Reprinted from

Geochimica et Cosmochimica Acta, 1967, Vol. 31, pp. 1701 to 1704. Pergamon Press Ltd. Printed in Northern Ireland

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Impact glass in the Cachari eucrite

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(*Received* 8 *May* 1967; *accepted in revised form* 12 *June* 1967)

PERGAMON PRESS
OXFORD NEW YORK LONDON PARIS

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Abstract—The black, glassy parts in the Cachari eucrite have been studied by optical microscopy, electron microprobe, and X-ray diffraction techniques. It is suggested that the glass formed by localized shock pressure caused by preatmospheric, hyper-velocity impact.

INTRODUCTION

THE CACHARI stone was found in 1921 in Argentina, and subsequently described by DUCLOUX (1921). LACROIX (1926) and DUCLOUX (1928) published more detailed descriptions of the meteorite and in particular remarked on the peculiar dark glassy veins in this stone. Both authors agreed that the veins were formed before the formation of the glassy crust; they suggest fusion of the meteorite in cracks due to some process which occurred before the entrance into the atmosphere and possibly on the meteorite parent body. DUCLOUX (1928) considered some kind of orogenic activity on the meteorite parent body more likely than a collision in space.

The specimen used for this study belongs to the Museum d'Histoire Naturelle, Paris, and has the number 1516.

PETROGRAPHY

The Cachari stone is a rather typical, brecciated eucrite consisting of orthopyroxene ($Fe_{59}Ca_2Mg_{39}$) and clinopyroxene ($Fe_{27}Ca_{42}Mg_{31}$), plagioclase (An_{88}), minor amounts of chromite (with 4·6% Ti), ilmenite (0·7% Mn), and troilite (FeS).* The general petrography of this type of meteorite has been described by DUKE (1963) and DUKE and SILVER (1967). The only unusual structural feature is the presence of large black glassy masses and/or thin veins of the same material. The plagioclase grains commonly show signs of reheating or partial melting, but they are mostly well crystallized with twin lamellae which are often bent. It is also noteworthy that the pyroxene grains in many cases show bent and displaced cleavage planes, obviously due to mechanical influence. In close proximity of the veins, some pyroxene is granulated and the plagioclase is partly altered to maskelynite.

CHEMISTRY AND MINERALOGY OF BLACK GLASS

Figure 1 shows a cut through a 6 mm wide glassy part with a conspicuous bubble in the center. The glass is entirely within the meteorite and does not show any apparent connection to the crust. The adjoining thinner veins which are cryptocrystalline die out in the main mass of the meteorite. In thin section, Fig. 2, the large

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* Mineral compositions were determined by electron probe analysis.

glass masses are clear, greenish-yellow in the center and contain a few unaltered crystals of pyroxene, chromite and ilmenite which, according to microprobe analyses, have the same composition as in the main mass of the meteorite. The edges of the large glass mass are cryptocrystalline with the crystallites arranged in a pattern at right angles to the edges. Thus there is no fluidal structure even along the edges. Figure 3 shows a relatively narrow vein which is intersected by the fusion crust. The thick part of the vein, where intersected by the crust, is clear, whereas the narrower part is turbid. Probe analyses show that the clear glass and the turbid part have the same bulk composition which, however, differs somewhat from the crust (Table 1). It is clear that the crust formed after vein, as was also concluded by Lacroix (1926) and Ducloux (1928). In Table 1, the bulk analysis by Ducloux (1928) is compared to probe analyses of the glassy vein as well as the fusion crust. The resemblance is apparent and it may be concluded that both veins and crust represent the bulk of the meteorite. Apparently the crust lost some of the plagioclase component during its formation, whereas the vein glass contains more of this component and somewhat less pyroxene, since the latter component partly survived (Fig. 2). The difference in iron content between the veins and the bulk is probably due to the content of unaltered chromite and ilmenite, and the occurrence of minute droplets of troilite; iron in these phases is not included in the glass analysis.

Table 1. Chemical composition of the Cachari eucrite

	Bulk analysis*	Shock glass†		Glass crust†
		Area I	Area II	
SiO_2	48·580	48·4	49·9	48·4
Al_2O_3	14·010	14·8	14·2	12·0
FeO	19·926	17·1	16·5	19·0
MnO	0·744	0·4	0·5	0·6
CaO	8·904	11·2	12·1	10·4
MgO	6·700	6·4	5·6	7·4
K_2O	0·132	$<0·1$	$<0·1$	$<0·1$
Na_2O	0·982	0·7	0·6	0·5
	99·978	99·2	99·5	98·4
Cr_2O_3	0·065			
TiO_2	0·078			
P_2O_5	0·055			
SO_3	0·060			
Loss on ignition	0·195			
	100·431			

Refractive indices

	Shock Glass	Glass Crust
n_F	1·626	1·651
n_D	1·618	1·640
n_C	1·611	1·632

* Analysis by Ducloux (1929).

† Electron probe analysis by J. Nelen, Division of Meteorites, Smithsonian Institution.

Discussion

Nininger (1956) suggested that the diamond found in Canyon Diablo specimens from the rim of the crater was formed by high pressure shock caused by the impact

Fig. 1. Cut section of black glass in the Cachari eucrite. The glass has the same composition as the bulk of the meteorite, see Table 1. Note the bubble in the center of the glass mass. The width of the glass is 6 mm.

Fig. 2. Photomicrograph of thin section of glass, light grey area, and cryptocrystalline rims and veins, black. A few pyroxene grains showing partial melting and heavy mechanical stress are enclosed in the glass. In the main mass of the meteorite the bent twin lamellae in the plagioclase and bent, displaced cleavage planes in the pyroxene are also noteworthy. Magnification 30 ×.

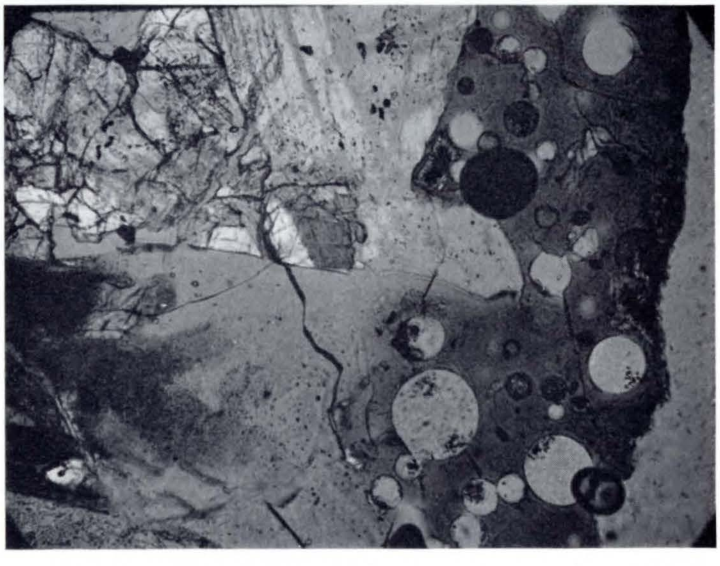

Fig. 3. Photomicrograph of glass vein intersected by the fusion crust, right porous portion. The thinner part of the vein, left, is cryptocrystalline. Note the bent twin lamellae in the plagioclase and displaced and bent cleavage planes in pyroxene. Magnification 100 ×.

Fig. 4. Photomicrograph of contact to shock glass. The plagioclase in the center is isotropic, maskelynite, grading into normal twinned plagioclase, An_{88}. The pyroxene is granulated to the left of the interface. In the adjacent glass, right, pyroxene is present as "clouds" of crystallites oriented perpendicular to the interface. Magnification 200 ×.

with the earth. This suggestion was substantiated by De Carli and Jamieson (1961), who produced diamonds from graphite by artificial shock, and by a careful study of Canyon Diablo specimens by Lipschutz and Anders (1961). These studies pointed to the possible importance of shock metamorphism in meteorites due to preatmospheric impacts, in space or on the meteorite parent body, and Fredriksson *et al.* (1962, 1963) showed that black cryptocrystalline veins in chondrites and probably the black chondrites can be ascribed to such shock metamorphism. Milton and De Carli (1963) produced maskelynite, feldspar glass, in terrestrial gabbro, as well as structural features resembling the Shergotty achondrite. Duke (1963) studied a number of eucrites and also pointed out that the brecciation as well as some glassy veins and certainly the maskelynite in Shergotty could well have formed by shock metamorphism.

It seems clear that the Cachari glass was produced by preatmospheric shock for the following reasons:

1. The glass has practically the same composition as the bulk of the meteorite, see Table 1.
2. The glass in the interior is distinct from, and older than the fusion crust.
3. Some glassy parts are completely enclosed within the main mass.
4. The presence of maskelynite, a shock transformed plagioclase, adjacent to the veins.
5. The troilite spherules in the glass resemble the spherules described by Fredriksson *et al.* (1963) from shock-produced veins in chondrites.

However, the vein glass has lower (and apparently normal) refractive index than the melt crust, Table 1, (the difference is probably due to ferric iron as well as higher total Fe in the crust) whereas shock produced glasses appear to show anomalously high refractive indices (Milton and De Carli, 1963, a.o.).* Probably the shock-produced glass in Cachari remained hot or even melted long enough after the passage of the shock waves to anneal and possibly partly devitrify; consequently it may not be much different from glass produced by ordinary melting. This would explain not only the low refractive index but also the remarkably thorough homogenization. The cryptocrystalline parts, Figs. 2 and 4, may be due to devitrification but could possibly also be the result of incomplete shock transformation if it is assumed that complete transformation occurred only in the highest pressure zones of colliding shock waves. A piece of vein glass devitrified completely into pigeonitic pyroxene and plagioclase when held at 900°C for five days whereas the semi-crystalline parts of the veins apparently contain only finegrained pyroxene. This, as well as incomplete transformation of plagioclase and granulation of pyroxene adjacent to the veins as illustrated in Fig. 4, may favor a direct shock origin also for the "devitrified" material.

Acknowledgment—A part of this work was carried out under a grant (NsG 688) from the National Aeronautics and Space Administration.

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* A small piece of vein glass was melted at 1050°C in a AgPd crucible under vacuum and quenched. The refractive index was reduced by 0·01 but microprobe analysis showed that about 2% Fe had been lost and the experiment was therefore not conclusive.

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