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THE MELTING OF JADEITE TO 60 KILOBARS*

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ABSTRACT. The melting of jadeite has been examined both by differential thermal analysis and by quenching techniques in piston-cylinder apparatus between 30 and 60 kb. Our results agree with Bell's (1964) experimental data to 40 kb, but our curve lies at higher temperatures than his extrapolated curve above 45 kb; our corrected curve is 55°C higher at 50 kb.

INTRODUCTION

The high-pressure mineral jadeite ($NaAlSi_2O_6$) is an important constituent of the pyroxene omphacite, and probably most of the Na_2O and some of the Al_2O_3 of the upper mantle are present as the jadeite component. Jadeite has been shown to be unstable at liquidus temperatures below 25 kb. It melts incongruently to albite + liquid between 25 to 28 kb and congruently between 28 to 43 kb (Bell, 1964).

Bell's melting line for jadeite has considerable curvature concave to the pressure axis; this is in part due to a slight change in slope at 28 kb on passing from incongruent to congruent melting. When Bell's melting data was plotted against the compression of the melting solid, a strong curvature, concave to the Δ V/Vo axis was observed (Gilbert, 1969).

Jadeite melting experiments have been extended to 60 kb in this work in order to determine the melting relationships and particularly to determine the curvature of the melting curve at high pressures.

EXPERIMENTAL METHOD

End-loaded piston-cylinder apparatus was used with half-inch diameter pistons. Details of the experimental assembly used for this work are the same as previously reported for the melting of diopside (Williams and Kennedy, 1969).

The starting material was a synthetic jadeite glass from the same batch used in Bell's experiments, prepared by Dr. J. F. Schairer, and kindly supplied by Dr. P. M. Bell.

The glass was dried before use at 1000°C for three-quarters of an hour.

Initially an attempt was made to detect melting by differential thermal analysis, the same technique used for diopside. However, the melting of jadeite crystals and the crystallization of jadeite liquids are sluggish, so that DTA signals are not readily obtained by cycling temperature. However when a sample was held above its liquidus for several minutes, sufficient melt was formed to give a small DTA freezing signal on cooling. It was, therefore, possible to determine the position of the melting curve by a series of hold-and-cool cycles. Melting was determined at several

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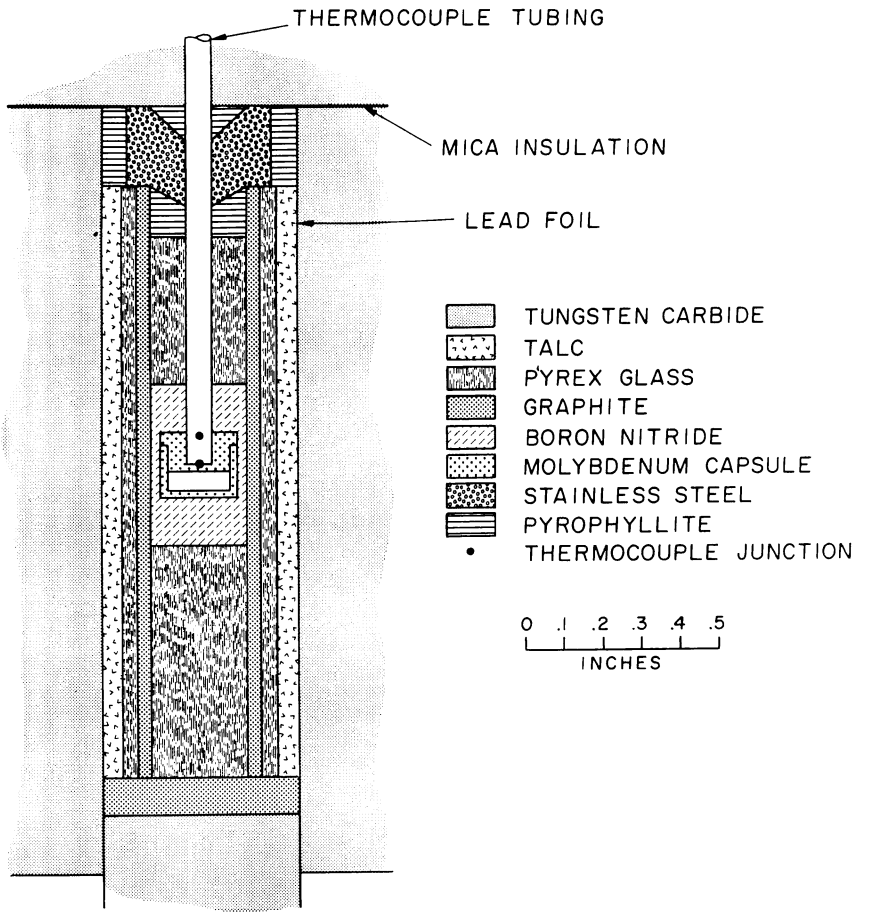


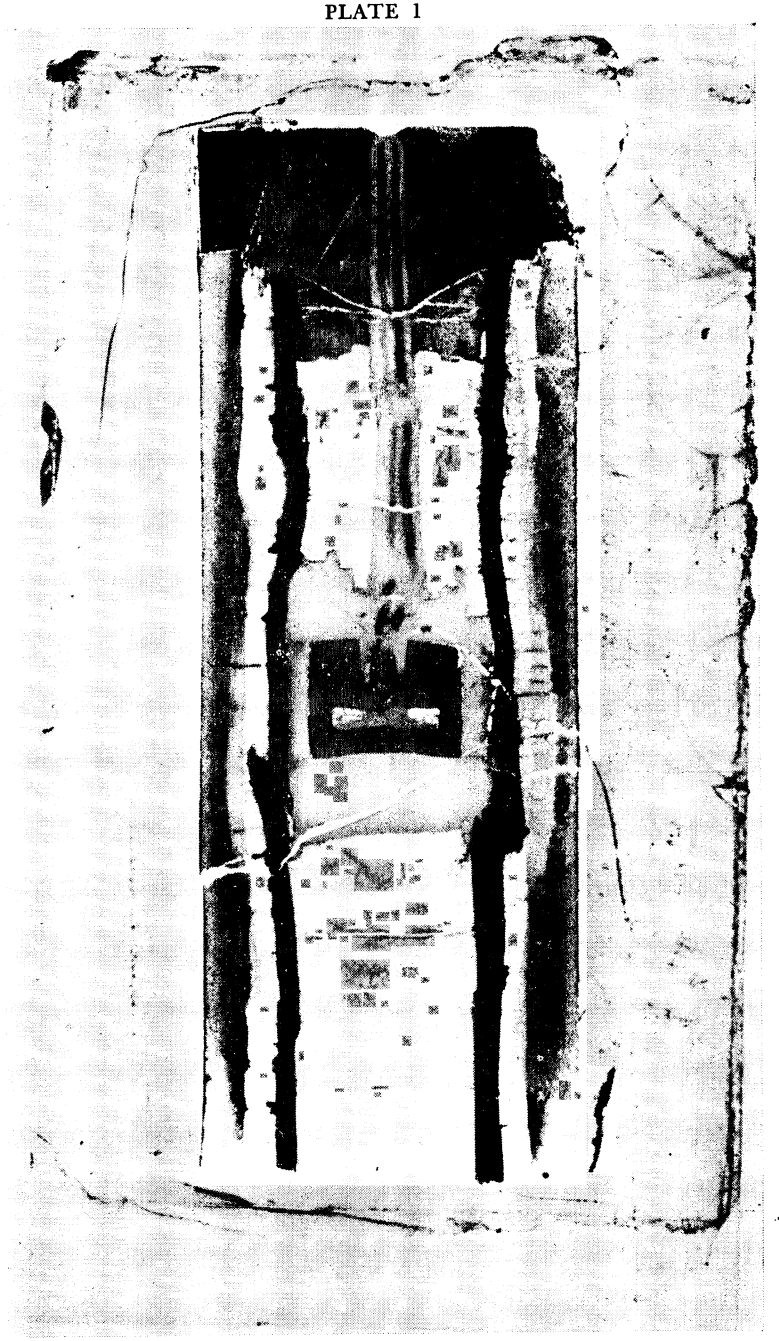
Fig. 1. Details of furnace assembly.

pressures on both compression and decompression cycles, in order to make the appropriate friction corrections.

In addition, a series of quenching experiments was carried out to locate the melting curve. Friction at high temperature and pressure was determined from a plot of piston position, monitored by an Ames dial gauge, versus nominal pressure.

All runs were made with 2 thermocouples, with an axial distance of six-hundredths to eight-hundredths of an inch between the junctions. Thus the temperature gradient in the vicinity of the sample could be measured. As the furnace deforms under pressure (pl. 1), the sample may lie slightly above or below the "hot spot". Normally the 2 thermocouples differed by less than 8°C, and since the sample is within two-hundredths of an inch of the lower thermocouple junction, it must lie at essentially

PLATE 1



Section of high pressure assembly at termination of pressure-temperature run. Compare with figure 1.

the same temperature as that thermocouple. The samples were held at appropriate pressures and temperatures for approximately 1 hour and then quenched. They cooled to less than 200°C within 30 secs. Products were either essentially crystalline or essentially clear glass, indicating that the time at temperature was sufficient for equilibrium to be established (Bell and Roseboom, 1969). No quench crystals were seen, as quenching rate was much more rapid than in DTA analyses. A sample quenched from circa 40 kb and 1200°C, after only 1 or 2 minutes at temperature, was about 90 percent small jadeite crystals and 10 percent glass, showing that the original glassy starting material rapidly crystallized to jadeite.

TABLE 1

Results of quenching experiments

Pressure	Temp °C (uncorrected)	Time (mins)	Products
40.4	1514	30	Jadeite
40.0	1520	60	Glass
45.8	1579	60	Jadeite
46.8	1600	30	80% glass; 20% jadeite
47.6	1600	60	Jadeite
49.0	1611	60	Jadeite
51.6	1629	40	Jadeite
50.9	1641	60	90% glass; 10% jadeite
52.8	1649	60	Jadeite (trace glass)
57.0	1709	60	90% glass; 10% jadeite
59.6	1709	60	Jadeite

RESULTS

Details of the crucial quenching runs are given in table 1, and the results of both these and the DTA experiments are shown in figure 2. Data points have been corrected for friction but not for the effect of pressure on the thermocouple emf. Since agreement of the DTA runs with Bell's data was very good to 40 kb, most of the quenching experiments were done at higher pressures in order to delineate the curve above 45 kb. The estimated precision of pressure and temperature measurement is indicated by the size of the symbols in the figure, namely $\pm$ 0.2 kb, $\pm$ 3°C.

There is virtually no difference between Bell's curve to 40 kb and our raw data; in fact only one of his data points (43 kb–1550°C = liquid) falls on the low temperature side of our curve—and only by 6°C, well within his temperature uncertainty. However, the line he extrapolates to higher pressure from his data shows too much curvature and so falls progressively below ours, lying some 30°C low at 50 kb. The phase fields around the triple points in figure 2 are from Bell (1964).

W-3Re/W-25Re thermocouples were used for these experiments since platinum/rhodium couples have been shown by experiment in our

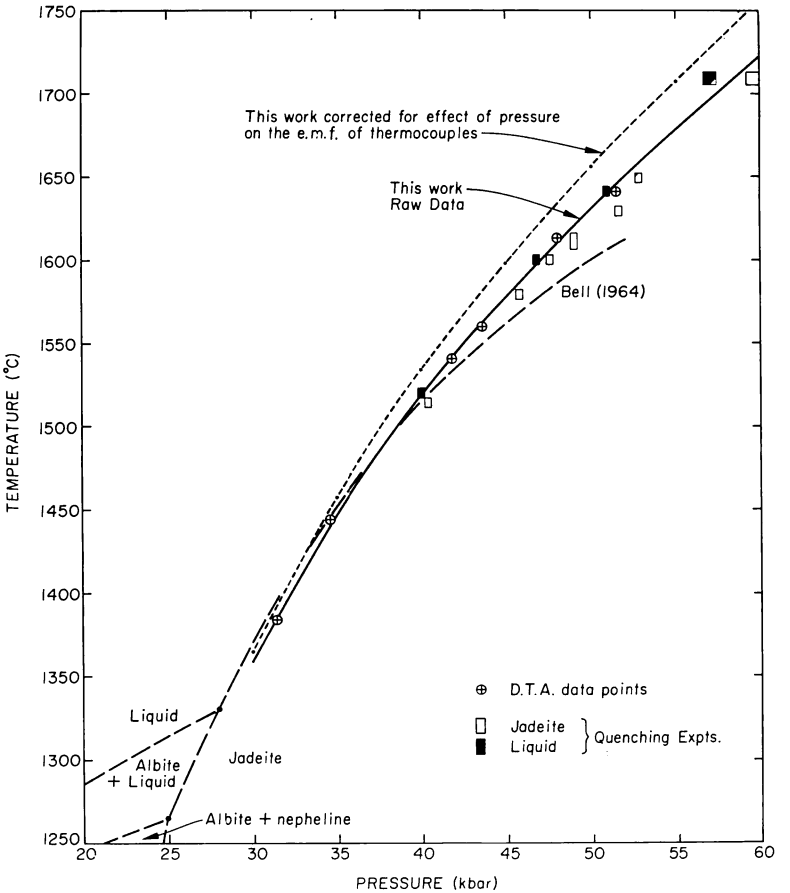


Fig. 2. Results of DTA runs and quenching experiments on melting of jadeite.

laboratory to lose calibration above 1500°C in similar experiments. Observed temperatures can be corrected for the effect of pressure on thermocouple emf, in two steps. The absolute correction for Pt/Pt-10Rh couples has been extrapolated from the single-wire experiments of Getting (1970), and the relative correction between Pt/Pt-10Rh W-3Re/W-25Rh has been determined from intercomparison experiments (Williams and Kennedy, 1969, table 1). The high pressure correction for the thermocouple is extrapolated from values obtained by Getting at 900°C to our temperature of 1500°C. The corrections applied to our raw data are given in table 2, and the corrected curve (dotted) shown on figure 2.

A melting relationship has been proposed by Kraut and Kennedy (1966) in the form

$$t = t_o\left[\ 1 + c\ \frac{\Delta V}{V_o}\ \right]$$

TABLE 2

Melting data for jadeite (°C)

Pressure (kb)	Melting temperature (raw data-fig. 2)	Pressure seal temperature	Correction for pressure effect on emf of thermocouple Pt/Pt10Rh couples (after Getting and Kennedy, 1970)	W-3Re/W-25Re couples	Corrected melting temperature
30	1359	180	+ 11	+ 6	1365
35	1447	185	+ 13	+ 10	1457
40	1518	190	+ 15	+ 16	1534
45	1578	200	+ 16	+ 20	1598
50	1631	205	+ 18	+ 25	1656
55	1678	210	+ 19	+ 29	1707
60	1721	215	+ 21	+ 34	1755

where t is the melting temperature, Δ V/Vo the compression of the solid phase at the same pressure, and t_0 and V_0 are the melting temperature and specific volume of the solid phase at 1 bar. Recently this melting relationship has been extended by Kennedy and Vaidya (1970). They have shown that the Kraut-Kennedy linear relationship holds only for metals. Van der Waals solids have curvatures of the melting curve concave toward the temperature axis, and ionic compounds have curvatures of the melting curve concave toward the volume axis. Thus, it is to be expected that the jadeite melting curve plotted against the volume of the melting solid would show slight concavity toward the volume axis. Unfortunately, there are no compressibility measurements for jadeite over the pressure range of these experiments. Yoder and Weir (1951) measured the compressibility of two jadeite samples immersed in liquid in piston cylinder apparatus between 2 kb and 10 kb. Unfortunately, their results on two different samples differ by approximately 25 percent in compressibility, and large uncertainties are inherent in their data. Nonetheless, we have taken the compressibility of their purer sample, Burmese jadeite, and linearly extrapolated their data to 60 kb. The plot of melting temperature versus this data is shown in figure 3. The curvature of the curve shown in figure 3 is erroneously large owing to the fact that we have used the linear extrapolation of the compressibility data, and silicates become less compressible at high pressures (Bridgman, 1948).

McQueen and Marsh (*in* Birch, 1966) gave shock wave results on jadeite at pressures ranging from 270 to 1150 kb. A Murnaghan equation has been used to adjust the initial compressibility of jadeite to fit the shock wave results. The equation is of the form

$$P = \frac{Bo}{Bo'}\left\{\left(\frac{Vo}{V}\right)^{Bo'} - 1\right\}$$

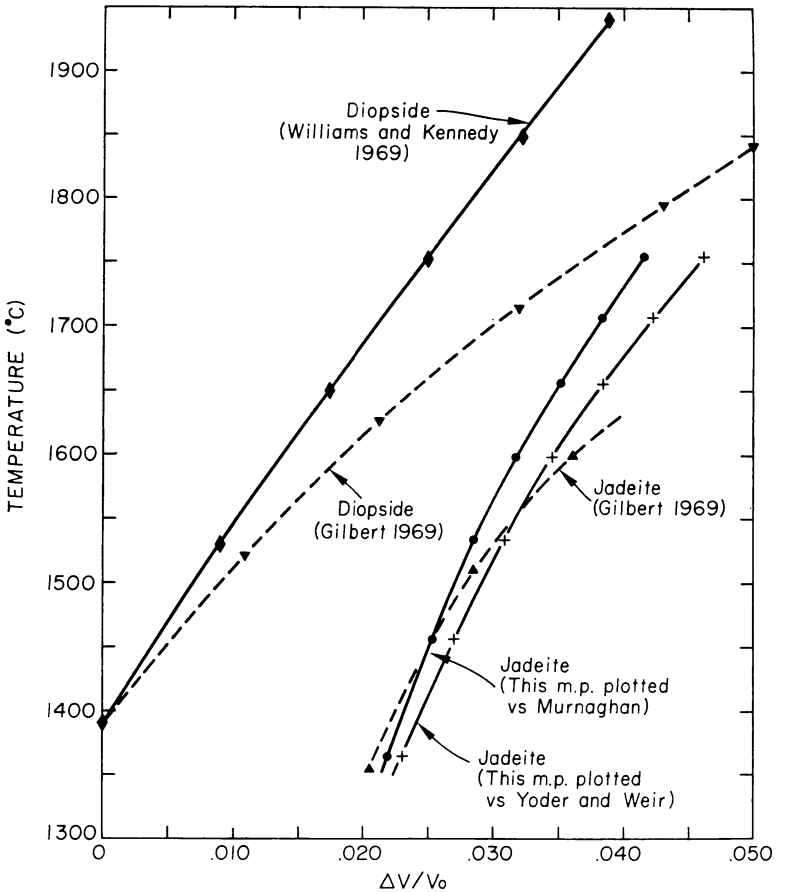


Fig. 3. Melting temperatures of diopside and jadeite plotted versus volume of solid.

where P is pressure, Bo and Bo′ are the bulk modulus and its pressure derivative at 1 bar, V and Vo are volumes at pressure P and at 1 bar respectively. The best fit to the shock wave data was obtained when Bo = 1300 kb and Bo′ = 4. We also show, in figure 3, our melting point data plotted versus compression measurements obtained in this fashion. In addition, in figure 3 we show curves for diopside and for jadeite as plotted by Gilbert (1969). Gilbert used the melting data of Boyd and England (1963) for diopside and the data by Bell (1964) for jadeite. Gilbert used the compressibility data for diopside by Adams and Williamson (*in* Birch 1966), whereas we have used Bridgman's (1948) figures.

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