tation of principal stress axes often can be deduced by analysis of translation and twin gliding features in minerals from deformed rocks. However, Carter and Raleigh (*9*) state that "amphiboles in tectonites rarely show any signs of plastic deformation." Our experiments suggest that the high stresses required for twinning accounts for the scarcity of ($\bar{1}01$) twins in naturally deformed amphiboles. We have observed ($\bar{1}01$) lamellar structures in shocked amphiboles from the Vredefort dome, and Chao (*10*) reports closely spaced planar structures in hornblende from a moderately shocked plagioclase amphibolite. We suggest that twinning may be a significant mechanism of deformation in shocked amphiboles.

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References and Notes

1. M. Ross, J. J. Papike, P. W. Weiblen, *Science* **159**, 1099 (1968).
2. H. W. Jaffe, P. Robinson, C. Klein, Jr., *ibid.* **160**, 776 (1968).
3. T. P. Rooney and R. E. Riecker, *AF Cambridge Res. Lab. Env. Res. Pap. No. 299* (Air Force Cambridge Research Laboratories, Bedford, Mass., 1969). This paper describes results obtained by deforming hornblende in Bridgeman-type shear apparatus. In these tests twinning was induced on (100) as well as (101); T. P. Rooney and R. E. Riecker, *Trans. Amer. Geophys. Union* **50**, 322 (1969); ———, *Amer. Mineral.* **55**, 310 (1970); R. E. Riecker and T. P. Rooney, *Nature* **224**, 1299 (1969).
4. D. T. Griggs, *Geophys. J. Roy. Astron. Soc.* **14**, 19 (1967).
5. Supplied by N. Carter, Yale University.
6. Chemical analysis by G. O. Riddle, Denver Rock Analysis Laboratory, U.S. Geological Survey, Denver, Colo. Summation on the basis of 46.00 charges.
7. Least squares refinement of cell dimensions from program devised by D. E. Appleman, D. S. Handwerker, H. T. Evans, *Annu. Mtg. Amer. Crystallogr. Ass. (Abstract)*, Cambridge, Mass. (1963). No internal standard used.
8. In the I2/*m* setting for clinoamphiboles the twin axis becomes *c**, the twin plane (001), and the direction of slip along *minus a* of the host.
9. N. Carter and C. B. Raleigh, *Bull. Geol. Soc. Amer.* **80**, 1231 (1969).
10. E. C. T. Chao, *Science* **156**, 192 (1967).
11. We thank Drs. J. Papike, J. Clark, and N. Yannoni for their help. The deformation apparatus was built with funds supplied by the Advanced Research Projects Agency.

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Anomalous Water: Attempts at High-Pressure Synthesis

Abstract. *The high density, 1.4 grams per cubic centimeter, reported for anomalous water suggests that high pressures should be conducive to the formation of anomalous water. Six attempts at 60 kilobars in which water was cooled from about 600°C in nickel or platinum tubes, with or without the presence of silica, did not produce any detectable amounts of anomalous water.*

The reports of Deryagin and Churayev (*1*) on a new, dense form of water with unusual properties has stimulated considerable experimentation (*2, 3*) and a surprising amount of theoretical speculation (*4*) on its structure. Lippincott *et al.* (*2*) proposed that the substance was a special, polymeric form of H_2O and suggested the name "polywater" for it. Only small amounts of this substance have been prepared by a method presumably based upon the condensation of water in small glass or vitreous silica tubes. Some recent work (*5*) has demonstrated the difficulties associated with the production of pure water of any kind by the conventional methods used for producing anomalous water, and it is possible that many of the unusual properties of polywater are the result of dissolved or suspended impurities.

It would be helpful to have larger samples, for example, 0.1 g, of polywater available for research. Leiga *et al.* (*6*) attempted to prepare it by a gaseous discharge method but obtained mainly an aqueous solution of nitric acid.

The reported relatively high density, 1.4 g cm^{-3}, of polywater suggests that high pressures ought to aid its formation. At room temperatures, compressed water ordinarily freezes as different forms of ice (*7*). Above about 23 kb Ice VII is stable, and Bridgman (*8*) found that its melting temperature goes from about 80°C at 23 kb to about 190°C at 40 kb. At 20°C and 50 kb the density of Ice VII is about 1.67 g cm^{-3}. However, no polywater has ever been reported as a result of the cold compression of water, perhaps because the solid state limits molecular rearrangement or perhaps because nobody thought to look.

In a recent discussion with E. U. Franck the possibility was considered of forming polywater by heating water to above 600°C at 60 kb, where it would be liquid with a density of at least 1.4 g cm^{-3}, and then cooling it under pressure so as to give it the maximum opportunity to form thermodynamically favored dense liquid phases.

The "belt" high-pressure apparatus (*9*) was used in these attempts. The water was contained in a nickel or platinum capsule about 3 mm in diameter and 10 mm long which was surrounded by pyrophyllite and heated electrically. Pressures were estimated by reference to calibrations with barium and bismuth in the usual way, and temperatures were estimated from the heating power dissipated in the samples. The temperature was raised to the range 500° to 700°C in a few minutes and reduced from its maximum to 25°C in about 7 minutes. The samples recovered were immediately placed in screw-capped vials pending further analysis.

Six attempts at high-pressure synthesis were made, four in nickel tubes and two in platinum. The platinum tubes could be recovered intact, but the hot water corroded the nickel slightly and made it brittle so that the nickel tubes were torn into three segments by the forces generated during pressure release. Part of the water thereby moistened adjacent fragments of pyrophyllite, but some water remained in the nickel tubes as they were placed, together with the moist pyrophyllite, in the glass vials. In one experiment with a nickel tube and one with platinum, one or two small fragments of vitreous silica were placed in the tube along with the water to serve as catalysts for the formation of polywater.

The infrared spectrum of a specimen of liquid from the plain platinum (no SiO_2) tube exhibited two of the peaks of normal water and no anomalous water peaks, although the specimen had nearly evaporated by the time the spectrum had been swept (*10*). The literature on polywater indicates that it should not evaporate this easily. The specimen from the platinum tube containing SiO_2 evaporated before its infrared spectrum could be obtained. The piece of SiO_2 left was opaque and white with a density exceeding 2.8 g cm^{-3} and was identified from its refractive index as coesite. The formation of coesite indicates that both water and silica were active in this experiment (at least 550°C), but no significant amounts of polywater were obtained.

The glass vials containing the products from the nickel tube were placed in a refrigerator at 2°C; all of them soon acquired a film of liquid droplets on their inside walls and no liquid could be found in the nickel tubes. The refractive index and viscosity of the droplets appeared to the eye to be similar to those of ordinary water droplets inside a similar vial, and both kinds of droplets froze and melted at about the same temperature, 0°C. The silica in the nickel tube was recovered as a pale green slurry (coesite bearing some Ni) which soon became dry. In one experiment water in a nickel tube was compressed to 40 kb at 25°C for 5 minutes, but only ordinary water was obtained in the product, as judged by measurements of viscosity and vapor pressure.

So far then no significant amounts of polywater have been obtained by cooling highly compressed liquid water from about 600°C at 60 kb, either in the presence or in the absence of silica. The catalytic powers of nickel and platinum also had no marked beneficial effects. If anomalous water exists as a polymorph of pure water, it is certainly not easy to form in measurable amounts under conditions that are more favorable thermodynamically than those previously used.

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References and Notes

1. B. V. Deryagin and N. V. Churayev, *Priroda (Russian) No. 4* (1968), p. 16; translation in *Joint Publ. Res. Serv. No. 45* (1968), p. 989.
2. E. R. Lippincott, R. R. Stromberg, W. H. Grant, G. L. Cessac, *Science* **164**, 1482 (1969).
3. G. A. Castellion, D. G. Grabar, J. Hession, H. Burkhard, *ibid.* **167**, 865 (1970); *Chem. Eng. News* (22 Sept. 1969), p. 39.
4. L. C. Allen and P. A. Kollman, *Science* **167**, 1443 (1970); R. P. Messmer, *ibid.* **168**, 479 (1970).
5. D. L. Rousseau and S. P. S. Porto, *ibid.* **167**, 1715 (1970); S. L. Kurtin, C. A. Mead, W. A. Mueller, B. C. Kurtin, E. D. Wolf, *ibid.*, p. 1720.
6. A. G. Leiga, D. W. Vance, A. T. Ward, *ibid.* **168**, 114 (1970).
7. L. F. Evans, *J. Appl. Phys.* **38**, 4930 (1967).
8. P. W. Bridgman, *Phys. Rev.* **48**, 893 (1935).
9. H. T. Hall, *Rev. Sci. Instrum.* **31**, 125 (1960).
10. Infrared spectra were recorded by R. Chrenko.

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Nuclear Explosions and Distant Earthquakes: A Search for Correlations

Abstract. *An apparent correlation between nuclear explosions and earthquakes has been reported for the events between September 1961 and September 1966. When data from the events between September 1966 and December 1968 are examined, this correlation disappears. No relationship between the size of the nuclear explosions and the number of distant earthquakes is apparent in the data.*

The possibility that nuclear explosions may trigger destructive earthquakes has been a matter of concern to seismologists, who have devoted an increasing amount of research to this question. It has been established that relatively small earthquakes are triggered close to the sites of some nuclear explosions, but attempts to show that the earthquakes extend more than a few tens of kilometers from those sites have been unsuccessful.

In a recent paper, Emiliani *et al.* (*1*) concluded that "Underground nuclear explosions trigger significant earthquake activity for at least 32 hours afterward and to distances up to at least 860 kilometers." Emiliani *et al.* go on to say, "By dividing the area under consideration into several annuli and by comparing, within each annulus, observed versus expected number of earthquakes, we have verified that the seismic effect of the explosion extends to the 860-km limit of our search."

This is an important conclusion, but it has not been borne out by our investigations or by the results of others who have looked for evidence of increased regional seismicity after nuclear tests. The conclusion of Emiliani *et al.* has not been effectively challenged (*2*), and a further clarification of the statistical nature of the data is appropriate.

We have examined the U.S. Coast and Geodetic Survey hypocenter data file (*3*) in an effort to find correlations between explosions and earthquakes and between earthquakes and other distant earthquakes. We studied the earthquakes in a large rectangular area that covered most of the western United States (Fig. 1) and found no correlations between earthquakes or between earthquakes and explosions other than the expected correlations within an aftershock sequence. One part of our study of the data was very similar to the study reported by Emiliani *et al.* We examined the data on earthquakes that occurred between 15 September 1961 and 19 December 1968 in an area bounded by latitudes 31.25° and 42.00°N and longitudes 109.00° and 124.50°W. From this data set, the earthquakes in a 2° by 2° square that includes the Nevada Test Site were excluded (see Fig. 1). We found that 446 earthquakes occurred in the 104-hour periods immediately following the 235 nuclear explosions and that 447 earthquakes occurred within similar periods immediately preceding the explosions (*4*).

These results differ markedly from the data presented by Emiliani *et al.* (*1*), even though the studies were similar. We therefore recomputed the figures, using the same time intervals and area (Table 1, column a). Although there are small differences, our calculation confirms their result.

Since it is well known that nuclear explosions are always followed by small earthquakes, which originate in the collapse zone above the cavity or along faults in its immediate vicinity (*5*), we removed the earthquakes near the explosions from the data set; that is, from a circle with an 860-km radius centered at 37.07°N, 116.25°W, we removed a 2° by 2° rectangle that includes the Nevada Test Site and tabulated the earthquakes for the time interval 15 September 1961 to 29 September 1966, excluding the test site (Table 1, column b). These data also showed more earthquakes in periods immediately following nuclear explosions than in similar periods immediately preceding the explosions. But when the data were extended to include the time interval between 29 September 1966 and 19 December 1968, this apparent correlation disappeared (Table 1, column d). Between September 1966 and December 1968 there were 205 earthquakes before the shots and 150 after the shots (Table 1, column c). These figures might be regarded as indicating that, in the first period, the nuclear explosions triggered the earthquakes and, in the second period, the earthquakes triggered the nuclear explosions—a ridiculous conclusion that dramatizes the danger of oversimplifying our statistical model.

If nuclear explosions do affect regional seismicity, the larger explosions presumably would cause more extensive earthquakes than smaller explosions. Of the explosions listed by the Atomic Energy Commission (AEC),