THE NATURE AND ORIGIN OF BOULDER 1, STATION 2, APOLLO 17

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Abstract. The Boulder 1 breccias are similar in composition to other Taurus-Littrow massif samples and therefore probably derived from the same source, undoubtedly the Serenitatis basin. However, they are substantially different in texture from other Apollo 17 massif rocks, indeed are very nearly unique among the rocks returned by all Apollo missions. The boulder is set apart by its content of dark, rounded inclusions or bombs, up to several tens of centimeters in dimension, consisting largely of very fine, angular, mineral debris, welded together by a lesser amount of extremely fine-grained material that appears to be devitrified glass.

To account for these uncommon structures, a phase of the basinforming impact event is sought that would produce relatively small amounts of debris and deposit them on or near the basin rim. It is suggested that the components of the boulder might represent very early, high angle ejecta from the Serenitatis event, and that the dark breccia inclusions are accretional structures formed from a cloud of hot mineral debris, melt droplets, and vapor that was ejected at high angles from the impact point soon after penetration of the Serenitatis meteoroid. This small amount of early high-angle ejecta would have remained in ballistic trajectories while the main phase of crater excavation deposited much larger amounts of deeper-derived debris and melt-rock on the rim of the basin, after which the early ejecta was deposited as a cooler ($\sim$450 °C) stratum on top. The matrix of this breccia gained its modest degree of coherency by thermal sintering as the capping stratum cooled. The boulder is a fragment of this layer, broken out and rolled to the foot of the South Massif $\leqslant$55 m.y. ago.

1. Introduction

The series of articles in this issue of *The Moon* completes the Consortium Indomitabile's collaborative study of four samples from a single boulder that lies at the foot of the North Massif, in the Valley of Taurus-Littrow on Earth's Moon. The samples were studied intensively by the Consortium. Some things can now be said with certainty, or at an extremely high level of confidence, about the boulder. In other areas our study was very enlightening, but did not lead to complete and unambiguous understanding. Predictably, this category includes the fundamental question of the origin of the boulder. Like many questions of lunar science, this is subject to individual interpretation. Below I present my own reading of the most probable origin of the boulder. I have made no attempt to incorporate or synthesize the interpretations of other Consortium members; the reader is advised to consult the other Consortium papers in this volume for alternative interpretations, and to keep in mind the real possibility that none of us is right.

I have divided this interpretive paper into two sections: the first contains conclusions we can draw confidently and unambiguously; the second deals speculatively with those larger questions that lie beyond the scope of the first section.

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2. Facts and Near-Facts

(1) The substance of Boulder 1, Station 2 lay buried deeply enough (several meters or more) to be shielded from cosmic radiation until ~55 m.y. ago. At about that time one or more events occurred that placed the boulder on the lunar surface, exposed to cosmic radiation (Leich *et al.*, 1975).

The boulder now lies at the break in slope at the foot of South Massif. Many other boulders lie along this topographic inflection bounding both massifs; it is clear from actual boulder tracks as well as general considerations that most of the boulders must have rolled there from original positions higher up on the massifs. Though no boulder track can be assigned to Boulder 1, it is very probable that this object also rolled down from some higher position on the South Massif. According to the cosmic ray exposure ages this must have happened within the last 55 m.y. Presumably one or more small cratering impacts on the South Massif exhumed the boulder and rolled it down, though a tectonic disturbance of regional scale is a less likely possibility.

(2) The boulder is composed of a polymict breccia. The low concentration of solar wind noble gases (Leich *et al.*, 1975) in the boulder samples and the absence of glassy spherules and shards prove this material is not a soil breccia: that is, the substance of the boulder did not have a previous existence as unconsolidated regolith material. Instead, the components of the breccia were disaggregated, exhumed, deposited, and reconsolidated in a single event, presumably a large cratering event. The boulder breccia is most easily understood as a remnant of a consolidated crater-ejecta blanket.

The boulder is conspicuously stratified (see Marvin, 1976), but the striking similarity in properties of samples taken from several different strata (Ryder *et al.*, 1975; Blanchard *et al.*, 1975; Morgan *et al.*, 1975) make it clear that these layers do not represent discrete epochs of deposition, separated in time. One depositional event produced the sequence of beds or strata from which the boulder was derived. Magnetic studies of the boulder samples indicate that the temperature of the ejecta blanket was ~450 °C after deposition (Banerjee and Swits, 1975).

(3) The major element composition of the boulder is quite similar to that of the noritic breccias and melt-rocks that comprise the bulk of the other highland samples collected at the Apollo 17 site (Table I). Only the levels of TiO_2 differ significantly. (This is a reversal from the impression we gained early in the life of the Consortium. At that time it appeared that Boulder 1, Station 2 was conspicuously different from other highland samples, because many of our early bulk analyses were of 72275 samples that contained large amounts of one particular clast-type, pigeonite basalt. Further studies have shown that these samples are not representative of the boulder in general.)

On the other hand, this characteristic Apollo 17 highlands composition is rather different from almost all other published lunar highlands compositions. Figure 1 is a plot of three important descriptive parameters for highlands rocks: KREEP content, normative plagioclase content, and the degree of silica saturation of the rock (expressed in terms of normative mineralogy). Eight hundred and fifty-three analyses of lunar

TABLE I

Compositions of Boulder 1, Station 2 and other similar lunar materials

	Representative boulder breccias			Other Apollo 17 noritic highland samples				Luna 20 lithic fragments		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
SiO_2	48.0	45.0	45.6	45.76	45.82	46.13	44.65	46.1	47.0	45.3
TiO_2	0.8	0.9	0.8	1.54	1.47	1.54	1.24	0.86	0.89	0.80
Al_2O_3	17.9	20.7	20.9	19.23	18.01	18.01	16.47	19.7	20.6	19.3
FeO	9.9	8.3	8.4	8.70	8.94	9.11	9.11	7.3	7.4	8.7
MnO	0.12	0.13	0.12	0.11	0.11	0.13	0.11	0.13	0.12	0.16
MgO	11.0	11.3	10.1	11.63	12.41	12.63	16.33	11.3	10.8	10.6
CaO	11.0	12.0	12.3	11.72	11.06	11.03	9.93	12.1	12.9	12.3
Na_2O	0.40	0.58	0.50	0.52	0.57	0.53	0.48	0.42	0.45	0.44
K_2O	0.22	0.21	0.25	0.23	0.27	0.30	0.20	0.23	0.17	0.24
P_2O_5	–	–	–	0.27	0.29	0.28	0.19	0.17	0.23	0.13
S	–	–	–	0.08	0.08	0.08	0.07	–	–	–
Cr_2O_3	0.25	0.23	0.22	0.20	0.19	0.20	0.19	0.24	0.19	0.20
Total	99.59	99.37	99.25	99.71	98.95	99.68	98.73	98.55	100.75	98.27

Key to Table

(1) 72275,57; LFBx. Blanchard *et al.* (1974).
(2) 72255,79; GCBx. *Ibid.*
(3) 72215,92; GCBx. *Ibid.*
(4) 72435,1 (LSPET, 1973); 'blue-gray breccia' from Boulder 3, Station 2; recrystallized polymict breccia.
(5) 76315,2 (*Ibid.*); 'blue-gray breccia' from Boulder 2, Station 6; melt-rock.
(6) 77135,2 (*Ibid.*); 'green-gray breccia' from the Station 7 boulder; melt-rock.
(7) 76055,5 (*Ibid.*); 'green-gray breccia' from Station 6; recrystallized polymict breccia.
(8) High-alumina basalt fragment 6, Section 10, from the Luna 20 soil sample. Conrad *et al.* (1973).
(9) High-alumina basalt fragment 40, Section 17, from the Luna 20 soil sample. *Ibid.*
(10) High-alumina basalt fragment 1, Section 9, from the Luna 20 soil sample. *Ibid.*

rocks and lithic fragments in a data file maintained by the writer (Wood, 1975) were computer processed, and all that were not obviously mare basalts, and whose properties allow them to fit in the box shown, were entered as 'pins'. The most representative boulder breccia analyses are shown as black-headed pins. The contents of a volume surrounding the left-most five black pinheads was assessed in detail: of the 12 other pinheads in this volume, all but three are Apollo 17 samples. The three exceptions are, interestingly, lithic fragments from the Luna 20 soil sample (Table I), analyzed by the Albuquerque group using the defocussed-beam-analysis (DBA) technique. These are texturally dissimilar to the boulder breccias, however (K. Keil, personal communication). The first two Luna 20 fragments reported in Table I are melt-rocks with basaltic textures; the third is a moderately recrystallized breccia. It appears that these Luna 20 samples are more closely related to other Apollo 17 massif samples than to our boulder.

The similarity of bulk compositions and the fact that this particular composition is not widespread on the Moon strongly suggest that all the Apollo 17 massif samples, including our boulder, had a common source. The main difference between the boulder and other massif samples is textural (Ryder *et al.*, 1975): the boulder is the least thermally processed of these samples, and must have been deposited at the lowest temperature. In addition, the boulder has a different component of meteoritic trace elements than the other massif samples (see Morgan *et al.*, 1975). (Curiously, some of the portions of 73215, a detached breccia sample from Station 3 that is texturally and

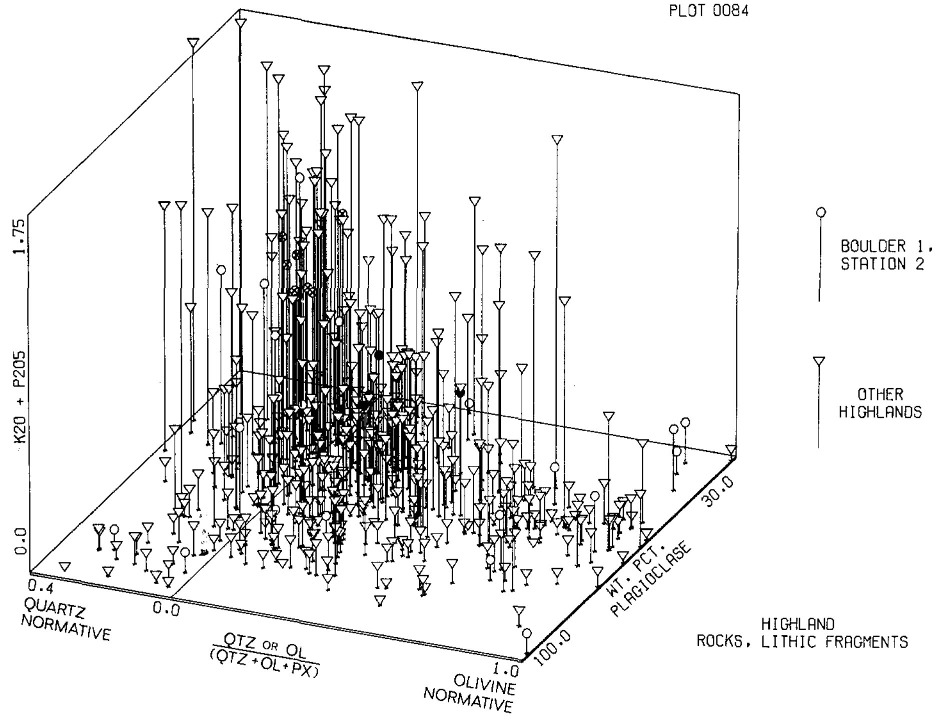

Fig. 1. A plot of three important compositional parameters for 500 highland rock and lithic fragment analyses in the author's data file (Wood, 1975). The line across the base of the diagram divides quartz-normative (left) from olivine-normative (right) samples. Most entries are defocussed-beam microprobe analyses of clasts and soil fragments, not whole-rock analyses. Black pinheads represent Boulder 1 breccias; pinheads with crosses are pigeonite basalts from 72275.

compositionally very similar to our boulder (James, 1975), contain the Group 2 meteoritic trace elements characteristic of other massif samples; other portions have the Group 3 meteoritic component common to our boulder samples (Morgan *et al.*, 1975).

No importance can be attached to the boulder composition in terms of magma evolution in the Moon, of course, since the rock is a polymict breccia.

(4) The ages of samples of the boulder generally reflect the $\sim 4.0 \times 10^9$ yr event ('cataclysm', or else a rapid tapering-off of an earlier epoch of very intense bombardment) that profoundly affected almost all of the lunar highland samples studied to date (see Leich *et al.*, 1975; Compston *et al.*, 1975). Some clasts in the boulder retain memories of events prior to the 'cataclysm'.

(5) The boulder breccia is characterized by the presence of dark (black to gray) rounded inclusions, ranging in size from tens of microns to tens of centimeters, that are composed largely of finely-comminuted, sharply angular mineral clasts. These structures dominate the character of the boulder samples, and probably comprise the bulk of the boulder. Sometimes this material surrounds lithic clasts, forming rinds; in places lithic and dark breccia material have been mechanically sheared and mingled; often large dark breccia clasts enclose earlier generations of smaller ones. This material and type of structure is discussed extensively in Stoeser *et al.* (1974a, b); and Ryder *et al.* (1975). It is referred to variously as dark matrix breccia (DMB), black competent breccia (BCBx) and gray competent breccia (GCBx).

Dark breccia inclusions having these properties are very nearly unique to the boulder (and to 73215). Similar structures are present in Apollo 14 breccia 14082, but I am not aware of any other lunar sample large enough to enclose these dark breccia inclusions that has them. It must be concluded that the dark breccia inclusions are created by some process that occurs relatively rarely on the Moon, or in some phase of the cratering process that is very restricted in time and space.

The dark breccia inclusions are dark because they contain extremely fine-grained ($\sim 0.1\ \mu$), evenly-disseminated metallic iron (Figure 2; Banerjee and Swits, 1975). This, again, is a property that is uncommon in highland clastic rocks, which are rarely black, as some of the boulder dark breccias are.

It is not easy to postulate a mechanism that would achieve the extremely small-scale, uniform dissemination of metal that is observed in BCBx samples from the boulder. This did not occur after the BCBx inclusions were consolidated; the effect of partial melting or solid state recrystallization in such an assemblage invariably would be to bring together and coarsen any metal grains that were present, not to further disperse them. I attach very great importance to this unusual property of a near-unique breccia type, and feel that a correct model of formation of the boulder material must account for it in a natural way.

(6) Apart from the dark breccia inclusions, the boulder breccia contains mineral and lithic clasts (few larger than about a millimeter), mostly of types that are abundantly encountered in highland rocks from all parts of the Moon. Several hitherto unreported lithic types, present as clasts, are described by Ryder *et al.* (1975).

It is difficult to account for the KREEP content of the boulder. Most of the lithic fragments present in it contain less KREEP than the boulder at large. One conspicuous exception is the pigeonite basalt rock-type, which is an abundant clastic component in 72275. This cannot be the source of boulder KREEP, however, because the pigeonite basalt contains an order of magnitude more Ge than does the boulder at large (Morgan *et al.*, 1975), but only slightly more K and P (Blanchard *et al.*, 1975). No possible mixture of pigeonite basalt and KREEP-poor materials could have these properties.

Another possible KREEP component is granitic rock, which is visible as clasts in many of the boulder thin sections (Ryder *et al.*, 1975); but an admixture of lunar granite (as we know it) could only bring up the K content of the boulder breccia: it could not account for the observed levels of P. We are forced to conclude that the

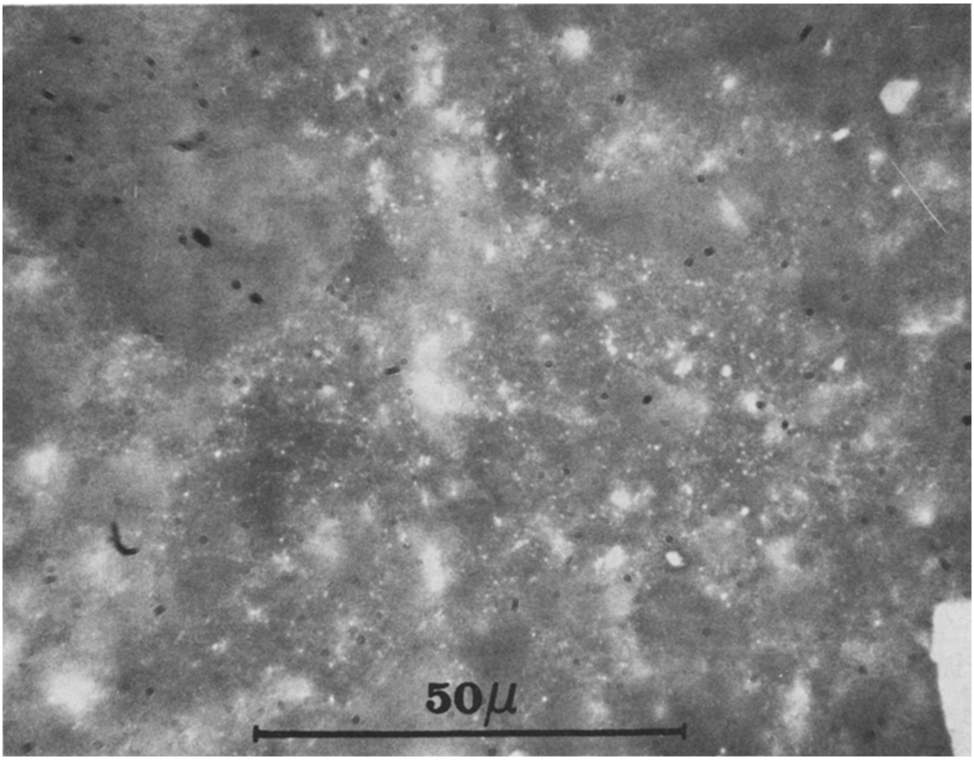

Fig. 2. High-magnification image of a portion of a BCBx clast in thin section 72275,12, showing disseminated metallic iron grains (white). In addition to relatively large (1–2 μ) grains, a cloud of very tiny ($\sim$0.1 μ) iron particles are scattered through the breccia matrix. Reflected light illumination, an oil immersion objective, and high-contrast film were used.

boulder breccia contains a KREEP-rich component other than the visible pigeonite basalt, all of which is very finely disseminated: none has survived as lithic clasts. We attempted to identify a 'cryptic' KREEP component by microprobing small areas of very-fine-grained materials between mineral clasts in various of the boulder breccia samples, but did not obtain compositions systematically different from the local bulk composition of the breccia.

3. Interpretations

(1) The mineral clasts that comprise the bulk of the dark breccia inclusions were very probably 'glued together' by melted rock, present in minor amounts; the inclusions had a brief existence as deformable blobs of mush. This would account for their generally rounded (though not spheroidal) forms. The material between angular mineral clasts in the dark breccia inclusions is generally a nondescript and uninformative, microcrystalline, polymineralic mixture of equidimensional grains. Locally, however, fine-grained igneous textures are visible between clasts. Very rarely, BCBx inclusions are seen to be vesicular (Figure III-16A and B, Stoeser *et al.*, 1974a). I interpret the

$\sim$25% of interclast material that occurs in dark breccia inclusions as glass that devitrified while the blobs or inclusions cooled.

The assembly of these blobs appears to demand special circumstances. These are not simply pieces of a breccia that was assembled by gravitational sedimentation on a surface, or by internal deformation and failure of a stressed rock system. Neither of these origins would account for the free forms that many of the inclusions display, or their tendency to surround lithic clasts as rinds, or to enclose other dark breccia inclusions. An accretionary process must be invoked to explain these properties: mineral and meteoritic debris were finely comminuted, melted, and perhaps vaporized in a high-energy environment; dispersed (with occasional surviving lithic fragments); and reassembled in temporarily plastic blobs as the latter were either suspended in space or rolling and tumbling over a surface. James (1975) has attached a very similar interpretation to 73215 and the dark breccias from Boulder 1.

Since impact cratering is overwhelmingly the dominant geologic process on the lunar surface, it is highly probable that the particular environment called for constitutes one element of the cratering process. I interpret the compositional uniformity of the boulder and other Apollo 17 massif samples to mean that all were deposited by the same major impact, and since this composition is dominant on the rim of the Serenitatis basin, where great thicknesses of Serenitatis ejecta must have been deposited, all these samples are very likely to represent Serenitatis basin ejecta. *Therefore, the peculiar structures of the boulder were created during some phase of the cratering impact that created the Serenitatis basin.* (Differences in compositions of the meteoritic components are addressed below.)

(2) *The particular environment or process that created the boulder inclusions deposited them relatively close to the crater that was being or had been formed.* This follows from (a) the fact that dark breccia inclusions are highly concentrated in the boulder; if they had been projected a great distance from the crater that formed them, they would have been widely dispersed and greatly diluted with surface material local to the regions where they impacted (and formed secondary craters); and (b) identification of the boulder as a form of Serenitatis ejecta ((1), above).

(3) Our conventional understanding of crater excavation and deposition (e.g., Oberbeck, 1975) is that the small amount of target material first ejected by the impact derives from the shallowest position in the target, is ejected at the highest velocities and angles, and travels farthest. At progressively later stages of the excavation event, material is excavated from deeper, in greater amounts, less energetically, and is deposited closer to the crater rim (Figure 3). The boulder material does not appear to fit naturally into this scheme. The need for a high-energy environment of formation, the presence of very finely dispersed meteoritic material, and the scarcity of breccias with textures like that of the boulder among lunar highland samples appear to argue that the boulder material was created in small amounts at an early stage of cratering; but deposition near the Serenitatis basin rim indicates a late stage.

There may be a way of rationalizing this discrepancy. Two fundamentally different stages of impact cratering are recognized. The first is termed by Gault *et al.* (1968) the compression stage; during this time the meteoritic projectile is engaging and compressing the target. Some material is ejected; the behavior of the ejected material is essentially hydrodynamic. The second or excavation stage is dominated by the elastic behavior of solid materials; in this period target rock compressed by the impact relaxes, and in the process large amounts of it are cast out of the crater.

The pattern of ejection shown in Figure 3 is based on the mechanics of the excavation stage of crater formation, which are reasonably well understood. Oberbeck (1975, Figure 7), citing Shoemaker (1962), points out that for a theoretical analysis of the formation of the lunar crater Copernicus, material ejected early, at angles greater than 43°, would have travelled at velocities sufficient to escape the Moon. However, these authors stress that the behavior of very-high-angle ejecta, most of which would have been produced during the compression stage of impact, is not well understood.

The degree of uncertainty in our understanding of the physical behavior of an impact system during the compression stage is illustrated by a comparison of Shoemaker's (1963) and Bjork's (1961) treatments of the formation of the Arizona Meteor Crater. Shoemaker rigorously applies physical laws to the process, but does not attempt to model it in detail. In his conception of the compression stage of impact, the cavity behind the penetrating meteorite grows continuously in size (Figure 4). Bjork computer-models the process, entering nothing more as program input than the initial geometries and velocity of impact, and the equations of state of target and projectile. He finds that a dispersed mixture of meteorite and target material closes behind the main projectile mass as it penetrates the target (Figure 5). As this fluidized material converges at the central axis of the system, part is deflected downward following the meteorite, and part upward and out of the crater. According to Bjork's analysis, material ejected at high angles at this stage moves at ~ 5 km s^{-1}, which is one-sixth the impact velocity he assumed. Bjork's approach to the problem is probably more realistic than Shoemaker's (Kaula, 1968, p. 303).

Clearly this stage of the impact process, especially at basin scales, is not well understood. It seems likely from Bjork's analysis that during the early stages of basin formation a small amount of heavily processed debris would be ejected at high angles, but at less than the lunar escape velocity. Most of this material would remain in ballistic trajectories while the excavation stage of basin formation, and probably the tectonic adjustment of the basin into a multi-ringed structure, proceeded. The early, high-angle debris would then deposit itself on (and mix with) the hot surface material on the rims and floor of the basin.

Such an origin would account for many of the properties of the unusual components of the boulder. I propose that *the mineral and meteorite components of the dark breccia inclusions were comminuted, in part melted and perhaps vaporized, accreted, and the accretions in some cases highly deformed* (e.g. the Marble Cake and Dying Dog clasts; Stoeser *et al.*, 1974b) *in the chaotic high-energy environment adjacent to and behind the penetrating Serenitatis meteorite, during the early stages of the Serenitatis event.* Plastic blobs of accreted debris were ejected at high angles, hardened in flight, and were deposited along with much dispersed mineral debris on top of the Serenitatis rim

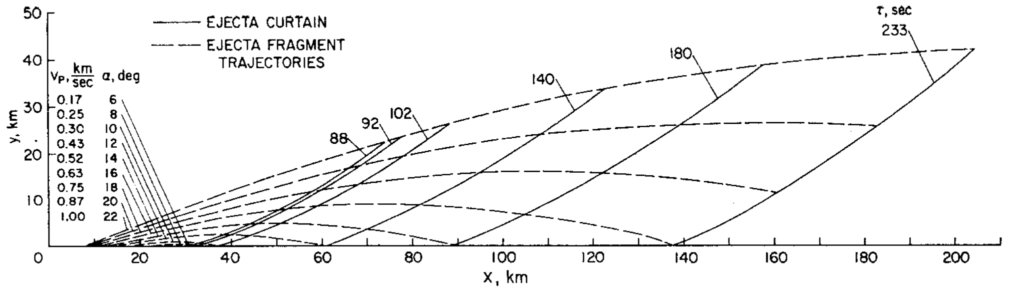

Fig. 3. Calculated trajectories and positions after several different times (τ) for material ejected at various velocities (V_p) and angles (α) from the lunar crater Copernicus (Figure from Oberbeck, 1975). Last material ejected from deepest in the crater is coarsest, has lowest velocity, but is deposited (on the basin rim) first because it has the shortest distance to travel.

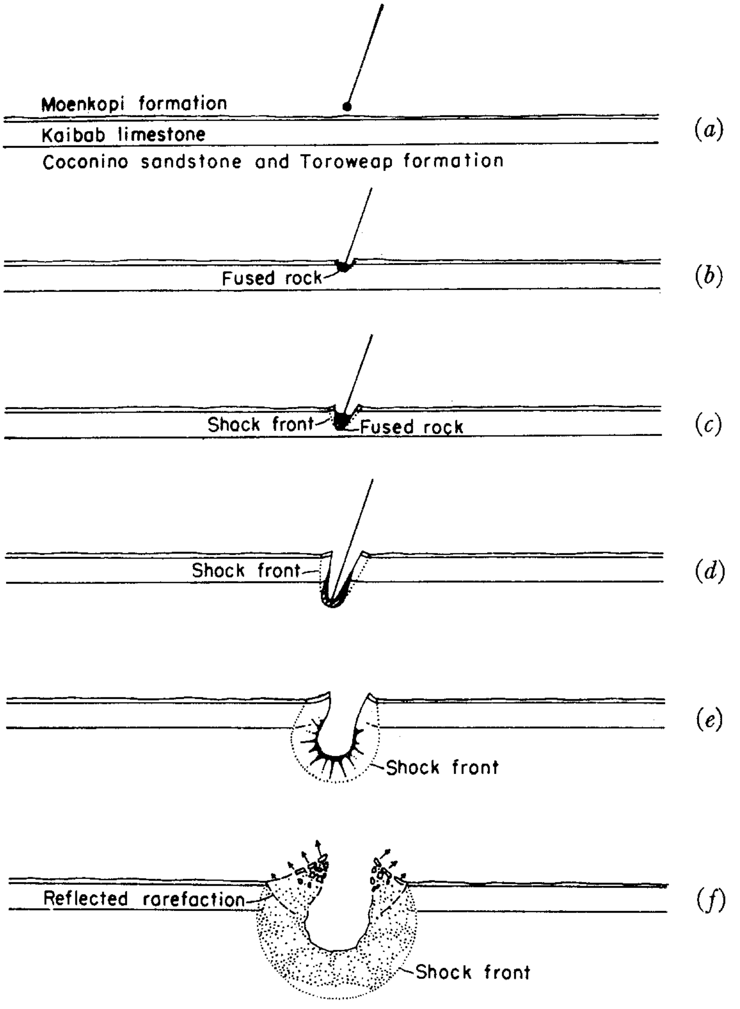

Fig. 4. Early stages of the formation of the Arizona Meteor Crater, according to the model of Shoemaker (1963). A cavity, lined with fused rock and meteoritic material, grows larger from the very beginning. Gault *et al.* (1968) would consider that the compression stage of this event ends at stage *b*, as this is the time at which a compression wave reaches the trailing edge of the meteorite. However, the compressed system does not begin relaxing and excavating significant amounts of target material until stage *e* or *f*. Figure from Shoemaker (1963), reproduced with permission of the University of Chicago Press.

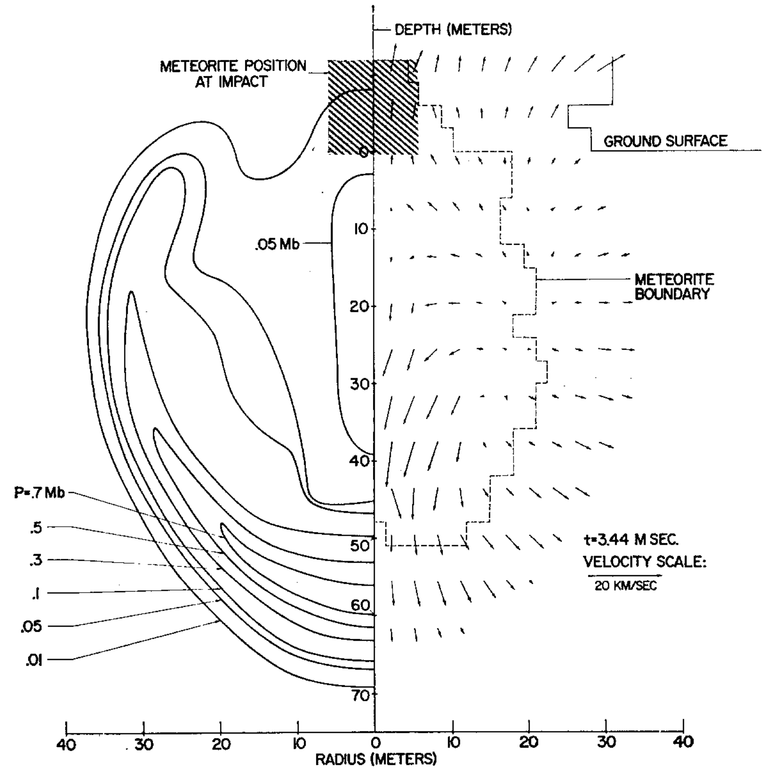

Fig. 5. Pressure and velocity fields in the Arizona Meteor Crater impact, 3.44 milliseconds after contact, according to the computer model of Bjork (1961). Arrows are vectors showing mass motion. The size and position of the meteorite at initial contact is shown as a hatched zone at the top of the figure; at the time represented by the figure, the substance of the meteorite is entirely dispersed and mingled with target rock inside the volume shown by dashed lines. Note that, above a 'stagnation point' at a depth of about 25 m, mixed rock and meteoritic material is reconverging on the central axis of the event and being channelled up and away from it. Figure from Bjork (1961).

ejecta that had been derived from deep in the basin. Presumably the blobs cooled through the Curie temperature of iron while in flight, and acquired their stable NRM component from a transient magnetic field that may have been associated with the cratering event. The material was deposited at ~450 °C, and during further slow cooling achieved the modest degree of coherence we observe in 72275. (The other three boulder samples consist entirely of glass-welded 'blob' material that was assembled at higher temperatures.) As they cooled, elements of the boulder acquired a well-aligned but less stable NRM component that reflected the lunar magnetic field at that time.

This origin would place the source-bed for the boulder at the top of the massifs, consistent with Schmitt's (1975) observation of a color-correspondence between the boulder and source-crops near the top of the South Massif. The relatively small amount of debris that would have been processed in this fashion, and the exposed position where it was deposited, accord with the scarcity of rocks similar to that of the boulder among highland samples.

If correct, this model implies that the pre-Serenitatis lunar crust was not chemically stratified to a depth of several tens of kilometers, since ejecta from very shallow and very deep in the source volume, both now present in the Taurus-Littrow massifs, are quite similar in composition.

(4) If the boulder material derives from an early, high-energy stage of basin formation, and other massif samples from a late, lower energy stage, why is the boulder less thermally processed than other massif samples (which are commonly melt-rocks and high-grade metamorphics)? Several factors would have contributed to this situation.

First, evidence from studies of terrestrial craters shows that the deepest-derived ejecta may in fact have been very energetically processed, even though its pattern of deposition indicates that it was not endowed with excessive amounts of kinetic energy. Thus suevite, the most thermally affected class of ejecta from the Ries crater, is derived from deepest in it (Chao, 1974 and other authors).

Second, it must be remembered that the intrinsic temperature of the deep lunar crust was still very high at the time of the Serenitatis impact and formation of the boulder. KREEP norite is thought to have been generated by partial melting in the deep crust some hundreds of millions of years after the origin of the Moon – perhaps even contemporaneously with the four-billion-year 'cataclysm', depending upon the interpretation placed on the Sr–Rb whole-rock isochron for Apollo 17 noritic breccias (Nyquist *et al.*, 1974). Thus the material excavated from deep in the Serenitatis basin was already quite hot, and even a relatively small amount of additional energy imparted to it by the basin-forming event may have been enough to melt volumes of it wholesale. These masses of melt-rock, together with coarse fragments of unmelted rock, comprised the bulk of the rim deposits of the Serenitatis basin. Third, the components of the boulder spent longer in their high-angle ballistic trajectories, and were probably in a more finely divided state while in flight, than was the case for the masses of deep-derived melt-rock that were deposited first on the basin rim. Thus the boulder components had a better chance to lose heat by radiation into space, before deposition, than did the melt-rock that comprises the bulk of the massifs.

(5) Why do the boulder and massif samples contain different components of meteoritic trace elements? The model offered predicts a more generous admixture of Serenitatis meteorite material in the boulder sample than in the deepest-derived basin debris that would have been deposited on the basin rim. The last-excavated material is simply target rock that was compressed and then relaxed; it is questionable whether any at all of the substance of the impacting projectile would have penetrated to this depth. (Morgan *et al.* (1975) find essentially no contamination of samples from the overturned flap of the Arizona Meteor Crater by meteoritic trace elements; but it is probably not valid to extrapolate from this to the scale of the Serenitatis event.) Even if projectile material did penetrate to the bottom of the Serenitatis basin, it is unlikely that it would have disseminated itself so evenly in the target rock, during this low-energy stage of the process, that the characteristic signature of the Serenitatis projectile would appear in every grab-sample taken from the rim deposit.

Thus the meteoritic component in the boulder should be that of the Serenitatis projectile plus whatever meteoritic trace elements were in the target rock prior to the impact; while the meteorite component in other massif samples would consist largely of this pre-impact subcomponent. A comparison of Table I of Morgan *et al.* (1975) with Table I of Higuchi and Morgan (1975) shows that the absolute amounts of meteoritic trace elements are essentially the same in the boulder and other massif samples, so the amount of siderophile elements added to the boulder samples by the Serenitatis projectile must be small. A Serenitatis meteorite component rich in Ir, such as some Group IIIA irons are (Morgan *et al.*, 1975), would serve to pervert the Group 2 character of normal Serenitatis ejecta to the Group 3 properties of the boulder samples.

This interpretation, if correct, would mean that the finely dispersed metal which imparts darkness to the Boulder 1 BCBx samples is not derived from the impacting meteorite at all, but was already present in the pre-impact crust, and was merely dispersed by the impact.

The above assumes, of course, that meteoritic trace elements were uniformly distributed vertically in the pre-impact crust, as the major elements seem to have been. If this was not the case, then the meteorite components in Boulder 1 and other massif samples can have had wholly different origins, and the finely disseminated metal in the boulder samples can have been derived from the Serenitatis projectile.

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