

to include vesicles; (3) mantled and unmantled sanidine; (4) at least two stages of formation of hydroxyl-bearing minerals; and (5) coexistence of ovoidal and euhedral grains of sanidine, plagioclase and quartz.

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<sup>1</sup> Sederholm, J. J., *Selected Works: Granites and Migmatites*, 501 (Wiley, New York, 1967).

<sup>2</sup> Noble, L. F., Wright, L. A., and Troxell, B. W., *Geologic Map of California, Trona Sheet* (1963).

## Compression of Aluminium up to About 200 kbar and Evidence of a Structure Change

THEORETICAL calculations of compression (the ratio of volume,  $V$ , at high pressure, relative to the volume,  $V_0$ , at ambient pressure) have evolved largely because of inadequacies in the quadratic expression used by Bridgman<sup>1</sup> in his early investigations above about 30 kbar.

Anderson<sup>2</sup> has shown that for reasonably compressible materials such as quartz and cadmium the previously neglected equation originally derived by Murnaghan<sup>3</sup>

$$\ln \frac{V}{V_0} = \frac{1}{B'_0} \ln \{ B'_0(P/B_0) + 1 \}$$

where  $B_0$  and  $B'_0$  are the ambient isothermal bulk modulus and its first pressure derivative, agrees well with experimental measurements at pressures up to about 200 kbar. The equation is based on an assumption that bulk modulus varies linearly with pressure. Alternatively, extending Bridgman's use of a quadratic equation, Anderson has developed a quartic:

$$V/V_0 = 1 - P/B_0 + m(P/B_0)^2 - n(P/B_0)^3 + q(P/B_0)^4$$

in which  $m$ ,  $n$ ,  $q$  involve only  $B_0$  and its pressure derivatives. With the same assumption concerning linearity of bulk modulus with pressure, he finds that this does not give agreement with experimental measurements

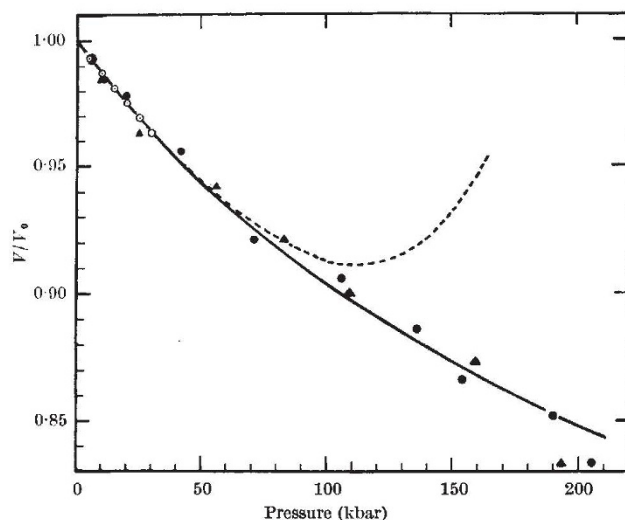


Fig. 1. The compression of aluminium. Solid and broken lines show theoretical values calculated using the logarithmic equation and the quartic equation respectively. Experimental measurements are shown as: ●, increasing pressure; ▲, decreasing pressure; ○, Bridgman's data.

at pressures in the 200–300 kbar region, except for materials of very low compressibility such as MgO. Both these approaches permit calculation of compression at very high pressures using only ambient-pressure data which can be measured accurately by modern ultrasonic interferometry<sup>4</sup>.

In this laboratory, measurements up to about 200 kbar on aluminium, with the opposed-anvil type of high pressure X-ray diffraction camera, agree very well with Murnaghan's logarithmic equation for compression (Fig. 1). The values of the isothermal bulk modulus and its pressure derivative used in the theoretical calculation were those reported by Schmunk and Smith<sup>5</sup>.

A further point of interest is that at the highest pressure used, 205 kbar, additional X-ray powder diffraction lines were observed. The  $d$ -spacings of these strongly suggest partial transformation of the structure from cubic to hexagonal close-packed. The lines index as 10 $\bar{1}$ 0, 10 $\bar{1}$ 1 and 10 $\bar{1}$ 2, with 0002 not separately detectable because of its equivalence to the 111 cubic spacing. Among metals, cobalt is an example of a thermally induced transformation of this type. Shear, likely to occur in the conditions in the opposed-anvil apparatus, is also a common mechanism; for example, the conversion of wurtzite to the blende structure of ZnS by grinding<sup>6</sup>.

Fuller details of these findings are to be published elsewhere. We thank Dr P. L. Smith for help and advice. The investigations were made under a contract from the Ministry of Technology.

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## Structure and Phase Transition in Solid Hydrogen and Deuterium Sulphides

SPECIFIC heat measurements<sup>1–3</sup> have shown that solid hydrogen sulphide undergoes a discontinuous transition at 103.5 K followed by a lambda transition which is completed at about 126.2 K. Similar transitions were found<sup>4</sup> in solid deuterium sulphide at somewhat higher temperatures, 107.8 and 132.9 K respectively. The lowest solid phase of both substances is optically anisotropic<sup>4</sup> whereas the two higher phases are isotropic. Dielectric constant measurements<sup>5–7</sup> suggested that the orientation of the hydrogen sulphide molecules is ordered in the lowest solid phase and disordered in the two higher phases. This view gained further support from infrared<sup>8–11</sup>, Raman<sup>12,13</sup> and nuclear magnetic resonance<sup>14,15</sup> studies. No model has been put forward for the structure of the ordered phase; the investigators could not agree even on its symmetry. Up to now eight different point group symmetries have been proposed, the majority favouring tetragonal symmetry with eight molecules in the primitive unit cell.

Early X-ray powder diffraction studies<sup>16–21</sup> proposed face-centred cubic structure for all three solid phases of both substances. More recent electron and X-ray diffraction studies<sup>22–24</sup> using better temperature control, however, led to the conclusion that the lowest solid phase of