renkov radiation is the basic mechanism. At threshold, they typically appear as a large, crescent-shaped flash in the peripheral regions of the field of view. These threshold flashes may occasionally be as large as one-third to one-half the field of view. They consistently appear in the regions of the field of view that correspond to the portion of the retina near where the particles exit. Visual phenomena observed at the AGS to date include large cloud-like flashes, large crescent-shaped flashes, brighter smaller flashes, wide streaks or bands, and large flashes with dark centers.

A dramatic demonstration of Cerenkov radiation was obtained when a near-threshold pulse of 7 Gev/c muons entered the subject's eyeball through the rear and exited through the cornea. The visual sensations appear as large flashes of light with dark centers. The lighted section of the flash fills the far periphery, and the dark central region is often so large it includes regions corresponding to the most sensitive areas on the retina. To the best of our knowledge, flashes with dark centers have not previously been reported. Nor could we explain them by any mechanism except Cerenkov radiation. When informed of our observations, Pinsky *et al.* (*6*) briefed the astronauts on Apollo 17 to look for similar effects. The observation of large flashes with dark centers was confirmed on Apollo 17.

Some significant statements can now be made regarding the role of Cerenkov radiation in producing the Apollo light-flash phenomena. The sensitivity of the retina to visible Cerenkov light is in general agreement with earlier optical measurements and consistent with theory. When the count rates to be expected in deep space are calculated on the basis of the known cosmic ray spectrum and the results are expressed as a function of the sensitivity of the retina (*7*) count rates equal to the 1 to 2 per minute observed on Apollo missions 11 through 17 are obtained for reasonable values of retinal sensitivity. Apollo astronauts have reported visual phenomena (*6*) that are similar in description to each of the PIVS described in our experiments. Moreover, the astronauts must also be dark-adapted. One of the most serious objections to the Cerenkov explanation of the Apollo flashes was based on an impromptu experiment performed by astronaut Edgar Mitchell on Apollo 14, which indicated that dark-adaptation was not required for observing flashes (*8*). After one of us (P.J.M.) observed that the technique used by Mitchell was probably insufficient for light-adaptation, the experiment was formally repeated in three sessions on Apollo 15 and the need for dark adaptation was confirmed (*6*).

Our data and calculations (*7*) indicate that, at least for some subjects, the threshold value for individual ions will be atomic number $Z < 10$, which corresponds to particles that have already been accelerated to relativistic velocities at existing facilities. This is also consistent with the ability of our subjects to detect with low efficiency barely relativistic nitrogen nuclei (*9*).

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References and Notes

1. P. J. McNulty, *Nature (Lond.)* **234**, 110 (1971); *Air Force Camb. Res. Lab. Rep. No. 71-0377* (1971).
2. F. J. D'Arcy and N. A. Porter, *Nature (Lond.)* **196**, 1013 (1962); W. N. Charman and C. M. Rowlands, *ibid.* **232**, 574 (1971); W. N. Charman, J. A. Dennis, G. G. Fazio, J. V. Jelley, *ibid.* **230**, 596 (1971); C. A. Tobias, T. F. Budinger, J. T. Lyman, *ibid.*, p. 596; T. F. Budinger, J. T. Lyman, C. A. Tobias, *ibid.* **239**, 209 (1972); J. H. Fremlin, *New Sci.* **47**, 42 (1970); T. F. Budinger, H. Bischel, C. A. Tobias, *Science* **172**, 868 (1971); C. A. Tobias, T. F. Budinger, J. T. Lyman, in *Proceedings of the National Symposium on Natural and Manmade Radiation in Space*, E. A. Warman, Ed. (NASA-TM X-2440, National Aeronautics and Space Administration, Washington, D.C., 1972), p. 416.
3. P. J. McNulty, V. P. Pease, V. P. Bond, in preparation.
4. M. H. Pirenne and F. H. Marriott, in *Psychology—A Study of Science*, S. Kich, Ed. (McGraw-Hill, New York, 1959), vol. 1, p. 288.
5. E. J. Denton and M. H. Pirenne, *J. Physiol. (Lond.)* **123**, 417 (1954).
6. L. S. Pinsky, W. F. Osborne, J. V. Baily, R. E. Benson, L. F. Thompson, *Science* **183**, 957 (1974).
7. R. Madey and P. J. McNulty, in *Proceedings of the National Symposium on Natural and Manmade Radiation in Space*, E. A. Warman, Ed. (NASA-TM X-2440, National Aeronautics and Space Administration, Washington, D.C., 1972), p. 757.
8. P. K. Chapman, L. S. Pinsky, R. E. Benson, T. F. Budinger, in *ibid.*, p. 1002.
9. P. J. McNulty, V. P. Pease, L. S. Pinsky, V. P. Bond, W. Schimmerling, K. G. Vosburgh, *Science* **178**, 160 (1972).
10. These experiments required considerable cooperation from the AGS support groups, the health physicists at Brookhaven, and the Columbia, Rochester, Harvard, and National Accelerator Laboratory muon collaboration. Particular thanks to W. R. Casey, D. Berley, H. Brown, Y. Lee, R. S. Stafford, W. P. Sims, and the members of the ad hoc safety committee. This research was carried out at Brookhaven National Laboratory under the auspices of the Atomic Energy Commission.

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High-Pressure Phase Transformation of $CaSO_4$ (Anhydrite) During a Nuclear Explosion

Abstract. *Examination of the postshot cores from the portion of the Tatum Salt Dome that had been subjected to a nuclear explosion (Salmon Event) has indicated evidence for the high-pressure phase transformation of anhydrite. This evidence consists of distinctly different optical domains within the shocked anhydrite. Evidence for the transition exists out to approximately 1.5 cavity radii. Excellent agreement exists between experimental work and the theoretical calculations of the predicted pressure profile.*

On 22 October 1964, a 5.3-kiloton device (Salmon Event) was detonated in the Tatum Salt Dome near Hattiesburg, Mississippi, at a depth of 2716 feet (830 m). The composition of the dome at this depth was approximately 90 percent NaCl (halite) and 10 percent $CaSO_4$ (anhydrite). The average in situ bulk density of the material was 2.24 g/cm^3 (*1*). The resulting cavity is approximately 55 feet in radius. Peak pressure and peak velocity have been calculated (*2*).

Stephens (*3*) reported a sluggish transition in the preshot anhydrite separated from the halite of the Tatum Dome beginning at 19.5 ± 0.5 kbar and ending at 34 kbar. The volume change was reported to be about 4 percent. Under the pressure regime generated by the nuclear explosive, one would expect the anhydrite to have un-

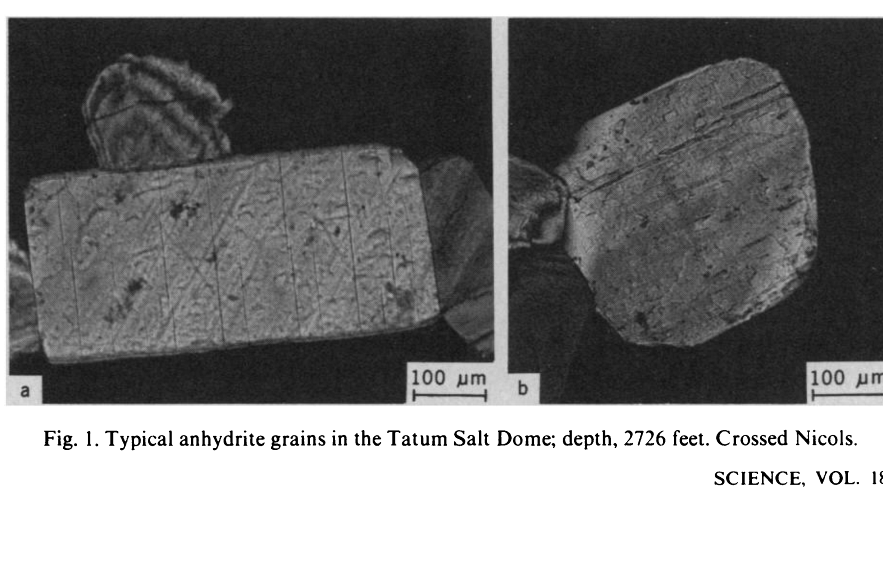


Fig. 1. Typical anhydrite grains in the Tatum Salt Dome; depth, 2726 feet. Crossed Nicols.

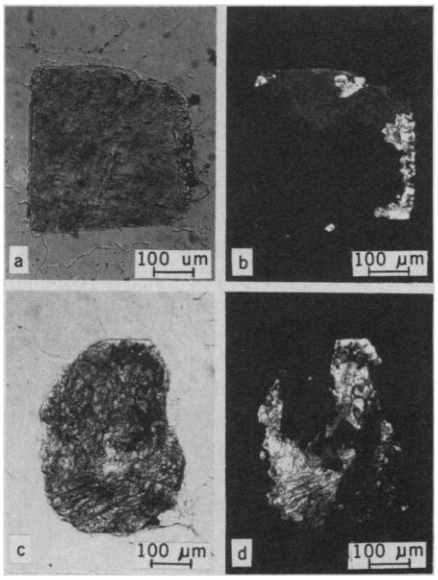


Fig. 2. Illustration of optical domains in postshot anhydrite: (a) crystal in plane-polarized light; (b) crystal with crossed Nicols; (c) crystal in plane-polarized light; and (d) crystal with crossed Nicols. All depths, 2773 feet.

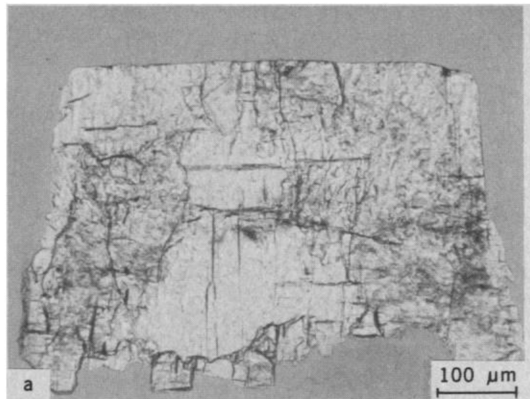
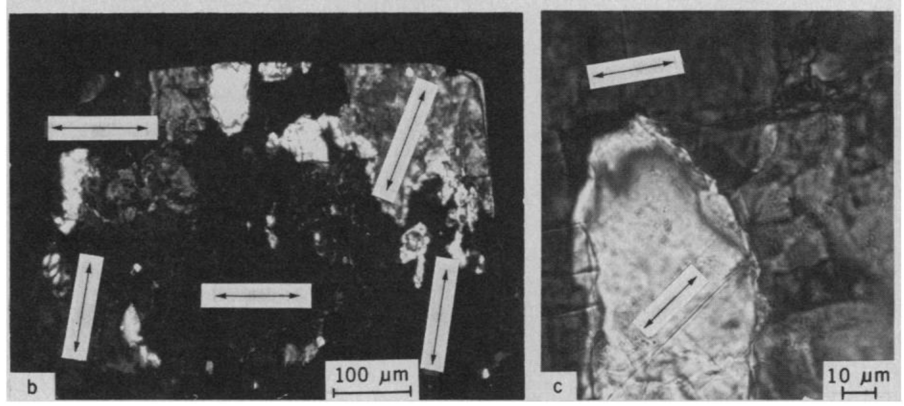


Fig. 3. Appearance of anhydrite grains in a postshot sample (depth, 2773 feet) of a Salmon core. (a) Plane-polarized light showing cleavage traces and cracks. Note cracks and cleavage traces within the cracked areas. (b) Same areas as (a) with crossed Nicols, showing optical domains. (c) Detail of crystallographic domains in anhydrite crystal, crossed Nicols. The relative misorientation due to the high-pressure transformation may be observed in the traces of the cleavages. Arrows indicate directions of the trace of the plane of the relatively faster vibration direction.



dergone a completely reversible phase transformation (*3*). Laboratory experiments on the preshot Tatum rock itself also showed evidence of the anhydrite phase change, but, because of dilution by the soft halite, the transformation was not evident below 24.5 kbar. This report describes the evidence for phase transformation as seen in postshot rock samples obtained from cores taken through the center, into the puddle of the cavity, and below the shot point.

The preshot anhydrite, enclosed in a matrix of halite, has a modal grain size of about 700 μm. The prismatic, euhedral grains are clear and free of gross imperfections (Fig. 1). Few twinned grains are observed. There is little evidence of strain; in all grains fractures are few, extinction is sharp and uniform, and undulose extinction is absent. The three pinacoidal cleavages are in evidence.

At depths from 2773 feet to approximately 2794 feet, the halite remains unfractured. However, the postshot anhydrite grains are at times partly cracked and contain distinctly different optical domains that may be seen quite easily under crossed Nicol prisms. Figures 2 and 3 illustrate this phenomenon in three different grains. A similar domain structure has been attributed to the high-temperature phase transformation of synthetic bromellite (*4*). At 2796 feet, strain induced by the shot is indicated by mechanical twins and slight undulose extinction; however, the optical domains are not distinct. X-ray analysis of the postshot anhydrite indicates the presence of only $CaSO_4$.

Using Stephens' data as a guide, one can place a peak radial stress of approximately 25 kbar at 2796 feet or approximately 1.5 cavity radii. Rogers (*2*) estimates the peak radial pressure at 2796 feet to have been on the order of 30 kbar. Considering the difficulties associated with evaluating the activation energies for high-pressure reactions, the differences in the experimental environments, and the errors involved in estimating the pressures, one must conclude that the agreement between Rogers' calculations and field measurements and Stephens' experimental work is excellent. In addition, recently completed experimental laboratory work by Schock (*5*) for Borg and Smith (*6*) has confirmed the existence of a high-pressure polymorph of anhydrite. The monoclinic monazite structure ($P2_1/n$) is considered the most likely configuration.

Because of the ease with which this pressure change may be observed, it would appear that anhydrite may be an excellent pressure indicator in future high-pressure experiments.

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References and Notes

1. D. E. Rawson, P. L. Randolph, C. R. Boardman, V. E. Wheeler, "Post-explosion environment resulting from the Salmon Event" (Report UCRL-14280 Rev. I, Lawrence Livermore Laboratory, Livermore, Calif., 27 December 1965).
2. L. A. Rogers, *J. Geophys. Res.* **71**, 3415 (1966).
3. D. R. Stephens, *ibid.* **69**, 2967 (1964).
4. D. K. Smith, C. F. Cline, V. D. Frechette, *J. Nucl. Mater.* **6**, 265 (1962).
5. R. N. Schock, personal communication.
6. I. Y. Borg and D. K. Smith, "The high-pressure polymorph of $CaSO_4$" (Lawrence Livermore Laboratory, Livermore, Calif., in press).
7. This work was performed under the auspices of the U.S. Atomic Energy Commission.

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Precipitation: Its Acidic Nature

Abstract. *A comparison of the free hydrogen ion concentration and the total hydrogen ion concentration of rain samples shows that rain is a weak acid. The weak acid nature of rain casts doubt on the concepts that the acidity of rain is increasing and that these increases are due to strong acids such as sulfuric acid.*

The term "acid rain" has come into widespread use to imply that precipitation may be influenced by anthropogenic activity in such a manner as to cause a decrease in the *p*H. Likens and Bormann (*1*) discuss the most commonly held opinions on "acid rain." They report that precipitation in the northeastern United States is acidic and is presumably due to air pollution. The relationship to air pollution is based upon two