THERMAL RELEASE PROFILES AND THE DISTRIBUTION OF CARBON AND NITROGEN AMONG MINERALS AND AGGREGATE PARTICLES SEPARATED FROM LUNAR SOIL, P. C. Wszolek, J. T. O'Connor, F. C. Walls and A. L. Burlingame, Space Sciences Lab., Univ. of Calif., Berkeley, Ca. 94720.

Soil sample 10086D was separated into fractions according to size, density, and magnetic susceptibility. The size fractions 105-420μ, 37-105μ, and <37μ were obtained by wet sieving with methanol. Size fractions concentrated in very fine particles <5μ and 5-10μ were obtained by application of Stoke's Law for settling rates in methanol of particles from a portion of the <37μ fraction. The 37-105μ fraction was further separated into the density fractions shown in Table 1, with diiodomethane and mixtures of diiodomethane and acetone whose densities were adjusted with appropriate sink-float standards. Subsequent magnetic susceptibility separations were carried out with a Frantz isodynamic separator. All parts of this separator which came into contact with the samples were coated with Teflon. The distribution of particle types in each of the fractions was determined with a petrographic microscope; detailed descriptions of the fractions and the weight distribution of the total recovered material are given in Table 1. A small portion of the <37μ fraction of 10086D was etched slightly with a dilute solution of HF (1 vol. 40% HF to 250 vol. water).

Separated fractions have been pyrolyzed under vacuum at a linear temperature program rate of 25°C/min. from ambient to 1400°C. All gaseous species evolved were continuously monitored using a high sensitivity, high resolution MS-902 mass spectrometer coupled to a computer (1). Total carbon (released as CO and CO_2) and total nitrogen (released as N_2) were determined by integrating the temperature release profiles for these gaseous species; these data are given in Table 1. The amount of CO evolved by the samples is a better measure of their carbon contents since most of the CO_2 is terrestrial contamination and is released below 600°C during pyrolysis.

The data show that carbon and nitrogen are concentrated in the <5μ, 5-10μ, and <37μ size fractions of 10086D and in the separates from the 37-105μ fraction (Table 1) which contain high proportions of glassy aggregates (#1, 4, and 5). Those fractions consisting chiefly of the minerals plagioclase (#7) and pyroxene (#13 and 14), on the other hand, have the lowest concentrations of carbon and nitrogen. These results agree in general with total carbon values for glassy agglutinates and feldspar isolated from several Apollo 15 soils (2) and with the data for concentrations of carbide and methane in agglutinate and mineral fractions separated from 10086D fines (3). Fractions 6 and 12 contain very high concentrations of carbon although the aggregates in these fractions amount to only about 20% and 30%, respectively. It may be significant that these aggregate grains contain opaque minerals, probably mostly gas retentive ilmenite, and might therefore suffer less loss of carbon containing gases at the higher temperatures (≥600°-800°C) associated with agglutinate and breccia formation (4). The nitrogen contents of the carbon-rich fractions 5, 6 and 12 are significantly lower than those of the carbon-rich glassy aggregate fractions 1 and 4 suggesting that different mechanisms control the distribution of carbon and nitrogen in these complex particles or that the grains incorporated into the two types of aggregates originally

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contained different amounts of nitrogen (relative to carbon). The latter possibility could be a result of varying mineral compositions with varying retentive properties.

Distinctive temperature release profiles for CO, CO_2, and N_2 were obtained for the various separated fractions. Most of the carbon and nitrogen was released as CO and N_2 below 900°C from the following samples: <5μ, 5-10μ, <37μ, <37μ slightly etched, and fraction #7 (plagioclase). Each of these samples exhibited a bimodal evolution of CO and N_2 at 600°-850°C and 950°-1200°C, with the lower temperature regions predominating by factors of about three or more. High temperature (950°-1200°C) evolution of CO_2 was observed only for the <37μ fraction and the <37μ slightly etched sample. In striking contrast, the coarser size aggregate-rich (5) fractions 37-105μ and 105-420μ and fractions #1 and #4, i.e. glassy aggregates which together make up about half of the 37-105μ sample, evolved most of their CO and N_2 above 950°C up to 1200°C. All of these samples also released CO_2 at 1000°-1200°C. These data suggest that surface related, recently implanted solar wind carbon and nitrogen are mostly associated with the lower temperature region of the characteristic bimodal evolution pattern of bulk lunar soils whereas the volume related carbon and nitrogen components are mostly associated with the higher temperature region. This interpretation of the data is supported by the evolution of ^{13}CO predominantly in the region 750°-900°C from plagioclase artificially irradiated with ^{13}C (6).

All of these temperature release profiles taken together suggest that substantial alteration (7) of carbon and nitrogen occurs during aggregate formation in lunar soils. The preliminary data for the <37μ etched sample indicate that its gas release profile is not substantially changed despite the loss of over half of the carbon and nitrogen. This result suggests that physico-chemical removal of the C and N alone, by diffusion losses during heating of grains to ≥800°C for example, would not enhance the relative amounts of carbon and nitrogen phase(s) represented in the 950°-1200°C evolution. The profiles for the aggregate particles may reflect the proposed synthesis of additional amounts of carbide (3) during agglutinate formation. Indeed our profiles for CO and CO_2 from the aggregate particles resemble those generated by a synthetic mixture of cohenite and silicate minerals (8) in which CO is released predominantly over 900°C.

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Table 1. Concentrations (ppm) of C, CO, CO_2 and N released by pyrolysis of separates from the 37-105μ fraction of 10086D fines.

	Density	M.S.*	Weight (%)	C	CO	CO_2	N	Description
#1	ρ< 2.73	H	10.0	165	123	42	69	gl. agg.
#2	"	I	1.0	n.d.	n.d.	n.d.	n.d.	pl > gl > gl agg. = op
#3	"	L	1.5	n.d.	n.d.	n.d.	n.d.	pl > gl > ol
#4	2.73 <ρ< 3.21	H	39.6	166	132	34	63	gl agg.
#5	"	I	8.3	144	109	35	16	gl agg. + br >> sg > gl > px > op
#6	"	I	1.9	170	140	30	16	pl > gl agg = sg = gl > px > op = br
#7	"	L	1.3	13	11	2	1.6	pl
#8	3.21 <ρ< 3.3	H	1.5	n.d.	n.d.	n.d.	n.d.	gl agg > op > px > gl
#9	"	I	2.2	n.d.	n.d.	n.d.	n.d.	gl agg > px > op > gl
#10	"	I	2.8	63	45	18	7.7	px > rf = gl agg > op > br > gl
#11	"	L	0.6	n.d.	n.d.	n.d.	n.d.	px >> gl
#12	ρ> 3.3	H	6.0	180	132	48	23	op > agg > px > ol
#13	"	I	17.8	20	14	6	3.9	px > op > gl agg
#14	"	L	2.5	27	14	13	4.5	px
#15	2.73 <ρ> 3.3	VH	3.1	n.d.	n.d.	n.d.	n.d.	n.d.

* - magnetic susceptibility
n.d. = not yet determined
pl = plagioclase
op = opaque minerals (ilmenite)

ol = olivine
px = pyroxene
gl = glass

agg = aggregate
br = breccia fragments
sg = silica growths
rf = rock fragments

H = high
I = intermediate
L = low
VH = very high