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MODERN MOBILE METHANE MEASUREMENTS IN MARSHES

by

Joel S. Leventhal[1]

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[1] U.S. Geological Survey, Federal Center, MS 973, P.O. Box 25046, Denver, CO 80225

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CONTENTS

FIGURES

TABLES

INTRODUCTION

Methane is an important greenhouse gas that contributes to global warming (IPCC, 1990; Lashof and Ahuja, 1990). One of the more obvious effects of global warming will be sea level rise (Titus, 1990; Gornitz, 1991) due to thermal expansion of seawater and melting glacier ice. Sea level rise will have the greatest impact in areas with low relief such as the Gulf Coast where coastal land loss has been documented since 1910 (Penland and others, 1990). Many other effects that are less predictable will also occur. These include positive feedback (Lashof, 1989) effecting atmospheric warming such as degassing of CO_2 from the ocean and decreased albedo as a result of glacier surface area decrease. By contrast, only a few negative feedbacks have been suggested, such as possibly increased cloud cover (that may be offset by increased water vapor). One negative feedback that has not been recognized in this regard is the decrease in methane production that will occur as a result of the conversion of fresh (low salinity) estuarine wetlands to brackish and (or) sea water-salinity conditions as a result of sea level rise (Leventhal, 1991). This occurs because bacterial sulfate reduction is energetically favored and thus always precedes bacterial methane production. Therefore, in sulfate-rich marine settings, methane production is much lower than in fresh water environments (Bartlett and others, 1985, 1987). This effect will be significant where estuarine and coastal wetlands are located on extensive Holocene/Recent terraces that will be inundated by the sea. The result will not merely be transient because these inundated wetlands will not be replaced (by new fresh water wetlands) at slightly higher elevations (Park and others, 1989) because (a) extensive terraces do not exist there, and (b) man-made barriers exist: structures, farm land or canals/water control devices.

The methane budget is complex with many natural and anthropogenic sources that are only known to within about a factor of two (Matthews and Fung, 1987; Cicerone and Oremland, 1988). This range of estimates for many major sources of methane leads to controversy on their relative importance (Aselmann and Crutzen, 1989). There is a need for more detailed "ground truth" on methane emissions from marshes to quantify the changes in methane flux due to wetland changes and losses. Currently, the primary controls on methane production and emission from wetlands are thought to be (in decreasing order of importance) salinity > water depth > temperature > organic carbon content, followed by several other variables (DeLaune and others, 1983; Crill, 1991; King and Weibe, 1978; Moore and others, 1990; Keller and others, 1990; Sass and others, 1990). The mode of release of methane from bottom sediment pore waters is by diffusion, ebullition (bubble formation) (Martens and Berner, 1974) and vascular transport/respiration (Dacey and Klug, 1979). However, the relative importance of these factors for methane production and release are not well established for many settings. In addition, the effects of disturbed and managed marsh areas (such as wildlife habitats) have not been well evaluated with respect to methane emissions.

In order to make these methane measurements in-situ, that is in real time, and numerous measurements, it is necessary to develop a method that is mobile, sensitive, and fast.

METHOD

For field measurements to be representative of the natural system, it is desirable to (a) have a remote field area away from anthropogenic influence, (b) disturb the field area as little as possible when making the measurements, and (c) make multiple measurements at the same time to evaluate and account for natural variation. Because of the many natural variables present, "real time" results are useful in order to be able to observe the immediate effects of these variables. Because of its sensitivity and specificity for gaseous hydrocarbons, some form of gas chromatography or "sniffing" using a flame ionization detector (FID) is the analytical method of choice by almost all investigators. The drawbacks of methods previously used are the necessity of transporting compressed gas tanks of carrier- and combustion-gas to the field and the necessity of large battery packs or generators for electric power in the field or lack of sensitivity (Leventhal and others, 1968; Swain, 1972, Zimmerman, 1979a, 1979b; Sebacher and Harriss, 1982). Some of these limitations also restrict the distance one can go into the field and (or) necessitates additional personnel to help in moving. It also limits the possibility of going into remote or inaccessible areas with this much equipment to transport. Another method that has been used is the collection of gas samples in the field and return to the lab for analysis gives no "real time" results (information) about the experiment. Our particular requirements included portability: transport on an airboat to the remote part (at least 5 km from inhabited areas of a marsh and 10 km from any permanent settlement) and then to the end of a 60 ft boardwalk (constructed from 2x10 in. lumber supported by 3-in.-diameter poles with 1 by 2 in. cross pieces) (fig. 1a). These field logistics make for difficult working conditions and often the locations and (or) number of samples needs to be compromised if the equipment is not portable and easy to operate.

Methane instrument:

After evaluation of all the commercially available portable hydrocarbon detection instruments, the SIP-1000 (Summit Interests, Lyons, Colo.) (fig. 1b) was selected. The important features of this instrument are: it is light weight (8 lbs including battery and hydrogen source); it has self-contained power and gases (the gas and power will last for at least 7 h); was one of the least expensive of the commercial units; has the necessary sensitivity with a flame ionization detector (FID); and can be used in a "sniffer" total hydrocarbon mode or a gas chromatographic mode.

[Units of measure are the ones actually used in the lab or field. They may be converted 1 in. = 2.54 cm = 25.4 mm]

The SIP 1000 has a small diaphragm pump (approximately 300 cc/min) that provides ambient air as combustion gas (and the sample in the "sniffer" mode). The hydrogen (30 L STP) is stored sorbed on a transition metal rare-earth element cartridge (Hydrogen Consultants Inc., Littleton, Colo.) as a metal hydride at relatively low pressure (<30 psi). The hydrogen is the combustion gas for the flame and also serves as the carrier gas for the column chromatography. We are using a 4 ft by 1/16 in. (ID, inside diameter) Teflon column packed with 50/80 mesh Porapak Q (Waters Assoc.). Because there is no make-up hydrogen gas at the flame, the maximum sample size is about 0.3 cc. Larger samples will displace too much hydrogen and extinguish the flame; therefore, our injected sample size is 0.2 cc. The signal from the FID is sampled 5 times each second, averaged, and read out on liquid crystal display (LCD, 4 digits—0000 to 9999) every 1 sec. The SIP 1000 has attenuations of 1, 2, 3, and 4, each 10X less sensitive than the previous. Thus, the dynamic range is 10,000 and the total range is 9.9×10^7. Although there is a calibration mode and memory that will allow the LCD to read out in "ppm" methane, we do not use this mode because it is inconvenient to calibrate with the standard in the field. In addition, the instrument sensitivity increases somewhat with increasing hydrogen pressure (fig. 2b), and there is variation of background with time in the marsh. Therefore, we use the raw count LCD output: recording (by hand) the background (counts due to atmospheric methane and instrument "noise") and then recording the signal from the methane collectors or sample syringe. The difference (net counts) is the methane in the sample. For the flow or "sniffer" mode, the instrument is calibrated using a plastic bag filled with (attached to) a methane standard from a gas cylinder (Scott Specialty Gases, Longmont, Colo.). The instrument is somewhat sensitive to hydrogen pressure (and flow rate), thus we keep the pressure between 6 and 7 psig. Figure 2 shows this dependence using a 8.8 ppm CH_4 standard (9.1 ppm THC, total hydrocarbons); the data are tabulated in table 1. Using both the 8.8 ppm and a 96 ppm CH_4 standard that actually have 9.1 and 101 ppm total hydrocarbons (Rick Schmeltekopf, Scott Gases, personal commun.), and a 50 ppm standard, the sensitivity is 17±1 counts per ppm hydrocarbon or methane in our collectors in the "sniffer" (total hydrocarbon mode). The "sniffer" mode does not use the Porapak column, but analyzes the total sample in air that is pumped through the FID. This is quite adequate sensitivity and stability for our measurements of the marsh environments that often show values of 1 to 5 ppm/min increases in the collector during the 20-40 min accumulation.

In the gas chromatograph mode, used mainly for determining methane in pore water samples, a 0.2 cc gas sample in a gas tight syringe (Model A-2, 0.5 cc, Precision Sampling Corp., Baton Rouge, La.), the sensitivity is 4.1±0.2 counts (per 2 sec) per ppm methane (using the above three standards) in the injection mode with separation of the methane on the Porapak column. [Note: this is different from the "sniffer" mode.] When used for methane dissolved in pore water samples taken at depth, this sensitivity is quite adequate because the methane concentration is usually hundreds to thousands of ppm. The instrument was originally set up using a portable 10 mv strip chart recorder to observe retention times and peak shapes). It was determined that the methane retention time was 15 sec and that the peak was well represented by the readout of the LCD over 2 sec (2 successive readings). The net methane was obtained by subtracting 2 sec of background counts. No ethane or other higher HC gases were ever detected ($CH_4 > 1000\ C_{2+}$) from the marshes.

Collectors:

Plastic buckets for emissions:

We did not choose to establish a few permanent "in-ground" collectors (cost, disturbance to the substrate, lack of ability to change locations) and, therefore, use four portable collectors that can float on the water or rest directly on the mud. This has the advantage of not disturbing the marsh surface or substrate and being able to make measurements at many different places in a marsh. The latter allowed us to choose many sites with different vegetation density, water depth, and other variations actually encountered in the marsh. We used 10-quart plastic (high-density polyethylene) buckets (Rubbermaid 2963). These plastic buckets are 25-cm tall, 21.3-cm ID at the bottom and 24.5 cm ID at the top (actually the bottom in the collection mode), thus the internal volume is 10.3 L (0.46 moles) for a bucket submerged 1 cm in the water and the cross-sectional area on the water is 0.0471 m^2. In order to float the buckets, five to seven 8-cm sections of annular polyfoam (used for water pipe insulation, 3/4 in. ID, 2 in. OD, outside diameter) on the (bottom) lip of the inverted bucket (fig. 1c). A 5-ft length of 1/4-in. (OD) nylon (or other volatile hydrocarbon/methane-free) tubing was inserted into a 1/4-in. hole in the bottom of the inverted bucket. The tubing end in the bucket was usually positioned near the center of the bucket, but about one third to one half of the way down into the bucket. Using a second hole (usually plugged) and tube, samples could be taken sequentially from other parts of the bucket to check for any gas stratification. No stratification was observed (fig. 3) and a small battery powered fan device was not needed. These collectors are a simpler version of those often used (Wilkening, 1990).

[In an earlier experimental set up we tried to use 10-mL vacutainers (red plug #6441) for storage of large 10-cc samples removed from the collector. Unfortunately we found that these Vacutainers contained unacceptably high amounts of methane, as well as acetylene, ethylene, ethane and propane (presumably from degassing of the septa. With cooperation of the manufacturer we also tried other types of septa: pink septum (#6440) and blue septum (#6526) which had less hydrocarbon gases, but still too much, relative to our collection requirements.]

Based on the volume of the collectors (10.3 L), a methane emission rate of 0.011 $mg/m^2/min$ corresponds to approximately 10 counts above background during 10 min of accumulation (see section on Calculations). A sample was measured by attaching the end of the tube to the probe (sniffer) and about 4 sec of operation were needed as the sample purged the tube and the FID output on the LCD increased to a value that was then stable for more than 30 sec. Readings were usually taken for 4 to 6 sec after the 5 sec pumping period. Initially, the sampling tubes were loosely capped (to allow equilibration of pressure) after each measurement. However, when some caps were left off during the accumulation time (during the sampling) it was found that loss of methane was not significant, thus the tubes were left uncapped during subsequent measurements. Background values (ambient air) were recorded before (and sometimes after) each sample measurement.

Syringes to collect methane that is dissolved in surface water and at depth:

Two types of syringes were used a 20-mL plastic (Becton Dickson B-D 9661) and a 10-mL glass body with plastic plunger (B-D 5294) both with neoprene rubber on the plungers. A plastic (nylon or polypropylene stopcock Baxter/Pharmaseal model K71) or three-way valve (model K75P) was fitted to the nose of the syringe. Syringes were usually filled 50 to 80 percent with sample water. In some cases this also includes gas from the collecting tube (1/16-in. OD tygon tubing) or from depth in the sediment by the "sipper." The "sipper" is a 1/8-in. OD (1/16 in. ID) rigid Plexiglas tube that is 60 to 110 cm in length with five sets of 1/32-in. holes drilled between 1/4 and 3/4 in. from the bottom end. The end of the sipper was plugged with 1.4 in. of silicone cement. The sipper was marked at 5-cm intervals so that the sampling depth was known.

Before laboratory analysis, at least 2 cc of air was added to the syringe and a septum (Aldrich Z10072-2) is securely fitted on the end of the valve. The sample is vigorously shaken for 30-60 sec to transfer the methane dissolved in the water to the head space and 0.2 cc of gas sample is removed with a gas tight syringe (Precision Sampling Corp., Baton Rouge, La., model A-2, 0.5 cc).

CALCULATIONS

Buckets:

(a) Dimensions: top ID 23.1 cm, bottom ID 24.5 cm, height 24.5 cm.
Volume: 10.3 L; 0.46 moles STP.
Bottom (inverted) area: 0.0471 m^2.
Therefore, 1 ppm methane in the bucket is 7.36 10^{-6} g or 7.36 10^{-3} mg.

(b) To get a rough idea of relative sizes/amounts consider the following: adding 1 cc of methane (in a 1-cc bubble) to the collector will result in the addition of 1/10300 of the volume (dilution of 1 cc of pure methane by 10300, approximately 10^4 times). Thus the methane content of the collector is increased by 0.01 percent or 100 ppm. The weight of 1 cc of methane is $1/22400 \times 16 = 7.14\times10^{-4}$ g (or 0.71 mg). The area of the bottom of the bucket is 0.0471 m^2. Therefore, the bubble addition air in the collector (bucket) represents 0.714 mg/0.0471 m^2 or 15.2 mg/m^2. If this occurred over 30 min, it could be expressed as 0.505 mg/m^2/min or 30.4 mg/m^2/h or 730 mg/m^2/day [0.73 g/m^2/day] (assuming constant emission over 24 h). This would translate into 133 g/m^2/yr, again assuming constant emissions for 180 days (to account for lesser emissions during the colder part of the year and when less vegetation is present). All these emissions are for methane; multiply by twelve-sixteenths to get in terms of carbon.

(c) A second example: if the bubble has a diameter of 0.6 cm (6 mm=1/4 in.), its volume is 0.113 cc. This is equivalent to 11 ppm methane increase. This will give a count response of 11x13 or 143 counts. This is 0.113/22400 moles x16 g/mole = 0.0807 mg of methane. The emission is thus .0807/.0471 m^2 or 1.7 mg/m^2 per unit of time during which the bubble entered.

(d) Based on the calibration data (fig. 2, table 2), an 8.8 ppm CH_4 (9.1 ppm THC) and the 96 ppm CH_4 (101 ppm THC) we use 16±2 counts per ppm as the conversion. Therefore for 1 ppm = 7.36×10^{-3} mg the conversion is 0.46 10^{-3} mg/count. To convert to mg/counts/m^2, multiply by 21.2 to get 9.8×10^{-3} mg/m^2/count (see fig. 4b). If the rate (counts/minute) is used, then multiply the count rate by 14.1 (0.0098 x 60 min x 24 h) to get in units of mg/m^2/day.

Syringes:

Using a 10-cc syringe: use a sample of liquid (water) of 8 cc and gas (from sample or added air) of 2 cc. If a 0.2 cc volume is taken from the collection syringe into the gas-tight injection syringe and injected into the gas chromatograph (gc), this represents only 0.1 of the total gas volume and of the total methane. However, in terms of methane per cc the result must be divided by 8 (cc volume of the water). Thus, the gc result is multiplied by 10/8.

The calibration of the GC-FID using three gas standard (8.8, 50, and 96 ppm) shows a sensitivity of 4.1 counts (gross–background) per ppm during 2 sec (the methane peak from the gc) for a 0.2 cc injection. Usually samples from depth give hundreds to thousands (or ten-thousands) of counts for a 0.2 cc injection.

FIELD OPERATION AND DISCUSSION

In addition to measurements made in Louisiana (Leventhal and others, 1992; Leventhal and Guntenspergen, in preparation), tests and measurements were made near the Federal Center in Lakewood, Colo. Figure 3 shows the methane emissions from Kendrick Lake, in a suburban park with extensive adjacent wetlands. The graph shows methane accumulations in four collectors placed at various locations near a fishing boardwalk. They show similar, but not identical, increases of methane (net counts vs time). For each collector a somewhat different amount of methane was evolved. This is not surprising because the collectors are in different depths of water and different distances from plants (and plant density) and presumably different sediment organic C contents. The carbon contents are 0.41, 0.36, 0.42 and 0.61 percent organic carbon for sediments at locations *a, b, c,* and *d* respectively.

Samples were measured from four collectors (I through IV) at four locations (*a, b, c, d*) during each of four time periods (table 2). These locations were over open water adjacent to a fishing pier; location *d* was near the edge of the lake with a 4- to 5-in. water depth, location *c* was near emergent vegetation with a water depth of 16 to 17 in., location *b* was also near vegetation with a water depth of 11 to 12 in.; location *a* was out the boardwalk away from vegetation with a water depth of 18-22 in. None of these locations were actually in a marsh and the emissions were not very high. The higher values for location *a* may be due to the fact that it was near one of the posts that supports the boardwalk (that disturbed the sediments at depth and (or) acted as a conduit). The 9 a.m. collections show evidence of ebullition at this time possibly because there was a wind coming across the lake making ripples on the water and possibly releasing gas from the sediments from locations *d* and *c* that were nearest the shore.

The rate, in counts per minute, can be calculated for each point or just for the final point (for a cumulative or summary result). For the collectors II and III on the figure, the smooth slope is the diffusion of methane from the water. Collectors I and IV show two different linear rates; a higher rate during the first 15 and 30 min, respectively, and a lower rate for the latter part of the collection.

To consider these rates in detail:

For collector II the rate is 20 counts increase per 54 min or 0.37 counts/min (table 2). Multiplying this by the factor to convert counts per minute (14.1) to mg/m^2/day, the result is 5.2 mg/m^2/day. Actually the measurement is really more typical of methane escape over the 50 min or perhaps 1 h and is more correctly 0.22 mg/m^2/h. However, most investigators express the results in per hour units.

For collector III: 20 counts/52 min = 0.38 counts/min or 5.4 mg/m^2/day. Collectors I and IV show a faster rate during the earlier part of their collection time (heavy line) and a slower rate during the later part. For collector I, the overall rate is 38/55.5 = 0.68 counts/min, equivalent to 9.6 mg/m^2/day; this is composed of the two parts 18/15.5 = 1.2 corresponding to 17 mg/m^2/day for the first slower part and (38-18)/(55-15) = 0.5 corresponding to 7 mg/m^2/day for the latter part of the collection. The slow rate 7 mg/m^2/day is not too different from the overall results for collectors II and III. For collector IV the overall rate is 53/49.2 = 1.1, which is 15.5 mg/m^2/day. The first part of the accumulation was 39/26 = 1.5 which is 21 mg/m^2/day and the latter part is 53 or 55-46/17 = 0.41 or 0.53 corresponding to 5.8 to 7.5 mg/m^2/day. These slow rates are in the same range as from the other collectors.

As can be seen on figure 4 (Sample IIc), sometimes the methane increases in one jump between one sampling time and the next. These jumps are presumably due to ebullition (bubbles). The methane emission for this collector was 10.7 counts/min up to 25 min (table 2) and then took a jump due to the bubble sometime between 26 and 31 min. The total count rate at 32 min was 298 counts/min. The total release of methane is the sum of the linear diffusion and the jumps due to ebullition. This was made up of the total 298, minus the linear 11, and, therefore, the bubble accounts for 287 counts/min of the total. The log scale (fig. 4b) shows the bubble jump and on the right vertical axis the conversion of net counts to mg/m^2 (no time units).

Figures 3, 4, and 5 show a series taken between 6 a.m. and 8 p.m. and table 3 shows a summary of the emission rates. In general the results are reproducible and consistent. Occasional jumps in methane results are seen, these are probably due to ebullition (bubble) of methane rather than diffusion.

The bubble availability can be tested by poking or stirring the sediment, which usually results in the release of gas as bubbles (ebullition); however these bubbles probably contain CO_2 as well as CH_4. Poking a stick below the bucket releases bubbles trapped in the sediment and will easily give an almost immediate increase of several hundred to several thousand counts. Conversely, in another experiment the buckets were set at the edge of a lake (reservoir) that had just had its level significantly increased. The buckets, which were near-shore in only 1 to 4 in. depth of water, showed no increase in counts over a 15-min time period. This was because the sediments below them, which were just a few days before an exposed soil, contained essentially no organic matter, which is necessary for methane production (and emission). Likewise, buckets set on a lawn or dirt also show no methane count increase (however, these were not well sealed against air leaks).

The method described here has been in use since June 1991 and works well for measurements of methane emission from wetlands.

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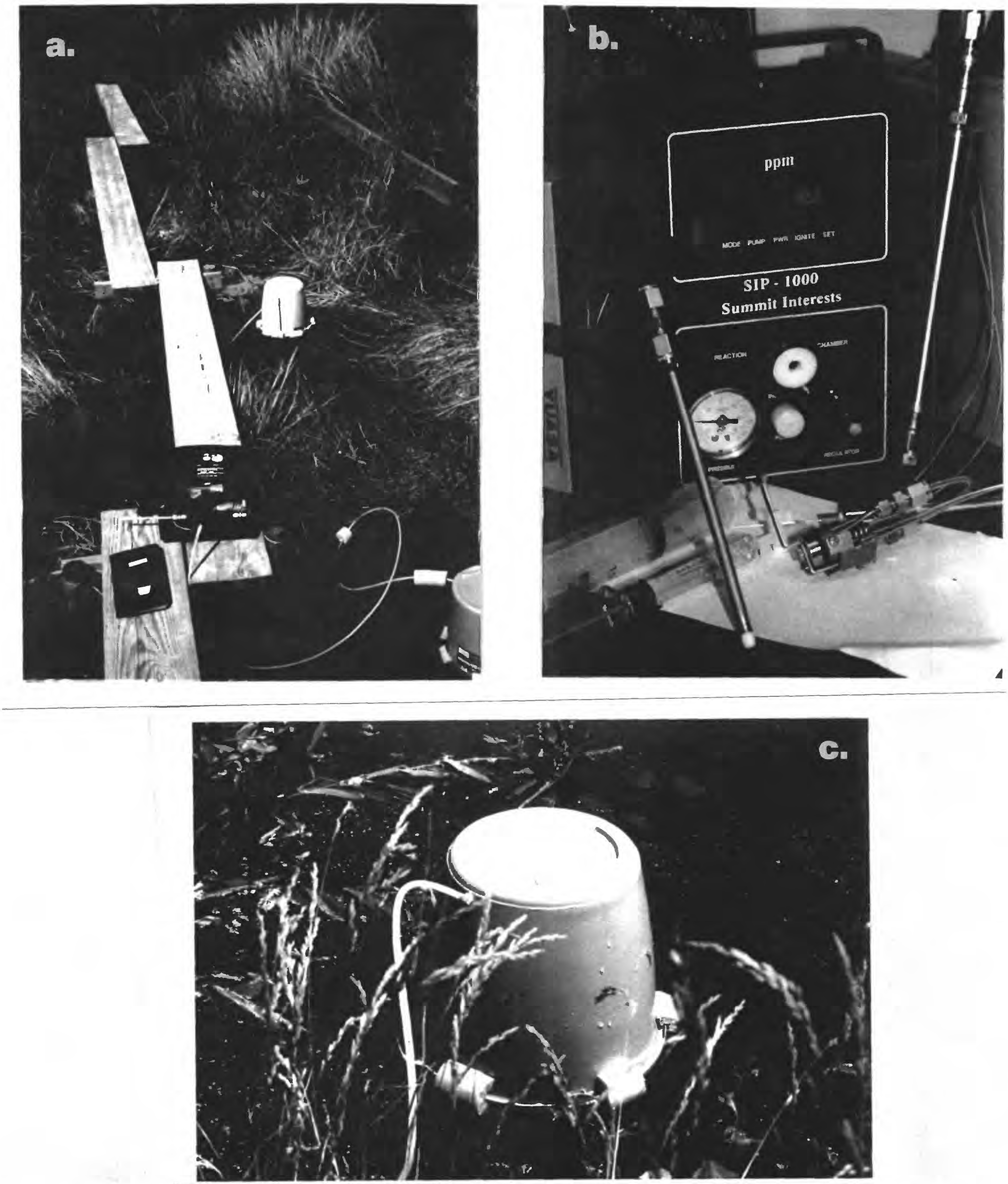

Figure 1. (a) Methane collectors and SIP-1000 deployed on boardwalk in Terrebonne Parish, Louisiana.
(b) Photograph of the SIP-1000. On the left is the battery, on the right is the hydrogen storage container, in front is the probe (upright with large black handle and tube with teflon nosepiece) for taking samples.
(c) Collector is an inverted plastic bucket (10 in. high); note polyfoam on bottom to keep it floating and sampling tubing that stays in place during complete measurement time.

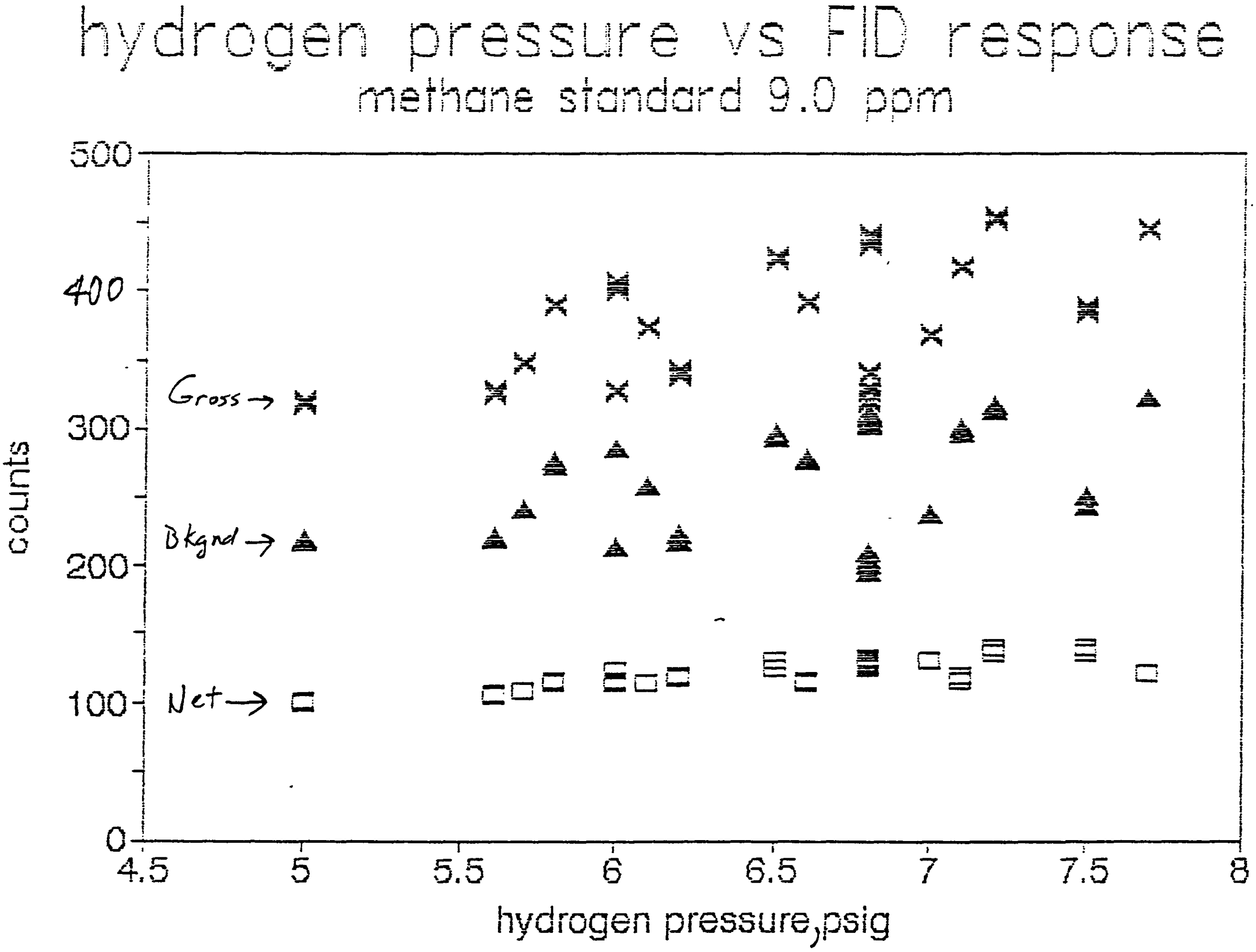

Figure 2. (a) Hydrogen pressure vs gross, background and net counts.

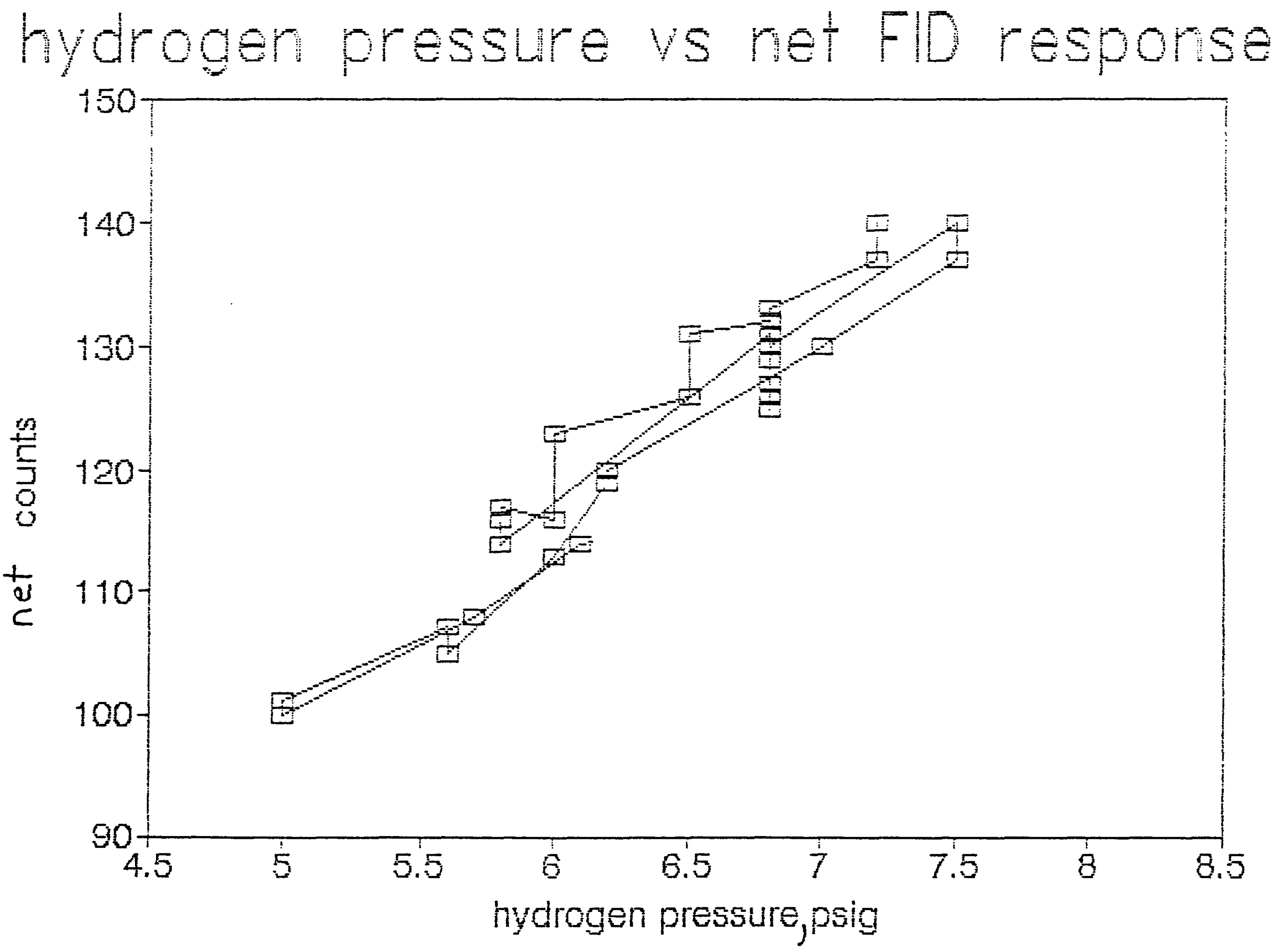

Figure 2. (b) Hydrogen pressure vs net counts. Precision of measurement is smaller than ±1 count and, therefore, is smaller than the symbol.

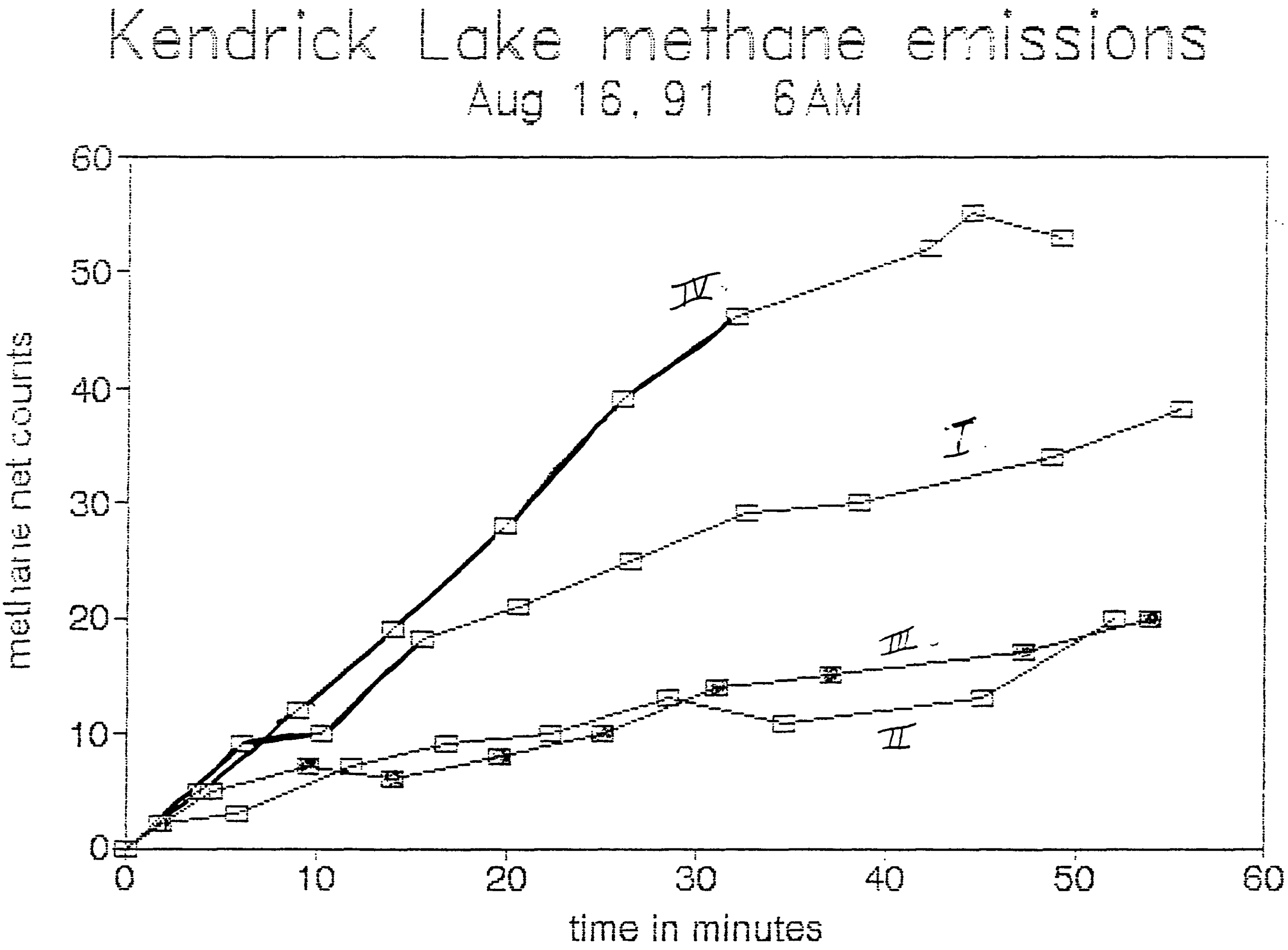

Figure 3. Methane emissions from four collectors at Kendrick Lake Park, August 16, 1991, 6 a.m. Heavy lines indicate the higher linear rate observed during the initial 15 min for collector I and 30 min for collector IV.

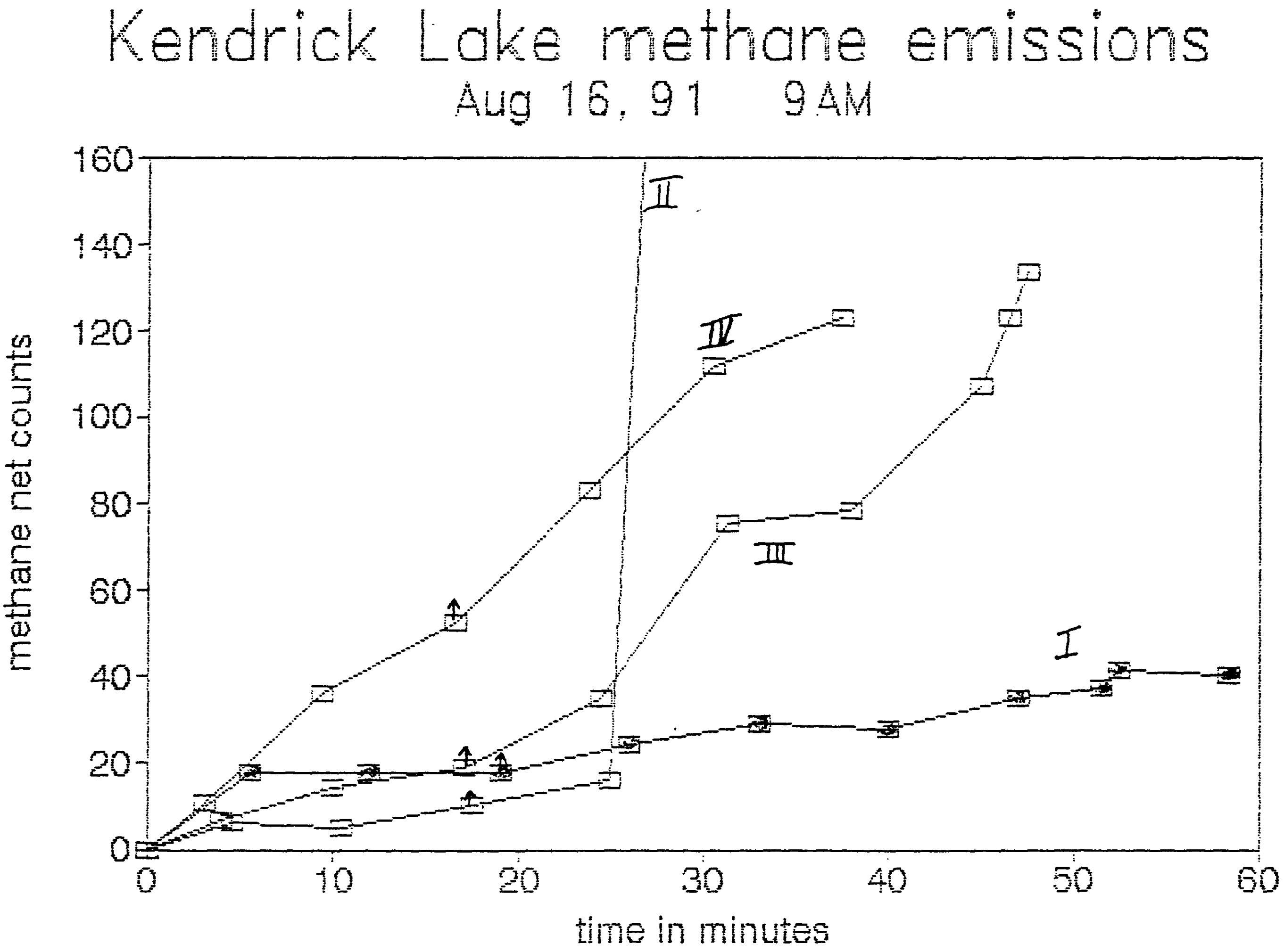

Figure 4. (a) Methane emissions from four collectors at Kendrick Lake Park, August 16, 1991, 9 a.m. Data for collector II goes off scale at 25 min due to ebullition. Collector III also shows abrupt increase at 25 and 38 min and later, presumably due to ebullition. Data taken at around 18 min (short up arrows) is low because hydrogen pressure was only 5.5 psi and data is depressed by ~ 5 percent.

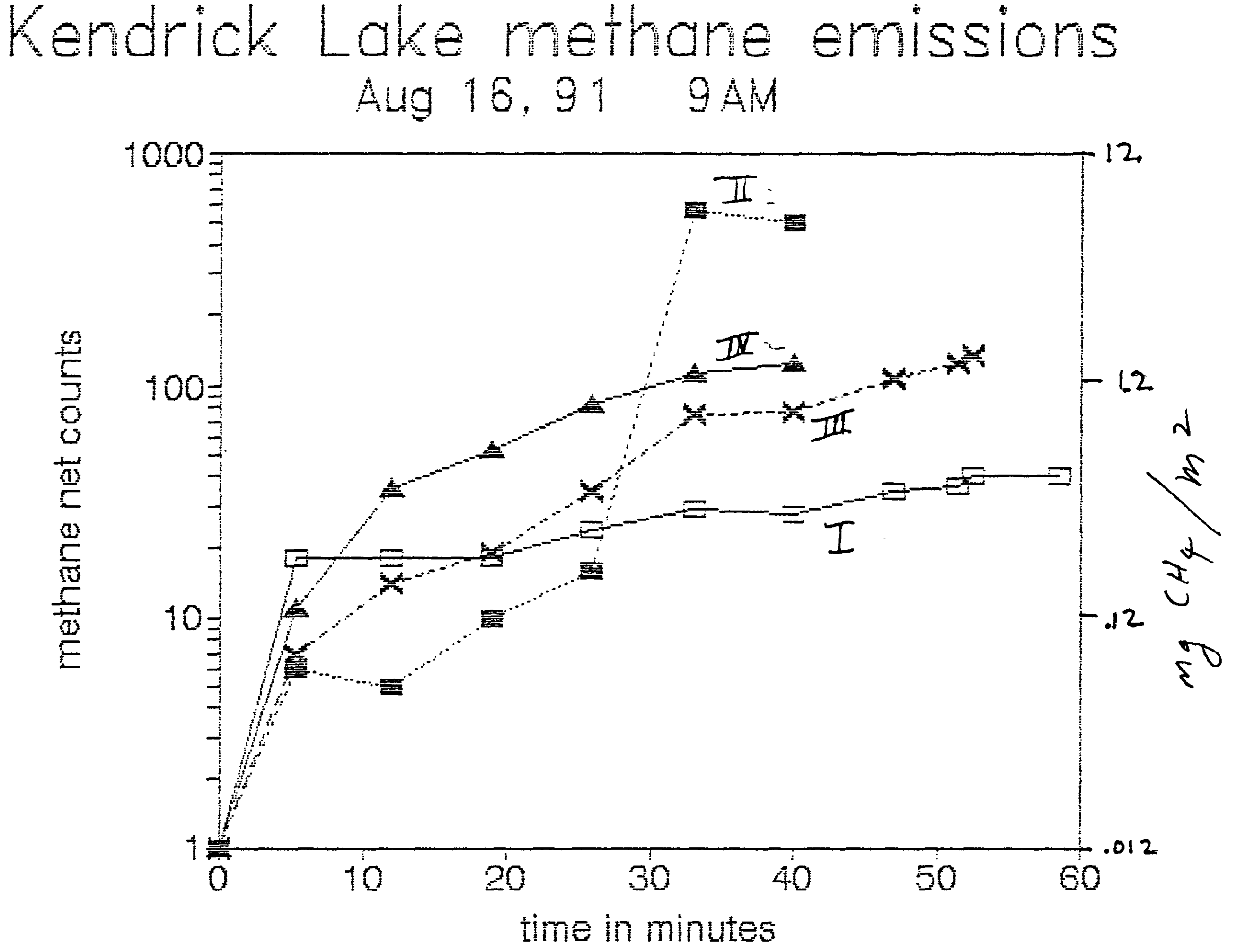

Figure 4. (b) Log scale for methane emissions from same four collectors at Kendrick Lake Park, August 16, 1991, 9 a.m. (the jump from 0 to 5 min is due to the log scale, not ebullition). Right axis shows equivalence between counts (not counts/min) and methane.

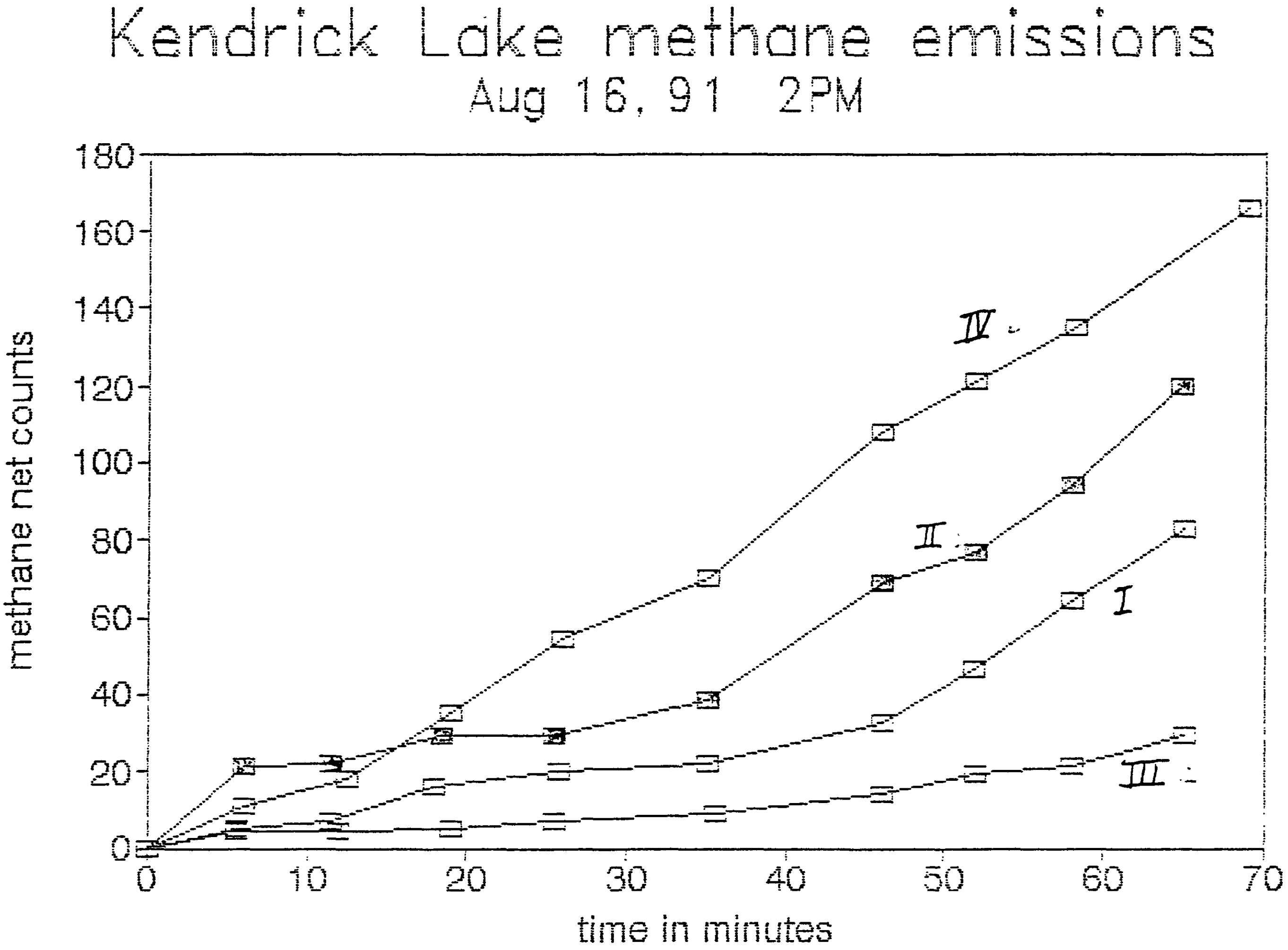

Figure 5. (a) Methane emissions from four collectors at Kendrick Lake Park, August 16, 1991, 2 p.m. Note jump for collector II at start; rates for I, II, and III are similar for 35 min, then for remainder of the collection, collectors assume the higher rate similar to collector IV.

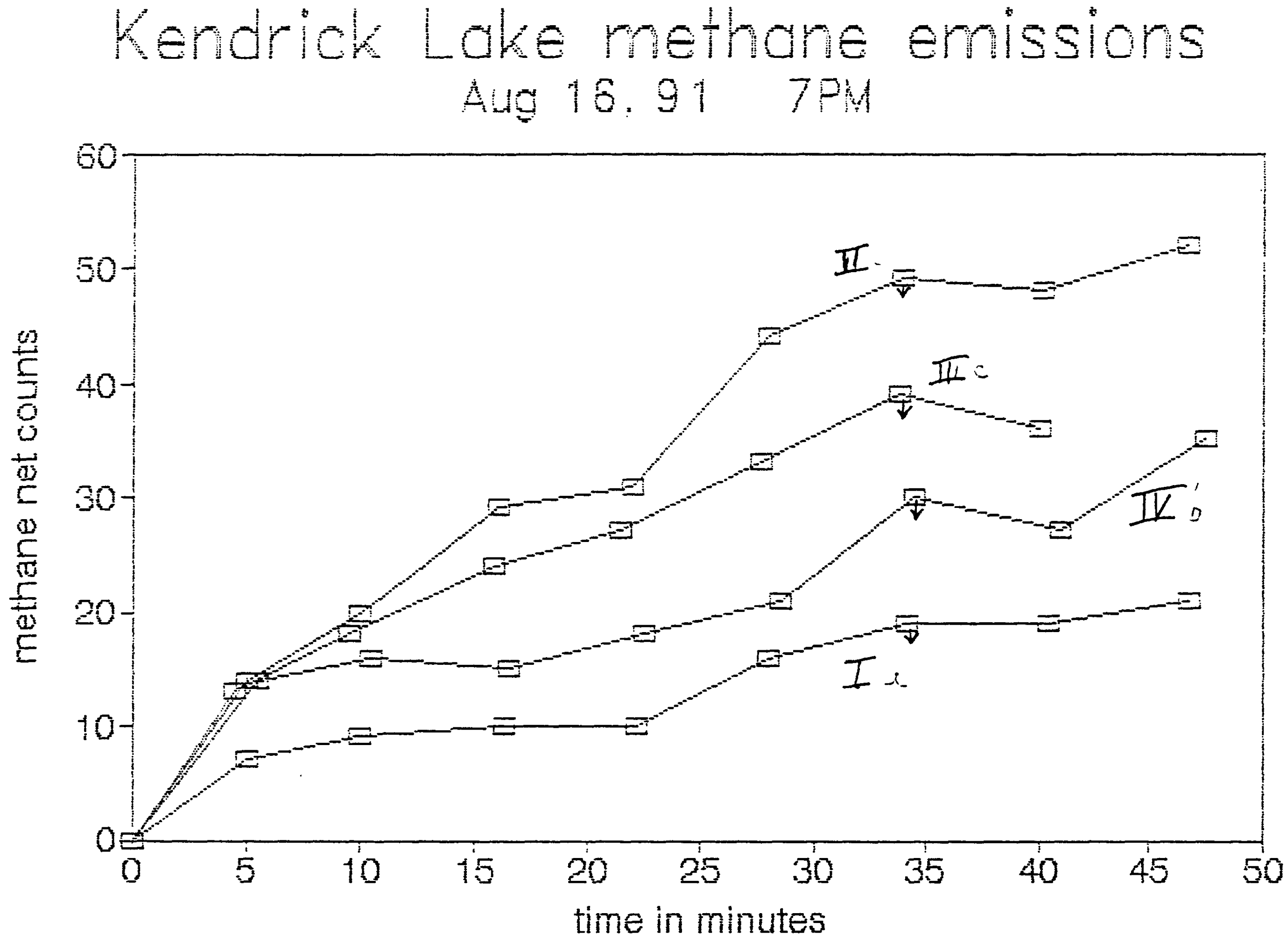

Figure 5. (b) Methane emissions from four collectors at Kendrick Lake Park, August 16, 1991, 7 p.m. Data around 35 min (short down arrows) was taken at a hydrogen pressure of 7.5 psi and is 5 percent elevated.

Table 1. Calibration of FID and H_2 pressure
9.0 ppm std jan 92

P H_2	bkgrd	grosCH_4	net CH_4
6.8	195	320	125
6.8	200	327	127
6.8	204	330	126
6.8	210	340	130
7.5	243	383	140
7.5	251	388	137
7	237	367	130
6.2	218	338	120
6.2	222	341	119
6	214	327	113
5.6	219	324	105
5.6	221	328	107
5	217	318	101
5	219	319	100
5.7	240	348	108
6.1	258	372	114
6.6	275	391	116
6.6	277	391	114
7.1	296	416	120
7.1	299	416	117
7.7	322	444	122
	refil bag		
7.2	312	452	140
7.2	316	453	137
6.8	301	434	133
6.8	303	435	132
6.5	292	423	131
6.5	296	422	126
6	284	407	123
6	284	400	116
5.8	273	390	117
5.8	273	389	116
5.8	275	389	114
6.8	307	438	131
6.8	308	438	130
6.8	309	438	129
6.8	310	439	129
6.8	311	440	129

Table 2. KENDRICK LAKE PARK

	Aug 16	6 AM	FishDock			rate	rate
collector	time	gross	bkgd	net	adt time	cts/min	mg/m2/day
I	1.5			0	0		
I	7.5	118	109	9	6	1.50	25.05
I	11.8	118	108	10	10.3	0.97	16.21
I	17	124	106	18	15.5	1.16	19.39
I	22	130	109	21	20.5	1.02	17.11
I	28	143	118	25	26.5	0.94	15.75
I	34	155	126	29	32.5	0.89	14.90
I	40	169	139	30	38.5	0.78	13.01
I	50.2	179	145	34	48.7	0.70	11.66
I	57	175	137	38	55.5	0.68	11.43
II	3.5			0	0		0.00
II	8	114	109	5	4.5	1.11	18.56
II	13	114	107	7	9.5	0.74	12.31
II	17.5	114	108	6	14	0.43	7.16
II	23	118	110	8	19.5	0.41	6.85
II	28.5	129	119	10	25	0.40	6.68
II	34.5	142	128	14	31	0.45	7.54
II	40.5	155	140	15	37	0.41	6.77
II	50.8	162	145	17	47.3	0.36	6.00
II	57.5	157	137	20	54	0.37	6.19
III	6.7			0	0		0.00
III	8.5	110	108	2	1.8	1.11	18.56
III	12.5	110	107	3	5.8	0.52	8.64
III	18.5	115	108	7	11.8	0.59	9.91
III	23.5	119	110	9	16.8	0.54	8.95
III	29	129	119	10	22.3	0.45	7.49
III	35.2	141	128	13	28.5	0.46	7.62
III	41.2	152	141	11	34.5	0.32	5.32
III	51.8	157	144	13	45.1	0.29	4.81
III	58.8	156	136	20	52.1	0.38	6.41
IV	10			0	0		0.00
IV	13.8	111	106	5	3.8	1.32	21.97
IV	19	119	107	12	9	1.33	22.27
IV	24	129	110	19	14	1.36	22.66
IV	29.8	146	118	28	19.8	1.41	23.62
IV	36	170	131	39	26	1.50	25.05
IV	42	188	142	46	32	1.44	24.01
IV	52.2	194	142	52	42.2	1.23	20.58
IV	54.5	194	139	55	44.5	1.24	20.64
IV	59.2	190	137	53	49.2	1.08	17.99

Table 2. (Continued)

	9 AM	second set					
coll	time	gross	bkgd	net	adt time	cts/min	mg/m2/day
I	3			1	0.1		0.00
I	8.5	141	123	18	5.5	3.27	54.65
I	15	169	151	18	12	1.50	25.05
I	22	189	171	18	19	0.95	15.82
I	29	222	198	24	26	0.92	15.42
I	36	222	193	29	33	0.88	14.68
I	43	228	200	28	40	0.70	11.69
I	50	212	180	35	47	0.74	12.44
I	54.5	242	205	37	51.5	0.72	12.00
I	55.5	239	198	41	52.5	0.78	13.04
I	61.5	236	196	40	58.5	0.68	11.42
II	5			1	0.1		0.00
II	9.5	129	123	6	4.5	1.33	22.27
II	15.5	162	157	5	10.5	0.48	7.95
II	22.5	182	172	10	17.5	0.57	9.54
II	30	215	199	16	25	0.64	10.69
II	36.5	760	197	563	31.5	17.87	298.48
II	43.5	705	202	503	38.5	13.06	218.18
III	6			1	0.1		0.00
III	10	132	125	7	4	1.75	29.23
III	16	171	157	14	10	1.40	23.38
III	23	193	174	19	17	1.12	18.66
III	30.5	237	202	35	24.5	1.43	23.86
III	37.3	273	198	75	31.3	2.40	40.02
III	44	279	201	78	38	2.05	34.28
III	51	276	179	107	45	2.38	39.71
III	52.5	288	176	123	46.5	2.65	44.17
III	53.5	345	212	133	47.5	2.80	46.76
IV	7.5			1	0.1		0.00
IV	10.5	139	128	11	3	3.67	61.23
IV	17	196	160	36	9.5	3.79	63.28
IV	24	224	172	52	16.5	3.15	52.63
IV	31.3	283	200	83	23.8	3.49	58.24
IV	38	309	197	112	30.5	3.67	61.32
IV	45	323	200	123	37.5	3.28	54.78
III	63	713	204	509	57	8.93	149.13
III	66	1665	211	1454	60	24.23	404.70

	3rd set	2 PM					
collect	time	gross	bkgnd	netCH4	adj T	cts/min	mg/m2/dy
IV	1			0	0		0.00
IV	7	261	250	11	6	1.83	30.62
IV	13.5	333	315	18	12.5	1.44	24.05
IV	20	434	399	35	19	1.84	30.76
IV	27	465	411	54	26	2.08	34.68
IV	36	470	400	70	35	2.00	33.40
IV	47	312	204	108	46	2.35	39.21
IV	53	322	201	121	52	2.33	38.86
IV	59.2	342	207	135	58.2	2.32	38.74
IV	70	387	221	166	69	2.41	40.18

Table 2. (Continued)

III	2			0	0		0.00
III	7.5	264	260	4	5.5	0.73	12.15
III	14	323	319	4	12	0.33	5.57
III	21	404	399	5	19	0.26	4.39
III	27.5	422	415	7	25.5	0.27	4.58
III	37.5	410	401	9	35.5	0.25	4.23
III	48	219	205	14	46	0.30	5.08
III	54	218	199	19	52	0.37	6.10
III	60	229	208	21	58	0.36	6.05
III	67	240	211	29	65	0.45	7.45
II	3			0	0		0.00
II	9	307	286	21	6	3.50	58.45
II	14.5	343	326	22	11.5	1.91	31.95
II	21.5	429	400	29	18.5	1.57	26.18
II	28.5	446	417	29	25.5	1.14	18.99
II	38	437	399	38	35	1.09	18.13
II	49	268	199	69	46	1.50	25.05
II	55	274	197	77	52	1.48	24.73
II	61	295	201	94	58	1.62	27.07
II	67.8	331	211	120	64.8	1.85	30.93
I	4			0	0		0.00
I	9.5	309	304	5	5.5	0.91	15.18
I	15.5	338	331	7	11.5	0.61	10.17
I	22	421	405	16	18	0.89	14.84
I	29.8	439	419	20	25.8	0.78	12.95
I	39	425	403	22	35	0.63	10.50
I	50	241	208	33	46	0.72	11.98
I	55.8	248	202	46	51.8	0.89	14.83
I	62	274	210	64	58	1.10	18.43
I	69	304	221	83	65	1.28	21.32

4th set 7 PM

collect	time	gross	bkgnd	netCH4	adj T	cts/min	mg/m2/dy
IV	0.5			0	0		0.00
IV	6	184	170	14	5.5	2.55	42.51
IV	11	209	193	16	10.5	1.52	25.45
IV	17	227	212	15	16.5	0.91	15.18
IV	23	231	213	18	22.5	0.80	13.36
IV	29	242	221	21	28.5	0.74	12.31
IV	35	258	228	30	34.5	0.87	14.52
IV	41.5	243	216	27	41	0.66	11.00
IV	48	249	214	35	47.5	0.74	12.31
III	2			0	0		0.00
III	6.5	186	173	13	4.5	2.89	48.24
III	11.5	213	195	18	9.5	1.89	31.64
III	17.8	234	210	24	15.8	1.52	25.37
III	23.5	241	214	27	21.5	1.26	20.97
III	29.7	254	221	33	27.7	1.19	19.90
III	35.8	268	229	39	33.8	1.15	19.27
III	42	249	213	36	40	0.90	15.03

Table 2. (Continued)

II	2.5			0	0		0.00
II	7.5	190	176	14	5	2.80	46.76
II	12.5	217	197	20	10	2.00	33.40
II	18.5	240	211	29	16	1.81	30.27
II	24.5	246	215	31	22	1.41	23.53
II	30.5	264	220	44	28	1.57	26.24
II	36.5	279	230	49	34	1.44	24.07
II	42.7	261	213	48	40.2	1.19	19.94
II	49.2	265	213	52	46.7	1.11	18.60
I	3			0	0		0.00
I	8	188	181	7	5	1.40	23.38
I	13	209	200	9	10	0.90	15.03
I	19.3	226	216	10	16.3	0.61	10.25
I	25.2	229	219	10	22.2	0.45	7.52
I	31	238	222	16	28	0.57	9.54
I	37.2	250	231	19	34.2	0.56	9.28
I	43.5	232	213	19	40.5	0.47	7.83
I	49.8	233	212	21	46.8	0.45	7.49

Table 3. METHANE EMISSIONS AT KENDRICK LAKE

Aug 16,91 mg/m2/day

	time	6 AM	9 AM	2 PM	7 PM	mean value	
location	H20 depth						incl *
a	18-22"	18	55	40	12	31	
b	11-12"	11	61* 11	21	8	13	28
c	16-17"	6.4	287* 11	31	19	17	88
d	4-5"	6.2	23* 24	7.5	15	13	19
mean value		10	25	25	14		
incl *			118				

xx* is ebullition

Temperatures		degrees C		
air	18	24	35	22
water	21	23	26	23
sediment	22	22	24	24