TEXTURAL VARIATIONS OF THE CRYSTALLINE MATRIX OF FRA MAURO BRECCIAS AND A MODEL OF BRECCIA FORMATION. D. Stöffler, H.-D. Knöll, Institute of Mineralogy, University of Münster, Germany, V. Stähle, and J. Ottemann, Institute of Mineralogy, University of Heidelberg, Germany.

Breccias with fine grained crystalline matrix are very common among the lunar highland rocks. In general, authors agreed in an impact melt origin of the matrix except for the Fra Mauro breccias. A model by Warner (1) in which the crystalline matrix was interpreted to result from a solid state recrystallization of impact detritus by thermal metamorphism had been adopted by most lunar scientists in spite of various evidence against this view (e.g. 2, 3, 4). Recently, Warner (5) abandoned his metamorphic model in favor of a two-component thermal model (mixture of impact melt and rock debri). Data from clast population studies (3,4) and from matrix analyses presented here lead to a similar, but somewhat modified concept of the role of impact melt in the formation of the Fra Mauro breccias.

An automated analysis of the matrix texture and simultaneous analysis of the matrix phases was started on selected samples of breccias with crystalline matrix (14066, 14311, 14320 and a breccia clast of 14306) of which the clast population was analyzed previously (3,4) except for 14306. The following parameters of the matrix texture were obtained by a computerized electronic scanning microscope recording 8 different constituents: n_i = number of particles i, d_i = average scanned length of chord of i, V_i(%) = volume percent of particles i, S_i/V_i = surface area of particles i per volume percentage of particles i (specific surface), S_i/V = surface area of particles i per total sample volume (inner specific surface). 1000 grain traverses per sample were measured in a matrix area of about 2 mm^2 (see Table 1).

Except for 14306, which displays a rather homogeneous dark matrix, a conspicuous variation of the matrix texture of all samples is observed within a millimeter scale. Two major types of matrix are <u>dark</u>, fine grained <u>matrix</u> and <u>light</u>, coarse grained <u>matrix</u> (1, 2). In some cases the boundaries between the two types are rather sharp, so that one type appears as a clast within the other type, in other cases the boundaries are diffuse. The light matrix tends to form schlieren-like bands or bodies of irregular shape between areas of dark matrix. The former is more densely packed with clasts. The following types of matrix were studied by stereometric and microprobe analysis: 066,46: light matrix (a), dark matrix with isometric (b) and lath-like (c) ilmenite, 306,3: dark matrix with dendritic ilmenite, 311,5: light matrix (a), dark matrix with isometric (b) and with prismatic (c) pyroxene and isometric ilmenite, 320,10: dark matrix with isometric ilmenite. The <u>modal composition</u> of the various types of matrix is most different for dark and light matrix (Table 1): the latter is higher in plagioclase and mesostasis glass and lower in mafics, ilmenite, and metal. The <u>grain size</u> distribution of plagioclase and pyroxene is bimodal in the dark matrix with a minimum near 6.5-9 μ which very probably separates small clasts (> 9 μ) from in-situ crystallized minerals (< 6.5 μm) (Fig. 1). The grain size distribution in the light matrix is more irregular. All phases of the light matrix are coarser grained than those of the dark matrix and consequently have the lowest values of specific surface S_i/V_i (Table 1). The <u>inner specific surface</u> of

TEXTURAL VARIATIONS OF CRYSTALLINE MATRIX

Stöffler, D. et al.

the matrix constituents which is a function of their volume percentage and of the grain size, varies characteristically with matrix type. In the dark matrix types (306; 066 b,c; 311 b,c; 320 a,b) plagioclase and pyroxene + olivine have almost identical values although the plag : px + ol ratio varies between 0.8 and 2.2 (Table 1). In contrast, in the light matrix the values are lower but distinctly higher for plagioclase than for pyroxene. The lath-like shape of ilmenite in 066 c is reflected by a higher inner specific surface compared to 066 b. The geometry of crystal intergrowth can be best seen from the "transition matrix" (Table 2) which gives the frequency of two-phase contact areas in percent of the total surface area of all constituent phases. Deviation from a ideal mosaic texture with random distribution of constituents is expressed by the deviation from the proportionality of the volume percentage of a phase and its contact frequency to another phase (compare Tables 1 and 2). A most important result is that all measured dark matrix types approach mosaic-like texture of plagioclase, pyroxene (+ olivine), and ilmenite except for 306, 066 b, and the light matrix (066a, 311a). In the latter the predominance of plagioclase-mesostasis contacts is conspicuous (Table 2). In summary, our quantitative textural data do not show a clear trend for a textural sequence in the matrix of 311, 320, and 066 (Warner's former grades 5,6,7) as postulated by (1,5). For the regular dark matrix a slight increase of the inner specific surface of plagioclase and pyroxene in the order 311, 320, 066 may be read from Table 2.

Plagioclase of each type of matrix shows a broad variation of the An-content (mostly 65-90 mol.%) and is, in general, higher in FeO than the clasts. Pyroxene occupies a very narrow range of composition and is very low in Ca in all dark matrix types. It tends to be more pigeonitic in the light matrix. Ilmenite is typically higher in Cr and Ti than the clasts. Its MgO-content ranges between 3.0 and 5.0 wt.%. Interstitial mesostasis glass contains 9-13 wt.% K_2O, 63-75 % SiO_2, 12-19 % Al_2O_3, and less than 1 % for each of the other main oxides. Composition and textural occurrence speak in favor of a residual melt origin. The composition of the complete metal population (fragmental and in-situ formed) measured in sections 066,7, 311,7, and 320,8 differs strongly from that one of Apollo 14 soil (6) because only a small portion of grains falls into the field for meteoritic composition (7, horizontal band in Fig. 2).

Discussion. Based on the present data and on other information (2,3,4, 9,10,11) we propose the following model for the formation of the Fra Mauro crystalline matrix breccias : (a) Formation of impact melt in one or more local, pre-Imbrian craters and mixing of melt and less shocked fragmented rock material during crater excavation with initial melt temperatures of at least some 1700°C (zircon reaction rims around baddeleyite). (b) Formation of a series of breccia types ranging from coherent fragment-laden melt rocks to suevite-type detrital breccias rich in discrete clods of melt in analogy to observations in terrestrial craters such as Lappajarvi, Dellen, Rochechouart (11,12). (c) Concentration of cold clastic material in schlieren-like bodies by flotation effects (10) to form the parent of the light matrix in the first breccia type or formation of an intimate mixture of impact detritus with independent clods of melt to form the parents of light and dark matrix in the

TEXTURAL VARIATIONS OF CRYSTALLINE MATRIX

Stöffler, D. et al.

second type (14311 most closely resembles the first type, 14066 and 14320 are transitional to the latter type). (d) First crystallization of melt in clast-rich areas (light matrix) at high temperatures with clasts acting as nucleation centers; formation of a relatively coarse grained texture with pigeonitic pyroxene and An-rich plagioclase. (e) Subsequent crystallization of melt in clast-poor areas (dark matrix) at lower temperatures (supercooled liquid (5)) with simultaneous formation of a large number of nuclei; formation of a fine grained mosaic-like texture with low Ca-pyroxene; further textural variation of the matrix most probably resulting from variation of the bulk chemistry due to different degrees of clast melting. (f) Breccia material now residing in a more or less thick impact formation with slow cooling from temperatures near 800°C as indicated by the preservation of highly siliceous glass.

Compared to (8) our model emphasises that the crystalline matrix breccias of Apollo 14 may include certain types which are not derived from fragment-laden melt but rather from very melt-rich, detrital suevitic parents.

References.(1)Warner J,L.(1972)PLSC,3rd,623-643 (2)Engelhardt,W.v.(1972)PLSC. 3rd,753-770 (3)Stöffler,D.et al.(1976)PLSC.7th,1965-1985 (4)Stöffler,D.and Knöll H.-D.(1977)PLSC.8th,1849-67 (5)Warner,J.L.et al.(1977) Lunar Sci.VIII,Houston,982-984 (6)Goldstein,J.I.et al. (1972)PLSC.3rd,1037-1064 (7) Goldstein,J.I.and Yakowitz,H. (1971)PLSC.2nd,177-191 (8) Simonds,C.H.et al.(1977)PLSC 8th,1869-1893 (9)Onorato, P.I.K.et al.(1976)PLSC.7th, 2449-2467 (10)Stähle,V. (1972)Earth Planet.Sci.Lett. 17,279-293 (11)Stöffler,D. unpublished (12)Lambert,P. (1977)Doct.Diss.Univ.Paris Sud.

Table 2

		2	3	4	5	7
2	a	4.6	21.3	1.4	0.2	12.2
	b	0	37.3	3.4	1.1	0.1
	c	0.7	33.0	4.2	0.9	0.1
3	a	20.6	1.4	0.1	0.2	4.6
	b	38.5	2.1	2.5	0.2	0.1
	c	32.8	2.9	4.3	0.3	0
4	a	1.3	0.4	0.1	0	0.1
	b	3.0	2.9	0	0	0
	c	4.6	4.0	0	0.1	0
5	a	0.1	0	0.1	0	0.1
	b	1.0	1.2	0	0	0
	c	0.9	0.5	0	0	0
7	a	13.0	3.9	0.2	0	0
	b	0.1	0.1	0	0	0
	c	0.1	0	0	0	0

Fig.2 →

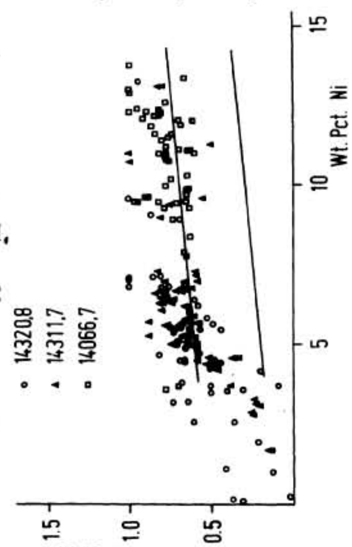
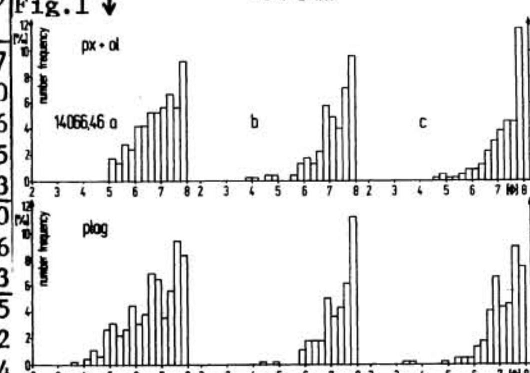


Table 1

		066,46			306,3	311,5			320,10
		a	b	c		a	b	c	a
V_i (%)	2	58.0	38.6	45.5	50.3	53.5	44.5	43.8	58.7
	3	25.1	46.2	38.9	36.2	28.1	38.4	40.6	34.0
	4	1.0	2.1	2.7	3.4	1.9	4.0	3.7	1.6
	5	.1	.4	.4	.2	.0	.2	.2	.5
	7	5.1	.2	.1	1.1	8.6	2.6	.0	1.3
S_i/V_i (μ^{-1})	2	.43	1.00	.86	.83	.41	.64	.83	.60
	3	.63	.86	1.01	1.13	.39	.75	.89	.96
	4	1.17	2.57	3.01	2.41	.89	2.04	2.69	2.73
S_i/V	2	.25	.38	.39	.42	.22	.31	.37	.35
	3	.16	.40	.39	.41	.11	.28	.36	.32
	4	.01	.05	.08	.08	.02	.08	.10	.04

2=plag,3=px+ol,4=ilm,5=metal,7=mesostasis

Fig.1 ↓



a,b,c = see text