IV. COMPRESSIBILITY MEASUREMENTS AT HIGH PRESSURE

A. DYNAMICS MEASUREMENTS -- SOUND VELOCITY STUDIES

1. Introduction

Newton showed that the velocity, v, of a compressional wave in a fluid (sustaining no shear traction) could be expressed as

$$v = \sqrt{\frac{K}{\rho}} \tag{11}$$

where K is the bulk modulus $-v\left(\frac{\partial P}{\partial V}\right)$ and ρ is the density. Laplace showed that the partial $\frac{\partial \rho}{\partial V}$ was at constant entropy $\left(\frac{\partial P}{\partial V}\right)_S$ rather than at constant temperature $\left(\frac{\partial \rho}{\partial V}\right)_T$ as assumed by Newton. The difference between the two, although significant in the case of gases, is small for liquids and solids given by

$$\beta_T - \beta_S = \frac{\alpha^2 VT}{C_V} \tag{12}$$

where

$\beta_T = -\frac{1}{V}\left(\frac{\partial V}{\partial \rho}\right)_T$, $\beta_S = -\left(\frac{\partial V}{\partial \rho}\right)_S$ α is the expansibility, $\frac{1}{V}\left(\frac{\partial V}{\partial T}\right)_\rho$, V is the volume and c_v is the specific heat at constant volume.

In a solid (or any material sustaining shear traction) where both the bulk compressibility $\beta = 1/K$ and the shear modulus μ are finite, both compressional and shear modes of vibration may be propagated with different velocities v_c and v_s respectively given by

$$v_c = \sqrt{\frac{K + 4/3\,\mu}{\rho}} \qquad \text{(a)} \tag{13}$$

and

$$v_s = \sqrt{\mu/\rho}\ . \qquad \text{(b)}$$

In this case, determination of the two velocities v_c and v_s allows the determination of K_S and hence very nearly K_T. Then if v is known, the equations of state may be known to at least two terms in the pressure. If the pressure dependance of K is known, then more terms in the equation of state are available.

Birch[24, 25, 26] has determined the velocity of compressional waves at pressures to 100 kilobars in a large number of minerals and rocks. His two papers in 1960 and 1961[26] give perhaps the best summary of the information available at that time in addition to his own measurements of some tens of rocks including granites, basalts, dunite, sandstones, linestones, etc.

His measurements were made in an essentially ideal hydrostatic environment. The sample was enclosed in a soft metallic or elastiomeric jacket to exclude the hydraulic fluid. Two transducers, a transmitter and a receiver, were used at opposite ends of a cylindrical specimen, operating through the jacket, for determination of the velocity of the compressional wave.

Simmons[27, 28] modified Birch's apparatus by enclosing the transducer within the jacket and was able thus to generate with AC-cut quartz crystals essentially pure shear waves with a minimum of compressional component. He has reported both compressional and shear velocities for 20 minerals and rocks. In addition Hughes [29, 30] using a similar apparatus has measured the velocity of sound in a number of rocks and minerals.

McSkimmin on the other hand, has an essentially interferometric method.[31, 32] Actually, it is a phase comparison method. An oscillator running at about 10 MHz is gated for pulses and a higher harmonic (about 60 MHz) is used to drive a quartz transducer sealed to the specimen. Phase contract is achieved by overlapping successive reflected pulses on an oscilloscope and observing the frequencies at which addition (or cancellation) occurs. Anderson has used this apparatus for the study of fused silica to 10 kilobars.[33]

Katz used essentially the same technique for measurement, but he achieved higher pressures up to 40 kilobars by pressing the sample between Bridgman anvils. He kept his transducers outside of the high-pressure environment by mounting them in a recess of the piston cap at the other end of the carbide punch.

2. Experimental Methods Proposed

a. Sample Configuration

An attempt was made to extend the pressure range by making measurements within the belt-type apparatus, shown in Figure 1. Initial experiments were to be performed with the 1 x 10^6 psi (66 kilobars) apparatus and the die-body dimensions used in the previous work. This die body can be opened up to allow the use of larger specimens (1.75-inch pressure) at lower pressures (30 kilobars). The 3 x 10^6 psi (200 kilobars) apparatus described above provides a sample diameter of 0.5 inch, but, can similarly be opened up to allow operation to 50 kilobars in a volume of approximately 1 inch in diameter and 1 inch in length.