(French, ms, p. 65-68; 1970, p. 17-19). These compounds could be detected by the distinctive odor produced on opening the reaction vessels and sample tube after synthesis, and their complex character was qualitatively identified by a cursory mass-spectrometric analysis kindly performed by Dr. T. C. Hoering of the Carnegie Institution of Washington Geophysical Laboratory.

The production of such organic compounds appears to be an integral part of the formation of siderite by this method. Such formation is probably promoted by: (1) the reducing character of the gases produced by decomposition of $FeC_2O_4 \cdot 2H_2O$ (see French and Eugster, 1965; French, 1966); (2) the low $f_{O_2}$ established by the hydrothermal vessel (approximately the Ni–NiO buffer, or $\log f_{O_2} \cong -30$ at 400°C; Eugster and Wones, 1962); (3) catalysis promoted by the iron-bearing solid phases or the pressure vessel.

Similar inorganic reactions may also have produced the organic compounds now found in meteorites (for detailed references, see French, 1970). These results also suggest that formation of organic compounds can occur at elevated temperatures and high gas pressures which correspond to moderate depths in a planetary crust, where the existence of a reduced gas phase may be favored by low $f_{O_2}$ values controlled by equilibrium between graphite or other minerals (French, 1966, 1970). Organic compounds formed during hydrothermal activity at moderate depth could then be released to the surface, providing material for biological development even in cases where such synthetic reactions were not possible in the planetary atmospheres or oceans themselves.

## EXPERIMENTAL RESULTS

*The equilibrium: siderite + hematite + magnetite + gas (SHMG).* —The univariant equilibrium: siderite + hematite + magnetite + gas (SHMG) is the intersection of three divariant surfaces in $P_F$–$f_{O_2}$–T space; the surface, siderite + hematite + gas (SHG); the surface, siderite + magnetite + gas (SMG); and the degenerate buffer surface, hematite + magnetite + gas (HM). The location of the SHMG curve was determined at 500 and 1000 bars $P_F$ by reversing reactions in samples of siderite surrounded by hematite–magnetite buffers (table 2; fig. 3). The values obtained are:

| $P_F$ | T(±10°C) | $-\log f_{O_2}$ (±0.8) |
|---|---|---|
| 500 | 363 | 24.7 |
| 1000 | 365 | 24.6 |

The greatest difficulty in determining equilibrium temperatures along the hematite–magnetite buffer was caused by the slight amount of reaction in both directions, under 5 percent. Determination of phases was made necessarily by optical study and by the detection of color changes and magnetism in the sample.

Limits on the equilibrium temperature of the isobaric invariant point SHMG at 500 bars are fixed by runs 108 (354°C) and 93 (372°C).

TABLE 2

Experimental data for determination of the equilibrium: siderite + hematite + magnetite + gas (SHMG) along the hematite–magnetite buffer

| Run no. | Sample | T°C | $-\log f_{O_2}$ (bars) | Time (hrs) | Products: Sample | Products: Buffer |
|---|---|---|---|---|---|---|
| $P_F = P_{CO_2} + P_{CO} = 2000$ bars | | | | | | |
| 25 | S | 203 | 37.5 | 185 | S | H + M + S |
| 29 | S | 230 | 34.8 | 328 | S | H + M + S |
| 33 | S | 249 | 33.0 | 501 | S | H + M + S |
| 30 | S | 270 | 31.2 | 329 | S | H + M |
| 34 | S | 274 | 30.8 | 506 | S | H + M + S |
| 42 | S | 276 | 30.7 | 473 | S + H + M | H + M + S |
| 38 | S | 283 | 30.1 | 354 | S + H + M | H + M + (S) |
| 43 | S | 289 | 29.6 | 473 | S | H + M |
| 54 | S | 290 | 29.5 | 710 | S + H + M | H + M + (S) |
| 39 | S | 291 | 29.5 | 355 | S | H + M |
| 53 | S | 292 | 29.4 | 432 | S | H + M |
| 18 | S | 301 | 28.8 | 91 | S + H + m | H + M + (S) |
| 26 | S | 302 | 28.7 | 185 | S + H + M | H + M |
| 131 | S | 302 | 28.7 | 335 | S + H + m | H + M + (S*) |
| 52 | S | 318 | 27.5 | 415 | S | H + M + (S) |
| 55 | S | 320 | 27.4 | 710 | S + H + M | H + M |
| 132 | HM | 254 | 32.6 | 335 | H + M + (S) | H + M + (S) |
| 133 | HM | 306 | 28.4 | 331 | H + M + (S) | H + M |
| $P_F = P_{CO_2} + P_{CO} = 1000$ bars | | | | | | |
| 44 | S | 241 | 33.9 | 238 | S | H + M + S |
| 45 | S | 280 | 30.5 | 190 | S | H + M + S |
| 58 | S | 294 | 29.4 | 356 | S | H + M + S |
| 70 | S | 303 | 28.6 | 356 | S | H + M + S |
| 71 | S | 325 | 27.1 | 356 | S | H + M + (S) |
| 79 | S | 348 | 25.6 | 567 | S | H + M + S |
| 49 | S | 360 | 24.8 | 531 | S | H + M + S |
| 120 | S | 360 | 24.8 | 372 | S + h + M | H + M + S |
| 65 | S | 370 | 24.2 | 373 | S + H + M | H + M + (S) |
| 124 | S | 380 | 23.6 | 385 | S + h + (M) | H + M + (S) |
| 121 | S | 389 | 23.1 | 371 | S + H + M | H + M + (S) |
| 59 | S | 400 | 22.5 | 356 | S + h + M | H + M + (S) |
| 125 | S | 418 | 21.5 | 291 | S + H + M | H + M + (S*) |
| 126 | HM | 349 | 25.5 | 387 | H + M + (S) | H + M + (S) |
| 127 | HM | 410 | >22.0 | 289 | M | M |
| $P_F = P_{CO_2} + P_{CO} = 500$ bars | | | | | | |
| 66 | S | 297 | 29.3 | 453 | S + (M) | H + M + S |
| 73 | S | 342 | 26.1 | 356 | S | H + M |
| 108 | S | 354 | 25.3 | 369 | S | H + M + S |
| 93 | S | 372 | 24.2 | 373 | S + H + M | H + M + S |
| 109 | S | 379 | 23.8 | 369 | S + h + M | H + M + S |
| 115 | S | 390 | 23.1 | 329 | S + H + M | H + M |
| 105 | S | 404 | 22.4 | 257 | S + H + M | H + M + (S) |
| 99 | S | 419 | 21.5 | 330 | S + H + M | M |
| 116 | HM | 365 | 24.6 | 327 | H + M + (S) | H + M + (S) |
| 117 | HM | 407 | 22.2 | 325 | H + M | H + M + (S) |