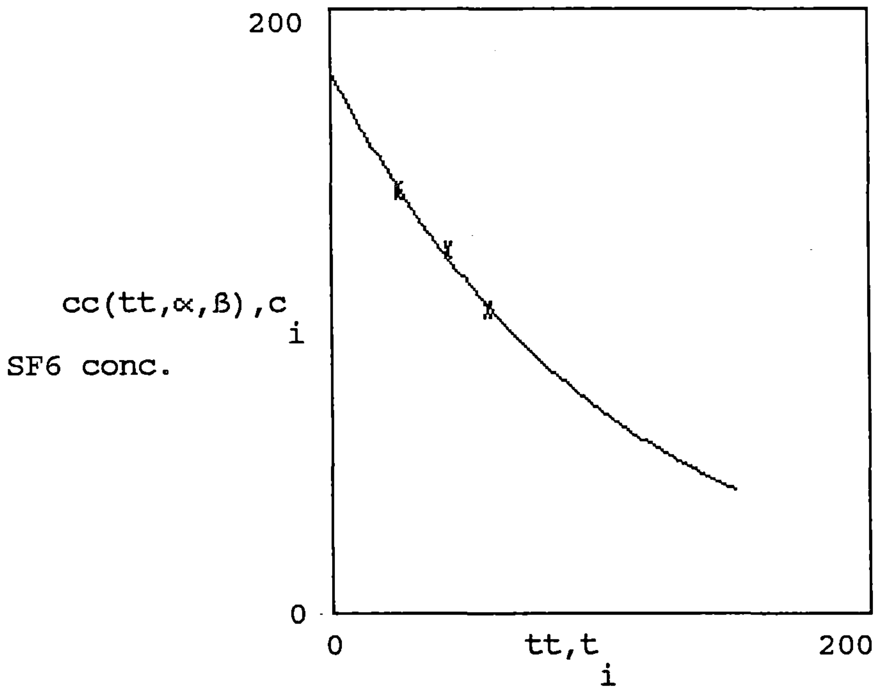
$\alpha = 0.01$
$\beta = 179.823$

Mean squared error

$$\frac{SSE(\alpha,\beta)}{4} = 3.481$$

Plot of fit:

tt := 1 ..150



time in minutes

Appendix D

GEOLOGIC LOGS

Monitor M69R

	Depth
Topsoil - silty sand, some organic matter	0 - 1.5 m
Organic Matter - medium sand mixed with organic matter	1.5 - 1.8 m
Sandy Silt - consolidated sandy silt, very wet	1.8 - 2.4 m
Sand - medium sand, dry, cohesionless	2.4 - 2.9 m

Installation M69RA - screen (2.6 - 2.9 m), gravel pack (2.4 - 2.9 m), bentonite seal (1.8 - 2.4 m)

Installation M69RB - screen and gravel pack (1.5 - 1.8 m), bentonite seal (.9 - 1.5 m)

Monitor M70IA

	Depth
Concrete	0 - .1 m
Gravel - sub-slab gravel	.1 - .2 m
Sand - medium sand, dry, cohesionless	.1 - 1.5 m

Installation M70JA - screen and gravel pack (1.4 - 1.5 m) native fill (.2 - 1.4 m), concrete seal (0 - .2 m)

Monitor M70IB

	Depth
Concrete	0 - .1 m
Gravel - sub-slab gravel	.1 - .2 m
Silty Sand - silty sand mixed with some organics	.2 - .4 m
Sand - Medium sand, dry, cohesionless	.4 - .6 m

Installation M70IB - screen and gravel pack (.5 - .6 m), native fill (.1 - .5 m), concrete seal (0 - .1 m)

Monitor M48F

	Depth
Topsoil - grass, topsoil	0 - .1 m
Sand - fine to very fine sand, some silt, slightly damp, occasional cobbles	.1 - 1.8 m
Silty Sand - brown, moist, increasing silt, increasing moisture	1.8 - 2.3 m

Installation M48F - screen and gravel pack (1.75 - 2.3 m), bentonite seal (1.1 - 1.75 m), native (0 - 1.1 m)

Monitor M48R

	Depth
Topsoil - grass, topsoil	0 - .1 m
Sand - fine to very fine sand, some silt, slightly damp, occasional cobbles	0 - 1.5 m
Sand - fine to medium sand, some coarse sand, brown to light brown, some gravel	1.5 - 2.3 m
Sand - fine to very sand, some silt, wet	2.3 - 2.7 m

Installation M48R - screen and gravel pack (2.1 - 2.7 m), bentonite seal (1.8 - 2.1 m), native fill (0 - 1.8 m)

Monitor M48IA

	Depth
Concrete	0 - .1 m
Gravel - sub-slab gravel	.1 - .2 m
Sand - fine to medium sand, cohesionless	.2 - .9 m

Installation M48IA - screen (.8 - .9 m), native fill (.1 - .8 m), concrete seal (0 - .1 m)