UNITED STATES DEPARTMENT OF THE INTERIOR

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Methane and Other Hydrocarbon Gases in Sediments of the Southern Pacific Ocean

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ABSTRACT

Hydrocarbon gases methane, ethane, ethene, propane, and propene are common but minor components in near-surface sediment from a variety of offshore areas in the South Pacific Ocean near Papua New Guinea, Solomon Islands, Vanuatu, Tonga, New Zealand and Antarctica. Wherever possible, sampling of sediment in these areas for hydrocarbon analyses was prejudiced toward finding possible migrated, thermogenic hydrocarbons based on sites selected from anomalies on marine seismic records. In none of the areas were thermogenic hydrocarbon gases clearly identified. The hydrocarbon gases appear to be the products of in situ process mediated mainly by microbial activity.

INTRODUCTION

Hydrocarbon gases are ubiquitous components of near-surface, modern marine sediments. Methane in particular has been studied in anoxic, low sulfate-containing sediments from a variety of restricted marine environments including saltwater marshes, bays, and shelf basins (Reeburgh, 1969; Whelan, 1974; Martens and Berner, 1974; Claypool and Kaplan, 1974; Oremland, 1975, Barnes and Goldberg, 1976; Kosiur and Warford, 1979; Bernard, 1979; Sansome and Martens, 1981; Oremland et al., 1982). The higher molecular weight hydrocarbon gases from near-surface marine sediments were first described by Emery and Hoggan (1958), who examined cores from the Santa Barbara Basin off southern California, and more recently these compounds have been reported to be present in sediments from the Gulf of Mexico (Bernard et al, 1978), off western Africa (Whelan et al., 1980), and off Alaska (Kvenvolden and Redden, 1980; Carlson et al., 1985)). In anoxic sediments, methane content can be high (0.05 to 2 standard volumes of gas per volume of sediment, v/v), but in near surface sediments of typical open-marine environments, concentrations of methane are as much as three to five orders of magnitude lower and concentrations of the higher molecular weight hydrocarbon gases are typically less than 10^{-7} v/v (Claypool and Kvenvolden, 1983).

The U.S. Geological Surveys' Operation Deep Sweep (Greene and Wong, 1984) and its marine geological and geophysical investigations of the Antarctic continental margin (Eittreim, Cooper, et al., 1984) provided opportunities to extend studies of hydrocarbon gases in near-surface sediment to a variety of settings in the South Pacific Ocean (Figure 1). Our sampling included sediments of New Ireland Basin, Papua New Guinea (I); Central Solomon Trough and Basin, Solomon Islands (II); South Aoba Basin, Vanuatu (III); Lau Basin, Tonga (IV); East Coast Continental Slope of North Island, New Zealand (V); and Wilkes Land Margin (VI) and Ross Sea (VII), Antarctica. Wherever possible, sampling sites for the study of hydrocarbon gases were targeted on geophysical anomalies as observed on either high or low resolution marine seismic records and attributed to sediment gas. Other sampling sites were chosen near seafloor features such as faults, slumps, canyons, and one spreading axis in order to try to increase the chances of finding hydrocarbons of subsurface or thermal origin. Some samples were those of opportunity; that is, selection of sampling sites was based only on sedimentological considerations and the timing and progress of the multichannel-seismic survey. In no case, however, did we find clear evidence for migrated hydrocarbons. This study covered a vast region of the southern Pacific Ocean (Fig. 1), and sampling density was very low. Therefore, this work should be considered to be a reconnaissance survey of hydrocarbon gases that defines the general background hydrocarbon levels that can be expected in sediments of a few localities of mid and high latitudes of the South Pacific. Our main objective was to determine the concentration, distribution, and possible sources of the following hydrocarbon gases: methane (C_1), ethane (C_2), ethene ($C_{2:1}$), propane (C_3), and propene ($C_{3:1}$). Both n-butane and isobutane were also monitored; however these compounds could not be detected in most samples and therefore, are not reported here.

PROCEDURES

Samples for extraction of hydrocarbon gases were obtained at most stations by gravity coring to depths not exceeding 4 m. Procedures follow those of Kvenvolden and Redden (1980). Sediment was recovered in 8-cm internal diameter plastic core liners. Segments of core from 8- to 10-cm long were cut from the liner at intervals down the core. Sediment samples were extruded from the segments of the liner into cans (approximately one-liter volume), each of which had two septa-covered entry ports for the later removal of gas. Distilled water, previously purged with helium to remove dissolved hydrocarbon gases, was added to fill each can, and then 100 ml of water was removed. Each can was sealed with a double friction seal top, and the resulting 100-ml headspace was purged with helium via the septa. Each can was shaken for 10 min to extract the gases from the sediment into the headspace. About 5 ml of headspace gas mixture was removed in a gas-tight syringe and analyzed on a Carle Model 311 Gas Chromatograph having a 1 ml sample loop and flame ionization and thermal conductivity detectors. Gases were separated on two columns both 3.2 mm in diameter: 5.2 m n-octane on Porasil C (100/120 mesh), and 2.1 m 50% Poropak N + 50% Poropak Q (60/80 mesh). The instrument, using a sequence of valve changes, was operated isothermally at 70°C. Concentrations of hydrocarbon gas were determined by integration (Hewlett-Packard Model 3390 Reporting Integrator) or in some cases by peak height measured on chromatograms. The chromatograph was calibrated with standard mixtures of hydrocarbon gases. Results are reported as nanoliters/liter of wet sediment (nL/L). Partition coefficients, based on averages from previous studies, were used to correct for differences in gas solubilities: $C_1 = 0.8$; C_2, C_3, $C_4 = 0.7$; $C_{2:1}$ and $C_{3:1} = 0.6$.

RESULTS

The concentration of hydrocarbon gases found in 77 samples from seven areas of the South Pacific Ocean are listed in Table 1. All samples came from subbottom depths less than 400 cm. Water depths spanned a wide range from 253 to 3,379 m. C_1 was the most abundant hydrocarbon gas ranging in concentration from 53 to 16,000 nL/L. C_2 and C_3 were often not detected, but when found were in concentrations less than 100 nL/L (4 to 78 nL/L). $C_{2:1}$ and $C_{3:1}$ were observed in most samples and, with one exception of 250 nL/L, were also present in concentrations less than 100 nL/L (4 to 98 nL/L). The concentrations of hydrocarbon gases in these sediments is generally low, in fact, lower than concentrations found in similar kinds of surveys in the Bering Sea of Alaska (Kvenvolden and Redden, 1980; Carlson et al., 1985) (Table 2). A description of our geochemical surveys in each of the seven South Pacific areas follows:

I. New Ireland Basin, Papua New Guinea

Small concentrations of hydrocarbon gases were found in eleven samples from six gravity-core stations in bottom sediment (calcareous clayey silt and silty sand) of the New Ireland Basin (Table 1). Depths of water ranged from 848 to 1,517 m. C_1 was most abundant (260 to 1,200 nL/L), and $C_{2:1}$ and $C_{3:1}$ were next most abundant with a maximum combined concentration of 30 nL/L. C_2 and C_3, when detected, had combined concentrations less than 10 nL/L.

Coring stations (Fig. 2) were targeted relative to various geophysical features in order to enhance the chances of sampling hydrocarbons from deep sources (Kvenvolden, in press). For example, core G-1 came from a small basin north of Manus Island whereas core G-3 came from the base of an abrupt scarp between Manus Island and New Hanover. Core G-6 was located in a canyon associated with a fault, and cores G-7 and G-8 came from canyons north of New Ireland. Core G-9 from near Tabar Island sampled surface sediment overlying dipping reflectors. At none of the stations, however, were anomalous concentrations of hydrocarbon gases observed; no evidence was found for petroleum-related hydrocarbons.

II. Central Solomon Trough and Basin, Solomon Islands

Gravity cores at six stations in the Central Solomon Trough and Basin (Colwell, Vedder et al., 1984) provided 15 sediment samples for gas analyses (Table 1). Water depths at these stations ranged from 1,118 to 1,682 m, and the sediment type recovered was hemipelagic mud with minor amounts of sand. Except for station 7, these cores were taken over or near the areas interpreted by Colwell and Tiffin (1984) to contain shallow-depth, gas-produced seismic features (Fig. 3). Examples of these seismic anomalies are shown in Fig. 4.

Small concentrations of hydrocarbon gases were found in each of the 15 samples analyzed. C_1 was most abundant, ranging in concentration from 190 to 2,600 nL/L. C_2, detected in only three samples, ranged from 8 to 62 nL/L, whereas C_3, measured in six samples, ranged from 4 to 80 nL/L. Unsaturated hydrocarbons were present in most samples: $C_{2:1}$ (8 to 250 nL/L) and $C_{3:1}$ (10 to 81 nL/L).

Stations 7, 16, and 16A were located away from seismic anomalies and stations 12, 13, and 18 were located on seismic anomalies (see Fig. 4 showing stations 12 and 18 located on Uniboom records exhibiting features attributed to shallow gas; the records correspond to segments 5C and 5B on lines 16 and 52, respectively (Fig. 3)). The concentrations of hydrocarbon gases obtained from samples associated with seismic anomalies were not significantly different from results obtained at stations away from the anomalies. Only one sample at station 16A (190-200 cm) has a gas composition which is unusual. C_1, at a concentration of 2,500 nL/L, is accompanied by heavier hydrocarbons, each one of which is at least ten times greater in abundance than the same compound in other samples. The higher amounts of C_2 and C_3 suggest the possibility of thermogenic gas. More significance would be attached to this observation if the underlying sample at this station also had unusually high concentrations of gas; however the deeper sample at this station had only background levels of hydrocarbons.

Therefore, our study has demonstrated that low concentrations of hydrocarbon gases are present in sediments of the Solomon Island area. In no instance, however, did the results of our gas analyses correlate with the gas-related features on marine seismic records. Although one sample has some characteristics associated with thermogenic gas, the evidence is insufficient to suggest a possible petroleum-related source.

III. South Aoba Basin, Vanuatu

One of the most promising areas for petroleum exploration in the New Hebrides Arc region of the South Pacific is the western flank of the South Aoba basin offshore Vanuatu (Fisher, in press). Geophysical anomalies are present that could be caused by gas in the sediment at depth, and well-developed faulting in this region could create migration pathways for gas to reach the surface. Nine samples of sediment composed of black, sandy volcanic silts from three stations were analyzed for hydrocarbon gases (Golan-Bac and Kvenvolden, in press). The stations (Fig. 5) were located along a transect parallel to a multichannel seismic-reflection line showing a region of turbid seismic energy (Greene and Wong, 1984) that may be caused by free gas in the sediments (Fig. 6). The intent was to sample over and nearby the region of turbid seismic energy to determine if an anomalous occurrence of gas coincides with the seismic anomaly. Unfortunately navigational errors placed station 10 about four kilometers from the anomaly, and the other two stations were even more distant (Fig. 6).

Sampling stations were located in water depths ranging from 2,445 to 2,482 m, and sediment samples were recovered using a Soutar - Van Veen grab sampler after gravity coring in these sediments was unsuccessful. Three subsamples from each grab sample were taken for gas analyses, and the average values are shown in Table 1. The amount of hydrocarbon gas observed is very low, with C_1 ranging from 98 to 140 nL/L and $C_{2:1}$ and $C_{3:1}$ ranging from 20 to 31 nL/L. Gas concentrations at station 10, located nearest the acoustic anomaly, do not differ significantly from the concentrations observed at stations 11 and 12, which are more distant from the anomaly.

IV. Lau Basin, Tonga

Only two gravity cores were taken within the Lau Basin in water depths of 2,475 and 2,500 m (Fig. 7). The idea was to sample sediments associated with an active, oceanic spreading center, and in this case, volcanic tuffs were recovered on the back arc side of the spreading center. Hydrocarbon gases were found in these volcanic sediments at very low concentrations (Table 1). The main components of the gas mixture are C_1, $C_{2:1}$ and $C_{3:1}$, with average concentrations of 83, 53, and 35 nL/L, respectively. The gas compositions here are similar to what was observed for sediment of Vanuatu.

V. East Coast Continental Slope, North Island, New Zealand

Five samples from three gravity cores were analyzed to test for hydrocarbon gases in upper slope sediment off the east coast of North Island, New Zealand (Figure 8). The sediment consisted of greenish gray, slightly silty mud. The three sampling stations were located along a transect approximately following the S39°50' latitude at water depths ranging from 750 m (station 1) to 269 m (station 3). Station 2 was placed in a major sea-floor slump whereas stations 1 and 3 were located below and above the slump deposit, respectively. To the east of station 1 (Fig., 8), previous mapping by Katz (1980, 1982) showed the inferred presence of gas hydrates, based on the occurrence of an anomalous bottom-simulating-reflector (BSR) on marine seismic records. Our idea was to sample upslope from this gas hydrate in order to determine if unusual concentrations of gas may have migrated from the region of the gas hydrate to the near-surface sediments.

Hydrocarbon gases were present in all five samples (Table 1). C_1, ranging from 1,300 to 5,300 nL/L, dominated the gas mixture, but its concentrations, although higher than most we observed in South Pacific sediments, was not significantly large to suggest migrated gas from gas hydrates. C_2 and C_3 were measured in all but one sample, and the unsaturated hydrocarbons $C_{2:1}$ and $C_{3:1}$ were present in all samples. Concentrations of the hydrocarbons heavier than C_1 ranged from 12 to 83 nL/L.

Onshore, directly west of the offshore transect, active gas seeps are common. Two of these seeps (Campbell and Brookby Stations, Fig. 8) have been studied in detail (Kvenvolden and Pettinga, in preparation), and these have been shown to release thermogenic gas. Thermogenic gas may be seeping offshore, but none of our samples from the three stations contained gas that can be attributed to thermogenic sources.

VI. Wilkes Land Margin Antarctica

Sediment samples were collected on the Wilkes Land Margin in order to provide a more comprehensive data base for this part of the Antarctic continental margin (Eittreim, Cooper et al., 1984). The concentration of hydrocarbon gases recovered in eight cores at seven sites (Fig. 9) are listed in Table 1. Water depths at the sites ranged from 253 to 3,379 m providing samples of fine-grained, glacial-marine sediment from the shelf, slope, and rise. The depths of penetration of the cores within the sediment was variable ranging in subbottom depths from 22 to 384 cm.

Hydrocarbon gas was present in all samples analyzed (Kvenvolden et al, 1987). C_1 was most abundant (53 to 16,000 nL/L) constituting 40 to 99% of the hydrocarbon gases measured; the other hydrocarbon gases were present in much lower amounts, and when detected, ranged from 4 to 78 nL/L. The deepest water site had an unusual distribution of hydrocarbon gases in that the amounts of C_1 and $C_{3:1}$ were comparable, ranging between 52 and 85 nL/L. For several samples, C_2 and larger hydrocarbon gases were not detected because shipboard motion increased the noise level on the gas chromatograph and obscured the peaks representing these compounds.

VII. Ross Sea, Antarctica

The collection of Ross Sea sediment for engineering and sedimentological studies provided samples of opportunity for gas analyses. Because of stormy weather, chromatographic analysis of hydrocarbon gas was difficult, if not impossible, to accomplish at the time of sediment core recovery at 9 sites in the Ross Sea where water depths of sampling varied from 549 to 1,029 m. (Fig. 9). Preliminary information was obtained from fine-grained, glacial marine sediments only on C_1. Consequently, the canned sediment samples were frozen and stored until the ship reached port in New Zealand. There the samples were unfrozen, (Rapp et al., 1987) reanalyzed, and the results are listed in Table 1. Hydrocarbon gases are present in all 21 samples. C_1 was most abundant (960 to 13,000 nL/L), and the other hydrocarbon gases C_2, $C_{2:1}$, C_3, and $C_{3:1}$ were present ranging in amounts from 10 to 140 nL/L. In seven cores where more than one sample was analyzed, C_1 was generally more abundant in the deepest sample than in the most shallow sample. The higher molecular weight gases showed no particularly distinctive trends with depth within the cores.

SOURCES OF HYDROCARBON GASES

The origin of the hydrocarbon gases in these near-surface sediments cannot be specifically defined, but our results suggest that much of the gas must have originated in place mediated mainly by biological processes; there is no compelling evidence for migrated gas having a strong thermogenic signature. The evidence relating to origin consists of the ubiquity of occurrence of hydrocarbon gases at all sample stations, the concentrations relative to anomalous features on seismic records, and the relative distributions of gases in each sample as defined by the ratios $C_1/(C_2 + C_3)$ and $C_2/C_{2:1}$ (Table 1). Although isotopic compositions would have aided in defining processes of hydrocarbon generation, in general, the concentrations were too low for use with the technologies available to us for obtaining isotopic values.

C_1 found in all of these near-surface sediments probably has had a complex history. If marine methanogens have been involved, then two metabolic pathways were available for C_1 production, namely fermentation of acetate and, more likely, reduction of carbon dioxide (Whiticar et al., 1986). In addition, because of the near-surface position of these samples, C_1 oxidation may also have been active in limiting the concentration of C_1. The amount of C_1 measured in these sediments ranged from 53 to 16,000 nL/L. Even the maximum concentrations are not particularly large. The concentrations of C_1, although variable, did not correlate with anomalous features on marine seismic records. These features were thought to enhance the possibility of finding migrated gas. Although C_1 is a major constituent of thermogenic gas, we have no compelling evidence that there is a significant thermal component in the C_1 we measured.

C_2, $C_{2:1}$, C_3, and $C_{3:1}$ hydrocarbons are known to be generated in connection with microbial processes (Davis and Squires, 1954; Primrose and Dilworth, 1976). Hunt (1974) demonstrated that marine organisms produce both $C_{2:1}$ and $C_{3:1}$ and Oremland (1981) showed that small quantities of C_2 can be formed by certain methanogenic bacteria. C_2 and C_3 are commonly produced in large amounts by thermogenic processes (Hunt, 1979), but $C_{2:1}$ and $C_{3:1}$ are not. In our study $C_{2:1}$ and $C_{3:1}$ were detected in most samples, and their presence undoubtedly resulted from microbial processes. C_2 and C_3, when measured, were present in about equal concentrations to the $C_{2:1}$ and $C_{3:1}$. The C_2 and C_3 are believed to be microbial in origin also mainly because there is no strong evidence to suggest a significant thermogenic source although low temperature thermal diagenesis can not be ruled out.

Two ratios are useful in comparing molecular compositions of hydrocarbon gases, namely $C_1/(C_2 + C_3)$ and $C_2/C_{2:1}$. Both of these have been used to distinquish biogenic from thermogenic gas in seeps (Bernard et al., 1976; Kvenvolden et al., 1981). Biogenic gas has $C_1/(C_2 + C_3)$ ratios greater than

1000 whereas for thermogenic gas this ratio is less than 50. If these limits are applied in our study, where this ratio ranges from 270 to 3.4, then hydrocarbon gases in near-surface sediments of the South Pacific would be classified as mainly mixtures from both biogenic and thermogenic sources with thermogenic sources dominating. The $C_2/C_{2:1}$ ratios would suggest the opposite in that in most cases the biogenic $C_{2:1}$ dominates C_2. Although these ratios have been useful in interpreting the origin of gas in gas seeps where concentrations of components are high (Kvenvolden et al., 1981), their use as an indicator of source is not clearly substantiated where low concentrations of hydrocarbon gases are dispersed within near-surface sediments (Kvenvolden and Redden, 1980). In our study, where the $C_1/(C_2 + C_3)$ ratios are particularly low as in core A10G1 (Table 1) from the Wilkes Land Margin of Antarctica (4.34 to 3.4), the result indicates a preferential loss of C_1 rather than the presence of thermogenic hydrocarbons. Also the low $C_2/C_{2:1}$ ratios do not signal thermogenic gas either.

CONCLUSIONS

Our evidence suggests that the hydrocarbon gases measured in this study represent the "background" concentrations that are present in the various areas that we briefly surveyed. These gases most likely are microbial in origin mainly because no compelling evidence was found suggesting that thermal processes were involved in their formation. Sampling was prejudiced toward finding migrated, and therefore, possibly thermogenic gas at several localities, but in no instance did our results strongly indicate a thermal component in the gas mixtures. In summary, hydrocarbon gases C_1, C_2, $C_{2:1}$, C_3, and $C_{3:1}$ are ubiquitous in near-surface sediments in a variety of settings in the South Pacific Ocean. The gases are likely the product of in situ processes strongly mediated by microbial activity.

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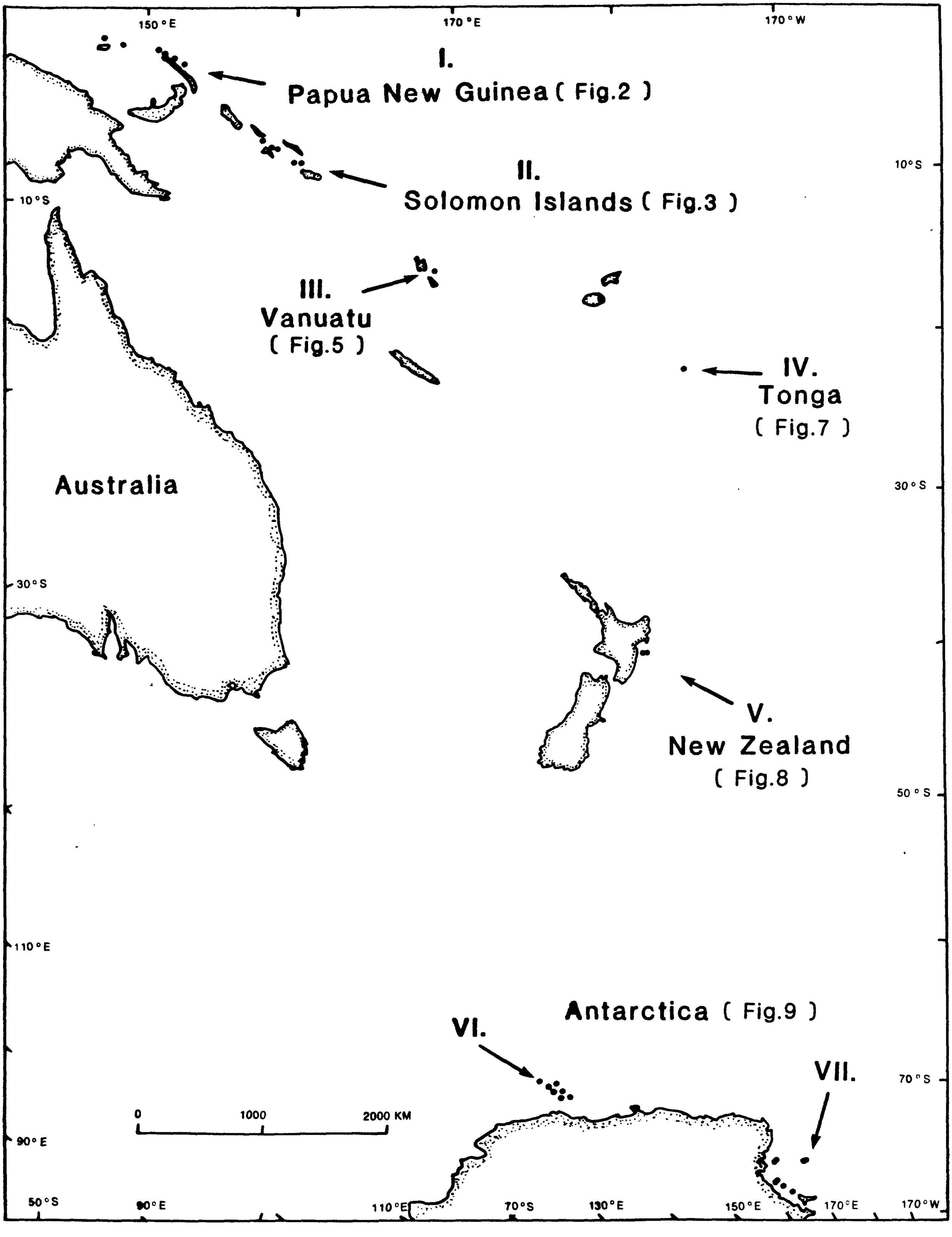

Figure 1. Map of the South Pacific Ocean showing localites where near-surface sediments were collected for analysis of hydrocarbon gases.

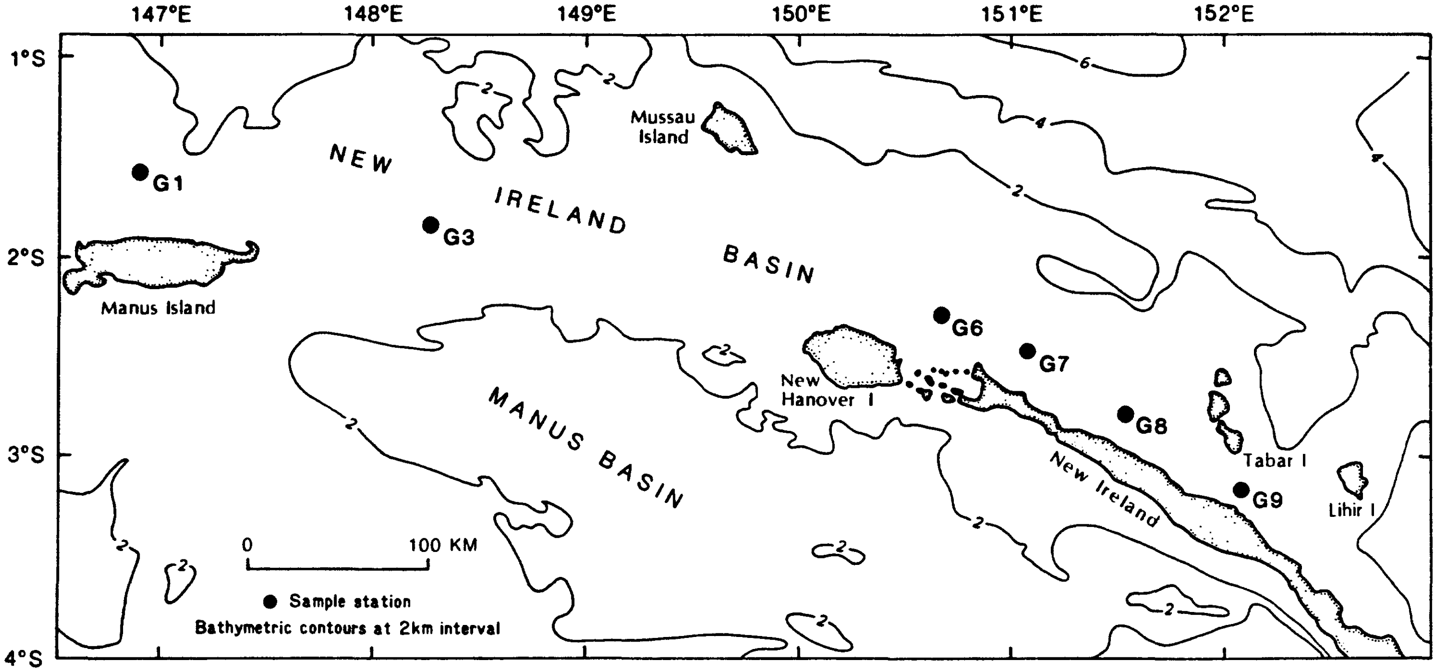

Figure 2. Map indicating coring stations in New Ireland Basin, Papua New Guinea, where sediments were collected and analyzed for hydrocarbon gases.

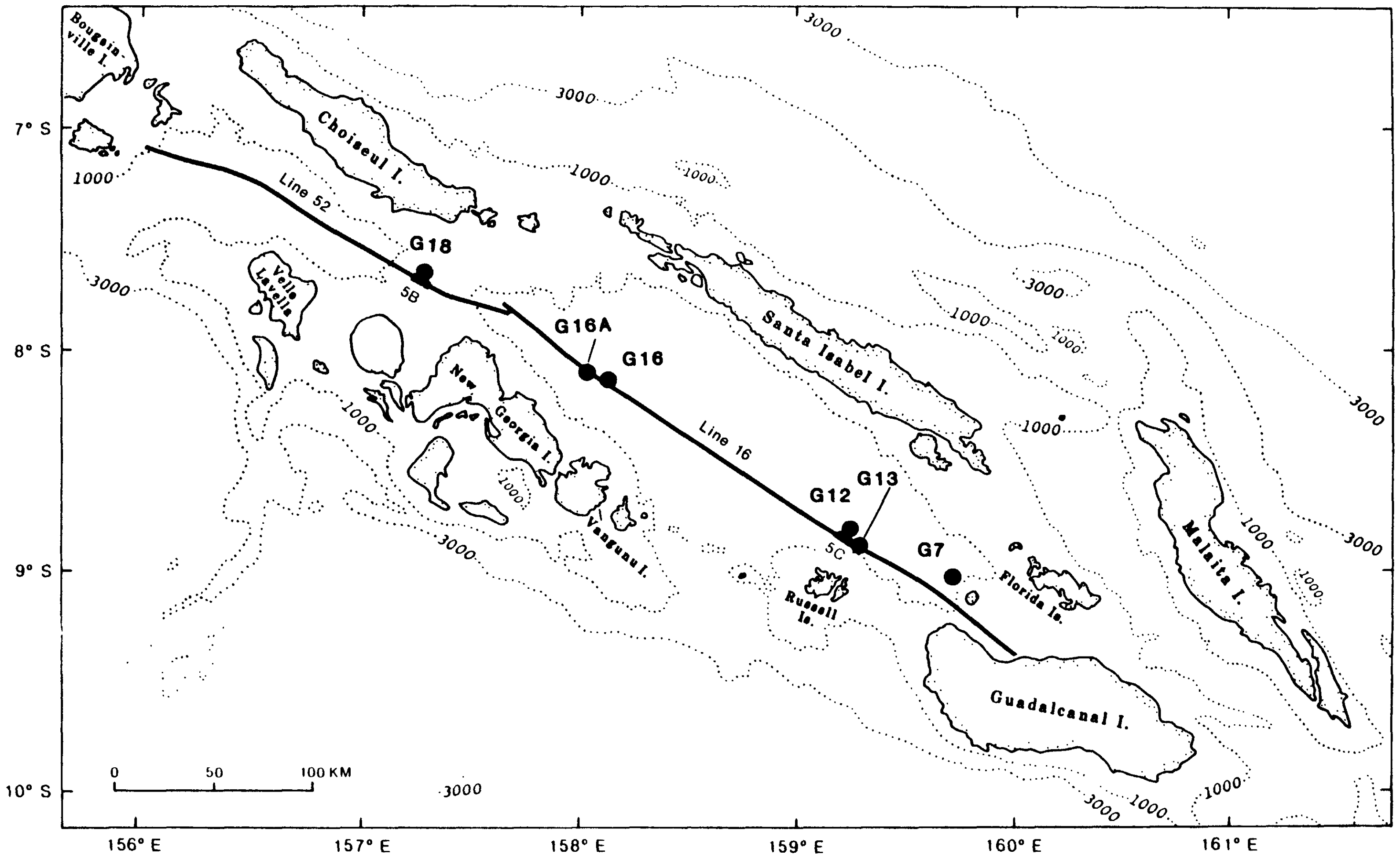

Figure 3. Map of the Central Solomons Trough showing sites where samples were obtained for gas analyses and areas inferred from seismic records to contain shallow accumulations of gas. Bathymetric contours are in meters.

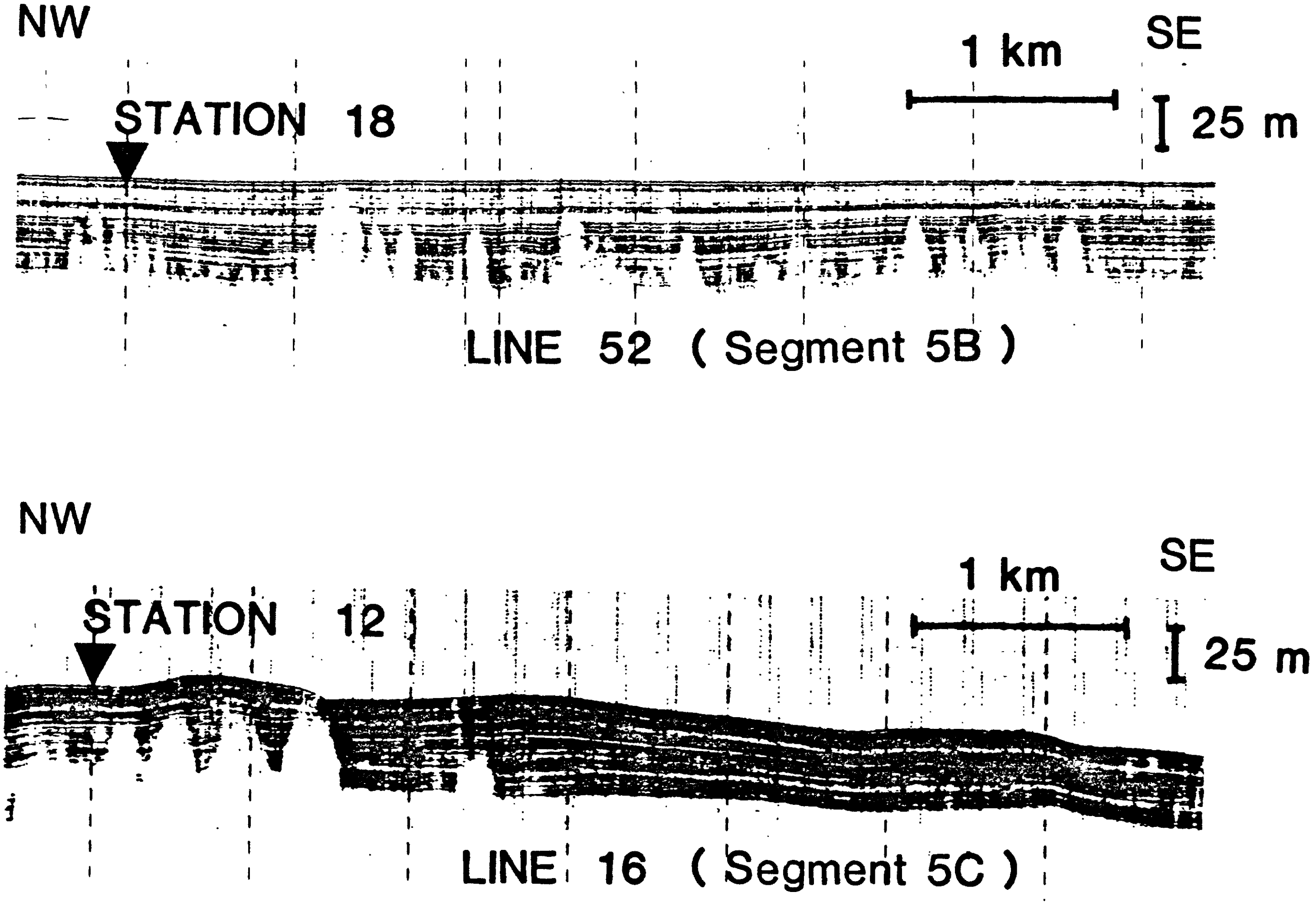

Figure 4. Examples of uniboom seismic records of acoustic anomalies, located in Figure 3, and believed to be caused by gas in the near-surface sediment.

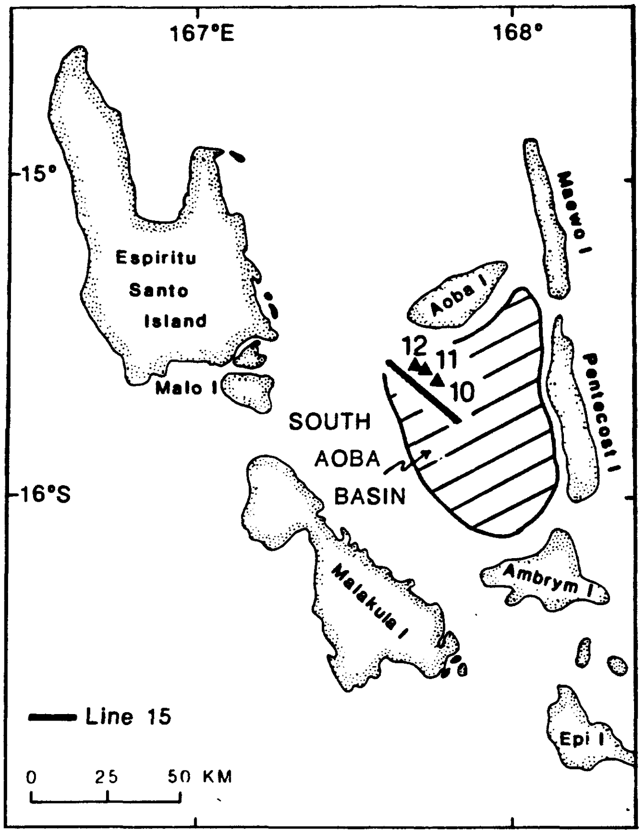

Figure 5. Map of the sampling transect in the South Aoba Basin, Vanuatu, where sediments were collected for gas analyses.

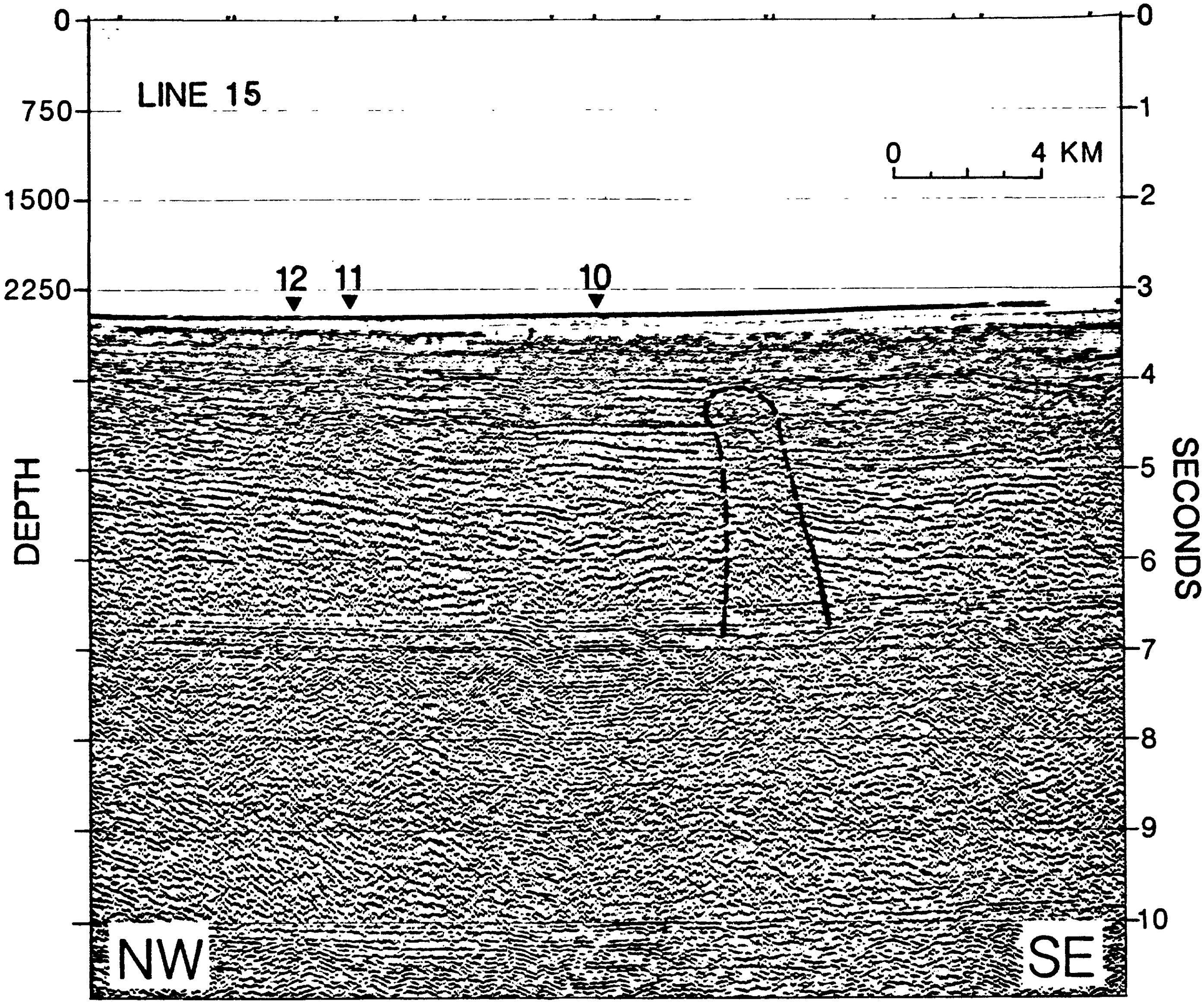

Figure 6. Multichannel seismic reflection line in the South Aoba Basin showing regions of turbid seismic energy inferred to be caused by gas. Sampling locations (Figure 5) are indicated relative to the seismic line.

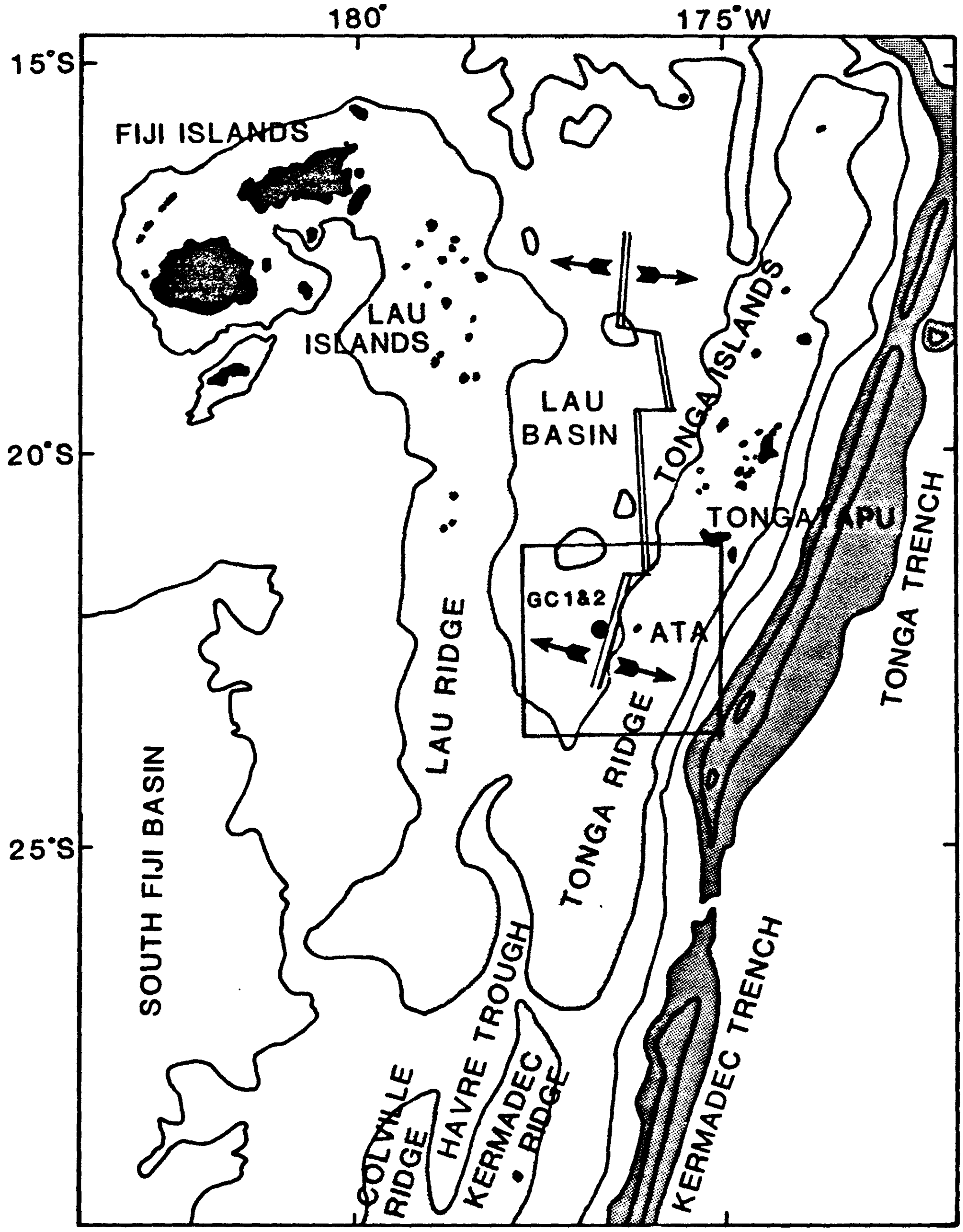

Figure 7. Map showing sampling site in the Lau Basin, Tonga, where hydrocarbon gases were measured. Location is indicated by the dot within the square. Bathymetric contour interval is 2,000 m. Light gray areas are shallower than 2,000 m; dark gray areas are deeper than 6,000 m. Spreading axis is indicated by parallel lines and arrows. After Morton and Sleep (1985).

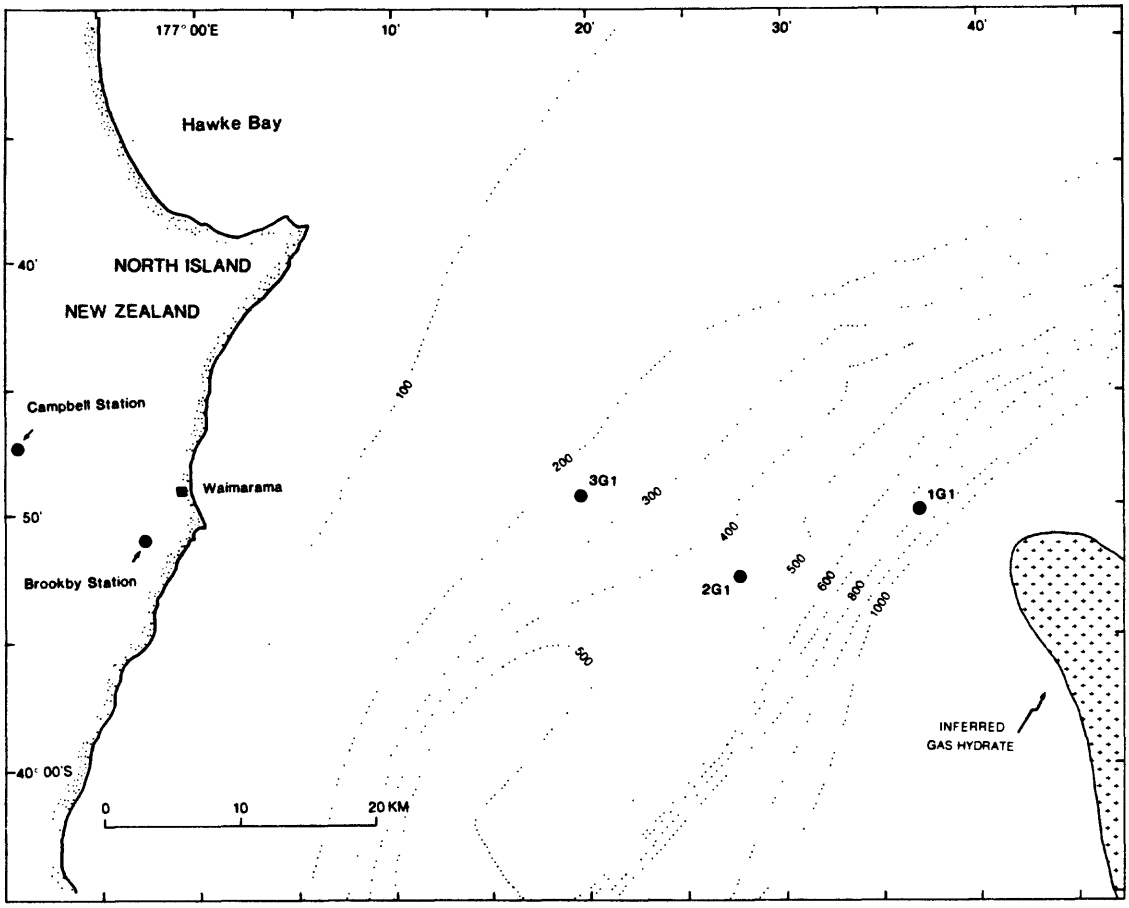

Figure 8. Map of the eastern continental margin of the North Island of New Zealand. Three sampling stations are located offshore, west of a region where the occurrence of gas hydrates has been inferred (patterned area). On land, two seep sites (Campbell Station and Brookby Station) are indicated where thermogenic hydrocarbons were measured by Kvenvolden and Pettinga (in preparation).

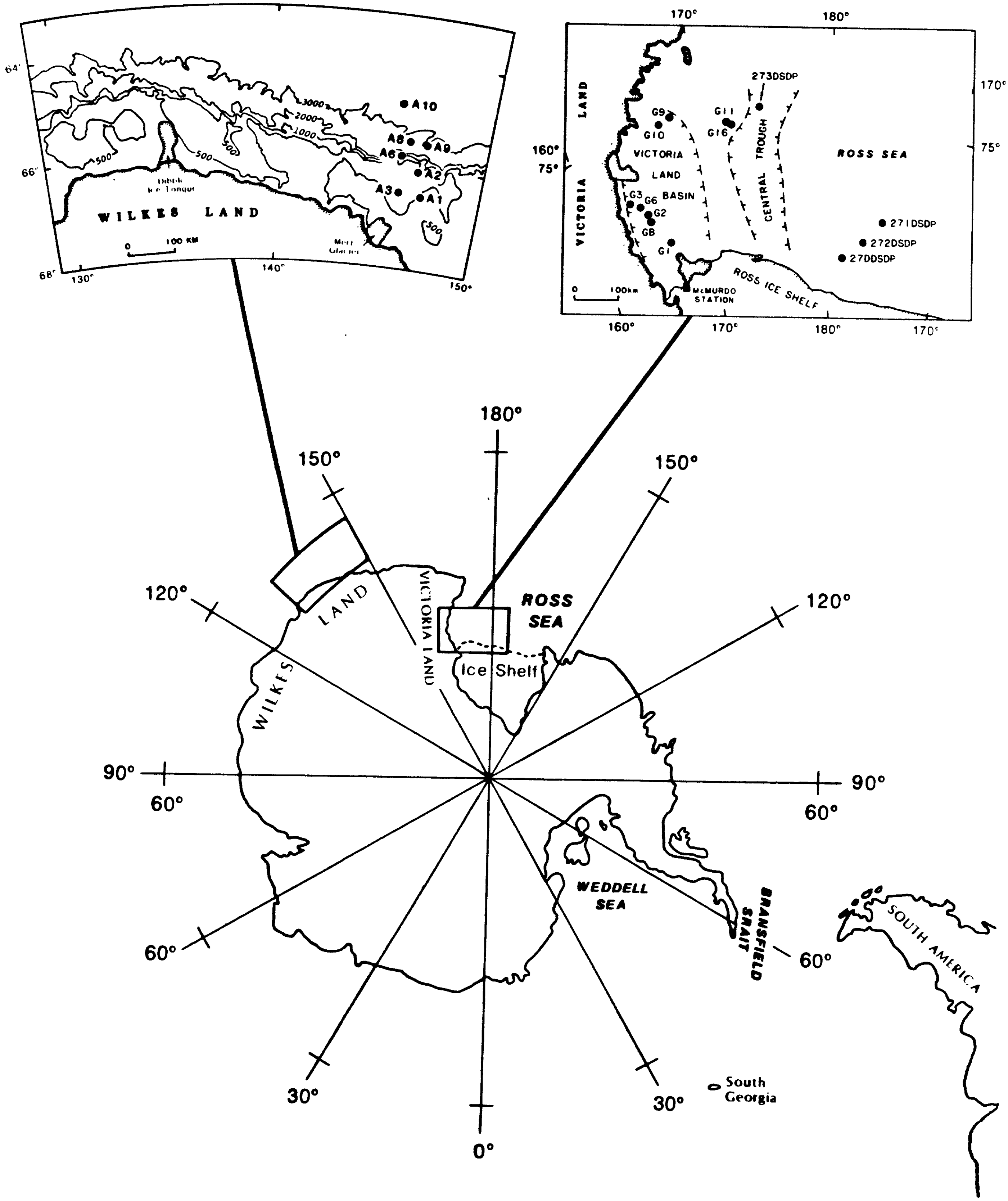

Figure 9. Maps showing sampling sites offshore Antarctica on the Wilkes Land continental margin and in the western Ross Sea. Hydrocarbon gases are present at all of these sites.

Table 1. Concentrations (nL/L of wet sediment) of hydrocarbon gases in sediment samples from seven areas of the South Pacific Ocean.

Core & int.	water depth	latitude	longitude	C1	C2	C2:1	C3	C3:1	C1 ---- C2+C3	C2 ---- C2:1
(cm)	(m)			--nanoliters per liter wet sediment--						
I. New Ireland Basin, Papua New Guinea										
G1 90-100	1517	01° 39.6' S	146° 51.1' E	520	nd	8	nd	10	nc	nc
G1 190-200				1200	nd	8	4	10	290	nc
G3 75-85	1089	01° 50.7' S	148° 16.2' E	410	nd	nd	nd	5	nc	nc
G6 90-100	848	02° 18.8' S	150° 39.2' E	700	nd	6	4	21	160	nc
G6 150-160				560	nd	12	9	11	64	nc
G7 90-100	1033	02° 29.2' S	151° 03.2' E	510	nd	6	4	16	120	nc
G7 190-200				570	nd	12	9	16	64	nc
G7 258-268				600	nd	12	9	16	68	nc
G8 90-100	1234	02° 48.4' S	151° 31.8' E	320	nd	nd	nd	nd	nc	nc
G8 132-141				390	nd	nd	nd	5	nc	nc
G9 82-92	1320	03° 08.5' S	152° 05.7' E	260	nd	nd	nd	nd	nc	nc
II. Central Solomon Trough and Basin, Solomon Islands										
G7 90-100	1290	09° 01.7' S	159° 41.2' E	990	nd	nd	nd	10	nc	nc
G7 115-125				890	nd	23	nd	19	nc	nc
G12 90-100	1612	08° 52.0' S	159° 13.9' E	360	nd	15	nd	10	nc	nc
G12 190-299				1100	nd	8	nd	10	nc	nc
G12 284-294				490	nd	23	4	72	120	nc
G13 90-100	1682	08° 47.8' S	159° 13.6' E	190	nd	nd	nd	10	nc	nc
G13 159-169				240	nd	23	8	19	30	nc
G16 90-100	1672	08° 07.2' S	158° 09.3' E	690	nd	15	nd	nd	nc	nc
G16 209-219				420	nd	23	nd	10	nc	nc
G16A 90-100	1444	08° 04.4' S	157° 58.2' E	770	nd	15	nd	10	nc	nc
G16A 190-200				2500	62	250	79	72	18	0.25
G16A 246-256				460	nd	15	nd	nd	nc	nc
G18 90-100	1118	07° 40.6' S	157° 17.5' E	930	nd	15	4	14	240	nc
G18 190-200				2600	8	23	8	14	160	0.35
G18 254-264				1400	16	60	20	81	40	0.26
III. South Aoba Basin, Vanuatu										
10-S1	2445	15° 40.0' S	167° 45.4' W	130	nd	28	nd	21	nc	nc
11-S1	2482	15° 38.0' S	167° 42.4' W	98	nd	31	11	20	9	nc
12-S1	2480	15° 37.5' S	167° 41.7' W	140	nd	29	nd	20	nc	nc
IV. Lau Basin, Tonga										
GC1 41-51.5	2500	22° 22.4' S	176° 37.2' W	75	nd	80	6	31	13	nc
GC2 42-51	2475	22° 21.6' S	176° 37.4' W	91	nd	26	nd	38	nc	nc
V. East Coast Continental Slope, North Island, New Zealand										
1G1 51-60	750	39° 50.0' S	177° 37.1' E	2100	28	69	23	44	42	0.41
2G1 75-84	462	39° 52.7' S	177° 27.9' E	3100	nd	20	16	40	200	nc
2G1 174-183				5300	68	49	22	71	59	1.4
3G1 55-64	269	39° 49.3' S	177° 19.9' E	3500	78	52	12	83	39	1.5
3G1 155-164				1300	41	18	14	32	24	2.3

Table 1. Concentrations (nL/L of wet sediment) of hydrocarbon gases in sediment samples from seven areas of the South Pacific Ocean(cont'd).

Core & int.	water depth	latitude	longitude	C1	C2	C2:1	C3	C3:1	C1	C2
(cm)	(m)			--nanoliters per liter wet sediment--					---- C2+C3	---- C2:1
VI. Wilkes Land Margin, Antarctica										
A1G1 87-96	611	66° 35.4' S	147° 21.7' E	1800	nd	13	10	8	190	nc
A1G1 176-184				3400	10	14	12	5	160	0.71
A1G1 283-292				5100	14	16	8	8	240	0.83
A1G1 336-345				5400	14	26	13	23	210	0.52
A2G1 61-70	460	66° 08.1' S	147° 05.5' E	7600	60	20	53	10	67	3.0
A2G2 139-148	458	66° 08.1' S	147° 05.4' E	16000	63	25	78	11	110	2.6
A3G1 13-22	253	66° 30.8' S	146° 10.9' E	900	20	33	22	8	21	0.62
A6G1 88-97	994	65° 52.5' S	146° 21.1' E	2800	50	20	21	13	40	2.5
A8G1 70-79	2635	65° 34.0' S	146° 25.4' E	220	8	14	4	8	17	0.59
A8G1 170-179				740	nd	nd	nd	6	nc	nc
A8G1 270-279				2500	10	14	nd	4	240	0.74
A8G1 369-378				3500	nd	nd	nd	4	nc	nc
A9G1 43-52	3037	65° 34.2' S	147° 21.6' E	100	nd	nd	nd	nd	nc	nc
A9G1 143-152				610	nd	8	nd	nd	nc	nc
A9G1 285-294				1300	23	18	16	12	33	1.3
A9G1 368-377				1500	10	18	10	6	75	0.57
A10G1 76-85	3379	64° 54.3' S	145° 59.9' E	85	13	20	7	72	4.3	0.62
A10G1 175-184				75	10	16	8	61	4	0.64
A10G1 275-284				53	8	14	5	54	3.9	0.59
A10G1 375-384				57	10	18	6	52	3.4	0.57
VII. Ross Sea, Antarctica										
G1-1 50-59	899	77° 01.8' S	166° 08.1' E	1700	42	37	31	45	23	1.2
G1-1 100-109				1500	29	25	27	45	26	1.2
G1-1 156-165				2200	37	38	30	77	33	0.97
G2-1 100-109	795	76° 28.7' S	164° 57.2' E	1200	27	58	13	65	29	0.46
G2-1 192-200				2000	36	40	20	98	35	0.90
G2-1 279-288				1800	33	35	21	28	33	0.94
G3-1 50-59	705	76° 11.7' S	164° 14.0' E	5800	66	60	41	63	54	1.1
G3-1 100-109				6300	53	28	50	42	61	1.9
G3-1 210-219				6400	46	33	23	53	93	1.4
G6-1 91-100	943	75° 58.1' S	164° 57.7' E	9200	27	28	30	67	160	0.95
G6-1 200-209				9100	24	20	17	38	220	1.2
G6-1 249-258				13000	63	35	54	65	270	1.8
G8-1 50-59	815	76° 28.8' S	164° 58.8' E	1300	33	23	16	65	27	1.4
G8-1 119-128				2000	40	97	20	68	33	0.41
G9-1 97-106	940	74° 30.1' S	168° 05.9' E	1400	20	17	10	38	46	1.2
G10-1 50-59	1029	74° 39.6' S	167° 06.5' E	970	27	30	23	55	19	0.90
G10-1 100-109				960	21	13	17	72	25	1.6
G10-1 221-230				1700	33	23	20	40	32	1.4
G11-1 92-101	567	74° 50.6' S	172° 25.0' E	3000	44	27	29	42	41	1.6
G16-1 50-59	549	74° 54.4' S	172° 46.9' E	4500	64	140	34	60	46	0.45
G16-1 105-114				6700	57	38	43	32	47	1.5

nd = not detected
nc = not calculated

Table 2. Comparison of ranges of hydrocarbon gas concentrations (nL/L of wet sediment).

Area	No. of Samples	C_1	C_2	C_3	$C_{2:1}$	$C_{3:1}$	Reference	Comments
South Pacific	77	53-16,000	<1-78	<1-79	<1-250	<1-98	This paper	<1 indicates that lower limit of the range of values is below the detection limit of 1nL/L.
Bering Sea	73	26-11,000	<1-340	<1-102	<1-110	<1-62	Kvenvolden and Redden (1980)	Original values were reported in vol of gas/vol interstitial water. These units have been converted to nL/L of wet sediment and appropriate partition coefficients applied.
Navarin Basin	314	$1\text{-}84 \times 10^6$	<1-7300	<1-3400	not reported		Carlson et al. (1985)	Maximum value of C_2 was inaccurately reported as 9300 nL/L in original reference.