Table 10. Modal composition of breccias (vol. %).

	Apollo 11					Apollo 12	
	M62	10085,26 M56	M54	10027,11 M55	Average	12010,4	12034,11
Matrix	35	31	27	50	36	25	23
Without matrix							
Basalt	17	13	29	24	21	37	6
Anorthosite	3	5	1	2	3	5	3
Breccia	—	—	2	—	0.5	—	1
Glass	33	29	35	26	31	20	54[1]
Regular glass bodies	1	1	4	2	2	< 1	< 1
Pyroxene + Olivine	27	30	11	24	23	27	20
Plagioclase	8	10	9	13	10	5	10
Opaques	11	7	8	8	8	4	5
Pyroxene/plagioclase	3.4	3.0	1.2	1.8	2.3	5.4	2.0

[1] Including 6% vitrophyric basalt (volcanic glass).

amount of rocks in breccias is probably due to the abundance of rock fragments in coarser fractions. The apparent higher value of the pyroxene/plagioclase ratio may, at least in part, be caused by the camouflage of small plagioclase particles in the matrix.

Breccia 12010 from the outer rim of Middle Crescent Crater differs from soils 12001 and 12070, collected 200 m away from the crater rim, by a higher amount of basalt and pyroxene fragments which may originate from an admixture of pyroxene rich basaltic rocks excavated by the Crescent Crater event. Soil (12034,74) and breccia (12034,11) from Head Crater have closely related compositions characterized by abundant maroon-brown "KREEP"-glasses. The soil contains fragments of the 12034 breccia type.

Careful microscopic thin section studies of large and small breccia fragments showed, that among the various breccias of both landing sites certain textural differences exist. We found that the following properties could be meaningful for classification and genesis of breccias: (1) matrix porosity, (2) amount of glass in the matrix, (3) texture of the matrix glass, (4) amount of shocked rock and mineral fragments, (5) presence or absence of delicate and fragile glassy agglomerates, (6) degree of compositional variation of glass fragments and regular bodies, and (7) glass coating of breccia fragments and its textural relationship to the matrix glass.

Because gradational transitions exist between all types which could be established according to these aspects, the attempt to classify the breccias should not only be based on petrographic observation but also on a tentative genetical model of the different formation processes of impact breccias under lunar conditions.

In a rather simplified approach, we distinguish between (1) large impacts penetrating deeply into the basement and (2) smaller impacts affecting only the regolith layer. In the case of large impacts, we have to expect (1a) suevite-like breccias with a high content of shocked rocks in all stages of shock metamorphism, including shock-fused glasses; and (1b) impact breccias with a low content, if any, of fused glasses and a low amount of shocked material. The latter breccia type which probably has a terrestrial analogue in the Bunte Breccie of the Ries ejecta blanket, would form by a lateral flow of disintegrated weakly shocked material. The constituents of type (1a) and (1b) breccias will originate mainly from the basement rocks and only subordinately from the regolith.

Breccia 12034 and similar breccia fragments in soil 12033 may be suevite-like breccias (1a) (QUAIDE *et al.*, 1971). Because of their unique composition and the location of the Apollo 12 site within ray systems of large craters excavated in the Fra Mauro formation these breccias are assumed to originate from an impact into this formation (e.g., LSPET, 1970). Breccias of the type (1b) have not been identified with sufficient certainty. Monomict anorthositic breccias rarely observed at both landing sites and discussed by WOOD *et al.* (1971) may perhaps belong to this type.

In the case of small impacts (2), shock compression will predominantly affect the regolith which, as a porous medium, reacts in a quite different way than nonporous rocks such as most lunar basalts. According to known Hugoniot data, distinctly more irreversible heat is produced by a particular shock pressure in porous materials than in nonporous media (see e.g. AHRENS and GREGSON, 1964). Consequently, in the loose regolith thermal effects will predominate over deformational shock effects.

Observations on shocked Coconino sandstone, Meteor Crater (KIEFFER, 1970), and results of recovery shock experiments (SHORT, 1968) provide some informations about progressive shock metamorphism of porous material which may be applied to the regolith. An impact into the regolith produces zones of decreasing pressure and temperature. Upon excavation the individual zones yield various mixtures of melt and solid fragments which, by quenching, consolidate as breccias. The following types of shocked regolith, produced by "small" impacts, listed with decreasing shock temperature are to be expected: (2a) highly vesiculated glass penetrating and bonding less shocked soil material; (2b) soil bonded by a vesiculated glassy matrix, formed in situ by local melting along grain boundaries and by softening or welding preexisting glass particles; (2c) soil bonded by a dense fine glass matrix formed by small scale melting along the walls of collapsed pores and by softening and welding preexisting glass particles; and (2d) soil compacted by shock compression to a dense but friable aggregate without melting along pore walls. It is to be expected that mineral fragments in breccias of types (2b) and (2c) will display only minor shock effects, such as planar deformation structures. Diaplectic glass will be subordinate or missing.

The preliminary study of more than 100 breccia fragments, mainly selected from soil samples, has shown that it should be possible to arrange them in the sequence (2a)–(2d) by a very careful microscopic investigation. Part of the particles called glassy agglomerates may belong to type (2a) of the sequence. They should differ from agglomerates formed by melt splashes on the soil surface by their content of shocked mineral and rock fragments.

Another type of breccia (2e) produced by impacts affecting only the regolith may be formed at the beginning of the excavation by lateral flow of weakly shocked material mixed with hot gases from vaporized rocks. Breccias characterized by higher porosity, the preservation of delicate, fragile and vesiculated glass particles, accretionary lapilli and a strikingly low content of shocked mineral fragments, may be formed in this way as it was suggested by MCKAY *et al.* (1970) and WATERS *et al.* (1971).