EJECTA FORMATIONS AND PRE-IMPACT STRATIGRAPHY OF LUNAR AND TERRESTRIAL CRATERS: POSSIBLE IMPLICATIONS FOR THE ANCIENT LUNAR CRUST

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Based on geologic-petrologic data from terrestrial and experimental impact craters and their ejecta formations and on petrographic and chemical data of regolith particles of the Apollo 14, 15, and 16 sites we have checked the relations between ejecta deposits and pre-impact stratigraphy for the crucial cratering events of these sites (Cone, North and South Ray craters) and tentatively also for the Imbrium event.

The regolith contains a wide range of non-mare particle types which reveal a complex history reflecting multiple processes of shock-induced melting, comminution, brecciation, shock lithification and post-impact thermal annealing. Using the information from hand specimens (1, 2) we have established the following genetic classification for o.5 - 2 mm particles: I. Impact prodused derivates of the local regolith: a) glassy agglutinates (class 1), b) irregular fragments and regular bodies of glass (class 2), regolith breccias (class 3). II. Monomict, cataclastic breccias of mainly anorthositic composition (class 4). III. Polymict metabreccias with holocrystalline matrix (class 5). IV. Crystallized impact melts with xenolithic clasts: a) devitrified or undevitrified glass fragments (class 2), b) semicrystalline and holocrystalline impactites (class 6). V. Igneous rock fragments (class 7). VI. Mineral fragments (class 8).

Results of petrographic modal analysis and microprobe bulk analysis of these particle types from Apollo 16 soils are given in Figs. 1 and 2 which contain also a number of previously published, comparative data from the Apollo 14 and 15 and Luna 2o sites. Modal analyses regarding the proportion of the two main types of metamorphic lithic fragments from the Apollo 14 soils (class 5 = dark metabreccias of (3) and class 6 = light metabreccias of (3))are reviewed in Fig. 4.

Apollo 16 soil particles show a rather uniform and distinct chemical composition (Fig. 1) which fits into a differentiation series called anorthositic-noritic-troctolitic (ANT). The main characteristics of the modal composition of soils are the high concentration of class 5 and 4 particles at the rim of North Ray crater, South Ray influenced composition at station 8 and lack of difference between Cayley derived and Descartes mountains-derived material. The chemical composition of Apollo 14 lithic particles differs distinctly from the Apollo 16 suite as well as from Luna 2o and Apollo 15 highland material by smaller Al- and Ca-, and higher Fe-abundances (Fig. 1). Petrographically they are less feldspathic. Only particles of class 5 and 6 are predominant (3, 4). The few Apollo 15 highland rocks sampled are members of the ANT-suite again. Petrographically, they are closely related to some rock types of Apollo 16 (2) and distinctly different from the Apollo 14 metabreccias (Fig. 1). According to (5) there are strong similarities between Luna 2o and Apollo 16 lithic fragments (Fig. 1).

Figs. 3 and 4 show model calculations for the radial distribution of North and South Ray and Cone (Fig. 4) crater ejecta. Thicknesses are calculated after (6) and (7)(solid and broken curves resp.). Dotted and broken-dotted lines indicate a linear subdivision of the ejecta thickness (percentagewise) into layers originating from different pre-impact depths (calculated after (7)). On the basis of three models - suevite and Bunte Breccia at Ries crater, Coconino sandstone and Kaibab limestone at Arizona crater and experimental craters in sand (7) - it seems highly probable that ejecta at station 11 originate from the upper 7o m of the Cayley basement assuming a regolith thickness of 1o m Similarly Cone crater has probably not sampled deeper than ~2o m of the Fra Mauro basement assuming a 8.5 m thick regolith (Fig. 4). The large boulders near the crater rims and in the boulder fields of both landing sites are considered to originate from the upper few meters of the basement rather than from deeper levels as commonly assumed. Evidence for this comes from terrestrial ejecta formations (Ries, Arizona) and experimental craters (7).

The fact that the young craters at the Apollo 14 and 16 sites have ejected material from much shallower layers than assumed so far questions the validity of the statigraphy of the Fra Mauro and Cayley formations proposed by several authors (1, 2, 8, 9). We conclude therefore that the original Fra Mauro formation ejected from the Imbrium basin was hardly sampled by Cone crater. Assuming steady state for 1 km craters on the original Fra Mauro formation we have to expect at least 15-2o m of reworked Fra Mauro (1) plus 8,5 m of regolith (sampling depth of Cone crater~3o m). Hence, the observed complexity of breccia textures may be, in part due to later reworking. Thermal metamorphism might have taken place in situ but at a deeper level and in a thicker Fra Mauro formation or otherwise in the pre-Imbrium terrane (1o). If we admit any analogy to terrestrial and experimental craters we should assume that the original Fra Mauro formation was ejected from an intermediate to upper level of the pre-Imbrium crust which is chemically characterized by a gabbroic-noritic composition whereas the rocks of Apollo 16 and Luna 2o represent the upper, early feldspathic cumulates of the lunar crust. The Apollo 15 highland suite probably belongs to the same crustal level representing the rim area of either Imbrium or Serenitatis predominantly composed of huge displaced crustal blocks rather than of ejecta thrown out ballistically from deeper levels. The constituents of the Cayley formation may be of rather local origin (11) derived from monomict bedrock breccias and impact melts of large impact craters. It seems improbable that the quite megascopic features of the Cayley breccias be produced by global high velocity ejecta travelling near the escape velocity of the moon (12). In such a case one should expect more finely crushed material.

References (1) H.G.Wilshire and E.D.Jackson, Geol.Survey Prof.Pap.785(1972).(2)H.G.Wilshire,D.E.Stuart-Alexander and E.D. Jackson,J.G.R.78,2379(1973).(3)M.H.Carr and C.E.Meyer 1,1o15 Geochim.Cosm.Acta,Suppl.3,(1972).(4)W.v.Engelhardt,J.Arndt,D.Stöffler and H.Schneider,Geochim.Cosm.Acta,Suppl.3,1,753(1972).(5)M.Prinz, E.Dowty,K.Keil and T.E.Bunch,Geochim.Cosm.Acta 37,979(1973).(6) T.R.McGetchin, M.Settle and J.W.Head,Earth.Planet.Sci.Lett.2o,226 (1973).(7)D.Stöffler,D.E.Gault,J.A.Wedekind,andG.Polkowski,in preparation(1974).(8)AFGIT Science 179,62(1973).(9)G.J.Taylor,M.J. Drake,M.E.Hallam,U.B.Marvin,and J.A.Wood,Geochim.Cosm.Acta.Suppl. 4,1,553(1973).(1o)M.R.Dence and A.G.Plant,Geochim.Cosm.Acta.Suppl. 3,1,379(1972).(11)V.R.Oberbeck,F.Hörz,R.H.Morrison,and W.L.Quaide, NASA TMX-62,3o2(1973).(12)E.C.T.Chao,L.A.Soderblom,J.M.Boyce,D.E. Wilhelms,and C.A.Hodges,Lunar Science IV,127,(1972).

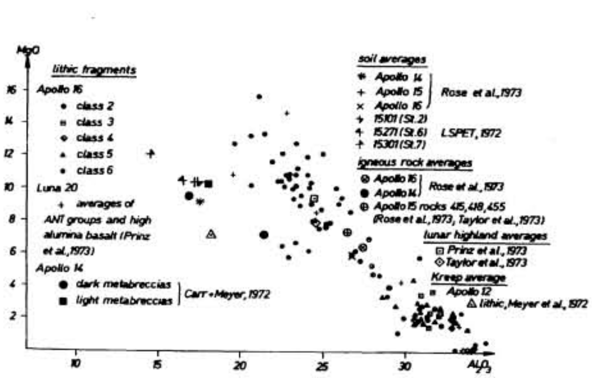

Fig. 1

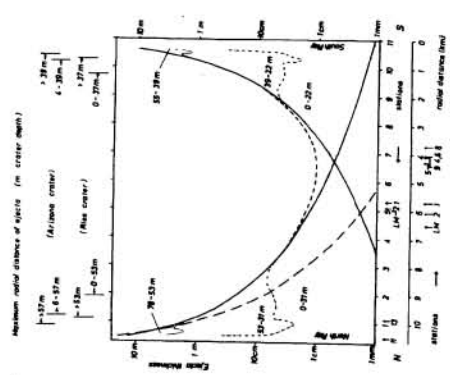

Fig. 3

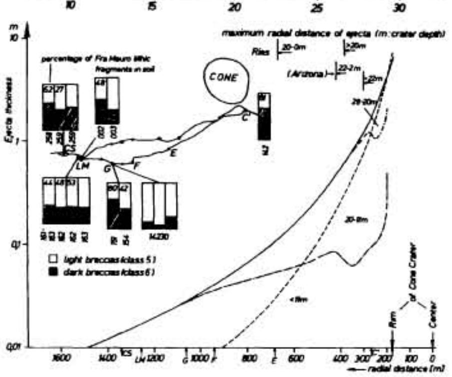

Fig. 4 modal data partly after (3, 13, 15)

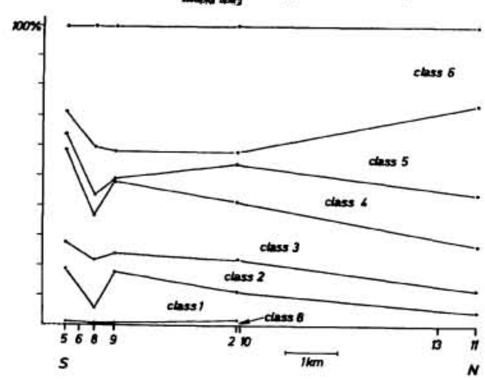

Fig. 2