Reports

Shock and Thermal Metamorphism of Basalt by Nuclear Explosion, Nevada Test Site

Abstract. *Olivine trachybasalt metamorphosed by nuclear explosion is classified into categories of progressive metamorphism: (i) Weak. Plagioclase is microfractured, and augite contains fine twin lamellae. (ii) Moderate. Plagioclase is converted to glass, and mafic minerals show intragranular deformation (undulatory extinction, twin lamellae, and, possibly, deformation lamellae), but rock texture is preserved. (iii) Moderately strong. Plagioclase glass shows small-scale flow, mafic minerals are fractured and show intragranular deformation, and rocks contain tension fractures. (iv) Strong. Plagioclase glass is vesicular, augite is minutely fractured, and olivine is coarsely fragmented, shows mosaic extinction, distinctive lamellar structures, and is locally recrystallized. (v) Intense. Rocks are converted to inhomogeneous basaltic glass.*

Preliminary examination of lunar surface material collected during the mission of Apollo 11 (*1*) suggests that many of the rock samples that will be returned from the moon will be mafic igneous rocks and that many of these samples may show shock metamorphism produced by meteorite impact. Unfortunately, the effects of shock on mafic rocks are not well known because terrestrial impact craters are rare in terrains that contain such rocks. To provide a basis for comparison with the lunar samples, detailed studies are being made of the shock and thermal metamorphism of olivine trachybasalt by nuclear explosion (*2*) at the Nevada Test Site (NTS). A suite of representative hand specimens and thin sections of the unmetamorphosed and metamorphosed basalt is described here.

The nuclear device was detonated in dense, blue-gray, nonvesicular trachybasalt. Most of the ejected fragments that form the crater rim and that floor the depression are fractured blocks of this rock (Fig. 1). The basalt consists of approximately 50 to 65 percent plagioclase, 10 to 15 percent olivine, 5 percent augite, as much as 8 percent pigeonite (now partly inverted to orthopyroxene), 5 percent opaque minerals, 5 to 15 percent alkali feldspar, as much as 15 percent interstitial glass, a trace apatite, and as much as 2 percent calcite (*3*). The rock is porphyritic and generally contains 3 to 5 percent subhedral phenocrysts of olivine (65 to 80 percent forsterite) (*4*). Rock texture is grossly trachytic and varies from intersertal (interstices between feldspar laths filled with pale brownish glass) to intergranular (interstices filled with grains of equant olivine, pigeonite, opaque minerals, and anhedral alkali feldspar) to ophitic (interstices filled with poikilitic pigeonite and augite). Pigeonite is commonly polysynthetically twinned, and in some specimens it mantles olivine. Plagioclase laths show oscillatory, normal progressive zoning, with cores of labradorite (50 to 60 percent anorthite) and broad homogeneous rims of alkali feldspar rich in potassium (*4*). Calcite fills pores and partly replaces feldspar. Secondary alteration is generally slight.

Sparse ejected blocks show the metamorphic effects of the nuclear explosion. For purposes of discussion (*5*), these rocks are classified into five categories of metamorphism: (i) weak, (ii) moderate, (iii) moderately strong, (iv) strong, and (v) intense. The categories are based primarily on progressive effects in feldspar: (i) fracturing; (ii) partial or complete conversion to glass, with perfect preservation of rock texture; (iii) conversion to glass that shows small-scale flow and homogenization; (iv) conversion to vesicular glass; and (v) conversion of the entire rock to inhomogeneous basaltic glass. Mafic minerals also show progressive changes that are roughly correlated with those in feldspar. As metamorphism of the rock increases from weak to strong, intragranular deformation features (twinning, possible deformation lamellae, undulatory extinction) and closely spaced fractures become increasingly abundant in augite; in strongly metamorphosed rocks the deformed and granulated fragments of pyroxene are dispersed into the surrounding feldspar glass. As metamorphism increases from weak to moderately strong, undulatory extinction and faint possible deformation lamellae appear and become pronounced in olivine; in rocks that show moderately strong and strong metamorphism, olivine has mosaic extinction (*6*) and unique lamellar structures (described below).

The rocks of each category are distinctive in hand specimen (Fig. 1). Weakly metamorphosed rocks are much lighter in color than unmetamorphosed rocks; they are speckled with abundant small white patches, and fracture surfaces are powdery white. The blocks are strongly fractured and break readily into small angular fragments. (Many of these blocks disintegrated on impact with the ground after ejection from the crater.) Moderately and moderately strongly metamorphosed rocks are appreciably less dense than unmetamorphosed rocks, and they commonly have discontinuous, closely spaced, parallel tension fractures (*7*). Strongly metamorphosed rocks range from light gray, aphanitic-appearing rocks, with microscopic vesicles and numerous tension fractures, to black glasses, with abundant large vesicles and no tension fractures. Many single blocks of strongly metamorphosed rock show this entire range of textures, grading from aphanitic-appearing and finely vesicular at their margins to vitreous and coarsely vesicular at their cores. (In the field, blocks of strongly metamorphosed rock are found draped over the edges of other blocks, indicating that the former were soft and easily deformed after ejection from the crater.) Intensely metamorphosed rocks have been entirely melted, and they form contorted fragments of basaltic glass ejecta or glass crusts coating surfaces of other blocks. The glass is vesicular and has dull ropy surfaces that locally show thin, fractured crusts. Most of the basaltic glass blocks contain abundant minute fragments of rocks and minerals caught in their surfaces and dispersed throughout their interiors during ejection from the crater.

Weakly metamorphosed rocks (Fig. 2) show abundant, pervasive microfractures and local patches of shear. Intragranular deformation appears in the more intensely fractured rocks: augite and olivine have weak undulatory and banded extinction; augite contains narrow lamellae of mechanical twins, generally parallel to (001); and olivine shows faint lamellae that may be deformation lamellae. A few grains of pigeonite have weak undulatory extinction, and a few grains of plagioclase show polysynthetic twinning that is clearly mechanical because it is related to bending of the laths; in general, however, intragranular deformation in pigeonite and plagioclase is difficult to detect because both minerals commonly contain growth twins and because plagioclase has fine lamellae of varying indices of refraction produced by oscillatory zoning.

In moderately metamorphosed rocks (Fig. 3), feldspar is partly or wholly converted to maskelynite [thetomorphic plagioclase glass (*8*)] and olivine and augite show pronounced intragranular deformation. Rock texture, however, is perfectly preserved, and the laths of thetomorphic glass retain exact grain outlines and oscillations in index of refraction. Plagioclase is converted to maskelynite in patches; feldspar in the transition region commonly shows fine, closely spaced, planar lamellae of alternating high and low indices of refraction [planar features (*9*)]. As plagioclase is progressively transformed to glass, microfracturing decreases in the mineral, and more widely spaced tension fractures become abundant in the rock. Intragranular deformation features in olivine and augite are similar to but are more abundant and pronounced than those in weakly metamorphosed rocks.

In rocks that show moderately strong metamorphism (Fig. 4), feldspar is completely converted to glass that shows small-scale flow and homogenization (bent laths, lack of preservation of fine oscillatory zoning). Augite is minutely fractured, and widely spaced fractures in olivine phenocrysts separate the grains into coarse fragments that retain approximately the original orientations. In the larger fragments of both olivine and augite, extinction is strongly undulatory, and a few of the olivine grains have mosaic extinction related to poorly developed lamellar structures. Primary interstitial glass and interstices between grains contain abundant minute vesicles.

In strongly metamorphosed rocks (Fig. 5), feldspar glass is vesicular. Where the vesicles are minute, rock texture is largely preserved: grains of feldspar glass retain gross lath shapes and cores of relatively high indices of refraction; grains of augite preserve ophitic outlines; and fragments of olivine derived from fracturing of phenocrysts are not greatly disoriented. The grains of feldspar glass are bent and contorted, however, and the grains of augite are abundantly fractured. Intragranular deformation is pronounced in mafic minerals: augite contains strong undulatory extinction, narrow twin lamellae parallel to (001), and faint lamellae that may be deformation lamellae; olivine contains distinctive lamellar structures and smooth undulatory extinction, banded extinction, or mosaic extinction. Olivine grains are altered along fractures and grain mar-

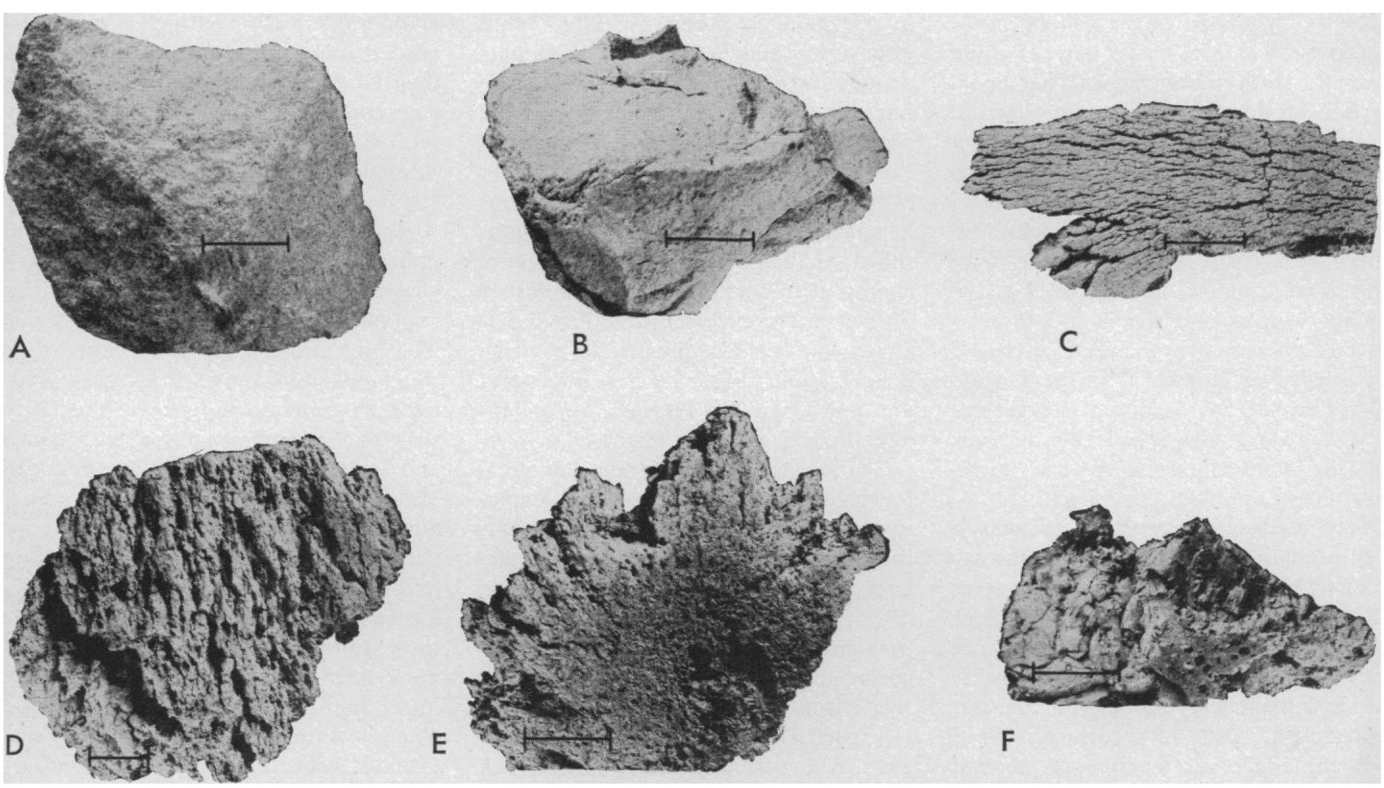
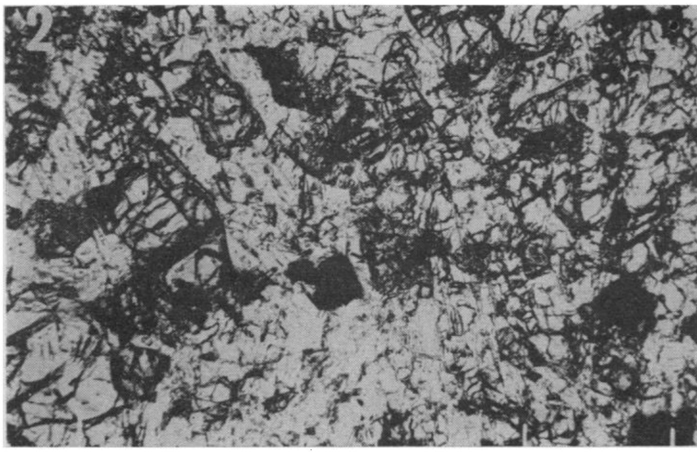


Fig. 1. Hand specimen photographs of fragments of basalt ejecta. Scale in each is 2 cm. (A) Unmetamorphosed basalt. Olivine phenocrysts form dark gray specks in the light gray groundmass. (B) Weakly metamorphosed basalt. The rock is lighter in color than unmetamorphosed rock and is strongly fractured. (C) Moderately strongly metamorphosed basalt (cut surface). Closely spaced subparallel tension fractures are abundant. (D) Strongly metamorphosed basalt (surface of block). The rock appears aphanitic with dark olivine phenocrysts and is cut by broad, irregular, subparallel tension fractures. (E) Strongly metamorphosed basalt (interior of block). The rock at the edge of the block appears aphanitic and has abundant radial tension fractures. Toward the center of the block, the rock darkens, luster becomes vitreous, and vesicles enlarge. (F) Intensely metamorphosed basalt converted to basaltic glass. Surface of the block is ropy and in places shows a thin, fractured crust (left), and the interior of the block is vesicular (right of scale).



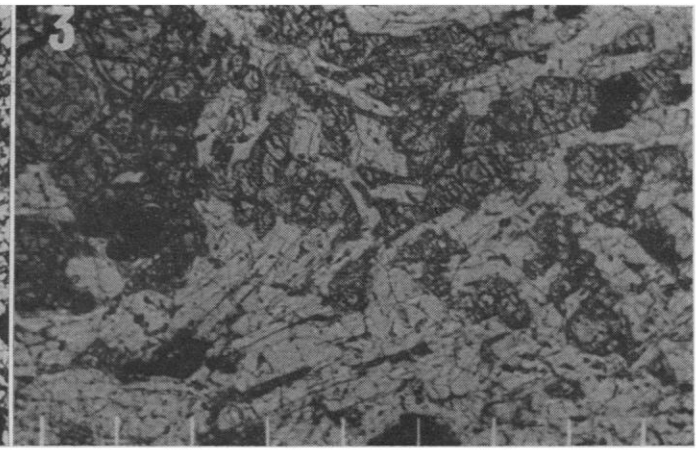


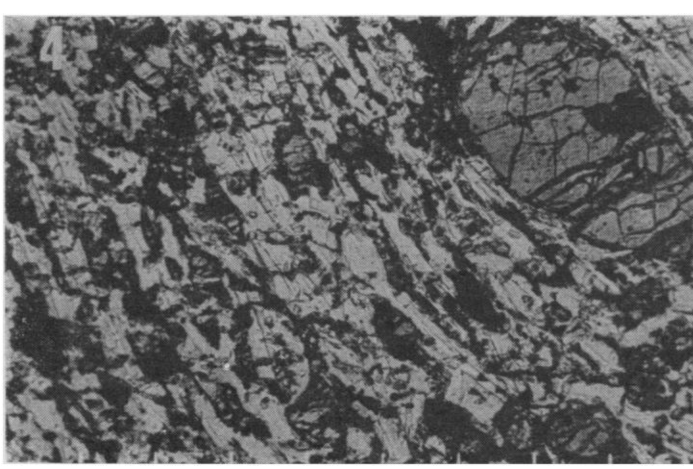
Fig. 2. Photomicrograph in plane light of weakly metamorphosed basalt. Olivine phenocrysts (bottom and center left), ophitic augite (right), and plagioclase show numerous microfractures. Scale interval is 0.1 mm. Fig. 3. Photomicrograph in plane light of moderately metamorphosed basalt. Rock texture is perfectly preserved. Ophitic augite (right) and phenocrysts of olivine (left) retain grain outlines and crystal structure. Plagioclase has been converted to thetomorphic glass that retains zonal variations in index of refraction. Blocky fracturing is produced by thin section preparation. Scale interval is 0.1 mm.

gins to hematite, to magnetite, or to both.

Blocks of strongly metamorphosed basalt typically become increasingly vesicular toward their interiors (Fig. 6). Original rock texture is progressively destroyed as the vesicles expand: feldspar glass becomes more contorted; fractured pyroxene grains are increasingly dispersed, forming streaks of minute fragments; and coarse fragments formed from olivine phenocrysts are increasingly separated and disoriented. Olivine is progressively recrystallized, and feldspar glass is locally recrystallized. In coarsely vesicular glass at the cores of the blocks, grains of olivine and pyroxene have narrow rims of pale brownish-green glass, and opaque mineral grains are surrounded by patches of dark brown glass. These glasses have higher indices of refraction than the surrounding feldspar glass and are streaked into it. Iron oxide alteration of olivine progressively changes; hematite dominates in the outer parts of the blocks, but magnetite dominates toward the interior.

Frothy black glasses like those at the cores of strongly metamorphosed blocks also form crusts clinging to surfaces of less metamorphosed blocks. In these glass crusts, fragments of olivine grains are rounded and rimmed by brownish glass, and they have partly recrystallized. Much minutely granular pyroxene has melted, and only rounded larger fragments remain. Heterogeneous glass forms narrow septa between coarse vesicles and locally contains patches of crystallites.

Intensely metamorphosed rock is converted to inhomogeneous basaltic glass (Fig. 7). The glass is pale brown, it shows vaguely defined streaks of varying indices of refraction, and it contains scattered small vesicles, numerous patches and streaks of feldspar glass, and sparse streaks of mafic glass. Inclusions caught up during ejection from the crater are abundant and consist of angular rock fragments as much as 2 cm across, scattered single mineral grains, and patches and streaks of minute mineral fragments. The inclusions are rimmed by small crystallites of plagioclase, pyroxene, and opaque miner-



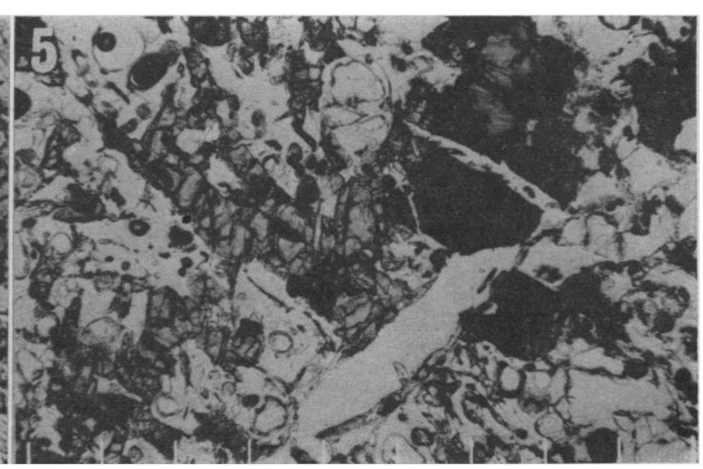
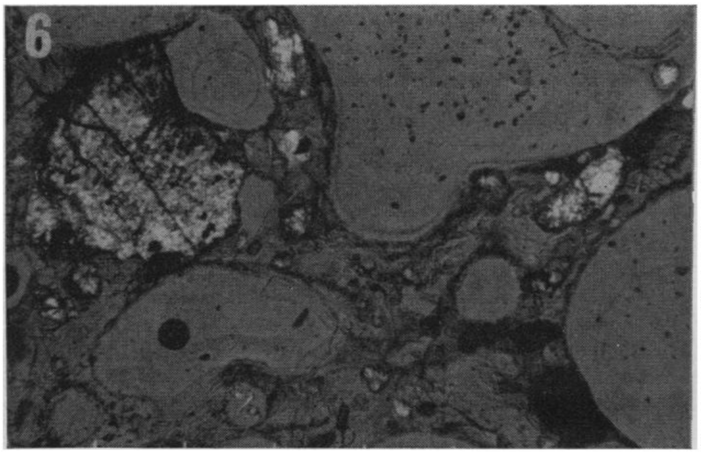


Fig. 4. Photomicrograph in plane light of moderately strongly metamorphosed basalt. Rock texture is nearly preserved. Augite (left) is ophitic and contains numerous minute fractures, and olivine phenocrysts (right) are cut by relatively widely spaced fractures and contain faint lamellar structures. Plagioclase is converted to glass and some of the laths are slightly bent. Interstices are packed with minute vesicles. Scale interval is 0.1 mm. Fig. 5. Photomicrograph in plane light of basalt from margin of strongly metamorphosed block. Rock texture is largely preserved. Augite (center) retains crystal structure and ophitic outlines. Olivine (top right) retains crystal structure and approximate grain outlines but is strongly fragmented and altered to hematite plus magnetite bordering fractures. Plagioclase retains gross lath shapes but contains numerous vesicles. The rock is cut by open tension fractures trending northeast–southwest. Scale interval is 0.1 mm.

als. Glass containing scattered small vesicles and sparse crystallites grades into glass that contains abundant large vesicles and is packed with crystallites; in many blocks the two types of glass are mixed together, forming irregular patches and schlieren.

Two aspects of the thermal history of the metamorphosed rocks may strongly modify their textures. The first is rate of cooling, an important factor in formation of crystallites in rock



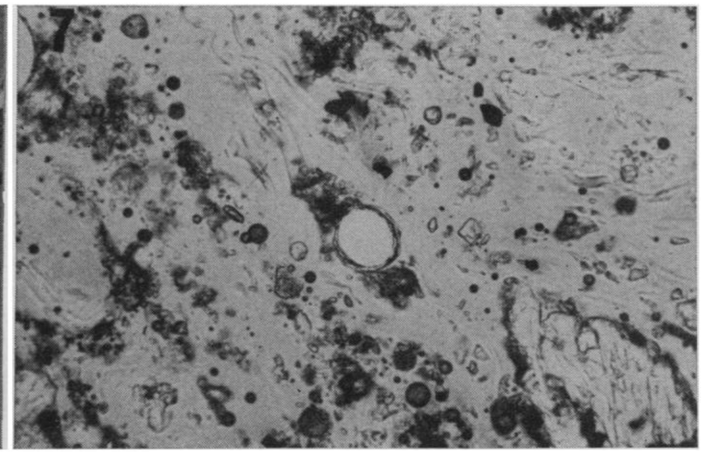


Fig. 6. Photomicrograph of basalt from center of strongly metamorphosed block, taken in light passed through crossed Nicol prisms (rotated slightly from perpendicular). Heterogeneous glass contains coarse vesicles, partly recrystallized olivine grains (left), small rounded pyroxene grains (center), opaque grains surrounded by patches of dark glass (bottom right), and schlieren varying in index of refraction and color. Scale interval is 0.1 mm. Fig. 7. Photomicrograph in plane light of intensely metamorphosed basalt converted to basaltic glass. The glass contains vesicles (center, top left), widely dispersed rock and mineral fragments, colorless low-refractive-index schlieren (top right) of feldspar melt, and dark high-refractive-index schlieren (top center) of mafic melt. The fragments are rimmed by crystallites. Scale interval is 0.1 mm.

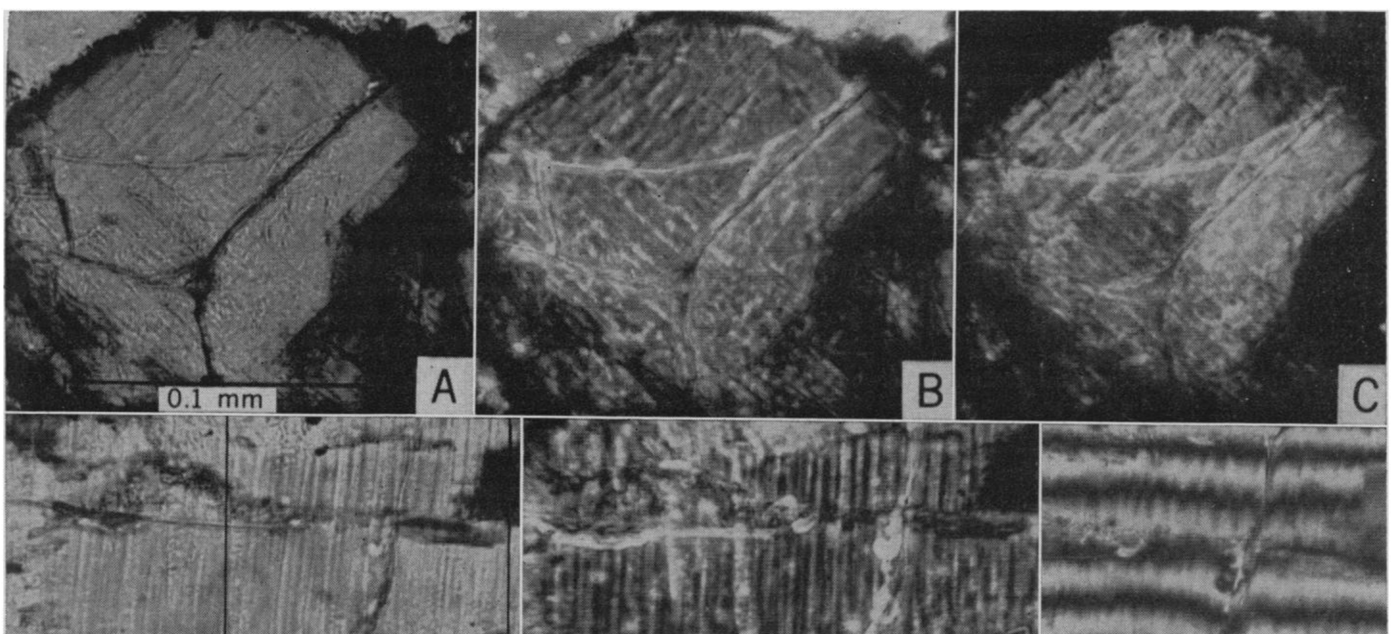


Fig. 8. Photomicrographs of lamellar structures in olivine. Parts A–C: The grain contains two prominent sets of lamellae with boundaries marked by fine dark lines. The set trending northwest–southeast contains minute perpendicular fractures. Part A, in plane light. Part B, with phase contrast. Part C, phase contrast and crossed Nicol prisms; extinction is mosaic and extinction position is different for areas containing differently oriented lamellae. Parts D–F: The grain contains one prominent set of lamellae that differ greatly in index of refraction and extinction position. Lamellae with lower index of refraction contain minute perpendicular fractures. Part D, in plane light. Part E, with phase contrast; lamellae of lower index are light and lamellae of higher index are dark. Part F, enlargement viewed with an interference microscope in monochromatic sodium light; the dark fringes are displaced upward in lamellae of higher index and downward in lamellae of lower index.

glasses and in recrystallization of minerals or mineral glasses (for example, recrystallization of plagioclase and of deformed olivine grains toward the centers of strongly metamorphosed blocks). The second is postexplosion heating in small rock fragments engulfed by basaltic melt during ejection from the crater; in many of these fragments, minerals show thermal melting rather than shock vitrification.

The distinctive lamellar structures in olivine (Fig. 8) consist of sets of narrow, subparallel, planar bands, from less than 1 to about 3 μm thick, of alternating high and low indices of refraction. With phase contrast illumination, the structures appear as lamellae of light and dark tint, and some boundaries are fine dark lines that mark a discontinuity in index of refraction. In many grains, bands of lower indices contain minute, closely spaced fractures perpendicular to their trends. There may be pronounced differences in extinction position between bands, sometimes as much as 12 degrees. Where only one set of lamellar structures is prominent in a grain, extinction generally progresses (either smoothly or in poorly defined bands) across the grain perpendicular to the trend of the lamellae.

Single grains, however, typically contain more than one set of lamellae; most commonly, two sets are prominent and two or three additional faint sets occur locally. Areas containing differently oriented lamellae have different extinction positions, and in these grains extinction appears mosaic. Where two sets of lamellae intersect, their boundaries show minute mutual displacements. Universal-stage studies of crystallographic orientation of lamellae show that sets most commonly developed are near {100}, in the region of the forms {112}, {122}, and {111}, and in a region broadly centering on {131}.

In meteorite impact rocks are metamorphosed by the high pressure and heat produced during passage of the shock wave, but in a nuclear explosion rocks may be heated by the nuclear reaction in addition. For the same peak shock pressure, then, rocks metamorphosed by nuclear explosion might be expected to have higher residual temperatures than rocks metamorphosed by passage of a shock wave alone, and they might vesiculate and melt at lower shock pressures. Comparisons with impact-metamorphosed granitic rocks and amphibolites from the Ries Crater, Germany (*10*), support this inference of higher temperatures in the NTS samples: (i) Many of the Ries samples contain maskelynite that shows no evidence of flowage, whereas such rocks are rare in the NTS basalts. (ii) The vesicular Ries specimens generally have fewer and smaller vesicles than the vesicular NTS samples. (iii) Olivine and pyroxene in the NTS basalts are converted to glass by thermal melting (indicated by the presence of rims of mafic glass).

Many of the metamorphic effects in the NTS basalts are clearly produced by the shock wave, however, and may be used as general indicators of shock metamorphism in mafic rocks. In weakly metamorphosed rocks, the shock features are microfracturing and shearing, and mechanical twinning of augite, dominantly on (001). Since it is possible to produce similar deformation at much slower strain rates (*11*), these features alone are not strictly definitive of shock. In moderately to strongly metamorphosed rocks, the characteristic shock features are (i) planar features in feldspar; (ii) thetomorphic feldspar glass; (iii) tension fractures; (iv) fragmented phenocrysts; (v) mechanical twinning and granulation of augite; (vi) extinction variation and possible deformation lamellae in olivine and pyroxene; and (vii) distinctive lamellar structures, with related mosaic extinction, in olivine. Of these, the first three are the most reliable indicators of shock (*12*), and it is likely that the distinctive lamellar structures in olivine are also diagnostic (I have observed identical structures in olivine artificially shocked to pressures above 250 kb by P. S. DeCarli). In the intensely metamorphosed rocks (the basaltic glasses) shock origin is indicated by the presence of abundant shocked rock and mineral fragments that were caught in the molten material during ejection from the crater.

Primary rock texture or internal growth structures of minerals may obscure critical evidence of shock metamorphism. In basalts in general, grain size less than 50 μm may make shock-induced internal structures difficult to detect in individual mineral grains. In the samples studied here, growth twinning and zoning in pigeonite and plagioclase limit the usefulness of these minerals as shock indicators, especially at low shock pressures. Moreover, it is possible that rock texture influences a mineral's response to shock; for example, the intense fracturing of ophitic augite grains may be produced by reflections of shock waves from complex grain boundaries (*13*).

There are other petrographic features characteristic of shock metamorphism that are not observed or are not diagnostic of shock in the NTS samples but that would be diagnostic in impact-metamorphosed basalts. Indicators of impact origin in rock glasses are evidence of extremely high temperatures (such as decomposition of refractory minerals) and the presence of meteoritic material (for example, nickel-iron spherules) (*12*). In rocks that have not been entirely melted by shock, conversion of minerals to phases that are stable only at very high pressure is evidence of impact (*12*). High-pressure polymorphs that have been proposed for the minerals of the basalt (*14*) are spinel structure with olivine composition, corundum structure with pyroxene composition, and hollandite structure with feldspar composition. At present, however, none of these polymorphs have been identified as shock products in impact-metamorphosed rocks. Alternatively, it is possible for minerals to be decomposed by shock and to form more than one shock phase. Oligoclase in some cases decomposes to form jadeite (*15*), but no shock decomposition reactions have as yet been observed for olivine, pyroxene, or calcic plagioclase.

ODETTE B. JAMES
Branch of Astrogeologic Studies, U.S. Geological Survey, Washington, D.C. 20242

References and Notes

1. Lunar Sample Preliminary Examination Team, *Science* **165**, 1211 (1969).
2. The nuclear device had a yield of 0.42 kton and was detonated at a depth of 33.5 m in a series of flows 70 m thick capping a mesa at the NTS; the explosion formed an apparent crater 66.5 m in diameter and 19 m deep [N. M. Short, *Goddard Space Flight Center preprint X-644-69-117* (National Aeronautics and Space Administration, Washington, D.C., 1969)].
3. Grain sizes of the minerals are as follows: olivine phenocrysts range from 0.2 to 1 mm; groundmass olivine ranges from 30 to 100 μm; pigeonite grains average about 100 μm; opaque mineral grains average about 75 μm; ophitic augite grains are optically continuous over areas as great as 1.5 mm; and plagioclase laths are as much as 0.5 mm and average about 0.2 mm in length.
4. Olivine compositions determined by measurements of refractive indices and electron microprobe analysis; plagioclase compositions determined by extinction angle measurements and microprobe analysis; and alkali feldspar composition estimated by microprobe analysis.
5. This classification is strictly descriptive and indicates progressively severe modification of the original basalt. It is possible that the nature of the changes observed in each mineral species, as well as the conditions that produce these changes, may be affected by grain size, mode, and mineral habit; thus, no quantitative significance may be attached to this classification scheme at present.

6. N. L. Carter, C. B. Raleigh, P. S. DeCarli, *J. Geophys. Res.* **73**, 5439 (1968).
7. E. C. T. Chao, in *Researches in Geochemistry*, P. H. Abelson, Ed. (Wiley, New York, 1967), vol. 2, p. 205.
8. The term thetomorphic was introduced by E. C. T. Chao, *ibid.*, p. 212, to describe glasses produced from minerals by shock transformation in the solid state.
9. N. L. Carter, *Amer. J. Sci.* **263**, 786 (1965); E. C. T. Chao, *Science* **156**, 192 (1967).
10. Origin of the Ries Crater by meteor impact has been established by the occurrence of the high-pressure polymorphs of quartz—coesite and stishovite [E. M. Shoemaker and E. C. T. Chao, *J. Geophys. Res.* **66**, 3371 (1961); E. C. T. Chao and J. Littler, *Geol. Soc. Amer. Abstr. 1962*, p. 127 (1963)]. Impact-metamorphosed rocks from this structure are described by E. C. T. Chao, in *Shock Metamorphism of Natural Materials*, B. M. French and N. M. Short, Eds. (Mono Book, Baltimore, 1968), p. 135; W. von Engelhardt and D. Stoffler, *ibid.*, p. 159.
11. Lamellar twinning of clinopyroxene on (100) and (001) occurs in tectonically deformed rocks and has been produced in static deformation experiments [C. B. Raleigh and J. L. Talbot, *Amer. J. Sci.* **265**, 151 (1967)].
12. E. C. T. Chao, in *Researches in Geochemistry*, P. H. Abelson, Ed. (Wiley, New York, 1967), vol. 2, p. 204; E. C. T. Chao, *Science* **156**, 192 (1967).
13. J. S. Rinehart, in *Shock Metamorphism of Natural Materials*, B. M. French and N. M. Short, Eds. (Mono Book, Baltimore, 1968), p. 31.
14. A. E. Ringwood, *J. Geophys. Res.* **67**, 4005 (1962); T. J. Ahrens, C. F. Peterson, J. T. Rosenberg, *ibid.* **74**, 2727 (1969).
15. O. B. James, *Science* **165**, 1005 (1969).
16. I thank N. G. Benjamin, who prepared the suite of fine doubly polished thin sections. This research was done on behalf of NASA by the U. S. Geological Survey under NASA contract R-66.

6 October 1969

Enterobius vermicularis: 10,000-Year-Old Human Infection

Abstract. *Eggs of* Enterobius vermicularis *(human pinworm) were found in human coprolites from Hogup and Danger Caves, western Utah. The caves were inhabited by man from 10,000 B.C. to A.D. 1400. The oldest coprolite containing* E. vermicularis *was radiocarbon dated at 7837 B.C. This represents the earliest known association between man and this exclusively human parasite.*

Accounts of *Enterobius vermicularis* (pinworm) infection in man date back to the beginning of recorded history (*1*). Early Chinese, Indian, Arabic-Persian and Greco-Roman medical writings all attest to the prevalence of this parasite in their native populations. The disease was recognized to produce intense anal pruritus, sometimes complicated by local secondary infection but without other serious sequelae. Hippocrates knew of the nocturnal symptoms of pinworm infection. In fact, the above clinicopathological description of enterobiasis, perhaps the most common worm infection of mankind today, remains unchanged (*2*). Direct evidence of infection in ancient populations has been provided by the finding of *E. vermicularis* eggs in dried fecal specimens (coprolites), about 1000 years old, recovered from Mesa Verde, Colorado (*3*). Our finding of *E. vermicularis eggs* in a 10,000-year-old human coprolite (Fig. 1) represents the earliest documented association of man with this ubiquitous and exclusively human parasite.

Danger Cave and Hogup Cave, in western Utah, were inhabited by prehistoric man for several thousand years (from about 10,000 B.C. to A.D. 20, Danger Cave; from about 6400 B.C. to A.D. 1400, Hogup Cave). Each has been the site of active archeological investigation (*4*). Sequential levels of major periods of human occupancy were established on the basis of analysis of several feet of cultural debris layering both caves (5 levels in Danger Cave, 16 levels and 4 major occupations in Hogup cave). Samples of a large variety of fecal and plant materials were used to date the levels with radiocarbon. Coprolites were found in nearly all levels and ascribed to human origin on the basis of form, color, and content.

Human coprolites contain a mixture of diverse plant material, bone, and charcoal, which distinguishes them from coprolites of other mammals (*5*). In all, 142 coprolites from both caves were examined microscopically for the presence of ova and parasites (*6*). Each specimen was first reconstituted in 0.5 percent trisodium phosphate for 72 hours (*7*). Six microscopic preparations were made from each coprolite—four suspensions in trisodium phosphate on coverslips and two preparations after concentration in formalin-ether (modified by substituting 0.5 percent trisodium phosphate for water) (*8*).

Eggs of *E. vermicularis* were found in one sample from level 10 of Hogup Cave (650 B.C. ± 100 years), in two coprolites from level 8 of Hogup Cave (1250 B.C. ± 140 years), in one coprolite from level 6 of Hogup Cave (4010 B.C. ± 100 years), and in one specimen from level 2 of Danger Cave (7837 B.C. ± 630 years) (*9*). In addition, eight specimens had eggs of *Acanthocephala* (thorny-headed worm) (*10*). No protozoans were encountered.

Although 2.8 percent of all coprolites (1.3 percent of all examinations) contained *E. vermicularis* eggs, this is not indicative of the true rate of infestation. Modern surveys utilizing direct fecal smears for examination show less than 5 percent of the actual infestation rate when compared to the superior cellophane tape and swab technique for the detection of *E. vermicularis* (*11*). The real rate of infestation in this aboriginal population, therefore, was probably comparable to those of modern populations. Since the worm is relatively harmless, there is no reason to believe community or individual health was seriously compromised, in contrast to the potentially lethal complications of *Acanthocephala* infection reported in this same population (*10*).

Fig. 1. *Enterobius vermicularis* egg found in human coprolite from Danger Cave, level 2 (7837 B.C. ± 630 years). Outer dimensions of egg are 55 by 30 μm.

GARY F. FRY
Department of Anthropology,
University of Utah,
Salt Lake City 84112

JOHN G. MOORE
Department of Medicine,
University of Utah

References and Notes

1. R. Hoeppli, *Parasites and Parasitic Infection in Early Medicine and Science* (Univ. of Malaya Press, Singapore, 1959).
2. A. W. Jones, *Introduction to Parasitology* (Addison-Wesley, Reading, Mass., 1967) chap. 18.
3. R. Samuels, *Amer. Antiquity* **31**, 175 (1965).
4. J. D. Jennings, *Univ. Utah Anthropol. Pap. No. 27* (1957) p. 1; C. M. Aikens, K. T. Harper, G. Fry, *Hogup Mt. Cave: Interim Report* (Society for American Archaeology, Washington, D.C., 1968).
5. G. F. Fry, *Univ. Utah Anthropol. Pap. No. 94*, in press.
6. Supported by the University of Utah Research Fund.
7. H. J. Van Cleave and J. A. Ross, *Science* **105**, 139 (1947); E. O. Callen, *New Sci.* **8**, 35 (1960).
8. L. S. Ritchie, *Bull. U.S. Army Med. Dep.* **8**, 326 (1948).
9. The most recent date obtained for each level is cited.
10. J. G. Moore, G. F. Fry, E. Englert, Jr., *Science* **163**, 1324 (1969).
11. A. C. Chandler and C. P. Read, *Introduction to Parasitology* (Wiley, New York, ed. 10, 1965), p. 442; R. B. Burrows, *Microscopic Diagnosis of the Parasites of Man* (Yale Univ. Press, New Haven, 1965), ch. 12.

9 October 1969; revised 10 November 1969