543 : 552.5

# Gaseous Composition in Thermal Decomposition of Organic Matter in Sediments and Sedimentary Rocks

Hiroshi YONETANI* and Nobuo OHBA*

Abstract

The thermal decomposition gases generated by heating at various temperatures (80, 150, 200, 300, 600 °C for 1 hr. and 400 °C for 10 min.) from the organic matter in sediments and sedimentary rocks are analysed by gas chromatography, and the results are summarized as follows:

1) With the exception of natural gas in Recent sediments, the contents of $H_2$ and olefins are very low in $CH_4$–type natural gas in sedimentary rocks. On the other hand, the contents of $H_2$ and olefins in the gases generated from sediments and sedimentary rocks by heating at temperatures above 80 °C are very high. This phenomenon indicates that the organic matters in sediments and sedimentary rocks are decomposed thermally at temperature as low as 80 °C.

2) The volume ratios of total amount of hydrocarbons** (carbon number ranging $C_1$ to $C_5$) generated by heating from the organic matters in sediments and sedimentary rocks are relatively high at 300 °C or 600 °C.

3) Kerogen is pyrolyzed at above 300 °C and it is assumed that the kerogen is more stable thermally than the soluble organic matter in sedimentary rocks.

4) Based on the experimental data, the authors educed that there is positive correlation between the composition of pyrolyzed gases and geologic age or buried depth of sedimentary rocks, however the clear conclusion cannot be drawn from these data due to the insufficient number of examined samples.

## I. Introduction

EVANS (1964), DUGLAS (1966) and ROBINSON (1969) have reported that the gaseous hydrocarbons could be detected in the pyrolysis gases generated from sedimentary rocks by heating above 200 °C. In this paper following subjects are investigated.

a) The relationship between thermal change of organic compounds in sedimentary rocks and genesis of petroleum, b) The chemical structure of kerogen.

The authors' experiments were performed in order to infer the pyrolysis temperature of organic matter in sediments and sedimentary rocks and to elucidate the relation between pyrolyzed gas composition and geologic age or depth of sedimentary rocks.

## II. Sample and experiment

### II. 1 Sample

a) Bottom sediment 6 (Recent; Naka-umi, Shimane Prefecture), Peat 7 (Recent; Ozegahara, Gunma Prefecture), b) Nittantakamatu-drilling core 8–11 (Tertiary; 9, 245, 415, 1050 m, Orio,

* Geochemistry & Technical Service Department

**The ratio display, (total amount of hydrocarbons by heating at 150°C/total amount of hydrocarbons by heating at 80°C), (total amount of hydrocarbons by heating at 200°C/total amount of hydrocarbons by heating at 150°C), (total amount of hydrocarbons by heating at 300°C/total amount of hydrocarbons by heating at 200°C) and (total amount of hydrocarbons by heating at 600°C/total amount of hydrocarbons by heating at 300°C).

Fukuoka Prefecture),c) Shimanto group 12 (Cretaceous; Uwajima),d) Kerogen (Miocene; Ikume, Miyazaki Prefecture), e) Coal 13 (Tertiary; Nittantakamatu, Fukuoka Prefecture), f) Ryoke-metamorphic rock 14, 15 (Kiso),g) Coral 16 (Recent; Kikaijima), Limestone 17–22 (Quaternary-Silurian; Kikaijima, Sagara, Garo, Akasaka, Ofunabara),h) Kasukabe-drilling core (Pliocene; 506, 800, 1028 m, Miocene; 1050, 1456, 1900, 2000, 2600, 2900 m).

### II. 2 Experimental condition

The total amount and chemical composition of pyrolyzed gases from sediments and sedimentary rocks are variable with heating temperature and time.

The experiment is operated under the following condition.

At first, 0.06 g of a powdered sample (siee between 100 and 150 mesh) is placed in platinum boat, then the boat is inserted in to the combustion tube of the SIMAZU PYR–A type pyrolyzer combined with a gas chromatograph. Second, air in the combustion tube is purged by passing argon through the tube, and then the tube is heated progressively at 80, 150, 200, 300 and 600°C each for 1 hr. or at 400°C for 10 min.

The pyrolyzed gases are analysed by a gas chromatograph. Gaseous components such as $H_2$, $N_2$, $CO_2$, $CH_4$, $C_2H_6$, $C_3H_8$, $C_3H_6$, i-$C_4H_{10}$, n-$C_4H_{10}$, 1–Butene, i-Butylene, i-$C_5H_{12}$ and n-$C_5H_{12}$, are analysed in this study.

## III. Results

The chemical components of pyrolyzed gases are listed in Tables 1 and 2. The components

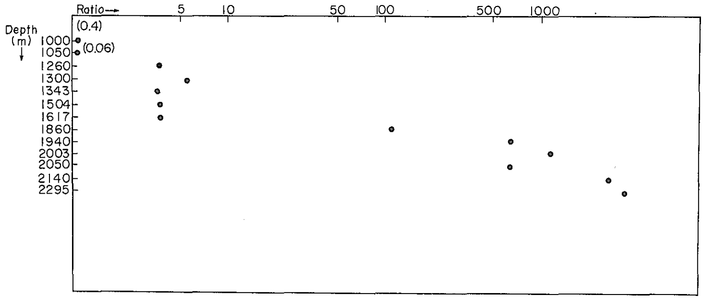


Fig. 1 Relation between the depth and the ($C_2H_6$/$C_2H_4$) ratios in extracted gases of Kasukabe-drilling cores.

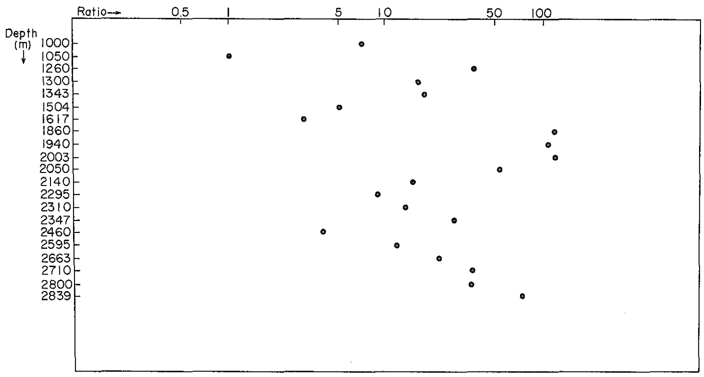


Fig. 2 Relation between the depth and the ($C_3H_8$/$C_3H_6$) ratios in exfracted gases of Kasukabe-drilling cores.

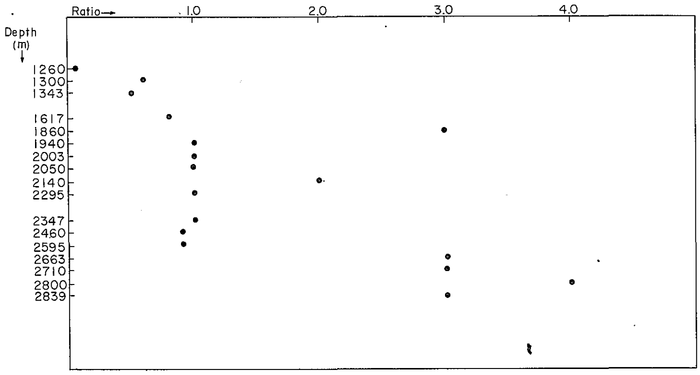


Fig. 3 Relation between the depth and the $i\text{–}C_4H_{10}/n\text{–}C_4H_{10}$ ratios in extracted gases of Kasukabe-drilling cores.

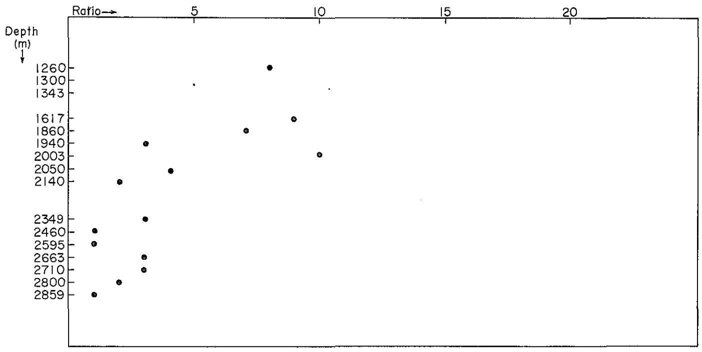


Fig. 4 Relation between the depth and the $i\text{–}C_5H_{12}/n\text{–}C_5H_{12}$ ratios in extracted gases of Kasukabe-drilling cores.

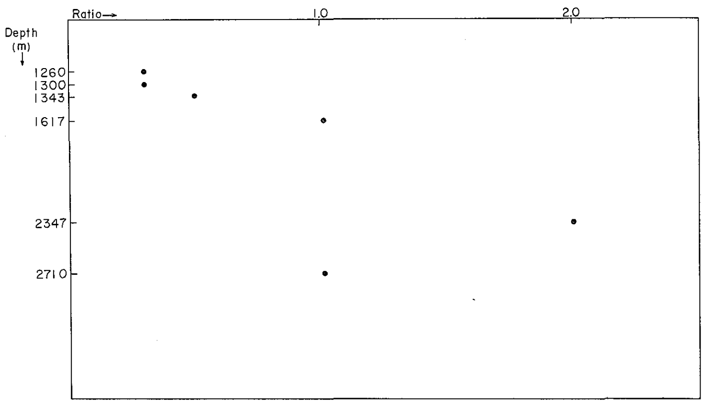


Fig. 5 Relation between the depth and the 1–Butene/i–Butylene ratios in extracted gases of Kasukabe-drilling cores.

of pyrolyzed gases are compared with those of the extracted gas from Kasukabe-drilling cores (YONETANI and HIRUKAWA, 1971) (Figs. 1–5).

### III. 1 The relation between the total amount of pyrolyzed gases and the temperature of heating

Table 1 Chemical components in pyrolysis gases generated at different temperature from various sediments and sedimentary rocks. ($\mu l$/0.06g.)

| Sample number | Sample name | Geologic age Depth (m) Lithofacies | Temp. (℃) | $H_2$ | $N_2$ | CO | $CO_2$ | $CH_4$ | $C_2H_6$ | $C_2H_4$ | $C_3H_8$ | $C_3H_6$ | i-$C_4H_{10}$ | n-$C_4H_{10}$ | 1-Butene | i-Butylene | i-$C_5H_{12}$ | n-$C_5H_{12}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 6 | Nakaumi bottom sediment | Recent | 80 | 0.6 | 830 | 0.00 | 4 | 0.06 | 0.030 | 0.014 | 0.008 | 0.056 | 0.000 | 0.000 | 0.001 | 0.096 | 0.000 | 0.000 |
| | | | 150 | 1.2 | 540 | 0.00 | 30 | 0.4 | 0.012 | 0.108 | 0.012 | 0.279 | 0.012 | 0.006 | 0.016 | 0.149 | 0.037 | 0.000 |
| | | | 200 | 3.1 | 720 | 1.30 | 405 | 2.6 | 0.018 | 0.180 | 0.046 | 0.461 | 0.020 | 0.020 | 0.028 | 0.252 | 0.030 | 0.006 |
| | | | 300 | 15.6 | 540 | 1.00 | 860 | 16 | 0.944 | 3.271 | 0.620 | 1.806 | 0.082 | 0.205 | 0.248 | 0.743 | 0.240 | 0.024 |
| | | | 600 | 190.8 | 620 | 1.80 | 4803 | 48 | 0.122 | 0.600 | 0.014 | 0.088 | 0.002 | 0.0004 | 0.014 | 0.014 | 0.002 | 0.002 |
| 7 | Ozegahara moor peat | Recent | 80 | 7.8 | 490 | 0.00 | 2000 | 1.3 | 1.329 | 0.609 | 0.409 | 2.137 | 0.209 | 0.310 | 0.300 | 0.300 | 0.251 | 0.108 |
| | | | 150 | 14.0 | 540 | 4.40 | 2300 | 8.8 | 0.569 | 1.138 | 0.619 | 2.440 | 0.200 | 0.200 | 0.567 | 0.669 | 0.390 | 0.001 |
| | | | 200 | 93.7 | 800 | 37.00 | 4000 | 51 | 1.725 | 8.609 | 0.819 | 8.265 | 0.341 | 6.420 | 2.503 | 2.503 | 2.110 | 0.522 |
| | | | 300 | 943.7 | 610 | 108.0 | 7750 | 1900 | 24.310 | 24.310 | 94.650 | 94.650 | 5.460 | 21.607 | 21.300 | 42.601 | 10.605 | 7.015 |
| | | | 600 | 26000 | 670 | 275.8 | 8020 | 440.200 | 11051 | 5513 | 221.01 | 884 | 88.40 | 88.40 | 41.221 | 81.553 | 20.751 | 10.374 |
| 8 | Nittan Takamatu drilling core | Tertiary 9 sand stone | 80 | 0.3 | 520 | 0.00 | 15 | 1.0 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| | | | 150 | 1.4 | 590 | 0.00 | 15 | 32 | 0.603 | 6.000 | 0.435 | 6.590 | 0.339 | 0.011 | 0.000 | 0.000 | 0.000 | 0.000 |
| | | | 200 | 3.1 | 700 | 0.00 | 24 | 75 | 0.375 | 2.200 | 0.370 | 1.000 | 0.340 | 0.012 | 0.000 | 0.000 | 0.000 | 0.000 |
| | | | 300 | 29.4 | 620 | 0.00 | 63 | 180 | 36.097 | 36.207 | 18.215 | 36.255 | 0.700 | 4.390 | 3.020 | 4.319 | 5.745 | 1.980 |
| | | | 600 | 676 | 660 | 0.30 | 445 | 1020 | 21.250 | 170.000 | 22.439 | — | 0.001 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 |
| 9 | Nittan Takamatu drilling core | Tertiary 245 silt | 80 | 0.04 | 500 | 0.00 | 20 | 0.01 | 0.001 | 0.005 | 0.000 | 0.000 | 0.005 | 0.001 | 0.005 | 0.002 | 0.002 | 0.003 |
| | | | 150 | 0.07 | 550 | 0.00 | 30 | 0.05 | 0.001 | 0.010 | 0.001 | 0.006 | 0.000 | 0.000 | 0.003 | 0.003 | 0.001 | 0.001 |
| | | | 200 | 0.1 | 740 | 0.00 | 20 | 0.7 | 0.020 | 0.120 | 0.002 | 0.007 | 0.001 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 |
| | | | 300 | 10.5 | 520 | 0.30 | 60 | 5.0 | 0.127 | 0.624 | 0.074 | 0.335 | 0.005 | 0.030 | 0.020 | 0.020 | 0.036 | 0.012 |
| | | | 600 | 63.4 | 610 | 0.20 | 230 | 30 | 0.115 | 10.000 | 0.089 | 4.961 | 0.803 | 0.128 | 0.133 | 0.154 | 0.960 | 0.010 |
| 10 | Nittan Takamatu drilling core | Tertiary 415 silt | 80 | 0.1 | 580 | 0.00 | 15 | 0.02 | — | — | — | — | 0.008 | 0.001 | 0.003 | 0.001 | 0.000 | 0.000 |
| | | | 150 | 0.1 | 500 | 0.0 | 12 | 0.20 | 0.007 | 0.015 | 0.021 | 0.125 | 0.010 | 0.001 | 0.040 | 0.080 | 0.000 | 0.000 |
| | | | 200 | 0.2 | 760 | 0.0 | 30 | 1.0 | 0.019 | 0.118 | 0.029 | 0.174 | 0.020 | 0.001 | 0.035 | 0.046 | 0.023 | 0.011 |
| | | | 300 | 162.5 | 640 | 0.3 | 520 | 12.0 | 1.241 | 1.110 | 0.576 | 1.987 | 0.074 | 0.192 | 0.178 | 0.500 | 0.277 | 0.097 |
| | | | 600 | 480 | 640 | 1.3 | 1520 | 106 | 0.850 | 6.191 | 0.100 | 1.030 | 0.001 | 0.020 | 0.055 | 0.111 | 0.020 | 0.001 |
| 11 | Nittan Takamatu drilling core | Tertiary 1050 silt | 80 | 0.1 | 760 | 0.0 | 15 | 0.005 | 0.003 | 0.003 | 0.001 | 0.003 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| | | | 150 | 0.3 | 530 | 0.0 | 20 | 0.05 | 0.002 | 0.020 | 0.004 | 0.025 | 0.003 | 0.006 | 0.000 | 0.000 | 0.000 | 0.000 |
| | | | 200 | 0.1 | 740 | 0.0 | 40 | 3.0 | 0.033 | 0.312 | 0.040 | 0.322 | 0.054 | 0.027 | 0.002 | 0.003 | 0.012 | 0.001 |
| | | | 300 | 7.8 | 560 | 0.3 | 150 | 12.0 | 1.362 | 1.559 | 0.602 | 1.207 | 0.080 | 0.0320 | 0.123 | 0.133 | 0.260 | 0.080 |
| | | | 600 | 236.8 | 550 | 0.5 | 480 | 120 | 1.321 | 13.210 | 0.044 | 2.250 | 0.120 | 0.041 | 0.061 | 0.071 | 0.000 | 0.000 |
| 12 | Sedimentary rock of Shimanto group | Cretaceous sand stone | 80 | 0.0 | 980 | 0.0 | 8 | 0.2 | 0.011 | 0.010 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| | | | 150 | 0.1 | 720 | 0.0 | 10 | 1.0 | 0.002 | 0.020 | 0.007 | 0.071 | 0.012 | 0.001 | 0.011 | 0.031 | 0.010 | 0.001 |
| | | | 200 | 1.5 | 780 | 0.0 | 20 | 16.1 | 0.107 | 0.530 | 0.239 | 1.218 | 0.184 | 0.061 | 0.129 | 0.278 | 0.278 | 0.001 |
| | | | 300 | 10.1 | 600 | 0.0 | 60 | 49.2 | 1.598 | 3.182 | 1.025 | 5.000 | 0.206 | 0.308 | 0.647 | 0.743 | 0.499 | 0.069 |
| | | | 600 | 165.6 | 720 | 0.3 | 180 | 36.5 | 0.598 | 4.189 | 0.151 | 9.090 | 0.104 | 0.052 | 0.100 | 0.100 | 0.051 | 0.001 |
| 13 | Coal (Nittan Takamatu) | Tertiary | 80 | 3.2 | 760 | 0.0 | 750 | 3.0 | 0.608 | 0.365 | 0.302 | 0.904 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| | | | 150 | 3.7 | 530 | 2.0 | 1260 | 18.1 | 1.980 | 2.593 | 1.205 | 3.031 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| | | | 200 | 3.9 | 740 | 2.0 | 2040 | 60.5 | 7.515 | 12.096 | 7.574 | 7.574 | 0.418 | 1.405 | 1.321 | 1.982 | 0.000 | 0.000 |
| | | | 300 | 191 | 560 | 26 | 5940 | 2226 | 741.20 | 369.00 | 184.51 | 922.53 | 18.50 | 22.23 | 8.854 | 18.532 | 13.205 | 8.043 |
| | | | 600 | 60600 | 550 | 2230 | 10800 | 34750 | 1935 | 967 | 80.600 | 115.55 | 58.127 | 58.127 | 3.428 | 21.050 | 4.525 | 9.036 |
| 14 | Ryōke metamorphic rock | Slate | 80 | — | — | — | — | 0.390 | 0.001 | 0.197 | 0.066 | 0.131 | 0.099 | 0.920 | 0.000 | 0.000 | 0.000 | 0.000 |
| | | | 150 | — | — | — | — | 0.470 | 0.001 | 0.190 | 0.061 | 0.061 | 0.049 | 0.252 | 0.000 | 0.000 | 0.000 | 0.000 |
| | | | 200 | — | — | — | — | 11.50 | — | — | — | — | — | — | — | — | — | — |
| | | | 300 | — | — | — | — | 32.50 | 1.545 | 0.534 | 0.706 | 0.162 | 0.027 | 0.191 | 0.000 | 0.000 | 0.000 | 0.000 |
| | | | 600 | — | — | — | — | 397 | 14.200 | 69.982 | 0.530 | 6.965 | 0.021 | 0.108 | 1.350 | 1.350 | 0.000 | 0.000 |

(Table 1 Continued)

| Sample number | Sample name | Geologic age Depth (m) Lithofacies | Temp. (°C) | $H_2$ | $N_2$ | CO | $CO_2$ | $CH_4$ | $C_2H_6$ | $C_2H_4$ | $C_3H_8$ | $C_3H_6$ | i-$C_4H_{10}$ | n-$C_4H_{10}$ | 1-Butene | i-Butylene | i-$C_5H_{12}$ | n-$C_5H_{12}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 15 | Ryōke metamorphic rock | Mica-schist | 80 | — | — | — | — | 0.00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| | | | 150 | — | — | — | — | 3.7 | 0.001 | 0.311 | 0.061 | 0.612 | 0.033 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 |
| | | | 200 | — | — | — | — | 29.3 | 0.326 | 0.865 | 0.226 | 1.125 | 0.133 | 0.133 | 0.711 | 2.660 | 0.000 | 0.000 |
| | | | 300 | — | — | — | — | 47.5 | 1.825 | 3.161 | 0.881 | 2.370 | 0.207 | 0.412 | 0.517 | 1.321 | 0.412 | 0.001 |
| | | | 600 | — | — | — | — | 225.0 | 11.805 | 62.550 | 0.000 | 5.360 | 0.000 | 0.000 | 21.400 | 26.805 | 0.000 | 0.000 |
| 16 | Coral | Recent | 80 | 0.0 | 790 | 0.0 | — | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| | | | 150 | 0.0 | 790 | 0.0 | — | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| | | | 200 | 0.0 | 630 | 0.0 | — | 0.01 | 0.001 | 0.002 | 0.001 | 0.011 | 0.000 | 0.000 | 0.001 | 0.007 | 0.001 | 0.0007 |
| | | | 300 | 3.9 | 480 | 0.0 | — | 0.80 | 0.040 | 0.050 | 0.020 | 0.030 | 0.003 | 0.006 | 0.002 | 0.003 | 0.001 | 0.001 |
| | | | 600 | 69.6 | 447 | 8.0 | — | 10.0 | 0.241 | 1.445 | 0.007 | 0.072 | 0.004 | 0.005 | 0.004 | 0.005 | 0.002 | 0.001 |
| 17 | Limestone (Kikaiji-ma) | Quarternary | 80 | 0.0 | 1330 | 0.0 | 0.0 | 0.01 | 0.00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| | | | 150 | $0.0_3$ | 450 | 0.0 | 0.0 | 0.10 | 0.001 | 0.010 | 0.001 | 0.010 | 0.000 | 0.000 | 0.007 | 0.021 | 0.000 | 0.000 |
| | | | 200 | $0.0_5$ | 520 | 0.0 | 40.0 | 0.90 | 0.011 | 0.033 | 0.011 | 0.097 | 0.000 | 0.000 | 0.002 | 0.004 | 0.002 | 0.002 |
| | | | 300 | 9.8 | 450 | 0.0 | 70.0 | 26.0 | 0.242 | 0.402 | 0.121 | 0.242 | 0.050 | 0.400 | 0.087 | 0.054 | 0.037 | 0.024 |
| | | | 600 | 53.1 | 550 | 14.0 | 2500 | 20.5 | 0.232 | 1.159 | 0.022 | 0.300 | 0.000 | 0.000 | 0.017 | 0.010 | 0.00 | 0.00 |
| 18 | Limestone (Sagara) | Tertiary | 80 | 0.0 | 470 | 0.0 | 0.0 | 0.16 | 0.001 | 0.008 | 0.001 | 0.100 | 0.000 | 0.000 | 0.001 | 0.220 | 0.000 | 0.000 |
| | | | 150 | $0.0_5$ | 490 | 0.0 | 12 | 0.8 | 0.081 | 0.162 | 0.004 | 0.040 | 0.020 | 0.001 | 0.083 | 0.415 | 0.209 | 0.001 |
| | | | 200 | $0.0_5$ | 670 | 0.0 | 25 | 3.0 | 0.119 | 0.481 | 0.106 | 0.136 | 0.209 | 0.292 | 0.159 | 0.319 | 0.257 | 0.001 |
| | | | 300 | 0.4 | 950 | 0.0 | 35 | 50.3 | 3.641 | 7.267 | 1.573 | 0.629 | 0.342 | 0.907 | 2.233 | 2.546 | 5.930 | 2.277 |
| | | | 600 | 40.6 | 550 | 1.5 | 160 | 190 | 0.032 | 0.605 | 0.005 | 0.093 | 0.021 | 0.021 | 0.002 | 0.001 | 0.005 | 0.001 |
| 19 | Limestone (Garo) | Triassic (presumptive age) | 80 | 0.0 | 770 | 0.0 | — | $0.000_5$ | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| | | | 150 | $0.0_3$ | 540 | 0.0 | — | 0.001 | $0.000_1$ | 0.002 | 0.000 | $0.000_2$ | 0.000 | 0.000 | $0.000_8$ | $0.000_6$ | 0.000 | 0.000 |
| | | | 200 | $0.0_3$ | 550 | 0.0 | — | $0.00_5$ | $0.000_1$ | $0.000_4$ | $0.000_8$ | $0.000_2$ | 0.000 | 0.001 | $0.000_8$ | $0.000_8$ | 0.000 | 0.000 |
| | | | 300 | 2.8 | 460 | 0.0 | — | 1.0 | 0.169 | 0.337 | 0.090 | 0.270 | 0.004 | 0.032 | 0.066 | 0.033 | 0.040 | 0.040 |
| | | | 600 | 118.7 | 660 | 1.7 | — | 45.2 | 0.389 | 10.950 | 0.104 | 1.249 | 0.000 | 0.000 | 0.105 | 0.053 | 0.000 | 0.000 |
| 20 | Limestone (Akasaka) | Permian | 80 | 0.0 | 480 | 0.0 | — | 0.1 | 0.001 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| | | | 150 | 0.0 | 440 | 0.0 | — | 0.5 | 0.007 | 0.007 | 0.006 | 0.018 | 0.000 | 0.000 | 0.003 | 0.009 | 0.003 | 0.001 |
| | | | 200 | 0.0 | 460 | 0.0 | — | 0.4 | 0.008 | 0.015 | 0.007 | 0.050 | 0.000 | 0.000 | 0.009 | 0.012 | 0.006 | 0.001 |
| | | | 300 | $0.0_1$ | 490 | 0.0 | — | 0.9 | 0.020 | 0.040 | 0.010 | 0.031 | 0.001 | 0.005 | 0.007 | 0.003 | 0.002 | 0.001 |
| | | | 600 | 24.2 | 450 | 0.0 | — | 5.0 | 0.025 | 0.590 | 0.007 | 0.075 | 0.005 | 0.002 | 0.010 | 0.010 | 0.010 | 0.005 |
| 21 | Limestone (Ō funato -4) | Carboniferous | 80 | $0.0_1$ | 3560 | 0.0 | — | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| | | | 150 | $0.0_1$ | 490 | 0.0 | — | 0.16 | 0.001 | 0.003 | 0.001 | 0.030 | 0.000 | 0.000 | 0.051 | 0.153 | 0.000 | 0.000 |
| | | | 200 | $0.0_1$ | 660 | 0.0 | — | 0.5 | 0.005 | 0.100 | 0.032 | 0.069 | 0.032 | 0.030 | 0.045 | 0.090 | 0.000 | 0.000 |
| | | | 300 | 7.9 | 520 | 0.0 | — | 5.0 | 0.403 | 1.005 | 0.203 | 0.792 | 0.062 | 0.124 | 0.251 | 0.181 | 0.040 | 0.001 |
| | | | 600 | 93.7 | 410 | 1.3 | — | 25.8 | 0.102 | 1.461 | 0.004 | 0.012 | 0.029 | 0.020 | 0.078 | 0.048 | 0.000 | 0.000 |
| 22 | Limestone (Ō funato -8) | Silurian | 80 | 0.0 | — | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| | | | 150 | 0.1 | 480 | 0.0 | 20 | 0.023 | $0.000_1$ | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.010 | 0.000 | 0.000 |
| | | | 200 | 0.1 | 1350 | 0.0 | 20 | 0.070 | 0.001 | 0.004 | 0.001 | 0.006 | 0.001 | 0.007 | 0.002 | 0.007 | 0.002 | 0.002 |
| | | | 300 | 4.6 | 480 | 0.0 | — | 1.0 | 0.041 | 0.102 | 0.011 | 0.032 | 0.003 | 0.010 | 0.025 | 0.015 | 0.007 | 0.007 |
| | | | 600 | 121.8 | 610 | 0.3 | 460 | 8.0 | 0.062 | 0.810 | 0.006 | 0.061 | 0.003 | 0.006 | 0.016 | 0.016 | 0.000 | 0.000 |
| 23 | Kerogen (Ikume, Miyazaki prefecture) | Miocene | 80 | 0.0 | — | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| | | | 150 | 0.0 | — | 0.0 | 0.0 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| | | | 200 | 0.0 | — | 0.0 | — | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| | | | 300 | 0.0 | — | — | — | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| | | | 600 | 850 | — | 14.0 | 1194 | 50.0 | 7.025 | 35.459 | 2.030 | 2.030 | 0.000 | 0.000 | 4.610 | 0.001 | 0.000 | 0.000 |

Table 2 Chemical components of Low-Molecular-Weight hydrocarbons in pyrolyzed gases from the Kasukabe-drilling cores, by heating at 400°C for 10 minutes ($\mu l$/0.06g).

| Components / Depth (m) | $CH_4$ | $C_2H_6$ | $C_2H_4$ | $C_3H_8$ | $C_3H_6$ | i-$C_4H_{10}$ | n-$C_4H_{10}$ | 1-Butene | i-Butylene | i-$C_5H_{12}$ | n-$C_5H_{12}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 506 | 62 | 3.260 | 10.333 | 1.161 | 4.427 | 0.100 | 0.203 | 0.207 | 0.240 | 0.286 | 0.010 |
| 800 | 16 | 0.122 | 3.209 | 0.073 | 0.506 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1028 | 48 | 0.640 | 9.605 | 0.298 | 8.000 | 0.018 | 0.015 | 0.257 | 0.149 | 0.251 | 0.014 |
| 1050 | 32 | 0.345 | 1.774 | 0.232 | 4.002 | 0.051 | 0.015 | 0.182 | 0.244 | 0.205 | 0.014 |
| 1456 | 55 | 4.236 | 5.505 | 0.981 | 3.053 | 0.080 | 0.154 | 0.257 | 0.451 | 0.197 | 0.018 |
| 1900 | 10 | 0.830 | 2.501 | 0.153 | 1.110 | 0.046 | 0.050 | 1.116 | 0.838 | 1.422 | 0.017 |
| 2000 | 40 | 10.000 | 13.336 | 2.000 | 8.000 | 0.011 | 0.378 | 0.631 | 1.216 | 0.749 | 0.142 |
| 2200 | 20 | 0.839 | 6.660 | 0.544 | 6.665 | 0.015 | 0.082 | 0.323 | 0.554 | 0.463 | 0.010 |
| 2600 | 30 | 4.281 | 3.755 | 1.150 | 2.505 | 0.013 | 0.229 | 0.139 | 0.181 | 0.215 | 0.050 |
| 2900 | 50 | 8.331 | 5.004 | 2.087 | 5.000 | 0.056 | 0.431 | 0.425 | 0.763 | 0.693 | 0.277 |

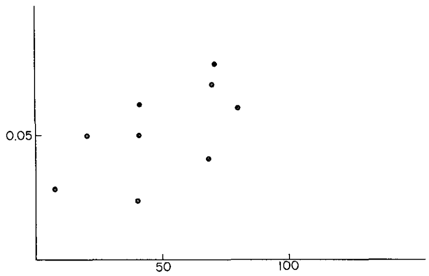


Fig. 6 Relation between the extracted organic matter and the sum of hydrocarbons in pyrolyzed gases Kasukabe-drilling cores.

Except for the total amount of pyrolyzed gases generated from coal, peat and petroleum reservoir rocks, the quantity of thermally decomposed gases, in general, is less than 1000 $\mu l$/0.06 g.

There is positive correlation between the temperature of pyrolysis and quantity of gases generated by heating sediments. The same tendency is shown in Fig. 6 as regards the relation between the amount of pyrolyzed gases and the content of soluble organic matter in sediments. Fig. 7 shows the volume ratios of total amount of hydrocarbons at different temperatures. Generally, the volume ratios of pyrolysis gases are relatively high at 300°C to 600°C. On the other hand, the volume ratios of most limestones is relatively high at about 300°C.

Eisma and Jurg (1964) reported that gaseous paraffins and olefins were generated remarkably by heating the behenic acid in the presence of clay minerals at temperatures ranging from 275 to 300°C.

Considering the results of Eisma and Jurg (1964) and the authors' experiment, it is estimated that the thermal change of organic matter in sediments and sedimentary rocks takes place extensively at temperatures above 300°C.

The thermal decomposition of kerogen takes place at higher temperature than 300°C. From this fact, it is assumed that the kerogen exists as a thermally stable form in sedimentary rocks.

### III. 2 $H_2$, $N_2$, $CO_2$ and CO

#### a) $H_2$

The quantity of $H_2$ in pyrolyzed gases from coal and peat by heating at 600°C is 60,600 $\mu l$/0.06 g and 26,000 $\mu l$/0.06 g respectively (Table 1), and this amount is very large compared with those of normal sediments and limestones.

Except for volcanic gas, $H_2$ content is generally low in natural gases (Yonetani, 1967b) and

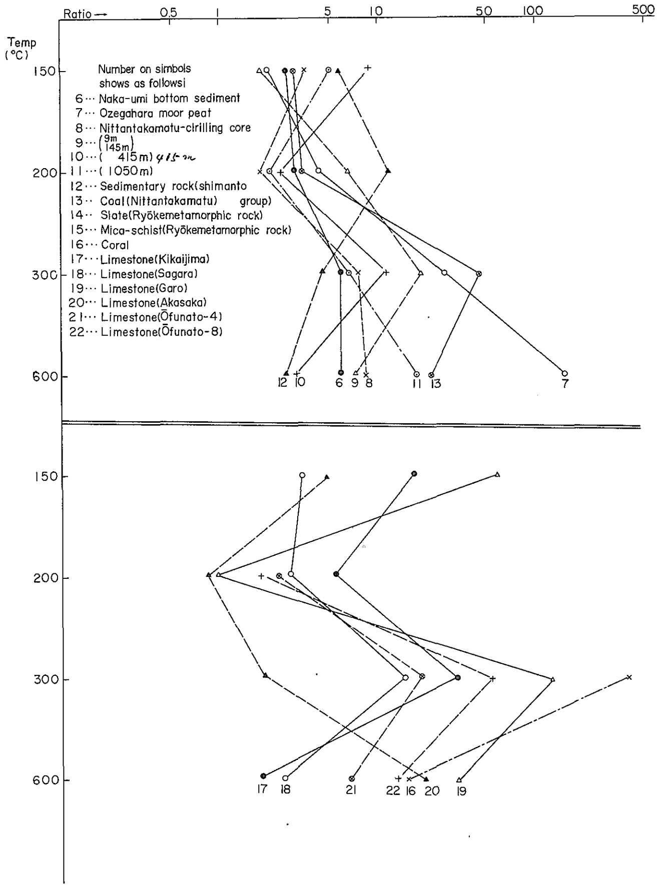


Fig. 7 The volume ratios of total amount of hydrocarbons generated at different temperatures.

the $CH_4/H_2$ ratio is more than 10,000. On the other hand, the values of thermally decomposed gases are mostly lower than 100.

On the basis of the fact that a larger amount of $H_2$ exists in pyrolyzed gases than the content of $H_2$ in natural gas in Japan (YONETANI, 1963, 1967, 1967b, 1971, 1972), it is presumed that the pyrolysis temperature of organic matter in sediments and sedimentary rocks is as low as 80°C.

**b) $N_2$**

Avery small amount of $O_2$ is detected in all pyrolyzed gases. This is probably due to insufficient substitution of air in combustion tube by argon. Accordingly $N_2$ in pyrolyzed gas is not under consideration.

**c) $CO_2$, CO**

When the air remains in the combustion tube there is a possibility that $O_2$ in remaining air combines with organic matter in sediments and sedimentary rocks forming $CO_2$ and CO. $CO_2$ is detected by heating the sample above 80°C

The quantity of $CO_2$ generated from coal and peat by heating is very large, reaching the maximum values of 10,800 $\mu l$/0.06 g and 8,020 $\mu l$/0.06 g (Table 1), although most of the values are less than 1,000 $\mu l$/0.06 g.

Judging from the amount of $N_2$ in pyrolyzed gases, all of measured $CO_2$ do not originate from the reaction with remaining $O_2$ in the tube, however as proposed by ROBINSON (1969), it is considered that a part of total $CO_2$ may be produced from the thermal decomposition of $-$COOH groups.

CO is detected in pyrolyzed gases from coal and peat by heating above 150°C. On the other hand, CO is detected at above 300°C from sediments and sedimentary rocks.

The maximum amount of CO in pyrolyzed gases obtained from coal and peat is 2,330 $\mu l$/0.06 g and 275 $\mu l$/0.06 g respectively (Table 1), however the amount of CO from sediments and sedimentary rocks does not exceed the value of 10 $\mu l$/0.06 g.

A part of total CO in pyrolyzed gas may be produced by the thermal decomposition of $-$CO groups in organic compounds.

### III. 3 Low-molecular-weight aliphatic hydrocarbons (carbon number $C_1$–$C_5$)

The mechanism of thermal decomposition of organic matter, which exists as various types of organic compounds in sediments and sedimentary rocks, is complicated. It is impossible to estimate the original organic compounds in the composition of pyrolyzed gas from sediments and sedimentary

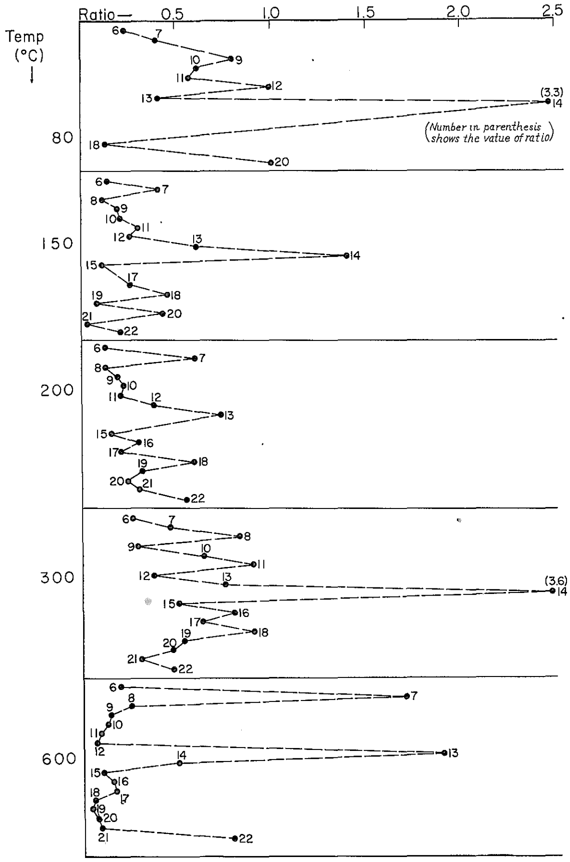


Fig. 8 Total paraffine/Total olefine ratios in pyrolyzed gases of varioustypes of sediments and sedimentary rocks at different heating temperatures.

rocks.

It is an interesting problem whether the degree of maturation and diagenesis of organic compounds in sediments and sedimentary rocks is reflected or not on pyrolyzed gas composition.

**a) paraffin and olefin**

The correlation between the values of total paraffin ($C_2$–$C_5$)/total olefin ($C_2$–$C_5$) ratios and pyrolysis temperature is listed in Fig. 8.

The values of total paraffin/total olefin ratio are generally more than 1.0 and these values (YONETANI, 1967) are similar to those of the natural gas in Recent sediments. The values of total paraffin/total olefine ratio in the natural gas (Quaternary-Cretaceous) produced from the gas fields in Japan are more than 10,000 (YONETANI, 1967b), and these values are remarkably high as compared with those of Recent gases. But a small amount of olefin is detected in natural gas involved in limestone (FUJINUKI, 1971) and $CO_2$–type natural gas. Consequently, the values of the above gas are less than 1.0 in some cases (YONETANI, 1967b, FUJINUKI, 1971).

The values of total paraffin/total olefin ratio in pyrolyzed gases from coal, peat and slate are extremely high at some temperatures.

In general, total paraffin/total olefine ratios are somewhat increased at 300°C.

Although it is obscure to some extent, the total paraffin/total olefin ratios of gases from Nittantakamatu-drilling cores increase with the depth of cores at the pyrolysis temperatures of 150, 200, and 300°C.

The same tendency is seen on Kasukabe-drilling cores (Fig. 9) by pyrolyzing at temperature 400°C for 10 minutes. It may be interesting to suggest that the degree of diagenesis of organic matter in sedimentary rocks is indirectly reflected on the pyrolyzed gas compositions.

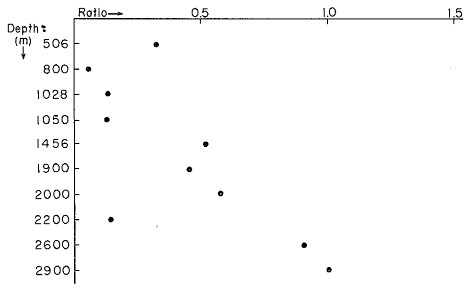


Fig. 9 Relation between the depth and the Total paraffin ($C_2 \sim C_5$)/Total olefin ($C_2 \sim C_5$) ratios in pyrolyzed gases of Kasukabe-drilling cores.

**b) $C_2H_4$ and $C_2H_6$**

In general, $C_2H_4$ may exist in trace amount of $CH_4$–type natural gas (YONETANI, 1967b), if $C_2H_4$ is present in it.

On the cotrary, $C_2H_4$ is detected very often in natural gas extracted from limestone and $CO_2$–type natural gas (YONETANI, 1967b; FUJINUKI, 1971) especially, a large amount of $C_2H_4$ (YONETANI, 1967) is found in the natural gas in Recent sediments.

The values of $C_2H_6/C_2H_4$ ratio in the pyrolyzed gases ordinarily fall below 1.0 (Fig. 10), but sometimes coal, peat and slate show the values of more than 1.0. Generally the values of $C_2H_6/C_2H_4$ ratio in pyrolyzed gases in various temperatures are comparatively high at 300°C.

GUGGENHEIM (1941) calculated the thermodynamic equilibrium constant between $C_2H_6$ and $C_2H_4$ at 400°C and 600°C, and obtained the values of equilibrium constant 12,000 and 32 respectively. Compared with the equilibrium constant calculated by GUGGENHEIM, the $C_2H_6/C_2H_4$ ratio in pyrolyzed gases of authors' data (Fig. 5) are higher at 300°C than 600°C, and the equilibrium does not exist between mutual components in pyrolyzed gases generated under 300°C. From the

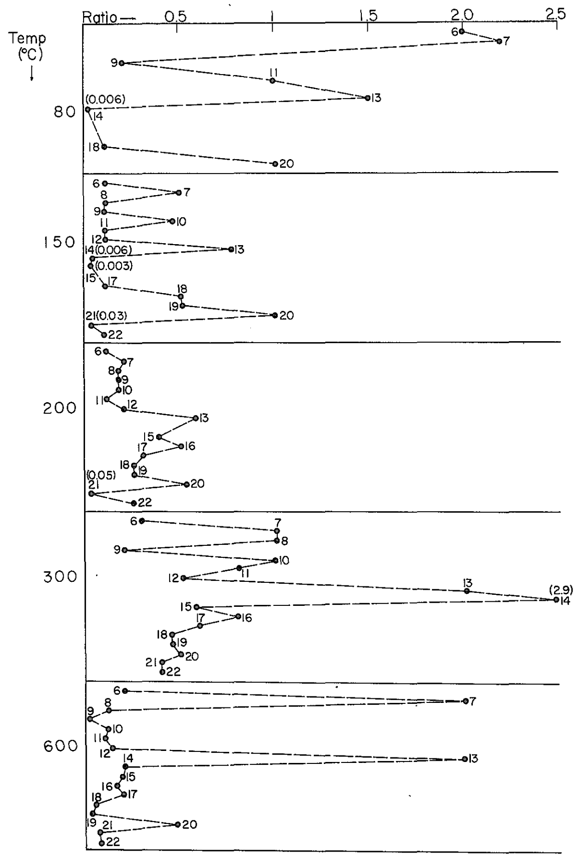


Fig. 10 $C_2H_6/C_2H_4$ ratios in pyrolyxed gases of various types of sediments and sedimentary rocks at heating temperatures.

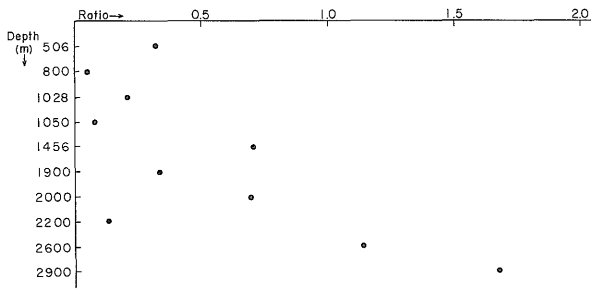


Fig. 11 Relation between the depth and the $C_2H_6/C_2H_4$ ratios in pyrolyzed gases of Kasukabe-drilling cores.

above phenomena, it is assumed, that the gas composition decomposed up to 300°C reflects indirectly the character of organic matter in sediments and sedimentary rocks.

It is presumed that $C_2H_6/C_2H_4$ ratios of pyrolyzed gases from limestones (geological age ranging from Recent to Silurian) at 200 and 300°C increase with the geological age, and on the contrary, as seen in Fig. 11, the $C_2H_6/C_2H_4$ ratios in pyrolyzed gases from Kasukabe-drilling cores increase with the depth.

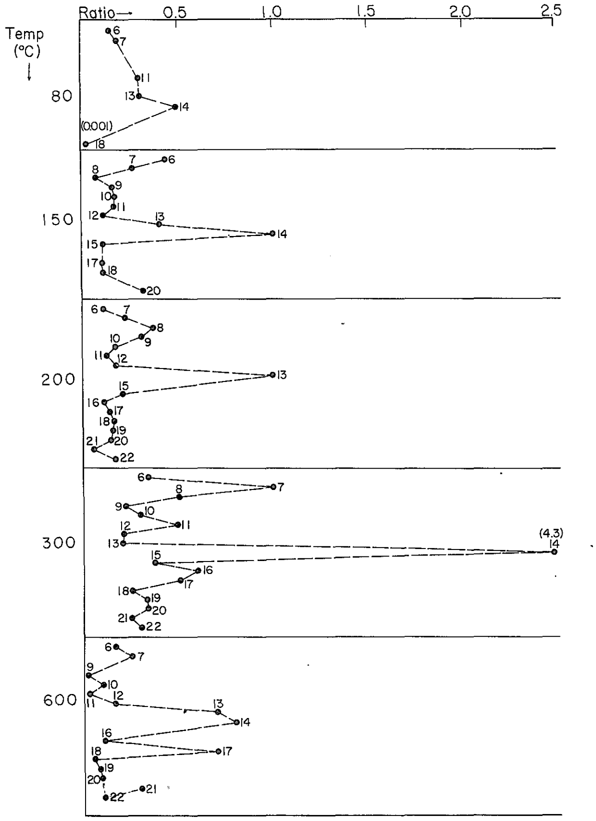


Fig. 12 $C_3H_8/C_3H_6$ ratios in pyrolyzed gases of various types of sediments and sedimentary rocks at different heating temperatures.

### c) $C_3H_8$ and $C_3H_6$

$C_3H_6$ component generally exists in Recent natural gas, and the values of $C_3H_8/C_3H_6$ ratio in the gases are more than 1.0 (YONETANI, 1967, 1972). While $C_3H_6$ is in trace amount of $CH_4$–type natural gas (YONETANI, 1967b). The values of $C_3H_8/C_3H_6$ ratio in most pyrolyzed gases are less than 1.0 (Fig. 12) and the relatively high values are found at 300°C.

As in the case of $C_2H_6/C_2H_4$ ratio, the pyrolyzed gases of coal, peat and slate have the higher values of $C_3H_8/C_3H_6$ ratio than others. The $C_3H_8/C_3H_6$ ratio is influenced by temperature and this value, as similar to $C_2H_6/C_2H_4$ ratio, appears to be the maximum at 300°C. On the other hand, as seen in Fig. 13, it is obscure there is the correlation between depth and the $C_3H_8/C_3H_6$ ratio in pyrolyzed gas of Kasukabe-drilling cores heated at 400°C for 10 minutes. A similar relation between depth and $C_3H_8/C_3H_6$ ratio in pyrolyzed gas is seen also in extracted gas

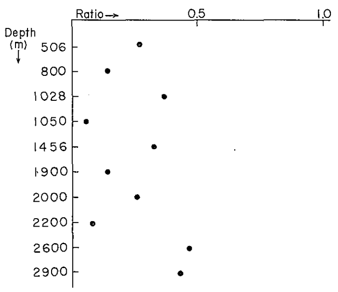


Fig. 13 Relation between the depth and the $C_3H_8/C_3H_6$ ratios in pylolyzed gases of Kasukabe-drilling cores.

from Kasukabe-drilling core.

**d) i-$C_4H_{10}$ and n-$C_4H_{10}$**

The oil field gas contains large amounts of i-$C_4H_{10}$ and n-$C_4H_{10}$ components. 50% of casinghead gases produced from gas fields, oil field and coal field regions in Japan are more than 1.0 (YONETANI, 1972) for i-$C_4H_{10}$/n-$C_4H_{10}$ ratios. The values of natural gas in Recent marine deposit are more than 1.0 (YONETANI, 1967). On the contrary, the values of peat are less than 1.0.

The values of i-$C_4H_{10}$/n-$C_4H_{10}$ ratio of thermal decomposition gases are predominantly in the range from 0.1 to 10 (Fig. 14) and the minimum values are indicated at 300°C. Compared with the notably high values of total paraffin/total olefin, $C_2H_6/C_2H_4$ and $C_3H_8/C_3H_6$

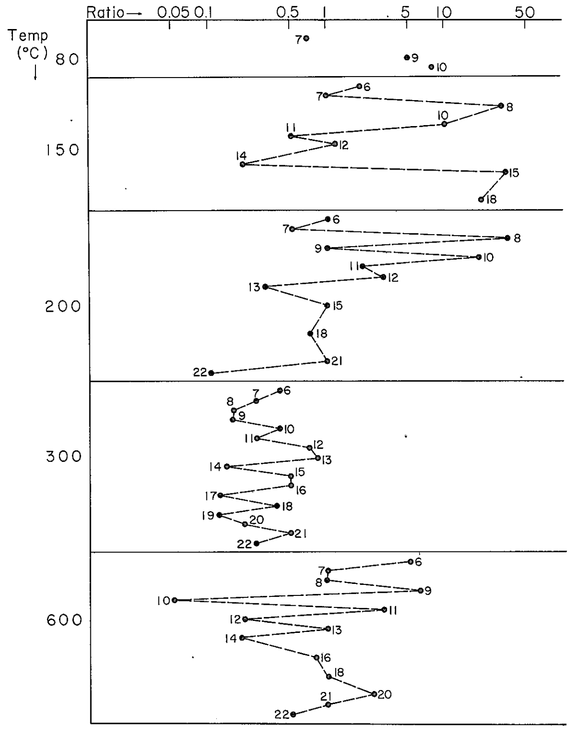


Fig. 14 i–$C_4H_{10}$/n–$C_4H_{10}$ ratios in pyrolyzed gases of various types of sediments and sedimentary rocks at different temperatures.

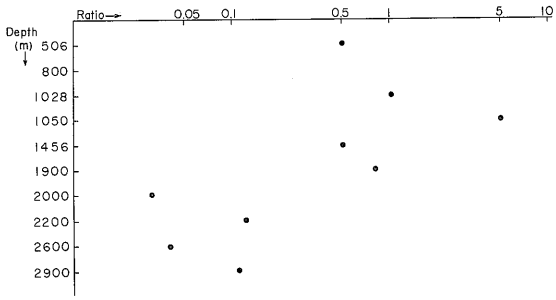


Fig. 15 Relation between the depth and the i–$C_4H_{10}$/n–$C_4H_{10}$ ratios in pyrolyzed gases of Kasukabe-drilling cores.

ratios in pyrolyzed gases from coal, peat and slate, in the case of i-$C_4H_{10}$/n-$C_4H_{10}$ ratio, there have not been seen such peculiar values in these samples. As seen in Figs. 14, 15, the values of i-$C_4H_{10}$/n-$C_4H_{10}$ ratio in pyrolyzed gases of Nittantakamatu-drilling cores heated at 150 and 200°C for 1 hr. and Kasukabe-drilling cores at 400°C for 10 minutes indicate a tendency to decrease with depth.

**e) i-$C_5H_{12}$ and n-$C_5H_{12}$**

The values of i-$C_5H_{12}$/n-$C_5H_{12}$ ratio in the natural gas in Japan are more than 1.0 (YONETANI, 1967b), while the pyrolyzed gases of sediments and sedimentary rocks give the values in a wide range of 1.0 to 50. However these values do not change notably by temperature (Fig. 16).

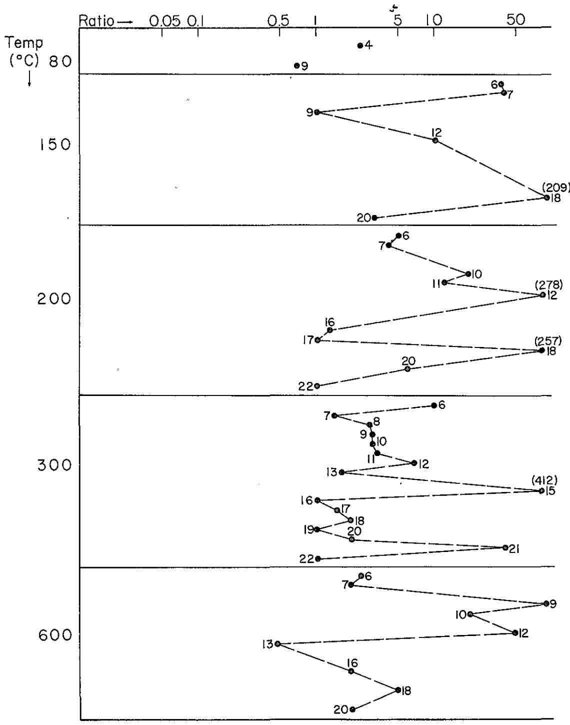


Fig. 16 i–$C_5H_{12}$/n–$C_5H_{12}$ ratios in pyrolyzed gases of various types of sediment and sedimentary rocks at different heating temperatures.

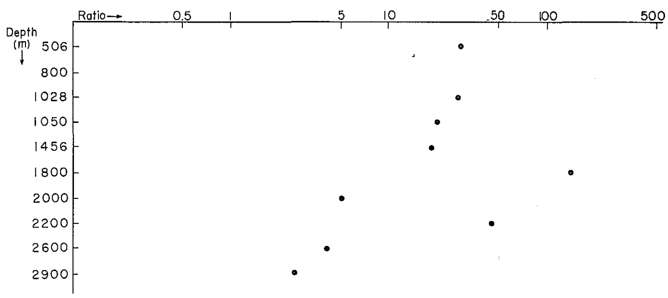


Fig. 17 Relation between the depth and the i–$C_5H_{12}$/n–$C_5H_{12}$ ratios in pyrolyzed gases of Kasukabe-drilling cores.

The values of i-$C_5H_{12}$/n-$C_5H_{12}$ ratio in pyrolyzed gases of Kasukabe-drilling cores indicate a tendency to decrease with depth (Fig. 17) and the same tendency for the values is seen in extracted gases of Kasukabe-drilling cores (Fig. 4).

**f) 1-Butene and i-Butylene**

1-butene and i-butylene must be contained in trace amounts of casinghead gases from oil, coal and gas field regions (YONETANI, 1967b), if these gas components exist in them, although 1-butene

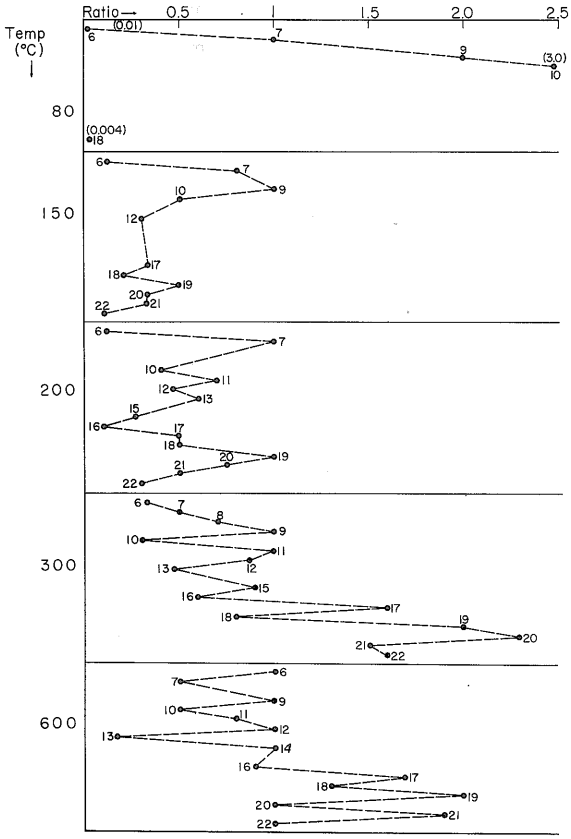


Fig. 18 1–Butene/i–Butylene ratios in pyrolyzed gases of various types of sediments and sedimentary rocks at different heating temperatures.

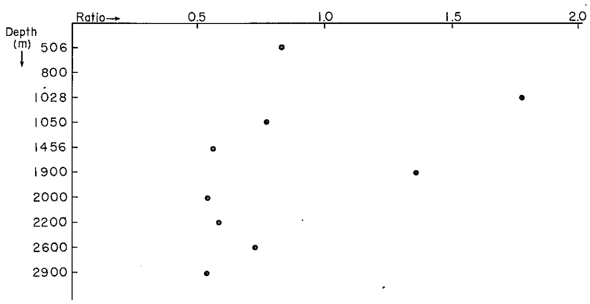


Fig. 19 Relation between the depth and the 1–Butene/i–Butylene ratios in pyrolyzed gases of Kusakabe-drilling cores.

and i-butylene are detected usually in the gases originated from Recent deposits and limestones (YONETANI, 1967, FUJINUKI, 1971).

Fig. 18 shows the values of 1-butene/i-butylene ratio in pyrolyzed gases at various temperatures. Generally, the values of 1-butene/i-butylene ratio in pyrolyzed gases do not exceed 1.0 and the value shows a tendency to increase with pyrolysis temperature. As seen in Figs. 18 and 19, the values of 1-butene/i-butylene ratio in pyrolyzed gases of Nittantakamatu-drilling cores by heating at 150 and 200°C and Kasukabe-drilling cores at 400°C for 10 minutes indicate a tendency to decrease with depth of cores. It is noteworthy that the pyrolyzed gases of limestones have high 1-butene/i-butylene ratio at 300 and 600°C.

**g) $CH_4$ and total amount of hydrocarbons ($C_2$–$C_5$)**

It is elucidated that the relations between geologic age and the values of $CH_4$/total hydrocarbons ($C_2$–$C_5$) ratio in natural gas in Japan are in the following order (YONETANI, 1967b):

(Recent and Quaternary natural gas) > (Tertiary natural gas dissolved in water and coal field gas) > (oil field gas) < (Cretaceous natural gas and other older gas)

Fig. 20 shows the values of $CH_4$/total hydrocarbons ($C_2$–$C_5$) ratio in pyrolyeed gases. Commonly, the values of $CH_4$/total hydrocarbons ($C_2$–$C_5$) ratio in pyrolyeed gases increase with depth of sediments and most of the values range from 1 to 20 at temperature above 200°C.

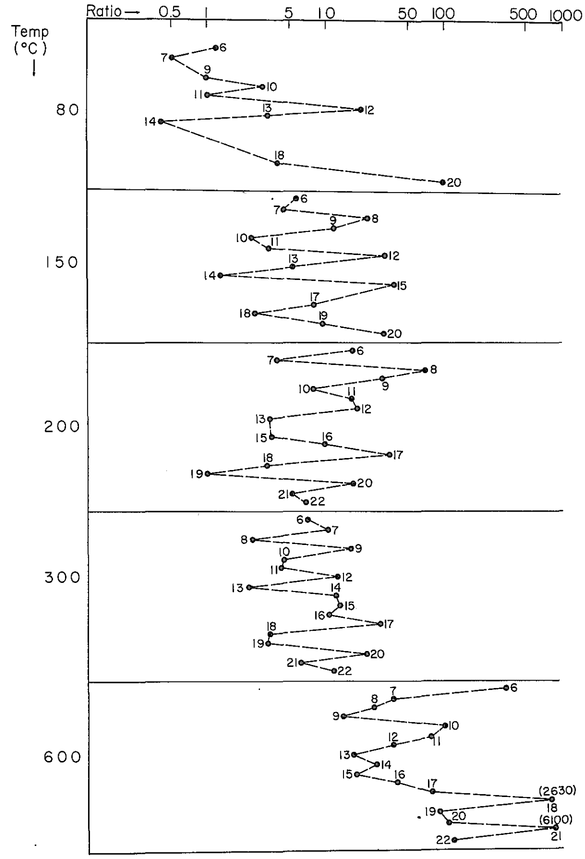


Fig. 20 $CH_4$/total hydrocarbons ($C_2 \sim C_5$) ratios in pyrolyzed gases of various types of sediments and sedimentary rocks at different heating temperatures.

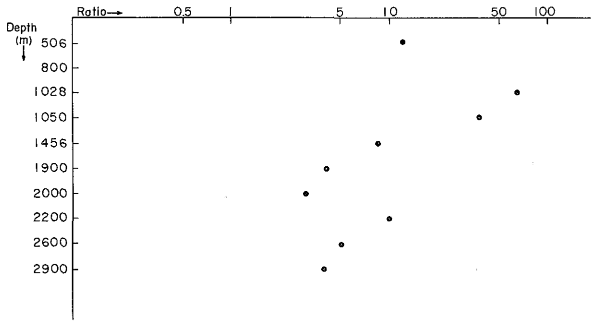


Fig. 21 Relation between the depth and the $CH_4$/total paraffine ($C_2 \sim C_5$) ratios in pyrolyzed gases of Kasukabe-drilling cores.

The clear relationship is not seen between geologic age, depth and $CH_4$/total hydrocarbons ($C_2$–$C_5$) ratio in pyrolyzed gases of Nittantakamatu-drilling cores (Fig. 20), but the values in pyrolyzed and abstracted gases of Kasukabe-drilling cores (Fig. 21) have a tendency to increase with depth.

## IV. Summary

In this study, it is an important problem whether the thermodynamic equilibrium relation exists or not among gas constituents in the pyrolyzed gas. According to the authors' experimental data, the degree of maturation and diagenesis of organic matter in sediments and sedimentary rocks is reflected to some extent on the gas composition generated from the sediments and sedimentary rocks by heating at temperature below 400°C. The above-mentioned phenomenon leaves some doubt because the authors' result is obtained from the insufficient number of experimental samples. Further study is needed to confirm this phenomenon.

In this experiment, authors demonstrate that the organic matter in sediments and sedimentary rocks is pyrolyzed even at 80°C. But, the $CH_4$–type natural gas originated from deeper zone (depth 2,000–3,000 m, estimated formation temperature exceeds 80°C) and natural gas accompanying with hot-spring water do not contain olefine at the limiting sensitivity level of 0.0001 in vol. %. This fact brings forward the interesting problem with regard to the metamorphic factor of organic matter in sedimentary rocks.

It is assumed that kerogen is pyrolyzed between 300 and 600°C. Namely, the kerogen exists in thermally more stable form than the soluble organic matter with benzene-methanol-acetone solvent. The kerogen is also the most stable form of organic matter to survive in sedimentary rocks.

## Acknowledgment

The authors thank Drs. M. Katada, A. Mizuno, T. Fujinuki, Mrs. S. Maki, and M. Nagata for giving them the valuable samples to this study.

## References

Duglas, A. G. and Eglinton, G. and Henderson, W. (1966): Thermal alteration of the organic matter in sediments. Advances in organic geochemistry (edited by Hobson, G. D. and Speers, G. C.), p. 369–388.

Eisma, E. and Jurg, J. W. (1964): Petroleum hydrocarbons: Generation from fatty acids. *Science*, vol. 144, no. 19, p. 1451–1452.

EVANS, W. D., COOPER, B. S. and GUNN, R. K. (1964): PYRO-chromatography. Advances in organic geochemistry (edited by COLOMBO, U. and HOBSON, G. D.), p. 417–421.

FUJINUKI, T., TONETANI, H. and NISHIMURA, T. (1971): On the contents of $C_1$–$C_5$ hydrocarbons, organic and elementary carbon in ancient limestone from Japan. *J. Jap. Assoc. Min. Pet. Econ. Geol.*, vol. 66, no. 5, p. 197–211.

GUGGENHEIM, E. A. (1941): Trans. Farady. Soc., vol. 37, p. 97.

ROBINSON, W. F. (1969): Kerogen of the Green River Formation. *Organic geochemistry* (edited by EGLINTON, G. and MURPHY, M. T. J.), p. 619–637.

YONETANI, H. (1963): Minor components in natural gas from natural gas accumulation with formation water in Japan. *Bull. Geol. Surv. Japan*, vol. 14, no. 11, p. 850–866.

————(1967): Some gas components in lake water and bottom sediments. *Bull. Geol. Surv. Japan*, vol. 18, no. 11, p. 731–757.

————(1967b): Minor gas components in natural gas. Ann. Meeting Geochem. Soc. Japan, Nagoya.

————and HIRUKAWA, T. (1971): Gaseous aliphatic hydrocarbons ($C_1$–$C_5$) in the sedimentary rocks. *Bull. Geol. Surv. Japan*, vol. 22, no. 1, p. 1–18.

————, NAGATA, M., KOMA, T. and OBA, N. (1972): Gaseous composition dissolved in pore water from peat bog. Ann. Meeting Geochem. Soc. Japan, Sendai.

## たい積物・たい積岩中の有機物の熱分解ガス組成

米谷 宏・大場 信雄

### 要 旨

たい積物・たい積岩を Ar 気相中で80～600℃に加熱し，そのさい発生したガスを分析して以下に述べる考察をまとめた．

1) たい積物・たい積岩を加熱したさい発生したガス中の $H_2$ およびオレフィン系炭化水素は，$CH_4$ 系天然ガスのそれと比較して，いちじるしく多い．このことは，たい積物・たい積岩中の有機物が80℃でも熱分解することを暗示する．

2) 加熱によって発生した炭化水素ガスの量は，300℃あるいは600℃で比較的多い．

3) Kerogen の熱分解は，300℃からみとめられた．このことは．Kerogenがたい積物・たい積岩中の抽出性有機物より熱的に安定であることを示す．

4) たい積岩の熱分解ガス組成と地質時代および深度との関係については，今後の検討に待つところが多い．