SHOCK EXPERIMENTS ON PARTICULATE LUNAR BASALT-A REGOLITH ANALOGUE

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INTRODUCTION

In order to evaluate the response of basaltic regoliths to meteorite impact, we have followed a methodical experimental program over the last three years by performing shock-recovery experiments on (a) a porous, particulate regolith analogue consisting of a mixture of terrestrial plagioclase and pyroxene grains (1) and, for comparison, on (b) a nonporous, crystalline basalt from Lonar Impact Crater, India(2) and on (c) a nonporous, crystalline lunar basalt, 75035 (3). The experimentally produced shock features effectively duplicated naturally created effects in basalts from Lonar Crater (2) and in lunar basalts 12054, 15684, and 79155 (3). We are reporting now on shock experiments on a powdered portion of the same lunar basalt (75035) which we used in previous crystalline rock experiments. Thus, we have a unique opportunity to examine the shock metamorphism of identical material as both a massive crystalline rock and as its porous, particulate counterpart. This complementary series of experiments should lead to a better assessment of shock metamorphism and shock lithification of basaltic planetary surfaces, consisting of either rocks or regolith. The shock effects, especially the production of impact melts, should vary significantly for these two surface conditions (4,5).

EXPERIMENTS

The experimental procedures were as follows: crystalline basalt 75035,8 was ground carefully in order to maximize the yield in the 100-150μm sieve fraction, a grain size best suited for maximum particle interaction during shock passage without losing optical resolution in the recovery products (1). The targets were prepared by packing 18-21 mg aliquots into metal sample capsules with cylindrical sample chambers measuring 5 mm in diameter and 0.5 mm in depth, resulting in effective target porosities of 36-45%. Details of the shock loading procedure were described previously (1,3); the samples were shock loaded in a CO/CO_2 gas mixture pumped down to a final pressure of $2.6\text{-}6.9\times10^{-6}$ torr. Eight experiments at pressures ranging from 66 to 388 kb have been completed; experiments at higher pressures are presently being performed.

PETROGRAPHY

Because we have observations only up to 388 kb, we cannot present a finite classification of shock effects; we prefer to differentiate at present only "weak" and "moderate" shock effects.

Weak Shock effects. Experiments at 66, 117, 133, and 200 kb created weak shock features comparable to those formed in experiments on the massive crystalline 75035 basalt. All the pore spaces are collapsed, but the particulate texture is preserved. Grain boundaries are well defined, being modified only by minor intergranular fragmentation. The samples were recovered as well-indurated discs. Feldspar grains show progressively more abundant and closer spaced fracturing with increase of pressure from 66 kb to 200 kb. Undulatory

extinction becomes progressively more pronounced and displacements are larger along microfaults in the 200 Kb shot than in the lower pressure shots. Bent twin lamellae and shock lamellae also characterize the shock deformation. Pyroxene grains also become progressively more severely fractured with increasing shock pressure. Radial concussion fractures in some grains and strong undulatory extinction attest to shock damage accompanying collapse of pore spaces.

Moderate shock effects. The basalts shocked to pressures of 242, 297, 332, and 388 kb exhibit petrographic effects in grain interiors which are comparable to those created in crystalline basalt 75035 between 200 and 400 kb; all the plagioclase grains are transformed into isotropic maskelynite and the pyroxene grains are intensely fractured. Very importantly, however, intergranular regions and corner junctions in the particulate basalt, unlike crystalline basalt at similar pressures, are sites of incipient melting. The following amounts of melt were observed: 200 kb - 1-2% melt; 242 kb - 5%; 297 kb - 6-7%; 332 kb - 10%; and 388 kb - 18%. These amounts of melt are consistent with those produced in particulate plagioclase/pyroxene mixtures shocked at 205 kb (1-2% melt), 288 kb (5%), and 381 kb (20%) (1).

The particulate texture is recognizable, in general, in the 242 to 388 kb shots although it is progressively modified by granulation of pyroxene grains, relaxation of plagioclase grain outlines, and, most significantly, by the presence of an intergranular melt which gives the sample a mosaic or jigsaw appearance.

At 332 kb the plagioclase grains remain identifiable though most of them have been transformed to maskelynite. The intergranular, colorless glass, however, shows signs of flow and therefore is 'plagioclase glass'. The colorless plagioclase glass is partially mixed with green pyroxene glass.

In the 388 kb sample intergranular glass is more abundant and consists of interflowed colorless, green, and brown schlieren. Pyroxene grain boundaries show signs of rounding by edge melting and their net grain sizes are smaller as a consequence of granulation and melting.

GLASS CHEMISTRY

The chemistry of the intergranular glass in the particulate targets displays more variation than typical Class 5 glasses (2,3) in shocked crystalline basalt as illustrated in Fig. 1. Large proportions of glass are nearly isochemical with plagioclase or pyroxene compositions or are varying mixtures of predominantly plagioclase plus pyroxene. In contrast, the brown glass (Class 5) from the nonporous crystalline basalt is typically a whole rock melt consisting of nearly equal parts of the three end-members plotting near the center of the ternary diagram with much fewer 'monomineralic' points. Table 1 shows the actual compositions of the glass spots, demonstrating, again, a general correlation between color and composition. The extent of mixing can be traced best with the TiO_2, Al_2O_3, and MgO concentrations. These findings attest to highly focused stress concentrations in particulates which favor melt formation along grain boundaries (1,4,5); because such areas are highly localized, wholesale homogenization to form "whole rock" melts is not accomplished at these relatively modest pressures.

SHOCK EXPERIMENTS

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CONCLUSIONS

This study has shown that shock-lithification is effective in a porous particulate aggregate shocked up to 400 kb. Below 200 kb the sample is indurated by collapse of pore spaces and general compaction. Between 200 and 400 kb intergranular melting accompanies collapse of pore space and forms an even more cohesive, compressed sample, consistent with other studies (1,4,5). In contrast we have found that pressures exceeding 800 kbar are required to mix pyroxene and feldspar glass in nonporous, crystalline basalts, attesting to the significant differences in the shock behavior of porous, particulate materials versus their nonporous, crystalline counterparts.

Table 1. Electron microprobe analyses of shocked granulated basalt, 75035,8

	1	2	3	4
SiO_2	47.67	48.96	49.49	45.97
TiO_2	0.09	1.16	1.86	3.29
Al_2O_3	32.18	1.45	2.26	12.79
FeO	0.85	18.97	19.12	15.21
MgO	0.35	13.18	12.62	8.37
CaO	17.19	14.07	14.37	13.47
Total	98.33	97.79	99.72	99.10

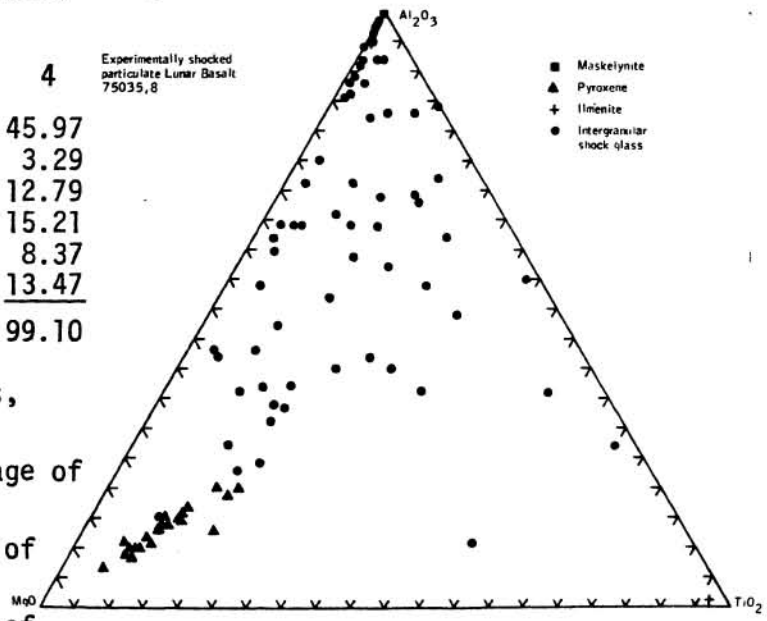
[1] Colorless plagioclase-glass, average of 10 spots.

[2] Green pyroxene-glass, average of 3 spots.

[3] Pyroxene crystals, average of 7 grains.

[4] Brown mixed glass, average of 8 spots.

Figure 1.



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