A NEW THEORY FOR THE SHOCK PRODUCTION OF GLASSES AND HIGH PRESSURE PHASES IN PLANETARY SILICATES, Thomas J. Ahrens, Seismological Laboratory 252-21, California Institute of Technology, Pasadena, CA 91125.

Glassy phases induced by shock pressures in excess of 35 GPa were recognized in laboratory experiments on quartz as early as 1959 [1], and in plagioclase in 1963 [2]. These results immediately suggested the shock-induced nature of amorphous plagioclase (maskelynite) in the achondrite Shergotty [3], tecto-silicates from suspected terrestrial impact craters [4], and later, glasses from the Moon [5]. Planar features in silicates observed both in nature and from laboratory experiments demonstrated that shocked silicates lose their strength and glasses occur within the ubiquitous planar elements [6-8]. Recent shock experiments on molten silicates indicate that these achieved higher densities than expected for tetrahedrally coordinated Si^{+4} and Al^{+3}, and the liquid readily achieves higher coordinations via Si-O bond bending [10]. Moreover, shear band temperatures from SiO_2 indicate that even at 30 GPa, the temperatures corresponding to molten stishovite in equilibrium with crystallizing solid stishovite are readily observed [11,12]. Infrared absorption spectra of silicate glasses compressed to 40 GPa, and decompressed, demonstrate that bond bending yields reversible changes in coordination even at room temperature [13].

I carried out theoretical pressure-volume-temperature calculations which explain, for the first time, the mixed phase region of the Hugoniots of silicates. Starting with either a fused quartz or crystal quartz and upon shocking to 15 and 20 GPa, respectively, transformation to a high-pressure dense, glassy, phase with an entropy of 1.3 R/mole-atom, greater than fused quartz, which has a pressure-density equation of state similar to stishovite, occurs. Transformation to this high density amorphous phase (which rapidly crystallizes to stishovite) is triggered by crossing the metastable extension of the melting curve of coesite as shown in Fig. 1. This is analogous to the transformation of the super dense amorphous H_2O-ice upon compression at 77 K through the extrapolation of the ice-I melting curve into the ice-VI field [14]. The theoretical Hugoniots for quartz and fused quartz of Figs. 2 and 3 were calculated using the same thermodynamic properties for the high pressure phase and assuming the entropy(S) within the mixed phase region is maximized according to $(\partial S/\partial \alpha)_E = 0$. Here α is the mass fraction of the high pressure phase and E is internal energy. The release adiabats shown, conserve both S and α, and both phases are in thermal equilibrium. Shock transformation of mafic silicates are speculated to occur at higher pressures on account of the higher pressures required to achieve local maxima in their melting curves.

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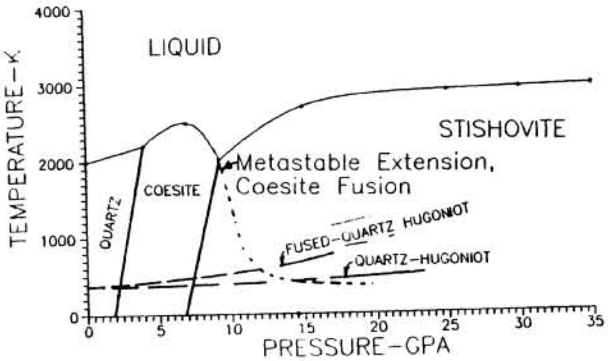

Fig. 1. Phase diagram for SiO_2 (after Schmitt and Ahrens, 1988). Shock temperatures are calculated for fused quartz with an average value of Grüneisen ratio of 1.4. Other equation of state values are standard.

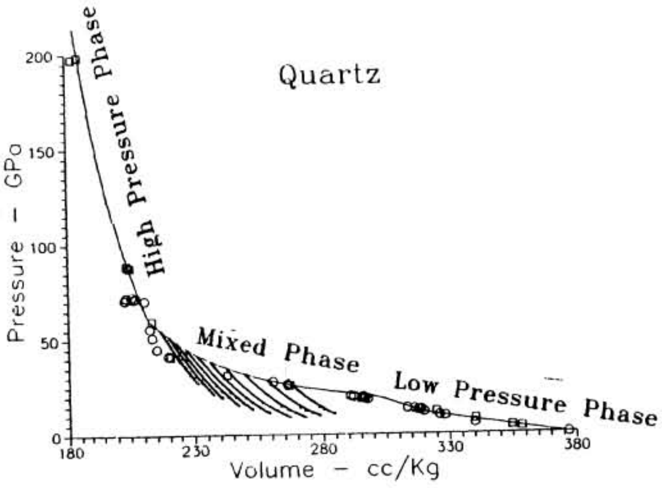

Fig. 2. Theoretical Hugoniot curve and release isentropes for crystal quartz. Data, circles, from Wackerle, 1962; squares, Trunin et al., 1971.

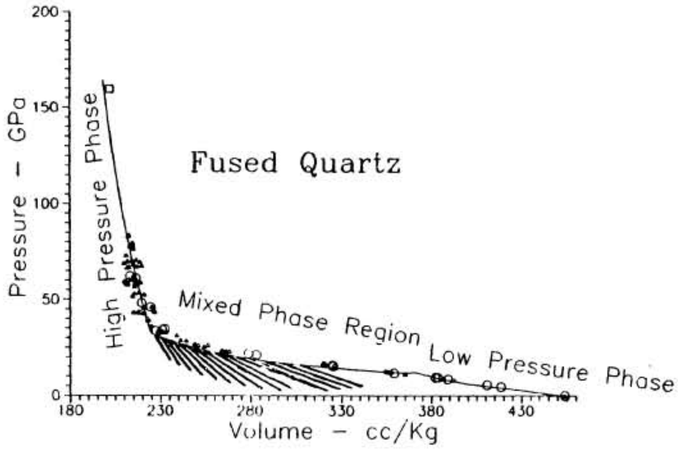

Fig. 3. Theoretical Hugoniot and release isentropes for fused quartz. Data circles, triangles, and squares from Wackerle, 1962, Marsh, 1980, and Jones et al., 1968.