by conventional flat-stage petrographic microscopy in both transmitted and reflected light (for details and additional data, see ref. [14]).

2. Shock metamorphic effects

2.1. *Introduction*

The Luna 16 soil fragments display numerous features characteristic of shock metamorphism produced by meteorite impact and virtually identical to features observed in Apollo 11 and Apollo 12 material. Two chief types of shock metamorphic effects were observed: (1) unusual deformational features in individual rock and mineral fragments; (2) homogeneous and heterogeneous glassses apparently formed by shock melting. Shock-deformed rock and mineral fragments constitute only 1–2 per cent of the fragments examined, and glasses and glass-bearing aggregates produced by shock melting and mixing constitute as much as 70–80 per cent. Both percentages are comparable to those observed in Apollo 11 samples [2–7].

2.2. *Shocked rock and mineral fragments*

Shock metamorphic effects observed in rock and mineral fragments from the Luna 16 sample include deformation twinning, development of multiple parallel sets of shock lamellae, partial to complete isotropization of minerals, and selective partial melting.

A relative scale of shock deformation based on plagioclase has been established from the Apollo 11 material [2]. However, in the small number of shocked fragments observed in the Luna 16 material, pyroxene grains exhibit the greatest variety of shock-produced deformation effects. In order of apparently increasing shock pressure, these include: (1) deformation twin lamellae, probably parallel to (001) [15]; (2) multiple sets of finer parallel lamellae, apparently produced at higher shock pressures [3, 16] (fig. 1); (3) extreme mosaicism; (4) possible partial isotropization (fig. 2).

Only a few shock-deformed fragments of plagioclase were observed. Multiple planar features (shock lamellae) were observed in one fragment (311,25). Completely isotropic plagioclase (maskelynite) was identified in another fragment (figs. 3, 4). The occurrence of colorless glasses with a plagioclase-rich composition implies the existence of shock-melted plagioclase in the Luna 16 material as well (e.g., [2]).

Neither shock-produced deformation twins in ilmenite [17] or deformation structures in olivine [15] were observed in the Luna 16 material examined. The presence of shock effects in both pyroxene and plagioclase implies that analogous shock effects are present in other minerals and should be observed with more intensive study.

Only two shocked basaltic rock fragments were observed. In one specimen (fragment 315,53), fractured pyroxene is associated with isotropic plagioclase (maskelynite) in a manner similar to that observed in some shocked Apollo 11 rocks [2, 4, 6]. In the other fragment, plagioclase is only partially isotropic, but part of the fragment has fused to an orange-brown glass apparently generated by the post-stock melting of opaque phases (fig. 5). In this specimen, the formation of glass, combined with the rapid quench implied by the preservation of plagioclase, is good evidence for shock-induced melting.

2.3. *Impact-produced glasses*

A variety of glasses occurs in the Luna 16 sample, both as individual fragments and in the matrix of aggregate particles. The glasses are virtually identical to those described from Apollo 11 and Apollo 12 material and are almost certainly of impact origin. The glasses display several features characteristic of origin by shock-induced melting (for more details and additional illustrations, see ref. [14]):

(1) Diversity in color (and presumably in chemical composition) [7]. The colors of dense, homogeneous glass fragments range from colorless through light green, greenish-brown, and brown, to dark reddish-brown and brownish-black. Several free-form fragments (spherules, droplets, etc.) were observed.

(2) Brightly reflecting spherules (Ni-Fe or troilite?) commonly present in the flowed heterogeneous glass fragments or in the glassy matrices of aggregate particles.

(3) Distinctive flow lines (schlieren) in heterogeneous glasses, composed of bands of glasses of different colors and implying partial mixing of materials of different compositions (fig. 6).

(4) Intimate mixing of glass and diverse rock fragments, some of which show shock metamorphic effects (fig. 6).

(5) Incipient fusion of some mineral grains included

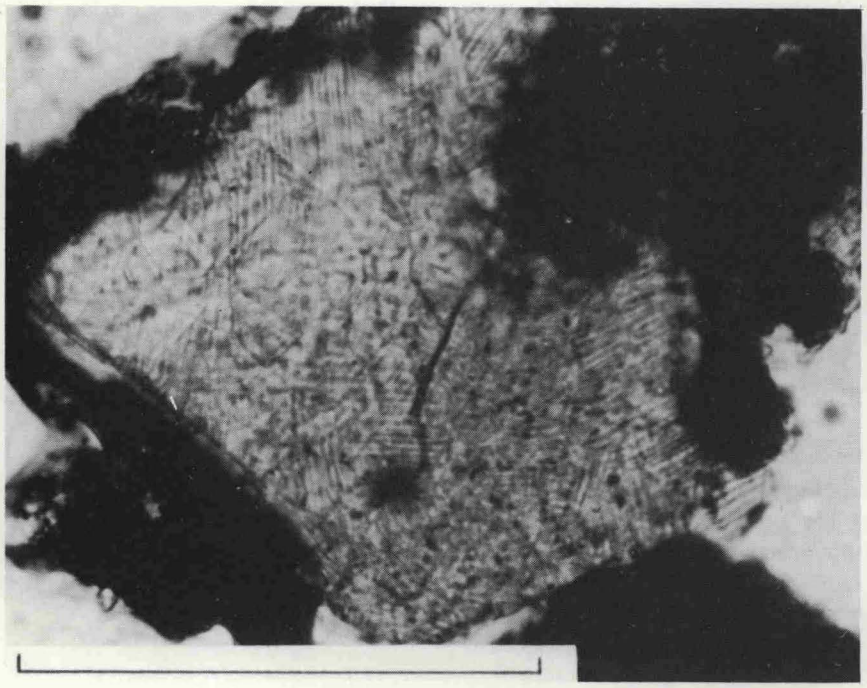

Fig. 1. Well-developed multiple sets of parallel shock lamellae in a pyroxene crystal. At least six separate sets can be distinguished. Fragment 318,512; plane polarized light; scale bar 0.1 mm.

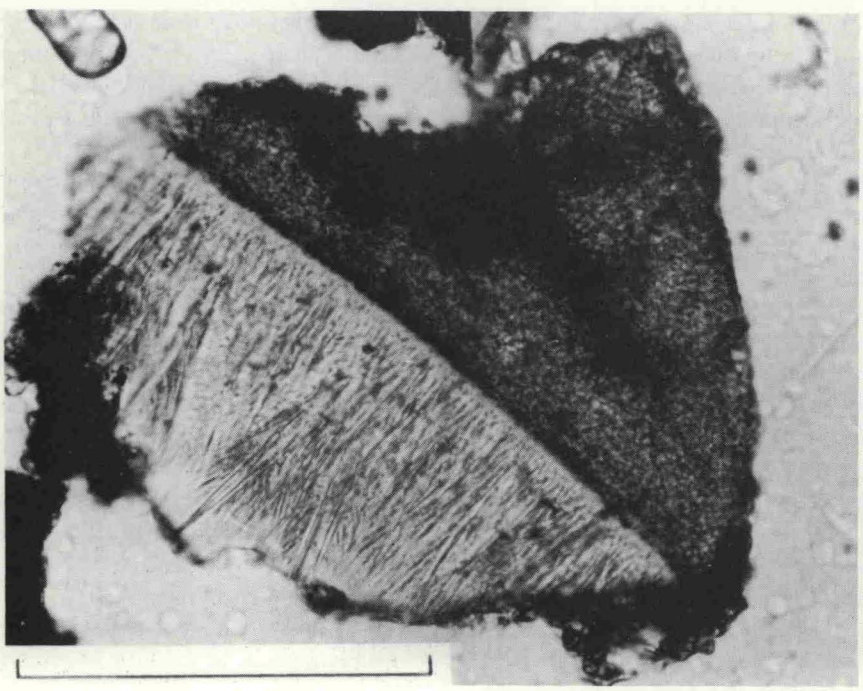

Fig. 2. Sharp contact between clear (plagioclase?) glass and a red-brown pyroxene(?) crystal which shows intense mosaic extinction and partial isotropization along dark veinlike regions. The plagioclase area, which was either maskelynite or shock-melted glass, is now partly devitrified to radiating and sheaflike plagioclase microlites. Fragment 318,362; plane polarized light; scale bar 0.1 mm.