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2002 J. Phys.: Condens. Matter 14 11381

(http://iopscience.iop.org/0953-8984/14/44/486)

INSTITUTE OF PHYSICS PUBLISHING JOURNAL OF PHYSICS: CONDENSED MATTER

J. Phys.: Condens. Matter **14** (2002) 11381–11384 PII: S0953-8984(02)39618-8

A method for experimental determination of compressional velocities in rocks and minerals at high pressure and high temperature

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Received 1 June 2002
Published 25 October 2002
Online at stacks.iop.org/JPhysCM/14/11381

Abstract

A new combined transmission–reflection method is presented for measuring elastic velocities of rocks and minerals at elevated temperature and pressure, which resolves the problems of gradients of temperature and pressure existing in the original sample assembly with a pyrophyllite cube. At temperature up to 900 °C and pressure up to 4 GPa, single-crystal quartz and serpentine were used as the samples tested. By the use of this new technique, more precise and reasonable data on elastic properties of rocks and minerals at elevated temperature and pressure can be achieved.

1. Introduction

Elastic velocities of rocks and minerals are essential to geophysics for the interpretation of seismic velocity in the Earth in terms of chemical composition and crystal structure. Laboratory measurements of elastic properties of natural rocks and minerals, provide a very direct way of aiding in the interpretation of seismic data, by applying to various candidate materials conditions similar to those in the Earth's interior.

Pulse-transmission [1, 2, 4] and pulse-reflection [3] methods are the two main kinds of technique used in elastic velocity measurements using static high-pressure equipment. Because of the anisotropy and serious ultrasonic attenuation in rocks, this kind of technique based on reflection method [3] is unsuitable for investigating natural rocks. So far, the pulse-transmission technique has been the method most often used in ultrasonic measurements on natural rocks however, they were mainly limited to room temperature [2] or pressure lower than 1 GPa [6]. Although, Xie *et al* [1] and Xu *et al* [6] successfully obtained ultrasonic velocities of various rocks up to 6.5 GPa and 1400 °C, but large temperature and pressure gradients across the sample in the z-direction exist in their experiment set-ups, which result in uncertainties in their experiments [7]. Based on the technique [1, 7], a new combined transmission–reflection technique is proposed in this paper.

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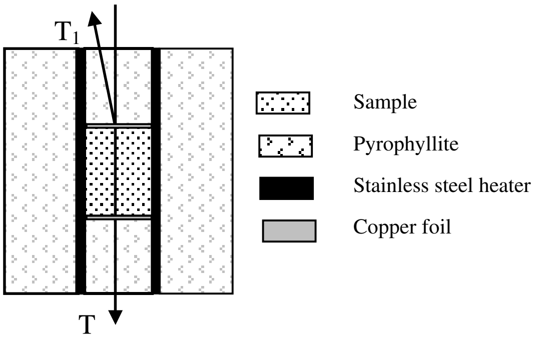

Figure 1. The sample assembly.

2. Experimental details

The method proposed in this paper has improved on the sample assembly and the principle of acoustic measurement. As seen in figure 1, the sample was centred within a cubic cell, 8 mm in length and 12 mm in diameter. In this way, the sample was positioned in a region of uniform temperature and quasi-hydrostatic pressure, so the problem of gradients of temperature and pressure of the previous experiment method was definitely resolved.

The experiments were performed in a high-temperature and high-pressure cell in the so-called YJ-3000 Press. Detailed descriptions of this press and ultrasonic measurement system have been given earlier [1, 5]. The principle of this new combined transmission–reflection method will be briefly presented below.

During applying this new method in measurements of the travel time of samples, the first step was to utilize the transmission method to measure the total travel time T between the upper ultrasonic probe and the lower one. The second step, as shown in figure 1, was to use reflection method to measure the round-trip time T_1 between the upper probe and upper interface (upper buffer/sample) and T_2 between the lower probe and lower interface (lower buffer/sample). Using the corresponding phases to determine travel times, we can reach a very high precision [8] less than 2 ns.

In figure 2 we show a typical oscilloscope record of ultrasonic signals in the measurements on single-crystal α-quartz (z-cut) at pressure 0.5 GPa. The transmitted wave was recorded in channel 1 and the reflected wave received by the upper probe is recorded in channel 2 during the experiment. The time difference $(T - T_1)$ of these two signals could be directly read out from two vertical built-in markers in oscilloscope and $(T - T_2)$ could also be read out symmetrically just by exchanging the output connections of the upper and lower probes. Finally, we can easily calculate the travel time from the formula $t = (T - T_1)/2 + (T - T_2)/2 - \delta = T - T_1/2 - T_2/2 - \delta$, in which δ is the correction for the 0.08 mm copper foil. According to the bulk modulus of copper, the calculated corrections [3] are such that the bond increases the travel time by about 16 ns.

The magnitude of length correction under pressure is usually less than 1% (see [3, 9]) in the pressure range of this study, so the maximum error estimate given by this new method is about 1.2%, far less than the 6% error estimate [7] for previous experiments. Because further technical developments are still required to obtain high-quality S-wave data, we only measured P-wave data in this work. The length changes of samples during compression were ignored and this does not influence the reliability and feasibility of our new method because the magnitude of the error is very small.

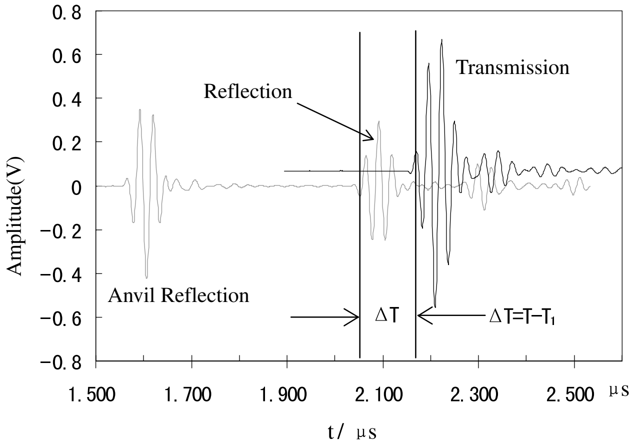

Figure 2. Ultrasonic reflection and transmission signals of α-quartz (z-cut) at 0.5 GPa.

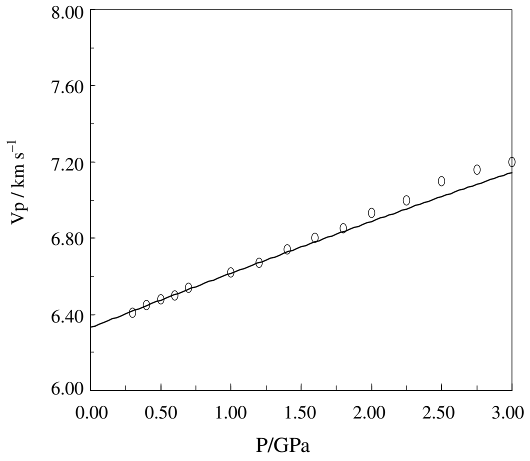

Figure 3. P-wave velocities for α-quartz as a function of pressure; ○: this study; ——: theoretical extrapolation.

3. Results and discussion

Using the new method we have made measurements on single-crystal quartz (z-cut) and serpentine.

The solid line in the figure 3 shows the calculated from single-crystal elastic moduli of McSkimin *et al* [10] measured under hydrostatic pressure conditions. The pressure dependence of the length change for α-quartz in different cuts has been investigated extensively; combining Olinger's data [11] with the travel times measured in this study, we can work out the velocity values at different pressures as shown in figure 3. In this figure, our results are consistent with the theoretical extrapolation of McSkimin's data within an error less than 1%.

In addition, as shown in figure 4, another sample, LW965, in this study is serpentine, which was studied at elevated temperature up to 900 °C at different pressures. In this figure, V_P decreased rapidly above temperatures of 600–700 °C, which means that the dehydration reactions can be considered to have taken place over 600 °C. From results shown in this figure,

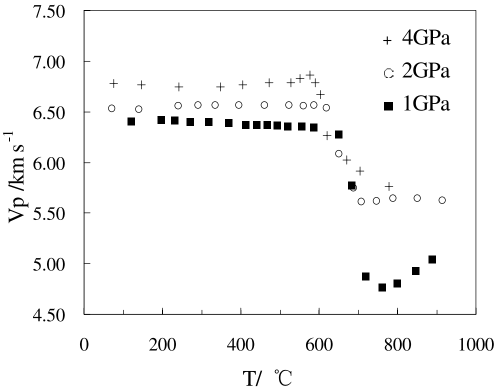

Figure 4. Temperature effects on P-wave velocities in the sample LW965.

the turning temperature for dehydration decreased when pressure increased, which is consistent with studies [12] made previously.

4. Conclusions

Using the new combined transmission–reflection method, we measured the P-wave velocities of different rocks and minerals at elevated pressure up to 4 GPa and temperature up to 900 °C. The results of this study agree with previous measurements well in the error range and demonstrate the feasibility of this new method. By using this new technique, more precise and reasonable data on elastic properties of rocks and minerals at simultaneously elevated temperature and pressure can be achieved.

Acknowledgment

This study was financially supported by the National Natural Science Foundation of China under Grants Nos 10032040 and 49902020, and partially by the Innovation Program (KJCX2-SW-No3) sponsored by Chinese Academy of Sciences.

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